NEXT STEP TO MARS: DEEP SPACE HABITATS

HEARING

BEFORE THE

SUBCOMMITTEE ON SPACE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

ONE HUNDRED FOURTEENTH CONGRESS

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May 18, 2016

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NEXT STEP TO MARS: DEEP SPACE HABITATS

WEDNESDAY, MAY 18, 2016

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

The Subcommittee met, pursuant to call, at 2:03 p.m., in Room 2318 of the Rayburn House Office Building, Hon. Bruce Babin [Chairman of the Subcommittee] presiding.

LAMAR S. SMITH, Texas
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RANKING MEMBER

Congress of the United States
House of Representatives
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
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Next Steps to Mars: Deep Space Habitats

Wednesday, May 18, 2016
2:00 p.m.
2318 Rayburn House Office Building

Witnesses

Mr. Jason Crusan, Director, Advanced Exploration Systems, Human Exploration and Operations Mission Directorate, NASA

Mr. John Elbon, Vice President and General Manager, Space Exploration, Boeing Defense, Space, and Security, the Boeing Company

Ms. Wanda Sigur, Vice President and General Manager, Civil Space, Lockheed Martin Corporation

Mr. Frank Culbertson, President, Space Systems Group, Orbital ATK

Mr. Andy Weir, Author, *The Martian*

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

Charter

TO:	Members, Subcommittee on Space
FROM:	Majority Staff, Committee on Science, Space, and Technology
SUBJECT:	Subcommittee Hearing: "*Next Steps to Mars: Deep Space Habitats*"
DATE:	May 11, 2016

On Wednesday, May 18, 2016 at 2:00 p.m. in Room 2318 of the Rayburn House Office Building, the Subcommittee on Space will hold a hearing titled, "*Next Steps to Mars: Deep Space Habitats*."

Hearing Purpose

The hearing will examine Mars exploration, specifically efforts to develop deep space habitation capabilities.

Witnesses

- Mr. Jason Crusan, Director, Advanced Exploration Systems, Human Exploration and Operations Mission Directorate, NASA
- Mr. John Elbon, Vice President and General Manager, Space Exploration, Boeing Defense, Space, and Security, the Boeing Company
- Ms. Wanda Sigur, Vice President and General Manager, Civil Space, Lockheed Martin Corporation
- Mr. Frank Culbertson, President, Space Systems Group, Orbital ATK
- Mr. Andy Weir, Author, *The Martian*

Staff Contact

For questions related to the hearing, please contact Mr. Tom Hammond, Staff Director, Space Subcommittee, Dr. Michael Mineiro, Counsel, Space Subcommittee, or Mr. Brian Corcoran, Policy Assistant, Space Subcommittee, at 202-225-6371.

Chairman BABIN. Good afternoon. The Subcommittee on Space will now come to order.

And without objection, the Chair is authorized to declare recesses of the Subcommittee at any time.

Welcome to today's hearing titled "The Next Steps to Mars: Deep Space Habitats." I recognize myself for five minutes for an opening statement.

The exploration of space, particularly human exploration of Mars, has intrigued generations around the world. Our sister planet holds many mysteries, and quite possibly, the keys to our past and our future. The profound goal of putting humans on Mars and perhaps establishing a settlement there, fuels our desire to push the boundaries of what is possible and to reach far beyond our own planet.

Space exploration is in our DNA. Americans of all ages watched on their black and white TVs as Neil Armstrong stepped onto the surface of the Moon. Our collective interests have not waned since that time. However, we now watch in full color and high definition as we launch off our planet, land a rover on Mars, and see our astronauts on the International Space Station do an EVA to assemble an orbital space laboratory enabled by the unwavering dedication and hard work of countless thousands who have contributed to the historical successes and immeasurable benefits spaceflight and exploration have brought humanity.

Last year's cinematic blockbuster, The Martian, based on the book written by Andy Weir, one of our witnesses today, wrote about the challenges an astronaut faced in order to survive the hostile environment of Mars faced with much hostility. This concept is directly related to the topic of our hearing: examining the challenges and discussing what it is going to take to turn this science fiction into a reality as we hope to do in the years ahead.

One of the foremost requirements for success in such a profound endeavor is the support of Congress, and undoubtedly, bipartisan, bicameral support is strongly behind this goal. In fact, bipartisan support for our spaceflight and exploration programs is so strong that the 2016 NASA Authorization Act passed the House by a unanimous voice vote. In this turbulent political climate, a vote like that is very exceptional for any agency. The House's intent is clear, and I strongly urge our colleagues in the Senate to join us by taking up and passing a NASA Authorization bill this year. Doing so, in this election year, is particularly important as it will provide NASA programs the stability that they need through the uncertainty that results during the transition of Presidential Administrations.

One of the most critical capabilities needed to sustain humans for a journey to Mars is a habitat. Without a viable habitat to protect our astronauts from the inhospitable environment of space, we cannot achieve our goals for human deep space exploration.

Congress demonstrated its very strong support of space exploration last year in passing the most significant update to commercial space law in decades and also by providing robust and increased funding levels for NASA exploration programs.

In the 2016 appropriations, Congress directed NASA to invest no less than $55 million for the development of a habitation augmentation module to maximize the potential of the SLS/Orion architecture in deep space and to develop a prototype module no later than 2018.

Astronaut Scott Kelly's nearly year-long mission aboard the International Space Station has provided substantial scientific data which we continue to assess, related to the physiological and psychological impacts humans face during long-duration space missions. However, much research still needs to be done to develop systems and operations to mitigate these impacts for sustaining crew health, and for this reason, it is critical that the ISS be fully utilized through 2024.

We know what goal we want to achieve: putting humans on Mars. What continues to be unclear is the detailed plan. How are we going to accomplish this bold and challenging goal? What are the requisite precursor missions, the technologies, sustaining systems, and habitation requirements and current capabilities? Until this detailed plan is outlined, there are many unknowns but what we do know is that NASA will need habitation and there are many questions that surround this requirement. How will NASA acquire habitation? How will development be funded? Will NASA develop the capability by contracting with a company on a cost-plus basis as it did for the programs in the past? Or will they seek to procure habitation as a service by leveraging previous development work? Will NASA use public-private partnerships? And if so, how will NASA divide the investment? How will it treat the intellectual property? And will the taxpayer get a deal on the price if it contributes to the development?

We have tremendous lessons learned related to systems development along with the pros and cons of various acquisition approaches. Regardless of the ultimate decision, the acquisition parameters and requirements must be clear before any action is taken. NASA simply doesn't have the time or the budget to experiment on unproven acquisition models. It's long past time to apply the lessons learned and make the decision based on what is the most assured and efficient way for NASA to acquire this capability.

Whatever NASA proposes, I sincerely hope it will be in the best interests of our American taxpayers. It would be a shame if we repeat the mistakes of the past: government paying for the development of habitation capabilities, and then turn around and pays again to procure the service from the same provider. NASA's decisions on "make" or "buy" will be critical.

Is it possible that industry may be able to provide turnkey cost-effective services that are developed with minimal taxpayer support? Is there a market for low-Earth orbit habitats, sufficient to support a post-ISS paradigm, which can be leveraged for deep space habit requirements?

We are an exceptional nation of doers, and as we forge a path through the high ground of space on our journey to Mars, I have strong faith in the ingenuity of American scientists, engineers, and the entire industry to address the challenges posed by deep space exploration and to develop the spaceflight systems needed to reach our goals in a safe, sustainable and affordable way.

I'm pleased to welcome our witnesses, and I look forward to hearing their perspectives as to how NASA should consider acquiring habitation goods and services to meet future mission requirements, and thank you all for participating.

And Mr. Weir, I'd like to personally thank you for your captivating work, The Martian. It has everyone talking about Mars, which I believe brings us one step closer to making science fiction, science fact. Thank you.

[The prepared statement of Chairman Babin follows:]

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

For Immediate Release
May 18, 2016

Media Contacts: Alicia Criscuolo, Thea McDonald
(202) 225-6371

Statement of Chairman Brian Babin (R-Texas)
Next Steps to Mars: Deep Space Habitats

Chairman Babin: The exploration of space, particularly human exploration of Mars, has intrigued generations around the world. Our sister planet holds many mysteries, and quite possibly, the keys to our past and our future. The profound goal of putting humans on Mars and perhaps establishing a settlement there, fuels our desire to push the boundaries of what is possible and to reach far beyond our own planet.

Space exploration is in our DNA. Americans of all ages watched on their black and white TVs as Neil Armstrong stepped onto the surface of the Moon. Our collective interests have not waned since that time. However, we now watch in full color and high definition as we launch off our planet, land a rover on Mars, and see our astronauts on the International Space Station do an EVA to assemble an orbital space laboratory.

Enabled by the unwavering dedication and hard work of countless thousands who have contributed to the historical successes and immeasurable benefits spaceflight and exploration have brought humanity.

Last year's cinematic blockbuster, *The Martian*, based on the book written by Andy Weir, one of our witnesses today, wrote about the challenges an astronaut faced in order to survive the hostile environment of Mars. This concept is directly related to the topic of our hearing – examining the challenges and discussing what it is going to take to turn this science fiction into reality…as we hope to do in the years ahead.

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We know what goal we want to achieve – *putting humans on Mars*. What continues to be unclear...is the detailed plan? How are we going to accomplish this bold and challenging goal? What are the requisite precursor missions, the technologies, sustaining systems, and habitation requirements and current capabilities?

While the ISS continues to provide us with a critical test-bed for technology development, we need to be careful not to use it as a "crutch" – a convenient low-Earth orbit safe haven, should it be needed during a deep space mission or flight test through 2024. What if we didn't have this back-up capability, as was the case during the Apollo missions to the Moon. What's our back-up plan...do we have one?

Until the detailed plan is outlined, there are many "unknowns" but what we do know is that NASA WILL need habitation and there are many questions that surround this requirement.

How will NASA acquire habitation? How will development be funded? Will NASA develop the capability by contracting with a company on a cost-plus basis as it did for programs in past? Or will they seek to procure habitation as a service by leveraging previous development work? Will NASA use public-private partnerships? And if so, how will NASA divide the investment? How will it treat the intellectual property? And will the taxpayer get a deal on the price if it contributes to the development?

We have tremendous "lessons learned" related to systems development along with the pros and cons of various acquisition approaches. Regardless of the ultimate decision, the acquisition parameters and requirements must be clear before ANY action is taken...NASA simply doesn't have the time or the budget to "experiment" on unproven acquisition models. It's long past time to apply the "lessons learned" and make the decision based on what is the most assured and efficient way for NASA to acquire this capability.

Whatever NASA proposes, I sincerely hope it will be in the best interests of the taxpayer. It would be a shame if we repeat the mistakes of the past...government paying for the development of habitation capabilities, then turns around and pays again to procure the service from the same provider. NASA's decisions on "make" or "buy" will be critical.

Is it possible that industry may be able to provide turn-key cost-effective services that are developed with minimal taxpayer support? Is there a market for low-Earth orbit habitats, sufficient to support a post-ISS paradigm, which can be leveraged for deep-space habit requirements?

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I'm pleased to welcome our witnesses and I look forward to hearing their perspectives as to how NASA should consider acquiring habitation goods and services to meet future mission requirements.

Thank you all for participating. And Mr. Weir, I would like to personally thank you for your captivating work, *The Martian*...it has everybody talking about Mars...which I believe brings us one step closer to making science fiction, science fact.

###

Chairman BABIN. I now recognize the Ranking Member, the gentlewoman from Maryland, for an opening statement.

Ms. EDWARDS. Thank you very much, Mr. Chairman, and thank you very much for holding this hearing today on the "Next Steps to Mars: Deep Space Habitats." Our Committee and Subcommittee have actively been examining aspects of the humans-to-Mars goal as well as how to implement it, and I'm looking forward to continuing the discussion this afternoon.

I too would like to welcome our distinguished panel of witnesses. It's a rare opportunity to have NASA, industry leaders, and a best-selling author together to discuss the opportunities and challenges involved in sending humans to Mars. I would also note that in our audience today are many representatives I see from the industry as well, and so I think this is an important time for us to really get on the same page about next directions.

And the fact that we will discuss today one of the critical elements that's needed to send humans to Mars, habitats, reflects the current situation that achieving the humans-to-Mars goal is no longer a question of "if" but rather a question of "when." The "when" will, in part, depend on public support, and so I'm glad that Mr. Weir is here as well today to provide his perspectives on how popular media, such as books, movies, and television can help further public support for the goal of sending humans to Mars.

Other questions we need to address; however, are, of course, how do we get there and what do we need to be working on now in technology development, research, and mission demonstrations if we are to achieve that goal?

This afternoon's hearing will focus on the habitats and habitat systems needed to protect a crew from the harshness of space during deep space missions. Habitats will need systems to provide clean air, water recovery, climate monitoring and control, and a means for food production. They'll also need to provide for fire safety within a closed environment, crew exercise, onboard medical services, and the ability to provide safe haven from solar particle storms and cosmic galactic rays that pose risks to crew health and mission operations. So I'm anxious to hear from our panelists about the concepts for addressing these challenges and the status of work to date on habitation systems.

Finally, getting humans to Mars will require much more than overcoming the technical challenges of developing habitation systems. It will require national commitment, sustained support, and resources over multiple decades. Public excitement, anticipation and engagement in sending humans to Mars will also play an important role in determining the extent to which the Nation prioritizes this as a goal.

So I'm pleased, Mr. Chairman, that we also have the opportunity today to discuss how we can stimulate and leverage public engagement in the goal of sending humans to Mars. And I would also say that I share the goal of trying to complete in this interim period a longer-term authorization for the agency to set on a path, a direction forward, particularly with respect to getting humans to Mars and the support of that goal so that in fact we can make the kind of appropriate transition from one Administration to the next that doesn't require us to start from square one. And so I look forward in these next several months to doing exactly that.

And lastly, I'd like to thank again our witnesses for being here, and I truly do look forward to your testimony.

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

[The prepared statement of Ms. Edwards follows:]

OPENING STATEMENT
Ranking Member Donna F. Edwards (D-MD)
of the Subcommittee on Space

House Committee on Science, Space, and Technology
Subcommittee on Space
"Next Steps to Mars: Deep Space Habitats"
May 18, 2016

Thank you, Mr. Chairman, for holding this hearing on *"Next Steps to Mars: Deep Space Habitats"*. Our Committee and Subcommittee have actively been examining aspects of the humans-to-Mars goal as well as how to implement it, and I'm looking forward to continuing the discussion this afternoon.

I'd also like to welcome our distinguished panel of witnesses. It is a rare opportunity to have NASA, industry leaders, and a best-selling author together to discuss the opportunities and challenges involved in sending humans to Mars.

And the fact that we will discuss today one of the critical elements needed to send humans to Mars—habitats—reflects the current situation that achieving the humans-to-Mars goal is no longer a question of "if" but rather a question of "when".

The "when" will, in part, depends on public support, and I'm glad that Mr. Weir is here today to provide his perspectives on how popular media, such as books and movies, can help further public support for the goal of sending humans to Mars.

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I'm pleased, Mr. Chairman, that we also have the opportunity today to discuss how we can stimulate and leverage public engagement in the goal of sending humans to Mars.

Again, I'd like to thank our witnesses for being here and I look forward to your testimony. Thank you Mr. Chairman, and I yield back.

Chairman BABIN. Thank you, Ms. Edwards.

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

Chairman SMITH. Thank you, Mr. Chairman, and I too appreciate our witnesses who are here today as well as the many stakeholders who are represented in the audience as well. It's nice to see a full room.

I also want to single out a gentleman sitting in the front row to my right and compliment him on his tee shirt that says "Occupy Mars." I won't ask any more questions right now but we'll talk later.

Our hearing covers a critical aspect of our Nation's future journey to Mars: how our astronauts will live and work during their journey, and I'm glad that best-selling author Andy Weir has agreed to join us today. His book, The Martian, along with the movie by the same name, ignited the world's imagination. It brought to life an adventure that we can envision in the not-too-distant future: journeys to Mars with heroic astronauts putting themselves to the test of overcoming dangers with ingenuity and courage.

I wrote an op-ed with our colleague, Ed Perlmutter, two months ago that I would like to submit for the record without objection, Mr. Chairman.

[The information appears in Appendix II]

Chairman SMITH. In this article, we discuss the persistence of purpose and careful planning that is needed to turn such a mission, the first human space flight to another planet in our solar system, into reality.

This is not merely a science fiction movie starring Matt Damon. This is a goal within America's reach. NASA and American space companies are building the critical components for such a journey: the Orion crew vehicle and Space Launch System.

The popularity of The Martian as a novel and a film has shown that the American public is very interested in making this vision a reality. That is why NASA should not stray from its primary goal of exploration.

Exploration programs at NASA, both robotic and human, need to be adequately funded. Unfortunately, the Obama Administration, year after year, woefully under-budgets the very programs that will get us to Mars.

At the same time, the Administration continues to push plans for an unjustified Asteroid Retrieval Mission. The Asteroid Retrieval Mission is a distraction without any connection to a larger roadmap to explore our solar system and is without support from the scientific community or NASA's own advisory committees. The Government Accountability Office recently estimated that the total cost for the Asteroid Retrieval Mission would be $1.72 billion. These funds would be better spent directly on space exploration with a connection to future missions to Mars, like deep space habitats and propulsion technologies.

America leads the world in space exploration but that is a leadership role we cannot take for granted. It has been over 40 years since astronaut Gene Cernan became the last person to walk on the moon. It is time to press forward. It is time to take longer strides. It is time to aim for Mars.

Thank you, Mr. Chairman. I yield back.

[The prepared statement of Chairman Smith follows:]

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

For Immediate Release
May 18, 2016

Media Contacts: Alicia Criscuolo, Thea McDonald
(202) 225-6371

Statement of Chairman Lamar Smith (R-Texas)
Next Steps to Mars: Deep Space Habitats

Chairman Smith: Thank you, Mr. Chairman, and thanks to our witnesses for being here today. Today's hearing covers a critical aspect of our nation's future journey to Mars—how our astronauts will live and work during their journey.

It's nice that best-selling author Andy Weir has agreed to join us today. His book, *The Martian*, along with the movie by the same name ignited the world's imagination. It brought to life an adventure that we can envision in the not-too-distant future: journeys to Mars with heroic astronauts putting themselves to the test of overcoming dangers with ingenuity and courage.

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Chairman BABIN. Thank you, Mr. Chairman.

Prior to today's hearing, the Committee received a number of letters, and I ask unanimous consent to include them in the record.

[The information follows:]

[The information appears in Appendix II]

Chairman BABIN. Now I'd like to introduce our distinguished witnesses. Our first witness today is Mr. Jason Crusan, Director of Advanced Exploration Systems, Human Exploration, and Operations Mission Directorate at NASA. In this role, Mr. Crusan is the Senior Executive, Manager, Principal Advisor, and Advocate on Technology and Innovation Approaches leading to new flight systems capabilities for human exploration. He manages 500 to 600 civil servants with an active portfolio of 20 to 30 engineering and design projects. He leads integration with the Space Technology Mission Directorate, and the other HEOMD programs such as the International Space Station and the Exploration System Divisional—Division programs. Mr. Crusan holds bachelor's degrees in electrical engineering and physics, a master's in computer information systems, and is currently a candidate for a Ph.D. in systems engineering and engineering management at George Washington University. Very impressive.

Secondly, Mr. John Elbon, who I've had the pleasure of knowing for a number of years. He is our second witness. John Elbon is Vice President and General Manager of Space Exploration at Boeing Defense, Space and Security at the Boeing Company. In his role at Boeing, Mr. Elbon is responsible for the strategic direction of Boeing's civil space programs and support of NASA programs such as the International Space Station, Commercial Crew Development program, and the Space Launch System, SLS. Prior to being named Vice President and General Manager of Space Exploration, Mr. Elbon served as Vice President and Program Manager for Boeing's commercial programs as well as the Boeing Program Manager for several NASA programs which include Constellation, ISS, and the Checkout Assembly and Payload Processing Services contractor, CAPPS, at Kennedy Space Center. Mr. Elbon holds a bachelor of aerospace engineering from Georgia Institute of Technology.

Our third witness today is Ms. Wanda Sigur, Vice President and General Manager, Civil Space, at Lockheed Martin Corporation. Ms. Sigur has executive responsibility for critical national space programs relating to human spaceflight and space science missions including planetary, solar, astrophysical, and Earth remote sensing for civil and governmental agencies. Some of these major programs include the Orion Multipurpose Crew Vehicle, Hubble and Spitzer space telescopes, the GOES–R weather satellites, Juno, GRAIL, MAVEN, Mars Reconnaissance Orbiter, Mars Odyssey, and OSIRIS–Rex planetary missions and the company's nuclear space power programs. She holds a bachelor's degree in mechanical and material sciences and engineering from Rice University and a master's degree in business administration from Tulane University. Welcome, Ms. Sigur.

Our fourth witness today is Mr. Frank Culbertson. Mr. Culbertson is President of Space Systems Group at Orbital ATK. Mr. Culbertson is responsible for the execution, business development, and finances of the company's human spaceflight science commercial communications and national security satellite activities as well as technical services to various government customers. These include some of Orbital's largest and most important programs such as NASA's Commercial Resupply Services, or CRS, these initiatives, as well as various national security-related programs. Throughout his distinguished career, Mr. Culbertson has received numerous honors including the Legion of Merit, the Navy Flying Cross, the Defense Superior Service Medal, the NAAFAI Gagarin Gold Medal, and the NASA Distinguished Service Medal. As an astronaut, he logged over 146 days in space over three flights. He is a graduate of the United States Naval Academy at Annapolis. Welcome.

Our final today is Mr. Andy Weir, author of The Martian. Mr. Weir was first hired as a programmer for a national laboratory at age 15, and he has been working as a software engineer ever since. He is also a self-proclaimed lifelong space nerd and a devoted hobbyist of subjects like relativistic physics, orbital mechanics, and the history of manned spaceflight. The Martian, which is his first novel, has won numerous awards and has been adapted to a film directed by Ridley Scott by the same name, and I'm sure many of us have seen it.

So I now recognize Mr. Crusan for five minutes to present his testimony.

TESTIMONY OF MR. JASON CRUSAN, DIRECTOR, ADVANCED EXPLORATION SYSTEMS, HUMAN EXPLORATION AND OPERATIONS MISSION DIRECTORATE, NASA

Mr. CRUSAN. Mr. Chairman and Members of the Subcommittee, thank you for this opportunity to appear before you today to discuss NASA's plans for development of habitation capabilities for the post-International Space Station era.

As you know, the agency plans to continue ISS operations and utilization through at least 2024. ISS and its successor capabilities are essential to conducting research on human health and performance, testing and demonstration of technologies critical for deep space missions, and expanding our knowledge of space. These activities comprise our Earth-reliant portion of our journey to Mars.

The Space Launch System and Orion crew vehicle now well under development will carry us into the proving ground of cislunar space where our primary goal for human spaceflight is to develop the crew capabilities necessary for long duration transit missions to and from Mars.

The next human exploration capabilities needed beyond SLS and Orion are deep space long-duration habitation and in-space propulsion.

Missions in the proving ground will simulate and test Mars transit systems and operations through limited interaction with Mission Control, limited cargo supply with no crew exchanges, and will culminate with a long-duration crew validation expedition within cislunar space or beyond by the end of the 2020s.

NASA is also actively working on low-Earth transition strategies for the post-ISS era as well and is encouraging the private sector to foster both commercial demand and supply for LEO services.

This will allow NASA to focus its resources on the agency's primary goal to expand human presence into the solar system and to Mars consistent with Presidential and Congressional direction.

ISS operations and LEO constitute a foundation for such expansion by performing key research and technology developments required for long-duration deep space missions. In addition to this ISS testing, NASA needs to begin operating at greater distances from Earth to perform deep space testing along with continuing to enable the transition of LEO to private platforms and capabilities.

There are a number of common capabilities that NASA and our partners must develop over the next five to ten years including habitation that we're here to discuss today. Such a capability is the foundation of human spaceflight missions beyond LEO supporting our plans for Mars-class missions of distance and duration.

An effective habitation capability comprises a pressurized volume plus an integrated array of complex systems and components that include docking capabilities, environmental control and life support systems, logistics management, radiation mitigation and monitoring, fire safety technologies, and crew health capabilities.

To support development of habitation capabilities, NASA is leveraging information gathered through its Next Space Technologies for Exploration Partnership, or NextSTEP, broad agency announcements. NextSTEP is a public-private partnership model that seeks commercial development approaches to long-duration deep space capabilities. In NextSTEP phase I, NASA selected 12 awards including seven in the area of habitation. The NextSTEP phase I contractors are performing advanced concept studies and technology development projects. In April of 2016 this year, the agency issued NextSTEP phase II, which is specifically addressing and focusing on the development of long-duration deep space habitation concepts that will result in prototype units. NASA plans to select multiple proposals under this solicitation in August of 2016, this year. And the agency intends to integrate functional systems into our prototype habitat for ground testing in 2018.

Through the NextSTEP effort, NASA and industry are identifying commercial capability developments for LEO that intersect with the agency's long-duration deep space habitation requirements along with any potential options to leverage these identified commercial advances toward meeting NASA's exploration needs while promoting commercial activity in LEO.

NextSTEP is a key aspect of informing the agency's acquisition strategy for its deep space long-duration habitation capability along with any considerations of international partner participation. It is NASA's intent that LEO eventually support private platforms and capabilities enabled by commercial markets, academia, and government agencies with an interest in LEO research and activities while the agency's primary human spaceflight focus shifts towards deep space beyond LEO. Private enterprise and affordable commercial operations in LEO will enable a sustainable step in our expansion into space. A robust, vibrant commercial enterprise with many providers and a wide range of private and public users will enable U.S. industry to support other government and commercial users safely, reliably and affordably.

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

[The prepared statement of Mr. Crusan follows:]

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BY WITNESS
May 18, 2016

Statement of
Jason Crusan
Director, Advanced Exploration Systems
Human Exploration and Operations Mission Directorate
National Aeronautics and Space Administration

before the

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

Mr. Chairman and Members of the Subcommittee, thank you for the opportunity to appear before you today to discuss NASA's plans for the development of habitation capabilities for the post-International-Space-Station (ISS) era. As you know, the Agency plans to continue ISS operations and utilization through at least 2024. The ISS and successor capabilities are essential to conduct research on human health and performance and test technologies critical for deep space missions as well as to expand our knowledge of space and test and demonstrate new space capabilities. These activities comprise the Earth-reliant portion of our Journey to Mars. The Space Launch System (SLS) and Orion will carry us into the Proving Ground of cislunar space. The next capabilities needed beyond SLS and Orion for human exploration are deep space, long duration habitation and in-space propulsion. Validation of these and related capabilities in cislunar space will mark our readiness to begin Earth-independent exploration beyond the Earth-Moon system. At that point, which we seek to reach by the end of the 2020s, we will be well along on our journey to Mars.

A deep space habitation capability is the foundation of human space missions beyond low-Earth orbit (LEO), supporting our plans for Mars-class mission distances and durations. An effective habitation capability is comprised of a pressurized volume, and an integrated array of complex systems and components that include a docking capability, environmental control and life support systems, logistics management, radiation mitigation and monitoring, fire safety technologies, and crew health capabilities. NASA's current strategy is to test these systems and components on the ground and in LEO, such as on ISS, then as an integrated habitation capability for long duration missions in cislunar space and Mars transit.

Collaborating with the private sector to leverage its growing interest and capabilities in access to and use of space is a core element of NASA's strategy. Another is testing long duration Mars-class habitation systems and components in LEO, such as on ISS. The progress and trajectory of private sector space activity is such that NASA is working toward the transition of LEO to be a commercially-led economic sphere by the mid-2020s.

Because habitation capabilities are key to both commercial activity in LEO and to human deep space exploration, and because public-private partnerships can potentially help make habitation capabilities more affordable, NASA has been undertaking substantial private-sector engagement to define habitation concepts, systems, and implementation approaches to achieve NASA's goals for deep space and enable progress towards LEO commercial space station capabilities.

Transitioning LEO

NASA is actively working transition strategies for the post-ISS era and is engaged with the private sector to foster both commercial demand and supply for LEO services. NASA's goal is to expand human presence into the solar system and to Mars, consistent with Presidential and Congressional direction. ISS operations in LEO constitute a foundation for such expansion, but once key research and technology development efforts have been completed, NASA plans to begin operating at greater distances from Earth. It is NASA's intention to transition LEO to private platforms and capabilities enabled by commercial markets, academia and government agencies, including NASA, with interest in LEO research and activities.

The Agency expects to support continued research needs in LEO after the end of the ISS program. The Agency will work with industry, academia, and other government agencies through consortia and other means to establish long-term LEO demand investment and research/technology development.

One area of technology development with potential commercial applications is habitation capability. NASA will require long duration habitation capabilities for its deep space missions, but the Agency also anticipates that commercially owned and operated habitation systems in LEO could support focused scientific research, industrial enterprises, and space tourism, to name just three potential areas. NASA's work with demonstrating habitation systems and technology aboard ISS supports both the Agency's own future exploration requirements as well as the evolution of commercial systems in LEO. The Agency is working with industry to define common interests between LEO and deep space habitation systems, architectures, requirements, common interfaces and standards, and investing in technology maturation efforts. NASA is conferring with industry to inform deep space habitation requirements while maximizing commercial capabilities for LEO. The Agency recognizes the importance of engaging stakeholders along the way to shape strategy and development approaches in this area.

One example of habitation technology being tested on ISS is the Bigelow Expandable Activity Module (BEAM), which was launched to ISS on the commercial SpaceX Dragon spacecraft on April 8, 2016, installed on April 16, and stands ready for deployment later this month, during which a pressurization system will be activated to expand the BEAM structure to its full size using air from the ISS and air stored within the packed module. BEAM will undergo a two-year demonstration period, during which station crew members and ground-based engineers will gather performance data on the module. While the BEAM demonstration supports a NASA objective to evaluate design options for the development of a long duration, deep space habitat for human missions beyond Earth orbit, the results of the demonstration will also have applications to private space stations/habitats, which is why Bigelow has co-funded the development of this module.

Habitation capability – whether for LEO or long duration, deep space application – includes technology development efforts beyond the pressure vessel or module involved. A habitation module must be outfitted with robust, reliable environmental control and life support systems, including those that provide breathable air (and the concomitant removal of carbon dioxide), thermal control, food and potable water, waste reclamation or removal, power generation and storage, overall crew health systems, and shielding from radiation and micrometeoroid/orbital debris (MMOD), among other systems. In order to support habitation capabilities, NASA will leverage information gathered through its Next Space Technologies for Exploration Partnerships (NextSTEP) Broad Agency Announcement (BAA), which supports such integrated and system development, coupled with a number of other internal and external development efforts to develop the vast number of habitation systems required for the overall habitation capability.

NextSTEP BAA

NASA's journey to deep space will include key partnerships with commercial industry for the development of advanced exploration systems. NextSTEP is a public-private partnership model that seeks commercial development of long duration, deep space exploration capabilities to support more extensive human spaceflight missions in the cislunar Proving Ground and beyond. NASA issued the original NextSTEP BAA to U.S. industry in late 2014. In March 2015, NASA selected 12 awardees – seven in habitation, three in propulsion, and two in small satellites. NASA has since entered into fixed-price contracts with the selectees, including technical/payment milestones, periodic technical interchange meetings with NASA, and regular status meetings with the contractors. Key components of NextSTEP are an emphasis on the contribution of private corporate resources to achieve goals and objectives, and leveraging LEO commercial capabilities. For Phase 1, NASA required a contribution of at least 50 percent of the overall effort to be provided by the awardees, and for Phase 2, a threshold of at least 30 percent is to be met through company investments which continues to demonstrate their commitment toward developing potential commercial applications. NextSTEP Phase 1 consists of 10-12-month studies. Deliverables include proposals for NextSTEP Phase 2 (which could include ISS demonstrations), along with an explanation of how the company would commercialize the developing technology and overall capability.

Of the seven habitation awards (with a total amount awarded of about $10 million), four focus on integrated habitation concepts, and three on advanced life support systems and integrated concepts:

- Lockheed Martin - Denver, CO: Habitat to augment Orion's capabilities. Design will draw strongly on LM and partner Thales Alenia's heritage designs in habitation and propulsion;
- Bigelow Aerospace LLC - Las Vegas, NV: The B330 for deep space habitation will support operations/missions in LEO, distant retrograde orbit, and beyond cislunar space;
- Orbital ATK - Dulles, VA: Habitat that employs a modular, building block approach that leverages the Cygnus spacecraft to expand cislunar and long duration deep space transit habitation capabilities and technologies;
- Boeing - Houston, TX: Developing a simple, low cost habitat that is affordable early on, allowing various technologies to be tested over time, and that is capable of evolving into a long-duration crew support system for cislunar and Mars exploration;
- Dynetics, Inc - Huntsville, AL: Miniature atmospheric scrubbing system for long duration exploration and habitation applications. Separates CO2 and other undesirable gases from spacecraft cabin air;
- UTC Aerospace Systems - Windsor Locks, CT: More modular ECLSS subsystems, requiring less integration and maximize component commonality; and
- Orbital Technologies Inc. - Madison, WI: Hybrid Life Support Systems integrating established Physical/Chemical life support with bioproduction systems.

Through these partnerships, NextSTEP contractors will provide advanced concept studies and technology development projects. In addition to advancing capabilities for NASA required for beyond-Earth-orbit habitation, the advances made through this effort by the selected commercial companies may be applicable to any private space stations or habitats.

NextSTEP-2 and Beyond

In April 2016, NASA issued a Next Space Technologies for Exploration Partnerships-2 (NextSTEP-2) BAA, an omnibus announcement covering all aspects of basic and applied supporting research and technology for human space exploration and robotic precursor activities. Specific research areas are announced by issuing Appendices to this BAA, to include, but not be limited to: long duration, deep space habitation system capabilities, studies to support mission architecture definition, new approaches to rapidly develop prototype systems, demonstration of key capabilities, validation of operational concepts for future human missions beyond LEO, and end-to-end design, development, test, and in-space evaluation of future flight systems.

The April release of the NextSTEP-2 BAA included Appendix A: Habitat Systems, which is focused on developing long duration, deep space habitation concepts, resulting in ground prototype units. This ground-based effort will support development of deep space long duration habitation concepts and demonstrate components that NASA will later need to test in the microgravity environment of space. The objective is to identify habitation concepts that can support extensive human spaceflight missions in the Proving Ground and beyond while encouraging application to commercial LEO habitation capabilities. NASA plans to continue some or all of the NextSTEP Phase 1 habitation studies into Phase 2, but Appendix A of the omnibus NextSTEP-2 BAA provides opportunity for other companies not selected previously to participate in Phase 1 to be added to the Phase 2 efforts. In moving forward with NextSTEP-2, a NASA-led standards working group will be implemented to ensure interoperability of the aggregate system. The Agency will work with industry to define common interfaces and standards to ensure that components provided by different companies can be integrated and function together.

The fixed price NextStep-2 contracts will be incrementally funded with payments based on milestone achievements; the milestones mark substantive technical achievements that buy down or retire risks. NASA will have insight into progress through quarterly and monthly status briefings or reports, as well as bi-weekly telecons. The Agency plans to select multiple proposals under NextSTEP-2, Appendix A, in August 2016, with an estimated period of performance to begin in September 2016 and extended out to about April 2018. NASA intends to integrate functional systems into a prototype habitat for ground testing in 2018. While funding levels will depend upon the availability of appropriated funds and proposed content, it is anticipated that the total amount of funding that could potentially be available in FY 2016-FY 2017 is about $65 million, with potential additional funding in FY 2018. There is a cost-sharing threshold for NextSTEP Phase 2 proposals that requires proposing companies to commit at least 30 percent contribution of corporate resources toward the total estimated cost. The corporate contribution could include direct contributions during the period of performance and may include limited prior industry investment.

Through the NextSTEP effort, NASA and industry will identify commercial capability development for LEO that intersects with the Agency's long duration, deep space habitation requirements, along with any potential options to leverage commercial LEO advancements towards meeting NASA long duration, deep space habitation needs while promoting commercial activity in LEO. The multiple phases of NextSTEP are informing NASA's acquisition strategy for its deep space, long duration habitation capability. In parallel with NextSTEP-2, NASA will define a reference habitat deep space architecture based on contractor concepts and identified overall government contributions, including Government Furnished Equipment (GFE), in preparation for Phase 3.

Preparing for the Journey to Mars in Cislunar Space

NASA's primary human spaceflight goal in the Proving Ground of cislunar space is to prepare and develop all the crew-related capabilities for long duration transit missions to Mars, culminating in a long-duration crewed validation expedition in cislunar space or beyond by the end of the 2020s. This will involve the development and deployment of an integrated habitat in cislunar space, aboard which crews will perform integration and final validation of research and technologies tested in LEO, including on the ISS. Missions in the Proving Ground will also simulate Mars transit operations through limited interaction with Mission Control (again, based on pathfinder experiments conducted in LEO), limited cargo resupply, and no crew exchanges.

Just as work in LEO is laying the foundation for human expeditions further afield, so Proving Ground expeditions will evolve the next steps in the development of knowledge and hardware required to extend human presence into the solar system in a sustainable way. NASA's Journey to Mars seeks to take advantage of capability advancements, leverage commercial investments and new scientific findings, and reuse/repurpose systems when it makes sense to do so. The Agency will gradually build up its exploration capability, create opportunities for U.S. industry to enhance its experience and business base, develop a resilient exploration architecture, and foster international and commercial partnerships. The development of long-duration, deep-space habitation capabilities will reflect these principles.

Conclusion

The Journey to Mars requires a resilient architecture that can embrace new technologies, and new international and commercial partners. There is a set of common capabilities that NASA and partners must develop over the next five to ten years, including long-duration, deep-space habitation.

It is NASA's intention that LEO eventually support private platforms and capabilities enabled by commercial markets, academia, and government agencies, including NASA, with interest in LEO research and activities, while NASA's primary human space exploration focus shifts toward deep space beyond LEO. Private enterprise and affordable commercial operations in LEO will enable a sustainable step in our expansion into space — a robust, vibrant, commercial enterprise with many providers and a wide range of private and public users will enable U.S. industry to support other government and commercial users safely, reliably, and affordably.

An important part of NASA's strategy is to stimulate the commercial space industry to help the Agency achieve its strategic goals and objectives for expanding the frontiers of knowledge, capability, and opportunities in space. A key component of the NextSTEP partnership model is that it provides an opportunity for NASA and industry to partner to develop affordable capabilities that meet NASA human space exploration objectives while also supporting industry commercialization plans. Additionally, the development of standards for habitation systems will allow for increased cooperation and ease of integration for decades of future exploration.

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

JASON CRUSAN
Director, Advanced Exploration Systems Division
NASA Human Exploration and Operations Mission Directorate

As Director for the Advanced Exploration Systems (AES) Division with the Human Exploration and Operations Mission Directorate (HEOMD) at the National Aeronautics and Space Administration (NASA), Jason Crusan is the senior executive, manager, principle advisor and advocate on technology and innovation approaches leading to new flight and system capabilities for human exploration. He manages 500-600 Civil Servants with an active portfolio of 20-30 engineering and design projects. He leads integration with the Space Technology Mission Directorate and the other HEOMD programs such as the International Space Station and the Exploration System Division Programs.

Using an integrated approach that leverages public-private partnerships, industry, international partners, and academia, Mr. Crusan leads AES across all NASA Centers, developing and maintaining critical human spaceflight capabilities; maturing new integrated systems, instruments, and ground systems; and delivering critical multi-million dollar flight hardware for NASA. He provides the executive management and leadership needed to develop the right technology development strategies, system acquisition strategies, contracting mechanisms, joint investment models and partnerships—in short, he develops the innovative approaches needed to maximize NASA's access to new technologies and capabilities for human spaceflight.

Crusan has held multiple titles at NASA since 2005, from Chief Technologist for Space Operations to Program Executive and project manager on various technical and management initiatives. He was part of the Mini-RF (Miniature Radio Frequency) Program, which flew two radar instruments to the moon to map the lunar poles, search for water ice, and demonstrate future NASA communication technologies. Currently he also serves as the Director of the Center of Excellence for Collaborative Innovation formed to advance the utilization of open innovation methodologies within the U.S. government.

Crusan holds Bachelor's Degrees in Electrical Engineering and Physics, a Master's in Computer Information Systems, and is currently a candidate for a Ph.D. in Systems Engineering and Engineering Management at George Washington University. Mr. Crusan is married and has two children.

Chairman BABIN. Thank you, Mr. Crusan.

I now recognize Mr. Elbon for five minutes to present his testimony.

TESTIMONY OF MR. JOHN ELBON, VICE PRESIDENT AND GENERAL MANAGER, SPACE EXPLORATION, BOEING DEFENSE, SPACE, AND SECURITY, THE BOEING COMPANY

Mr. ELBON. Thank you, Chairman Babin, Ranking Member Edwards, Chairman Smith, members of the Committee. On behalf of the Boeing Company, thank you for the opportunity to testify today.

Our Nation is on a journey to put humans on Mars. Sometimes I think those words roll off our tongue too easily. I'm trained as an engineer, and I often don't feel I have the capability to articulate with the enthusiasm and awe that those words deserve.

If you know where to look in the sky, you can find Mars, and it's a small dot. When you're there and looking back, Earth will be a small dot, and we're going there. This is an incredible feat.

Our longest missions to date have been around a year. The mission to Mars will be at least three years long. The largest payload we've landed on Mars to date is just under a ton. To put humans on the surface of Mars, we'll need to be able to land 20 to 30 tons.

We've traveled to low-Earth orbit and to the Moon, where communications delays are up to three seconds. On the journey to Mars, communication delays will be over 40 minutes. And when the Mars and the Earth are on opposite sides of the sun, there will be a blackout for a period of two weeks. We must learn to operate in space without constant monitoring and control capability from the ground.

These challenges are difficult, but solving difficult challenges is what our Nation's human spaceflight is focused on since its inception.

The key to meeting these challenges is to attack them in phases, first by developing the necessary technologies close to home in low-Earth orbit aboard the International Space Station. Second, by developing systems based on these technologies and validating them in a proving ground in the area around the Moon. We refer to this area as cislunar. And then once these systems are proven safe and reliable, using them to accomplish our greatest achievement as humans to date: putting humans on Mars.

We're making great progress through our work aboard the International Space Station. In addition to breakthrough scientific discoveries on ISS, we're learning to live for long periods of time in space and developing reliable systems such as life support systems that are necessary. This work needs to continue for the next decade or so when we will be well underway on the next step.

The next step, of course, is to put a habitat, an outpost, if you will, in the vicinity of the Moon. This habitat will not only support validation of the capabilities we need to make the long journey to Mars but can also enable private industry or international partners to descend to the lunar surface. Asteroids could be returned to that outpost for scientific investigation, perhaps mining. Commercial resupply vehicles can be contracted for logistic support. And telerobotic exploration of the far side of the Moon can be conducted from this outpost.

The primary objective of taking the next step to cislunar is to validate we're ready to go to Mars, but being there will enable a whole suite of exciting activities.

There is currently an ongoing dialog around the model that ought to be used for the procurement of this habitation capability. Habitation developed for use in cislunar will be expanded for use during the journey to Mars and could also be used at least in part for a low-Earth orbit vehicle after retirement of the International Space Station.

As the leader of programs operating under both public-private partnerships such as Commercial Crew and cost-plus development contracts such as International Space Station and the Space Launch System, I've seen the advantages and challenges of both models. I look forward to discussing these as well as diving deeper into why cislunar is the next-step destination during our discussion today.

I'll close by asking you to consider this: somewhere in the world is a student about 10 to 20 years old, probably studying math or science, and that student will be the first person to set foot on Mars. In my view, that's amazing to think about.

Thank you very much, and I look forward to your questions.

[The prepared statement of Mr. Elbon follows:]

Testimony of John Elbon

Vice President and General Manager

Boeing Space Exploration

May 18, 2016

Chairman Babin, Ranking Member Edwards and members of the Committee, on behalf of The Boeing Company, thank you for the opportunity to testify today to provide an update on Boeing's role in NASA's next steps in deep space exploration and our deep space habitat work as we build the stepping stones toward a human journey to Mars.

Boeing is proud to be NASA's prime contractor on the International Space Station and a partner on the Commercial Crew Program, where we are building the CST-100 Starliner to transport our crews from U.S. soil to and from low-Earth orbit.

We are also under contract with NASA to build the core stages and avionics of the Space Launch System, the largest and most powerful rocket ever built. The SLS enables exploration beyond low Earth orbit and will take us to cislunar space, Mars and beyond.

In addition, Boeing is under contract as part of NASA's NextSTEP program. NextSTEP is a public-private partnership model that seeks commercial development of deep space exploration capabilities. We are working with NASA to enable more extensive human space flight missions in the Proving Ground around, and beyond, cislunar space--the space near Earth that extends beyond our moon.

NASA's Journey to Mars

Let's start with the fact that sending humans to Mars will be challenging! Imagine an 800 to 1,100 day mission with up to 45 minutes of delayed communication. When you're behind the sun, there are two weeks of blacked out communication between you and any help from mission control back on Earth. Once in the vicinity of Mars, after seven to eight months of travel, there is a thin atmosphere to enter as you face dusty conditions, attempting to stick the landing of a 20 to 30 ton payload. And you'll need to bring your oxygen with you—about 20 tons, which is required for your ascent back to the rendezvous vehicle. Sounds like an excerpt out of Andy Weir's "The Martian," but I assure you, the challenge is very real.

Overcoming these obstacles is doable, but it will take a deliberate, phased approach to send humans to Mars and then return them safely to Earth. If you ask NASA-and the world… they will agree that the returning safely to Earth part is pretty important.

ISS: Deep Space Platform

I'd be remiss if we talk about our journey to Mars without first speaking about the International Space Station, the base camp, and our platform for proving space technology and science that will be vital to a human mission to Mars.

Through the remainder of the station's life, our focus is on reducing cost, increasing efficiencies and maximizing research utilization while supporting a new commercial model for transportation. Over the past 10 years, we have reduced the cost of our sustainment role by more than 30 percent.

ISS continues to be used for developing multiple technologies for deep space exploration such as critical life support systems and environment monitoring systems. NASA is developing and testing highly reliable life support systems to address needs for future exploration habitation systems. This includes important carbon dioxide removal systems, oxygen generation systems, and the systems needed to monitor and detect things like trace gases, water contaminants and microbes. All of this is critically important to learn on the ISS before we make longer duration missions farther into our solar system, such as future missions to Mars.

Lessons learned from ISS

We've already learned a lot from the ISS for how we live and work in space. We've seen groundbreaking research on ISS that will help humanity on the ground and we're also seeing invaluable research that will help us sustain life on the three-year round trip journey to Mars.

In March, Astronaut Scott Kelly returned after a 340-day historic mission aboard the ISS. During that time the station crew conducted almost 400 investigations, many which included research into how the human body adjusts to weightlessness, isolation, radiation and the stress of a long-duration space mission.

From ISS operations we've learned that we'll need an environmental control and life support system that is more efficient at recycling air and water in deep space applications. We've learned that we'll face the challenges of the effects of radiation on the body and on hardware. Typically, large amounts of metal is the answer for protecting against an event like a solar flare, but mass and long duration deep space missions don't mix, and we'll need to develop a more efficient way to protect our Astronauts on the way to Mars.

We've learned that closing the business case for commercial involvement in low-Earth orbit has been challenging. Through the Center for the Advancement of Science in Space (CASIS) we've found that investors will spend hundreds of thousands of dollars, but we don't have the "killer app" that will stimulate the $1-2 billion it takes to fully sustain the station.

We've also learned that international involvement in the station has been a key to success. The ISS has also served as common ground for the U.S. to work closely with other nations including Canada, Japan, Russian and eleven member states from the European Space Agency. We hope to leverage those existing relationships in international partnerships as we build the bridge to deep space. The ISS also serves as a bridge for other international diplomatic discussions. As a leader and the major supporter of the ISS, the United States is in position to continue to champion a global vision for space exploration.

Commercial Low-Earth Orbit Habitats

Current U.S. policy is also examining the feasibility of deploying commercial habitats to eventually replace the capabilities currently provided by the International Space Station. While the technical difficulty of this application is well understood, estimating the commercial market growth and operating a commercial habitat profitably represent the greatest challenges. Today the ISS through CASIS is starting to reveal commercial demand for micro-gravity science applications. The current commercial utilization environment is best characterized as heavily subsidized with the government covering the large obligations including, transportation, utilities, and astronaut time. Current ISS operations requires two-thirds of the ISS budget to transport crew and cargo. At this time it is too early to make valid projections of a commercial market, yet alone predict the impacts created by the transitioning from a heavily subsidized to a commercial business model.

Why Cislunar?

On ISS we are continuously learning from maintaining complex operations and that work is informing our efforts for how we live and work in deep space. Boeing is leveraging NASA's investment, lessons learned and our experience of building, integrating and operating the ISS into how we build a habitat for deep space.

We cannot afford to leave a gap between our human presence in space, or risk losing support from interested international partners. NASA and the industry must ensure a smooth transition from a continuous human presence in low-Earth orbit to deep space.

After ISS, the next step in our journey to Mars is the cislunar proving ground. In the area around the moon we plan to establish a habitat that is essential for proving out second generation technologies in deep space like a closed-loop environmental system, solar electric propulsion technology and radiation-hardened avionics.

The cislunar proving ground ensures responsible risk management prior to a Mars mission and allows us to reduce the amount of staging for a mission outside of Earth's gravity well. The moon is close enough to return our astronauts to Earth in three to seven days in case of an emergency.

Enabling International and Commercial Partnerships

Not only does a cislunar habitat enable NASA's missions, but it opens the door to additional government and commercial partnerships. International partners and private enterprises have expressed interest in a variety of moon missions from human missions to the surface, scientific robotic missions to explore the dark side of the Moon and studies to validate the validity of future resource utilization to potentially develop oxygen, water and fuel, which may be on ramped once proven.

NASA and its international agency partners will pave the way for this future commercial utilization of the moon, however it's crucial as we focus on Mars that commercial partnership does not become part of the critical path.

At the conclusion of the proving ground missions we envision a shakeout mission that would simulate an Earth-independent Mars mission. This mission would ensure the highest probability of success and simulate the transit time from the Moon to Mars while checking out life-sustaining equipment.

Pieces to Mars

Including the cislunar habitat there are six essential pieces to get to Mars. The first two pieces, the Space Launch System and Orion are already being built, and showing great progress. Those pieces get us in and out of the Earth's gravity well.

Two more pieces are required to go between Earth and Mars; a deep space tug and a deep space transportation habitat derived from the cislunar habitat. Transportation from the Moon to Mars will be in the form of a solar electric tug that will harness the power from the sun to drive the propulsion system. The crew will live in the deep space habitat during the seven-to-eight-month transit time to Mars. We'll leave that habitat in the Martian orbit as the crew descends to the surface. That brings us to the final two pieces. The lander, which will have an inflatable heat shield, will take the crew through the Martian atmosphere and then land the crew on the surface of Mars. After the crews have completed their mission on the surface, we'll need the final piece, a small rocket to propel the crew back up through the atmosphere, back to the habitat.

All of these six pieces are feasible within projected NASA funding.

Conclusion

Somewhere in the world is a student, about ten to twenty years old, probably studying math or science--that student will be the first person to ever set foot on Mars. That's amazing to think about.

Interest in NASA's future is at a high, and the next generation is excited about deep space exploration and a human mission to Mars. Applications for the 2016 Astronaut Corps reached an all-time record of 18,300 entries. I can imagine many of those entrants dream about one day stepping foot on the Martian surface.

Today's Astronauts will prove the technologies in low-Earth Orbit and in cislunar space that the next generation will take with them to Mars.

We at The Boeing Company are a committed partner to NASA's human journey to Mars. We have a difficult journey ahead, but we're poised and excited to stand with and support NASA as they plant the first American flag on Mars.

Thank you.

BOEING

Biography

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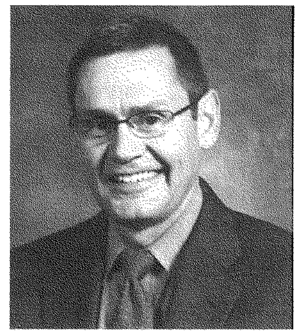

JOHN ELBON

Vice President and General Manager
Space Exploration

John Elbon is vice president and general manager, Space Exploration, a division of Boeing Defense, Space & Security at The Boeing Company. He is responsible for the strategic direction of Boeing's civil space programs, and support of NASA programs such as the International Space Station (ISS), Commercial Crew Development (CCDev) program, and the Space Launch System. He assumed his present position on August 29, 2011.

Elbon served as vice president and program manager for Boeing's Commercial Programs. In this position, Elbon managed Boeing's efforts on NASA's Commercial Crew Space Act Agreements, including the first two phases of the Commercial Crew Development program. He has leveraged innovations and capabilities from across Boeing in the development of crew transportation systems to support NASA and commercial customers in accessing destinations in Low Earth Orbit.

He has been Boeing vice president of Systems Integration for the Army's Future Combat Systems, and the Boeing program manager for several NASA programs including Constellation, ISS, and the, Checkout, Assembly & Payload Processing Services (CAPPS) contract at Kennedy Space Center.

As vice president and program manager of ISS, Elbon led Boeing in its role as prime integrating contractor for NASA's ISS contract to design, develop, test, launch and operate this orbiting facility. The multi-billion dollar contract required the coordination of several thousand Boeing employees in five major locations as well as subcontractors and suppliers located in 23 states across the United States.

Prior to leading the ISS team, Elbon managed the CAPPS contract at Kennedy Space Center, Fla., responsible for final assembly and testing of elements of the ISS as well as other space shuttle payloads.

He holds a Bachelor of Aerospace Engineering degree from the Georgia Institute of Technology.

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December 2013

Chairman BABIN. Thank you, Mr. Elbon.

And I now recognize Ms. Sigur for five minutes to present her testimony.

TESTIMONY OF MS. WANDA SIGUR, VICE PRESIDENT AND GENERAL MANAGER, CIVIL SPACE, LOCKHEED MARTIN CORPORATION

Ms. SIGUR. Chairman Babin, Ranking Member Edwards, and Members of the Committee, I'm pleased to have the opportunity to talk with you today about the next steps to Mars.

The technologies we're building today will enable human exploration of deep space. I actually have a few slides.

[Slide.]

So this slide shows the Orion crew module. It is actually the module that we're going to use on the next exploration mission, Exploration Mission-1, to fly in 2018, and what you see here is the crew module being put into the test fixtures for the proof test. I'm pleased to say that over the last few weeks, completed the proof test. Everything passed extremely well, and not only the folks that helped build it but the analysts excited about the performance that we see.

The vehicle is different. It's a vehicle that's been designed for deep space exploration from the beginning. And what's different, of course, is that deep space is so very different from low-Earth orbit. The requirements are much more severe, and as Mr. Elbon mentioned, the focus has to be for a much longer tenure.

This is a thousand-day-plus spacecraft. The capabilities include radiation-hardened command and control systems. It provides a radiation storm shelter. There's redundancy. Recognizing how far away we are from Earth, there needs to be redundancy in propulsion systems, computers, engines and other systems. It's got an amazing computing capability. It's got what we call time-triggered ethernet that's 10 times faster than your internet at home, which is going to be required for passing files, for passing videos and information. It's got a life support system. The life support system accommodates exercise and it accommodates all those things necessary for those long missions. It's got a thermal protection system that not only accommodates the extremely cold environments of deep space but allows for safe landing whether the mission was to the Moon or Mars. So we feel that the future of the Orion spacecraft is a strong one.

I don't know how many of you remember EFT–1. That was the exploration flight test of the Orion vehicle, the very first one in 2014. We learned so much from that flight, and we are building on that success. This vehicle that you see here is 4,000 pounds lighter to accommodate the life support systems. And so with a focus on performance, affordability, recognizing that every dollar matters, we've taken a view on what technologies are necessary to allow us to lean into the future. Let's go to the next slide, please.

[Slide.]

This is not something that's new for us. Lockheed Martin has had the great privilege of being involved on every mission to the planet Mars, and as you look at the progression of a dozen-plus different missions, you'll see that we've been able to leverage the smarts of the structures, of the computing systems to provide an affordable solution to the very hard challenges that we see. Next slide, please.

[Slide.]

So that concept of building on performance and capability is one that we've leveraged into our system or habitats. In order to minimize costs and maximize crew safety, we have an inclusive view of our architectures to say wouldn't it be great if we could take advantage of all those capabilities that are inherent in the Orion system and find ways to produce a lower-cost solution. In support of NASA's NextSTEP study, we've designed a deep space habitat that does that. It leverages that investment in Orion. Next slide.

[Slide.]

Now, this is a great day. This is the day when you see the Orion and the NextSTEP habitat relying on each other's systems in order to assure overall success.

But there's more. Next slide, please.

[Slide.]

We're not stopping at habitats. By leaning forward in accommodating what tasks have to be accomplished in the schedule that's head of us, you see that leaning forward in closing on those milestones will allow us to explore NASA's vision faster. We call this Mars Base Camp.

The concept is simple: transport astronauts from Earth to a Mars orbiting science laboratory where they can perform real-time science exploration, analyze the first Martian rock, make real-time decisions while they're at the planet.

Mars is closer than you think, and we're very much interested in accelerating the journey.

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

[The prepared statement of Ms. Sigur follows:]

Statement of Ms. Wanda A. Sigur
Vice President and General Manager, Civil Space, Space Systems Company
Lockheed Martin

Before the
Subcommittee on Space
Committee on Science, Space, & Technology
U.S. House of Representatives

Hearing on "Next Steps to Mars: Deep Space Habitats"
18 May 2016

Chairman Babin, Ranking Member Edwards, and Members of the Committee, thank you for the invitation to testify today. I am pleased to have the opportunity to talk with you about the next steps to Mars.

The technologies we are building today will enable the human exploration of Mars.

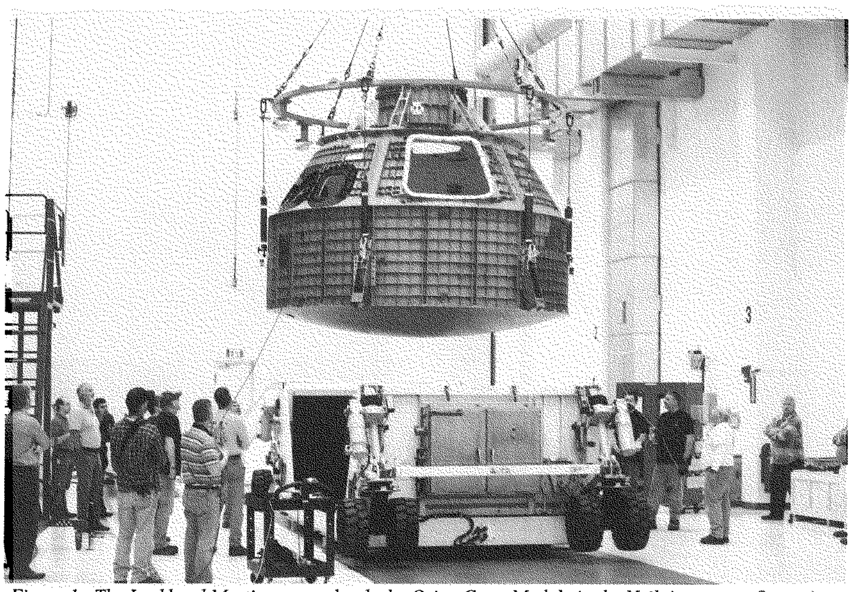

Figure 1. The Lockheed Martin team unloads the Orion Crew Module in the Neil Armstrong Operations and Checkout Building at NASA's Kennedy Space Center in Florida to begin full spacecraft assembly for the 2018 Exploration Mission-1 (EM-1).

The Orion spacecraft (Figure 1) was designed from the beginning for human exploration of deep space. The requirements for deep space, such as propulsion capability, re-entry speeds, reliability and redundancy, and the micrometeoroid and radiation environments, are much different than those for low Earth orbit and it is those requirements that have led to the development of a deep-space, human-rated spacecraft capable of missions in excess of 1,000-days. A straight shot, one way to Mars is 35 million miles – or 140,000 times farther than the International Space Station. If you're going, you want a spacecraft built for the long haul that will safely get you there and back.

For example, Orion has:

- radiation hardened avionics and a radiation storm shelter for astronaut safety;
- redundancy in propulsion, computers, and engines, which eliminate the risk of single-point failures;
- a time-triggered Ethernet that is 10 times faster than your internet at home and is capable of allowing the crew to transfer high-rate data like video, all while maintaining vehicle command and control at the same time;
- a life support system that can accommodate exercise by compensating for extra heat and moisture; and
- a thermal protection system designed to protect against the extreme cold of deep space and the extreme heat experienced when facing the sun and during re-entry.

With our own investment, we have conducted studies that verified Orion's Mars re-entry capability and verified our design meets life limit requirements on all parts of the spacecraft required to support multi-year (1,000 day) missions. As you can see, Orion is a key enabler of human Mars exploration.

The future of the Orion spacecraft is a strong one.

Our experience building and flying Exploration Flight Test-1 (EFT-1) – Orion's first flight in December 2014 – has allowed us to improve the build and test processes for Exploration Mission-1 (EM-1). We've made improvements to our factories, manufacturing processes, test schedules, and Orion's mass. For example, the EM-1 Orion spacecraft has been reduced by 4,000 pounds and the time it takes to produce the cutting-edge heat shield has been reduced by 30%. The team has also transitioned to 3-D printed drill templates to very precisely assemble the structural pieces of Orion saving more than $2 million just in the past three months, as compared to our EFT-1 process. These innovations are occurring every day making the spacecraft more affordable and easier to build, which will improve the production time and cost of future Orions.

Orion was highlighted as a flagship program for a NASA small business report noting that more than 800 small businesses from 47 states have played a role in the program's success with their innovative, efficient, and affordable solutions on everything from thermal protection to engineering and procurement services. Orion development has also provided more than 800 products to NASA's commercial crew program since 2011, including technical design data and test data and results. The innovations required for a spacecraft that will carry humans where they have never gone before is enabling future commercial opportunities and supporting the industrial base.

Our unique and extensive planetary experience (Figure 2) positions us with decades of deep space operations and expertise to apply to the human exploration of Mars.

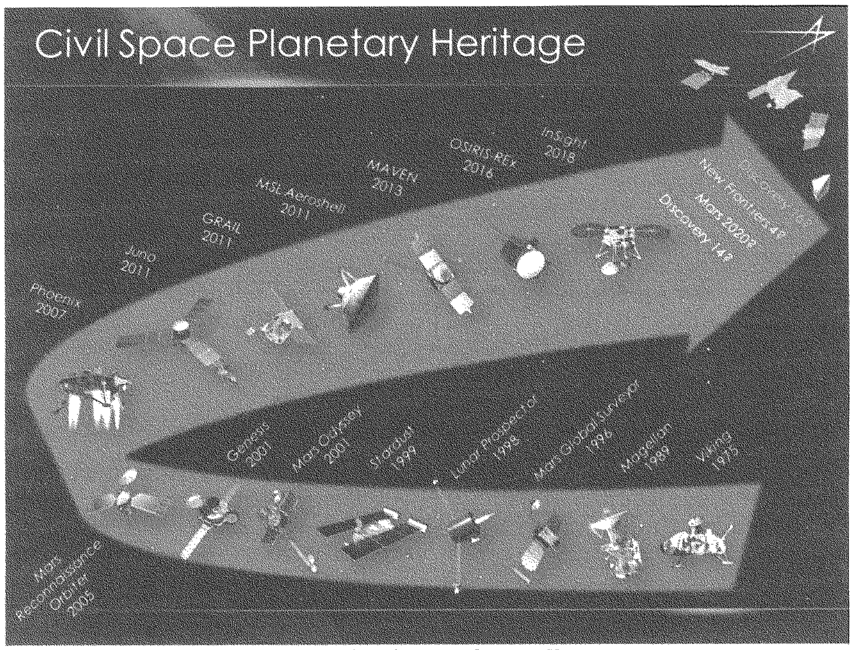

Figure 2. Lockheed Martin Planetary Heritage.

We are currently operating five NASA missions (Spitzer Space Telescope, Juno, Mars Odyssey, Mars Reconnaissance Orbiter (MRO), and MAVEN) from our Mission Support Area at our Waterton Campus in Colorado, as well as operating the Hubble Space Telescope from Greenbelt, Maryland. Notably, we have been continuously operating assets at Mars for almost 20 years. Engineers come into our Colorado operations facility every day taking science measurements, relaying data, and scouting for future landing sites. The question is not "When are we going to Mars?" We are already there. The question is when will we take that next step to get our scientists and engineers out of the office and on their way to Mars as astronauts?

Lockheed Martin has been supporting NASA in the exploration of Mars since the Mariner and Viking Missions of the 1970s – and on every single U.S. Mars mission since. We have competitively won roles on NASA's Mars missions by providing the best return for the dollar while ensuring the highest probability for mission success. We have done this by making internal investments in landing technologies, remote operations, and onboard spacecraft autonomy to ensure that we continue to be the industry leader in deep space missions.

Since 2000, we have built and launched nine successful spacecraft beyond Earth's orbit while helping to land three more on the surface of Mars. We have two more in development with OSIRIS-REx set to launch in September 2016 and InSight scheduled for May 2018.

InSight – NASA's next mission to Mars – will land a spacecraft on Mars that employs decades of our deep space exploration experience. InSight will study Mars' seismic activity to help us understand the formation, composition, and evolution of rocky planets in the inner solar system. Insight will also measure the sub-surface temperature improving our knowledge of the planet's history, ability to foster life – past or present – and inform us on possible future human habitability.

We're not just working on the here-and-now; we're planning ahead and looking at long-term, viable solutions for the future.

In support of NASA's NextSTEP study contract, we're designing a deep space habitat (Figure 3) that leverages the investment and advanced technology in Orion—technology that is already being designed and built today for deep space. For this Phase I of NextSTEP, the habitat is designed for the "proving ground" in cis-lunar space (Figure 4), or the area around the moon, as a transitional step from low Earth orbit to Mars.

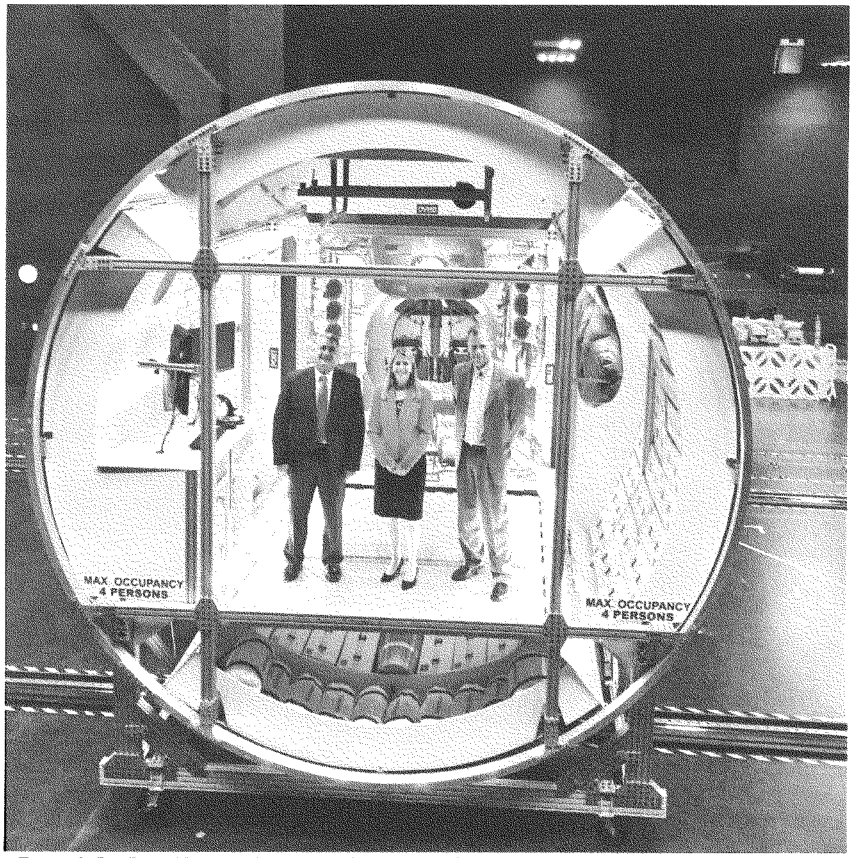

Figure 3. Dr. Dava Newman (center), NASA Deputy Administrator, in a mock-up of Lockheed Martin's cis-lunar habitat at the Lockheed Martin Waterton Campus in Colorado.

By leveraging the functionality already available within Orion, such as power-coupling, communications, radiation protection, and life support systems, we can absolutely reduce the complexity of the habitat and increase its affordability.

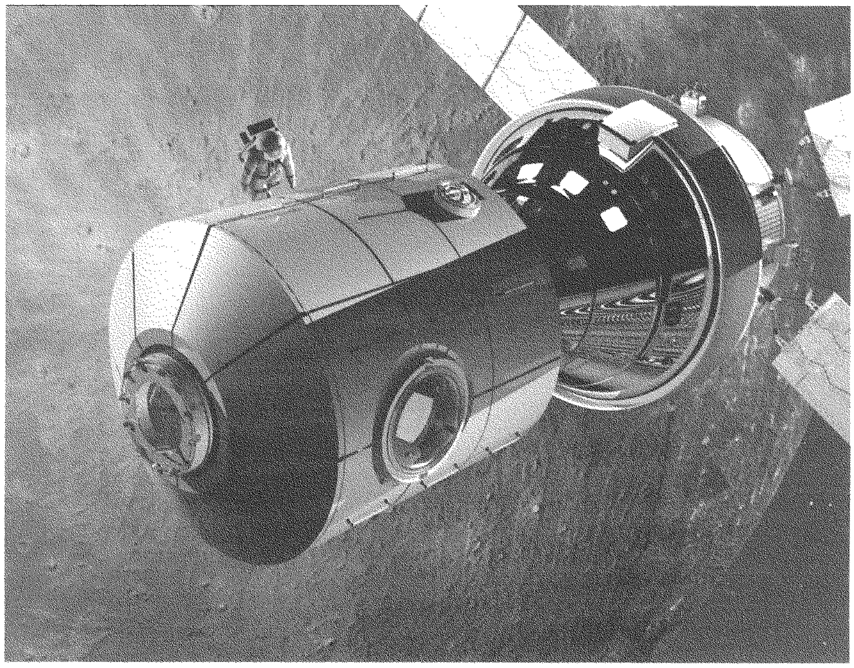

Figure 4. Proving Grounds: Orion and the NextSTEP habitat in the cis-lunar proving ground – the next step from low Earth orbit on the way to Mars.

We know that habitats are essential for exploration of the outer bounds of space. We're leveraging our extensive deep space experience and working on concepts that we can continue to build on, adding functionality as needed, and support specific mission requirements as they evolve.

We're not stopping at habitats though.

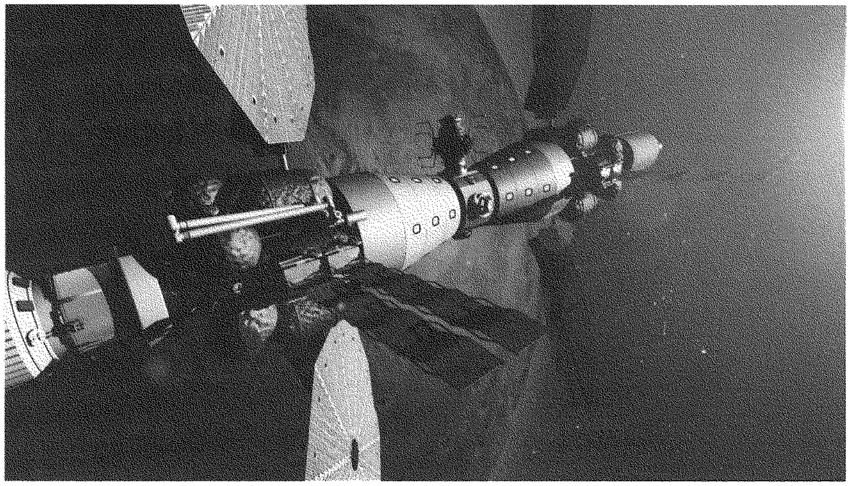

Figure 5. Humanity Becomes an Interplanetary Species: Artist's rendition of the Mars Base Camp architecture in Martian orbit. By leveraging developed technologies and the taxpayers' investment in SLS and Orion, Lockheed Martin believes a human science Mission to Mars is feasible by 2028.

We have plans to then build upon the systems in-work today to achieve the earliest, most affordable approach for sending humans to Mars - we call this Mars Base Camp and we think we can do it by 2028 (Figure 5).

The concept is simple: transport astronauts from Earth to a Mars-orbiting science laboratory where they can perform real-time scientific exploration, analyze Martian rock and soil samples, and confirm the ideal place to land humans on the surface.

Since before the first Viking lander touched down on Mars 40 years ago, humanity has been fascinated with the Red Planet. Lockheed Martin built NASA's first Mars lander and has been a part of every single NASA Mars mission since.

We're looking forward to humanity's next giant leap and to answering the Big 3 Science Questions: Where did we come from? Where are we going? Are we alone?

Mars is closer than you think. And at Lockheed Martin we're very ready to accelerate the journey.

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

LOCKHEED MARTIN

Wanda A. Sigur
Vice President and General Manager
Civil Space Space Systems Company
Lockheed Martin

Wanda A. Sigur is Vice President and General Manager of the Civil Space line of business for Lockheed Martin Corporation's Space Systems Company. In this role, she is responsible for all elements of Civil Space within Space Systems. She has executive responsibility for national space programs relating to human space flight and space science missions, including planetary, solar, astrophysical and Earth remote sensing for civil government agencies. These programs include Orion spacecraft, Hubble and Spitzer space telescopes, GOES-R weather satellites, InSight, OSIRIS-REx, Juno, MAVEN, Mars Reconnaissance Orbiter and Mars Odyssey planetary missions, and nuclear space power programs. Ms. Sigur is also responsible for Michoud Operations and related activity at Stennis Space Center.

Her previous leadership roles at SSC include Vice President and Deputy of Civil Space, Vice President of Engineering and Vice President and Program Manager of the Space Shuttle External Tank Program at NASA's Michoud Assembly Facility in New Orleans, La. As Vice President of Engineering, she was responsible for leading the Corporation's Space Systems engineering personnel development, engineering process development and deployment, engineering tools and training, and product technical validation, with emphasis on ensuring operational excellence and first-time-right engineering.

As Vice President of the Space Shuttle External Tank Program, Ms. Sigur was responsible for all aspects of the build, delivery, design enhancement and flight of the large cryogenic system, the largest element and structural backbone of the Space Shuttle. In that role, she also served as the Lockheed Martin External Tank Lead on the Columbia Accident Investigation.

Ms. Sigur has a Bachelor of Science degree in Mechanical Engineering and Materials Sciences from Rice University. She is also a Beta Gamma Sigma honors graduate with an MBA from Tulane University.

She served on the Board of Directors for the National Defense Industrial Association and has received numerous awards; including the Black Engineer of the Year award for Career Achievement, the Rotary National Award for Space Achievement Stellar Award, the National Space Club award for Manned Space Flight and Outstanding Rice University Engineering Alumnus. New Orleans City Business named her one of the "Women of the Year."

Chairman BABIN. Thank you, Ms. Sigur.

I now recognize Mr. Culbertson for five minutes to present his testimony.

TESTIMONY OF MR. FRANK CULBERTSON, PRESIDENT, SPACE SYSTEMS GROUP, ORBITAL ATK

Mr. CULBERTSON. Thank you, sir. Do we have time with the——

Chairman BABIN. We do. We're going to try to get through both you and Mr. Weir, and then we're going to recess to go vote, and we'll come immediately back, okay? So let's go ahead.

Mr. CULBERTSON. Good afternoon, Mr. Chairman and Ranking Member Edwards, Mr. Chairman Smith, distinguished Members of the Subcommittee and the staff. It's a real honor for me to be here. I appreciate the opportunity to testify before you on behalf of Orbital ATK regarding our concept for deep space habitat as a part of the long-term path to Mars exploration.

The Committee leadership has framed the issues very well, I think, in your opening remarks, and I think my colleagues have done a good job of talking about the things that are going to be a challenge for us and how we might be able to move forward on that. It's an exciting and inspiring time for our Nation's human space exploration program. NASA is on course to send humans beyond low-Earth orbit, leveraging what we're doing on the ISS, Commercial Crew and Cargo programs, as well as the Space Launch System, Orion, and the new cislunar habitat that is being proposed and studied.

We want to achieve the goal of landing humans on Mars in the early 2030s, and we're proud to be supporting our NASA customer every step of the way.

I think that U.S. leadership in cislunar space is critical to continue the leadership we have had for a long time in space in general. It is the high ground but it also is a great example of what we can do as Americans, and it inspires the next generation and gives them a place to go.

By combining the new NASA and commercial space sector capabilities such as on SLS, Orion, Cygnus, we can develop a deep space habitat and high-power solar electric propulsion, two of the building blocks for moving on to Mars.

We think a crew-tended lunar orbital station within the next five years is doable, feasible, and something that we should be working towards.

Orbital ATK is a global leader in aerospace and defense technologies. We have delivered a lot of satellites. We have numbers in here, and they're in my testimony. We have over 1,300 successful years of on-orbit satellite experience, 268 human-rated boosters, and we are building the boosters for the SLS program. We have 91 satellites currently operating in space, and we're continuing to collaborate with NASA and our other customers.

But we do think it's important to transition beyond low-Earth orbit and to do that soon. The commercial approach that we've used to develop the Commercial Cargo Resupply Service we think is a good model for that. I think it'll be a combination of government programs, public-private partnership, and commercial endeavors in order to achieve this. We think that cislunar space does give us the testing ground.

For my colleague, Mr. Bridenstine, who was here earlier, it's like a shakedown cruise. You've got to go out and test what you've got before you go and do it for real operationally, and I think this gives us the opportunity to do that.

If I can have my first slide, please?

[Slide.]

This is an artist's conception of the cislunar habitat based on the Cygnus module that we used for delivering cargo to the International Space Station. We think it's a great starting point, one that's already mature and developed and actually on the Space Station right now and will finish a 90-day mission in June. So it can be developed to go beyond low-Earth orbit. Next picture, please.

[Slide.]

Here's a good picture of the Cygnus itself at the Space Station, and the next slide, it's a crew selfie, if you will, of the interior of that module once we delivered the cargo to the crew, which always is a good day for them. This arrived on Easter, so they were looking for the Easter eggs. But we're happy to be able to support that. We think that Cygnus provides the technology reduction needed to move into cislunar because there will be challenges there. There will be things that we have to overcome there that are going to challenge us on the way to Mars including the radiation environment, the autonomous operations that are necessary for such a long trip. We're already using Cygnus for technology development, and at the end of this current mission, we will activate the Spacecraft Fire Experiment, or SAFFIRE–1, during free flight as we leave the station to generate the largest fire ever generated manmade in space to see how things burn in space, and we know how they burn on Mars now, Andy, but I think this'll be a great experiment to enhance the safety of the crew going forward.

Commercial acquisition practices are important and will be a part of it. I think that encouraging business to move into low-Earth orbit on a much more comprehensive basis is part of what's happening right now with Commercial Cargo, Commercial Crew, and then moving beyond that is a challenge we're going to have to meet but we think that it will come also. Obviously humans in space is the big key.

Let me just mention something one of my kids said when I was training for the Space Station, and I won't embarrass him by telling you which one. When I was putting him to bed one night, he said, "You know, Dad, you're getting pretty old," and he wasn't even a teenager yet, and I said, "What's your point?" He said, "Well, I know you wanted to go to Mars when you became an astronaut but it's probably not going to happen while you're active. So I'll tell you what, I'll go for you." Well, he's in his 20s now, and his generation is going to go for me. And by the way I said, "Well, you know, John Glenn flew at 77 so don't write me off yet."

I would love to go to Mars, and I would do it. I think that we are doing at Orbital ATK and our colleagues throughout industry, working with NASA to move into this realm, is very, very important and critical to U.S. leadership and critical to inspiring the next generation to stay involved, to get into science, technology, engineering and math, and keep this country great.

Thank you very much. I look forward to your questions.

[The prepared statement of Mr. Culbertson follows:]

Statement

Of

Frank L. Culbertson, Jr

President, Space Systems Group

Orbital ATK

Before the

House Committee on Science, Space and Technology

Subcommittee on Space

May 18, 2016

Good Morning, Chairman Babin, Ranking Member Edwards, and distinguished Members of the Subcommittee and Staff. I appreciate this opportunity to testify before you on behalf of Orbital ATK regarding our concept for a deep space habitat as part of a long term path to Mars exploration.

This is an exciting and inspiring time for our nation's human space exploration program. NASA is on course to send humans beyond low earth orbit leveraging the current International Space Station (ISS), Commercial Crew and Cargo programs, as well as the Space Launch System (SLS), Orion and the new cislunar habitat, to achieve the goal of landing humans on Mars in 2033. Orbital ATK is proud to be supporting our NASA customer every step of the way.

Orbital ATK Introduction

Orbital ATK is a global leader in aerospace and defense technologies. We design, build and deliver space, defense and aviation systems for customers around the world, both as a prime contractor and as a merchant supplier. Our spacecraft operate in low earth orbit, geosynchronous orbit and in deep space. Our Cygnus spacecraft has "human-rated" features required to rendezvous and berth with the International Space Station. The OA-6 Cygnus spacecraft is currently berthed to ISS, and will remain there until June 14, spending over 90 days on-orbit, providing vital supplies to the astronauts on board and conducting important scientific research in microgravity.

Our space launch vehicles support a range of missions for commercial, civil government, and national security customers. We are a prime contractor for the NASA SLS, building the world's largest solid rocket boosters that will launch the Orion spacecraft beyond low earth orbit to cislunar habitats and eventually to Mars.

Over its history, Orbital ATK has built and launched 174 satellites, 71 space launch vehicles, 268 human-rated boosters, and more than 1300 strap-on boosters. Today we have over 1346 successful years of on-orbit satellite experience, and there are currently 91 of our satellites in operating in space. Orbital ATK is committed to continuing its collaboration with NASA to transition our knowledge base into a safe and cost effective solution for cislunar habitation.

Transition to Beyond Low Earth Orbit

NASA's next major milestone on the path toward deep space exploration is the unmanned launch of Orion atop the SLS for Exploration Mission-1 in 2018. In 2021, a crewed Orion spacecraft will be launched to cislunar space. Following these missions, the SLS and Orion will conduct increasingly ambitious missions throughout the proving ground of cislunar space. In order to increase stay times in cislunar space and accommodate a range of technology demonstrations and scientific experiments, additional habitat space and consumables are necessary. A habitat in cislunar space can be accomplished at relatively modest cost by leveraging NASA, U.S. commercial and international resources. The experience gained in the cislunar proving ground will lead directly to longer mission durations in deep space and eventually enable a manned mission to Mars.

The roadmap to human Mars exploration has been studied by many organizations, including NASA, the International Cooperation Mission (ICM), and the International Space Exploration Coordination Group (ISECG). All groups concluded that the next step beyond low earth orbit is a habitat in the vicinity of the moon, called cislunar. The key feature of the cislunar proving ground is that it provides the experience of operating independent of Earth. Currently, if there is an emergency aboard ISS, astronauts can return to Earth in a matter of hours. Returning from cislunar space requires days, in the best case, and provides an effective proving ground for Mars missions that will require autonomy from Earth for months to years.

More recently, Orbital ATK was selected to study an initial version of a cislunar habitat that could evolve over time to a much larger habitat with capabilities for a human mission to Mars. These studies fall under NASA's Next STEP Phase 1. Figure 1 shows a cislunar habitat concept from our Next STEP study. The earliest variant of a cislunar habitat should be as simple and cost effective as possible and augment the capability of the Orion capsule to achieve missions of 60 days in deep space. A very good starting point for the design of a cislunar habitat is the Orbital ATK Cygnus spacecraft. Cygnus (shown in Figure 2) is a flexible design that meets the human-rating design requirements of the ISS. Figure 3 shows Cygnus on-orbit with the ISS crew inside the module. Our cislunar habitat design incorporates all of the lessons learned" from delivering cargo to ISS.

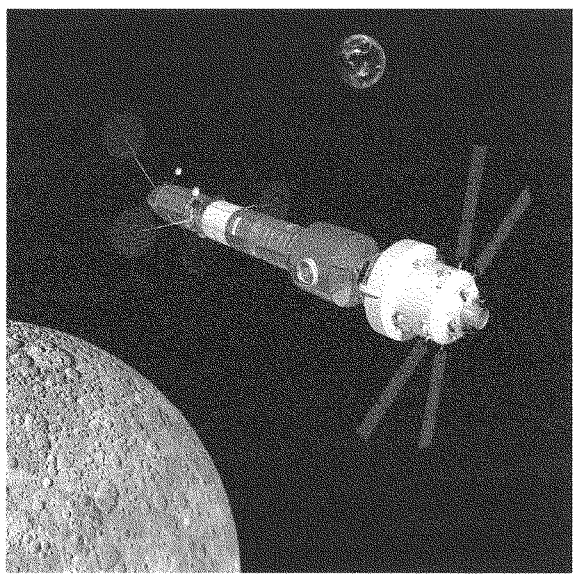

Figure 1: Orbital ATK Concept of a Cislunar Habitat

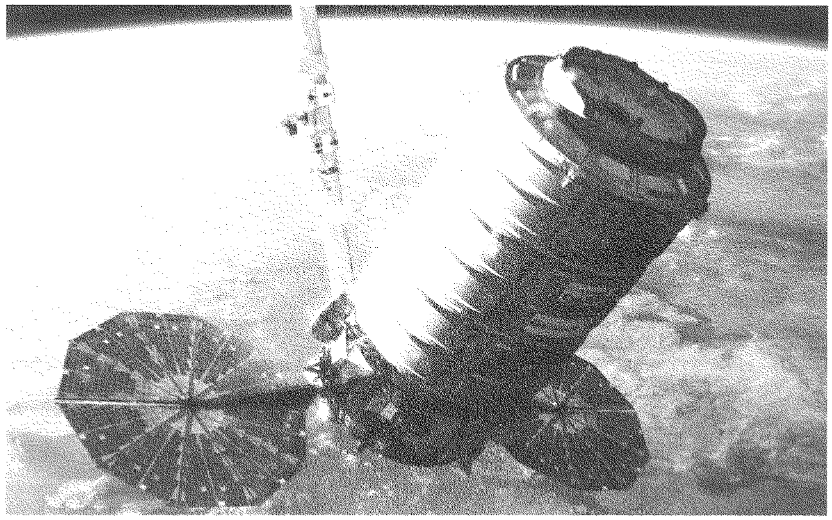

Figure 2: Cygnus Cargo Vehicle

Figure 3: Human Rated Cygnus with the Space Station Crew inside

Technology Risk Reduction Using Cygnus and ISS

Cygnus and the ISS will play integral roles in establishing a cislunar habitat. Cygnus has regular flights to the ISS scheduled over the next eight years. Technology demonstrations of subsystems intended eventually for deep space, and new science instruments can all be flown in test mode as part of a Cygnus cargo mission to the ISS. The first technology demonstration is currently on-orbit on the OA-6 Cygnus. Following its departure from the ISS, Cygnus will conduct the Spacecraft Fire Experiment-I (SAFFIRE-I), designed by the Glenn Research Center, that will intentionally light a large-scale fire in the Cygnus' Pressurized Cargo Module. SAFFIRE will be the largest man-made fire ever in space. Up until now, NASA could only conduct small combustion experiments in the microgravity environment of the ISS. Fire on a space station is one of the most significant dangers to astronauts. The SAFFIRE experiment will enable NASA to investigate fire detection, advanced fire extinguishing methods, and post-fire clean up.

This type of technology demonstration and scientific experimentation will be vital for the development of systems that will eventually fly to Mars. Testing them on existing operational systems such as Cygnus can be done at a much lower cost than on dedicated missions.

Commercial Acquisition Practices

The implementation of a cislunar habitat is a good opportunity to apply commercial acquisition practices and commercial development standards. This approach worked well under the NASA Commercial Resupply Services contract, resulting in the government having two operational systems operated by two different companies. The emphasis on services, instead of hardware, and the use of commercial development technical standards and contracting saved the government substantial costs.

International Collaboration

A cislunar habitat is integral part to the U.S. government's overall plans for space exploration. Operations in the cislunar proving ground will be international in nature. The habitat could be a focal point for additional space systems provided by other nations. For example, an international partner could develop and provide a lunar lander compatible with docking at the cislunar habitat. From this central node, robotic lunar surface exploration could be accomplished. Early missions could lay out a sensitive radio astronomy antenna on the radio quiet far side of the moon. Other missions could search for water at the lunar South Pole – Aitken impact basin. Lunar samples could be returned to the habitat and from there on to Earth. This operations concept could be applied to a Mars mission where initially a manned outpost on a moon of Mars (Phobos or Diemos) could teleoperate a rover on the surface of Mars. These are just a couple of examples of how international cooperation could significantly expand capabilities developed for cislunar and beyond.

Human Research in Deep Space

As an astronaut who lived aboard the ISS myself, I am particularly interested in Human Research beyond Low Earth Orbit. The environment in deep space is different than on the Earth or at the International Space Station. Trips to the moon or Mars take us beyond the protective Magnetosphere that deflects much of the galactic and solar radiation. A cislunar habitat is a perfect location to both characterize the radiation environment and determine effects on humans. We can also study possible mitigation. This is a high priority for long duration deep space missions.

Commercial Role/Market for Cislunar Habitats

The non-government/commercial market for the cislunar proving ground is speculative in the near term. Many of the applications that require a space environment could more efficiently be accomplished in low earth orbit. There are certainly some activities that would involve utilization of the resources of the lunar surface, but may be too risky for private industry to take on without first establishing a basic transportation and habitation infrastructure funded by the government.

Conclusion

I believe NASA is following congressional guidance contained in the NASA Reauthorization Acts and is pursuing the human to Mars option. It is important that Congress continue robust funding to allow NASA to focus its attention, capabilities and resources on the Mars goal. NASA is developing a plan to achieve that goal, putting into place the critical pieces of an architecture and defining precursor missions, including the cislunar habitats we are discussing today.

Human exploration of Mars can be accomplished and my presentation today lays out a methodical, affordable approach to a new level of national and commercial achievement in deep space. NASA has designated cislunar space the "Proving Ground" for a good reason. Many aspects of operations in deep space are as yet untested and confidence must be developed through repeated flights to cislunar space. This complex, multi-decade approach to space exploration will bring out the best in our nation. Orbital ATK continues to operate our Cygnus cargo resupply vehicle as a flagship product. We are ready to quickly and affordably implement a habitat in cislunar space based on the flight proven heritage of the Cygnus spacecraft. But more than anything else, Orbital ATK is ready to be a partner in this adventure called Deep Space Exploration.

Thank you.

Orbital ATK

Frank L. Culbertson, Jr.

President, Space Systems Group

Frank L. Culbertson, Jr. is President of Orbital ATK's Space Systems Group. Orbital ATK is a global leader in aerospace and defense technologies, with annual revenues of approximately $4.5 billion and a workforce of more than 12,000 people. The company designs, builds and delivers space, defense and aviation-related systems for customers around the globe, both as a prime contractor and merchant supplier.

Mr. Culbertson is responsible for the execution, business development and financial performance of the company's human spaceflight, science, commercial communications and national security satellite activities, as well as Technical Services to various government customers. These include some of Orbital's largest and most important programs such as NASA's Commercial Resupply Services (CRS) initiatives as well as various national security-related programs.

Previously, Mr. Culbertson served as Executive Vice President and General Manager of the Advanced Programs Group at the Orbital Sciences Corp. Prior to joining Orbital, Mr. Culbertson was a Senior Vice President at SAIC, following an eighteen-year career as a NASA astronaut. He has flown three space missions and logged over 144 days in space as shuttle commander, pilot, and station commander. His last mission launched on the Shuttle Discovery and lasted for 129 days, from August 10 until December 17, 2001, returning on the shuttle Endeavour. During that mission, he and his two Russian crewmates, lived and worked aboard the International Space Station for 125 days which included observing the attacks of September 11, 2001, as the only American in orbit at the time. Mr. Culbertson also held several key management positions within the NASA Shuttle and ISS programs and was Program Manager of the Shuttle-Mir Program.

Mr. Culbertson is a 1971 graduate of the US Naval Academy at Annapolis. He was a naval aviator, a fighter pilot, and a test pilot, and he retired from the Navy as a Captain in 1997. Mr. Culbertson has received numerous honors, including the Legion of Merit, the Navy Flying Cross, the Defense Superior Service Medal, the NAA/FAI Gagarin Gold Medal, and the NASA Distinguished Service Medal.

Chairman BABIN. Thank you, Mr. Culbertson.

Mr. Weir, I am deeply apologetic but I've just been told most of our members have already run to vote. They've already called for votes. If you don't mind, we'll come back as soon as the voting is over and reconvene. Is that okay with you?

Mr. WEIR. Sure, that works for me.

Chairman BABIN. All right.

Mr. CULBERTSON. Do you want him to put a helmet on or hold his breath?

Chairman BABIN. We will reconvene following the last vote in this series, and you don't have to have a helmet.

[Recess.]

Chairman BABIN. I now reconvene this session of the Subcommittee on Space, and I apologize. We had to run down and vote. But that's the nature of the beast here in the United States Congress.

I now recognize Mr. Andy Weir for five minutes to present his testimony.

TESTIMONY OF MR. ANDY WEIR, AUTHOR, THE MARTIAN

Mr. WEIR. Mr. Chairman, Members of the Subcommittee, thank you for inviting me to this hearing.

Unlike the other people you've heard today, I am not a space expert. I'm just an enthusiast, and I know that. But I do spend a lot of time thinking about the future of manned spaceflight and the challenges that come with it. And, to me, one issue stands out as the largest problem facing long-term space habitation. The human body is simply not suited to living for long periods in zero-g. Until this issue is solved, we have no hope of landing humans on the surface of Mars, nor can we create permanent residences in space.

Astronauts who spend months in zero-g suffer bone loss and muscle degradation. Once they return to earth, they have to be carried out of their capsule by ground crew. It takes days, sometimes weeks for them to readapt to gravity because their muscles are simply too weak to stand. Imagine, then, a crew of astronauts setting foot on the surface of Mars after eight months in space to get there. They would be unable to move, let alone execute their mission. This is not an option.

And that's not even the worst part. Weightlessness also causes degradation of the eyes, and, unlike the bone and muscle loss which the body will repair once it returns to gravity, the eye damage is permanent and irreversible.

Astronauts aboard the International Space Station have to spend two hours per day exercising just to stay remotely healthy. This means that we dedicate one eighth of all waking person-hours in space to counteracting the effects of zero-g habitation. That time could be better spent on experiments, station upkeep, or simply rest for the crew.

Instead of concentrating on ameliorating the effects of zero-g, we should concentrate on inventing artificial gravity. This is not some magical technology straight out of science fiction. We already know how to do it. You just need to spin the space station to provide centripetal force. This conjures up images of huge wheel-in-space constructions that we simply can't afford to build but centripetal gravity can be accomplished much more cheaply and easily than the flashy futuristic visions you've see in films.

For our next space station, we should have the crew compartment connected to a counterweight by a long cable and set the entire system spinning. This creates the centrifuge, which will generate constant outward force for the crew. Inside the crew compartment, it would be virtually identical to the gravity we experience on Earth. All physiological problems of zero-g would be solved.

Some would argue that one of the main purposes of a space station is to do experiments in zero-g. This is easily accommodated. We could have a node in the center. This would provide an area of zero-g for whatever experiments require it. The astronauts would work in there as needed, but spend most of their time in the crew node where their bodies get the gravity they need to remain healthy.

While the concept is simple, the engineering is very complex. If you were standing in that crew compartment, the downward force on your head would be less than the downward force on your feet because your head is closer to the center of the centrifuge than your feet are. NASA conducted experiments on the ground with centrifuges in the 1960s. They found that humans get significant vertigo and dizziness from this effect if the rotation rate is faster than two revolutions per minute. I'll spare you the math, but this means the cable connecting the two nodes would have to be 450 meters long, which is over a quarter mile.

I have no delusions that such a station would be easy to accomplish. Not only would it be the most massive space station ever built, but it would also have to stand up to the forces that its own artificial gravity creates. Plus, a rotating station would need very advanced control systems to keep its solar panels and thermal radiators properly aligned. It would be a huge engineering challenge to design and implement this station but huge engineering challenges are what NASA is all about. I have no doubt they could rise to the occasion.

Once this station were built, its rotation rate could be adjusted to provide whatever gravity we wanted. We could test the long-term health effects of lunar gravity or Martian gravity, or we could leave it at Earth gravity to ensure crew health. And when the time comes for a human mission to Mars, the artificial gravity technology proven by this station will be employed in the vehicle that transports the astronauts there, ensuring that they are fully healthy and capable when they first set foot on the red planet.

Thank you, and I'd be happy to answer any questions.

[The prepared statement of Mr. Weir follows:]

Address to House Committee on Science, Space, and Technology

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And when the time comes for a human mission to Mars, the artificial gravity technology proven by this station will be employed in the vehicle that transports the astronauts there, ensuring that they are fully healthy and capable when they first set foot on the red planet.

Thank you.

Andy Weir was first hired as a programmer for a national laboratory at age fifteen and has been working as a software engineer ever since. He is also a lifelong space nerd and a devoted hobbyist of subjects like relativistic physics, orbital mechanics, and the history of manned spaceflight. The Martian is his first novel.

Chairman BABIN. Thank you, Mr. Weir. I appreciate that. I appreciate all the testimonies, and we're elated and delighted that all of you people are here to testify before us. Now the Chair recognizes himself for five minutes.

All of the testimony was fascinating, especially what Mr. Weir just said on centrifugal force and spinning creating artificial gravity. But another problem when we send our astronauts beyond low-Earth orbit is we're exposing them to the dangers of deep space radiation, and without the Earth's protective magnetic field, future explorers are vulnerable to ionizing radiation, solar particle events and galactic cosmic rays, which pose an increased risk for cancer. This is perhaps the most serious scientific challenge that we face on the journey to Mars. And I'm wondering how we protected Matt Damon that entire time from this radiation and had him return safely.

This is a question for all of you. What kinds of technologies are being developed that protect our astronauts from deep space radiation? What are some of the ideas? How are we integrating radiation protection into our deep space habitation designs? And I would appreciate an answer from any one of you or all of you.

Mr. CRUSAN. So I'll start. Currently, we're doing investments in a couple different areas. First and foremost, the monitoring of events starting with our heliophysics efforts of monitoring the sun on an ongoing basis, then actually figuring out the modeling effects of the transfer from the sun into wherever our spacecraft should be, and then actually doing high-quality monitoring of the actual radiation particles that come when they get there.

All of our studies internal and the ones we're doing under the NextSTEP analysis as well with the commercial folks are looking at optimizing the ability for storm shelters and deployable storm shelters and the integration of things like water walls into crew quarters and such. That helps with your SPE events and such. Galactic cosmic rays are still a challenge, and there isn't any current technology to address the high-energy GCR beyond the ability to monitor it and factor it in the overall dosing that we have, and I'll leave it to my colleagues to add to that.

Chairman BABIN. Thank you, Mr. Crusan.

Mr. Culbertson?

Mr. CULBERTSON. Yes, sir. My personal experience was that NASA spends a lot of time investigating what's happening to the astronauts both while they're in space and after they return. We go through an annual physical to see whether there are any residual effects, and the effects that Mr. Weir talked about are there and real, and we do do a lot of exercising and other countermeasures.

The radiation aspect is a serious one too, and when you leave, as you said, the magnetosphere, you're exposed to it much more, and the types of technologies that Jason mentioned such as water protection, there's also PVC. People are working on actually superconductivity as a potential way of protecting the crew inside. But I think if we use the opportunity to go to cislunar space and when we first have a module arrive, have enough sensors on there to really characterize the interior of what the crew might be exposed to when they arrive later, then we might be better prepared, and of course, we start with the short missions there and investigate the effects on the crew before we actually send them on their long voyages. I think we'll learn a lot. I do think we will figure out a way to counter those. I don't think it's impossible.

Chairman BABIN. Same here.

Mr. Weir?

Mr. WEIR. Yeah, I'll just speak to that a little bit. First off, NASA recently upped its acceptable radiation lifetime limit for astronauts in the event that these astronauts were going to the Moon. So first off, a lot of this, believe it or not, is solved by a simple policy decision. A very, very diligent fan sent me a paper that he wrote and later got published about the radiation dosage received by all of the members of the Aries program including Mr. Watney on the surface of Mars, and actually found that the worst of them would have had an additional four percent mortality likelihood, and that would've been actually the sys op, Beth Johanssen, played by Kate Mara in the movie. She would've had the highest mortality odds added to her because while Mark was on Mars and Mars was guarding him from half of the galactic radiation that might be getting at him, the rest of the crew were in space that entire time, and Johanssen is the youngest and she's female, both of which are things that increase your mortality likelihood from radiation.

But just to be clear, we're not talking about people dying of horrendous radiation sickness. We're talking about a slight increase in mortality, and astronauts are willing to take risks, so on the surface of it, I don't think that much needs to be done at all, and then finally, the best way to deal with radiation amelioration is mass, just putting water between the astronauts and the sources of radiation and getting more mass to LEO. If you want to do that, put more money into private space travel. They'll drive the price down.

Chairman BABIN. Amen.

I think that expends my—unless either one of you would like to add to that?

Mr. ELBON. I think they covered it. The best solutions that we know of take a lot of weight so we have to work through that whole scenario.

Chairman BABIN. Right.

Ms. SIGUR. I have very little to add, only that we're going to get smarter the very first mission that we make. Exploration Mission-1 will have sensors and information that we'll be able to use to figure out which of these potential solutions makes sense for us. We're also looking at individual protection strategies for astronauts, and that might also be something that would be fruitful as we go forward. So there's more to come.

Chairman BABIN. You bet. Thank you, Ms. Sigur.

You know, I've got a couple of staffers in here I wanted to introduce real quick, Will Carter and Lauren Jones, and also my wife, Roxanne, is sitting back there. I just noticed them there. Thank you for being here.

I'd next like to hear from the gentlewoman from Maryland, Ms. Edwards.

Ms. EDWARDS. Thank you, Mr. Chairman, and thank you for the witnesses too and for your patience.

I want to begin with Mr. Crusan. NASA's Journey to Mars strategy outlines the plans to develop an initial habitation capability for short-duration missions in cislunar space in the early 2020s and then to evolve that capability over some period of time, and I guess the question is whether NASA intends to accomplish that with habitation demonstrations in cislunar and what would be needed to extend those capabilities to a habitat that could support a human mission to Mars. And additionally, if you could address the question of whether you envision testing out multiple habitat developments or a single habitat. These are all details, frankly, that we should be getting to in a more complex roadmap that the Congress has asked for over some period of time, but if you could address that, I'd appreciate it.

Mr. CRUSAN. Yes, no problem. I appreciate the question. One of the key aspects of what we're asking for in our NextSTEP activities with industry is exactly that. We know we need to get to a habitable volume for a transit to and from Mars that's greater than 300 cubic meters in volume. There's many different strategies by which you get to that total volume, though. You could launch it as a one single unit on one single flight. You could incrementally build it over a series of modules during the early 2020s out to the late 2020s. And one of the things we're asking industry to do is help us optimize, how do you split up the individual buildout pieces over that period of time that gets us to the end goal, the larger volume we need, that also still encourages that LEO transition as well, and looking for the optimal piece parts that you would actually come up with for that.

That gets to your second question, is it going to one habitat or multiple habitats. It could be either. We know we need to get to that total volume. One of the lessons learned that we have learned related to the International Space Station and Mir before that is separate habitable volumes is actually extremely valuable for us for the event of emergencies like fire and depressurization. So there will be some semblance of multiple structures that are assembled together that can be isolated from a safety perspective but the actual implementation strategy is what we're exactly studying during this phase of NextSTEP.

Ms. EDWARDS. Mr. Elbon and Ms. Sigur and Mr. Culbertson?

Mr. ELBON. I would add a thought to that. I think it is a critical and important thing that we develop a habitat capability in cislunar that is evolvable to be the Mars transit capability. That means that it's going to need to grow and become more robust as it takes on that larger mission. To some degree, that's counter to moving the other way, which is bringing that habitat down to low-Earth orbit. I'll use an example. When we started the development of the Starliner, the commercial capsule, the first requirement I wrote across the top of the board was, it will go nowhere but LEO, and the reason was, because if we let things creep in there that would have it a beyond LEO, it would increase the costs and it wouldn't be a good thin got operate in a commercial environment.

So I think there's a little bit of a tension there between expecting whatever we put in cislunar to go on to Mars and also be able to serve as a basis for a future LEO station, and it's important that we consider that and work through it as we address a procurement approach for that cislunar capability.

Ms. EDWARDS. Thank you.

Ms. Sigur?

Ms. SIGUR. I think that as Mr. Crusan said, we're in the process of developing the elements of what the solution needs to be, but what I would offer is that what our ultimate objectives and goals are matter. If we are working on an opportunity to perform test like you fly assessments at each of the opportunities that are available whether it's low-Earth orbit or around the Moon with an eventual objective to head to Mars, solutions are going to be vastly different. If we acknowledge that this could be a multinational endeavor, as I personally think it should be with an opportunity for everybody to play with ways to consider public-private partnership and even just flat-out commercialization on our way to reaching Mars, we establish different requirements. If you're developing a habitat that will have an ability to be a safe haven, it would feel different as you're considering design solutions. If you're looking for standards that allow for various companies to dock to a consistent geometry, then you're talking about investing in a plug-and-play configuration perhaps as we're looking at ways to build things out.

If we're expecting to work in the vicinity of the Moon or Mars as kind of an anchor location for lots of other great things to happen, the solution again might be different. So again, the vision's important, and I think we'll eventually get through those things but it's going to be a very interesting couple of years.

Ms. EDWARDS. Mr. Chairman, can we hear from Mr. Culbertson? Do you mind?

Chairman BABIN. Yes, absolutely.

Mr. CULBERTSON. Thank you. I'll try to be brief.

I agree with what the others have said so far, and I think there are some really important principles here. One is that if we have a habitat in the vicinity of the Moon, we have a destination for Orion. We also have prepositioned supplies, we have the ability to provide backup capabilities such as power, maybe even propulsion, and maybe even a way home if the spacecraft were to have any other problems of some sort, and it is a dangerous environment where things can happen, so a certain amount of redundancy early on in testing is important.

As I mentioned earlier, you have to think of this as a shakedown cruise where you are testing not just the systems but the people, and not just the people in space but the people on the ground who are designing things, who are operating, who are supporting the crew. There's going to be a lot of complicated aspects to that that are going to have to be more than what we're doing now in low-Earth orbit. The modular approach I think is extremely important just like the watertight compartments on a ship protect the crew if there's anything that happens to any part of the hull. You may need the same capability as we learned on the Mir on basically an outpost around the Moon.

I remember thinking as I was on the Space Station when I was a little bit more naive about what industry can do that I could just take the station, and if I had enough propulsion, I could go on to the Moon or on to Mars, and might want to pick a different crew but it still was, I think, a technical capability, and I think that basic principle, even though we would have to change some of the specifics is what we have to have as we go beyond low-Earth orbit.

Ms. EDWARDS. Thank you, Mr. Chairman.

Chairman BABIN. You're welcome.

Now I'd like to recognize the gentleman from Alabama, Mr. Brooks.

Mr. BROOKS. Thank you, Mr. Chairman.

While I support development of American-made alternatives to the RD–180 rocket engine, according to Undersecretary of Defense for Acquisition, Technology and Logistics, Frank Kendall, ending the use of the RD–180 prior to the availability of a comparable domestic rocket engine will cost taxpayers over a billion dollars. What effect will restrictions on the purchase of RD–180 engines have on NASA and Boeing's CST–100 Starliner commercial crew space system? And my question is directed to Mr. Elbon.

Mr. ELBON. Thank you. Let's see. We're concerned about that, even though the legislation that's being discussed doesn't necessarily target civil space uses, reduction in flight rate for the Atlas V, which CST–100 flies on, and other users, by the way, fly on as well to Space Station, reduction in flight rate could increase the cost of that, and eventually be an impact. So we're hopeful that that doesn't happen, that it's able to keep flying and then the flight rate as planned will allow us to continue to use that for the Starliner as planned.

Mr. BROOKS. Thank you, Mr. Elbon.

My next question will be for Mr. Weir, and I want you to be thinking of why the American people won't go to Mars, and as a backdrop, I'm going to mention America's financial condition because that's going to be what we have to weigh, the pros and cons. I'm not sure if you're familiar with America's financial condition but in summary, we're headed to an insolvency and bankruptcy probably within the next 20 years, maybe in the next ten years, as a country. I say that looking at a $19 trillion debt accumulation predominantly over the last decade and a half, and reports by the Comptroller General, James Daro, and the Congressional Budget Office waring us that our current financial path is unsustainable, which is accounting language for, if you keep doing this, there's going to be a total collapse of the system.

Additionally, the CBO has warned us that while we had a series of trillion-dollar deficits under Democratic rule of the House and Senate in 2007 and 2008 coupled with Barack Obama in 2009 and 2010, since the 2010 elections, we've slowly but surely gotten our deficits down to $439 billion, which is where we were last year. This year's deficit, however, has taken a dramatic turn for the worse. Now it's projected to be in the neighborhood of $534 billion within six years, a trillion dollars a year—nonstop trillion-dollar-a-year deficits until we go insolvent.

So with that kind of financial backdrop, what can you say to help persuade the American people that Mars is a goal that we should undertake despite the financial risks that our country faces?

Mr. WEIR. It's funny you should mention the potential insolvency because in the 1930s, the United States was not in a great state solvency-wide either, and during that time the government invested very heavily in building up the commercial airline space, which cost a lot of money. It required the government to basically take a bunch of land from various cities under eminent-domain laws that was worth a lot. It spent enormous amounts of money in the form of tax breaks and policy decisions in order to build the burgeoning airline industry. Since then, it has definitely paid itself off far more than we ever spent on it in the form of tax revenue from that industry.

So I would say that my answer to your question is that putting money into a mission to Mars or anything related to space as long as a lot of that money ends up going toward commercial development will help bring the commercial space industry into a profitable situation.

Once the price to low-Earth orbit gets down to the point where a middle-class American can afford to go into space, there will be a boom. There will be an economic boom in the space industry and the United States government will receive the benefits of that boom in the form of taxes and revenues.

Mr. BROOKS. Anybody else want to add to the comments of Mr. Weir?

Hearing nothing, thank you, Mr. Chairman.

Chairman BABIN. Yes, sir. Thank you, Mr. Brooks.

And now I recognize the gentleman from Virginia, Mr. Beyer.

Mr. BEYER. Thank you, Mr. Chairman.

This past weekend, the students of Longfellow Middle School in my district participated in the Aerospace Industry Association 2016 Team America Rocketry Challenge, and they are with us here today. So they'll stand up and we'll recognize you. Thank you for competing and for your excellence in math and engineering and technology and science.

And Mr. Weir, of all the protagonists I've run into in my life, Mark Watney was easily the most adaptable and creative I've ever seen. You know, he's a great role model, confronting life-and-death challenges daily and somehow doing it with good cheer, with humor, and moving forward with extraordinary resilience. They say every first novel is autobiographical. Who was your role model for Mark Watney?

Mr. WEIR. Well, I admit I based him pretty much on myself although he's better at all the things I'm good at than I am, and he doesn't have any of my flaws. So he's what I wish I were.

Mr. BEYER. That's great. Will there be a sequel?

Mr. WEIR. No plans for a sequel. Sorry. I'm working on an unrelated novel now.

Mr. BEYER. Okay. Great. Excellent. Thank you.

Mr. Crusan, our distinguished Chair in his opening comments talked about the unjustified Asteroid Retrieval Mission. Do you have any comments either on behalf of NASA or as a person paying attention to all those things?

Mr. CRUSAN. In my remarks and in my testimony, I highlighted the two required things for sending humans into deep space. First is habitation, and second is in-space propulsion. The Asteroid Redirect Mission gives us that in-space propulsion aspect that we're looking for. To me, that's the fundamental piece of the Asteroid Redirect Mission along with operating large-scale solar electric propulsion in deep space because that will be the experience that we will need to send cargo into Mars and eventually our crew into Mars as well. So there is a nice synergy between that.

Mr. BEYER. So it really could well be interpreted as an essential part of getting to Mars?

Mr. CRUSAN. Yes.

Mr. BEYER. Great. Well, thank you very much.

And Ms. Sigur, you—in your written testimony, you talked about how Orion has a time-triggered ethernet that's 10 times faster than your ethernet at home. I'd like to point out that Lockheed is in my Congressional district, and if you could get 10 times faster internet for all of us, we'd be very grateful.

Is there any commercial application for the 10 times faster ethernet, Ms. Sigur?

Ms. SIGUR. I will have to get that information and have it added to my hearing testimony.

Mr. BEYER. That was a very careful response. I appreciate that.

Mr. Elbon, you talked about how we lack the killer app to develop the $1 to $2 billion annually needed to get some of the stuff off the ground. What would the killer app look like?

Mr. ELBON. I'm not sure. If we knew, we would probably get it out there. The point is, I think we need to focus on developing demand for activities in low-Earth orbit. We've done a good job of developing capability, and by that, I mean the ability to transport cargo and crew there, and we have destination, the Space Station, and talk of future destinations. We're very good at providing the supply. We need to work on the demand, users with money willing to spend on space. Today we have users willing to spend order of magnitude hundreds of thousands of dollars to do research or other activities in space, and to really have a commercial market, we have to generate revenue in the order of magnitude of at least a billion or two to support activities like that. So I think there's a real effort needed to be working on the demand side of that whole equation.

Mr. BEYER. Well, thank you for putting the challenge out for all of us. We passed the Science Prize Act earlier this year. Maybe we can put that as one of the Science Prize challenges is what needs to be done.

Mr. Weir, I love your idea of abandoning the zero-g gravity and just spinning the Space Station as they do so often. How difficult is it going to be to have a counterweight a quarter-mile away as they travel through space——

Mr. WEIR. Well——

Mr. BEYER. —as opposed to when they're stationary.

Mr. WEIR. Right. Well, the cable itself—if your space station were approximately the same size as the International Space Station, the forces would require the cable itself to be—I forget the exact diameter but I worked out the mass. The cable itself would weigh about 10,000 kilograms. Compare that to the 385,000 kilograms that the International Space Station weighs. We're talking about one part in 40 of the total mass of the station would be the cabling. But other than that, that's it. That's the additional mass. And the counterweight would not just be some wasted weight. That would be the other half of the station. There might be another crew node or it might be other station keeping. You would not have dead weight.

Mr. BEYER. Is there anything in our discovery of gravitational waves that leads you to some creative thought about another approach to this?

Mr. WEIR. Unfortunately, no. The only technology we have available to us for artificial gravity is centrifugal force.

Mr. BEYER. Thank you, Mr. Chair. I yield back.

Chairman BABIN. Yes, sir. Thank you.

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

Mr. ROHRABACHER. Pardon me for being in and out. That's the way we are in Congress sometimes. We've got 10 things to do at one time.

And let me just note right off the bat that we seem to be having dual movies here. It's, you know, the Martian versus Gravity or something like that, you know, because in fact, there as a movie, Gravity, and this is what I'd like to ask Mr. Weir. Okay, I take it that you saw the movie Gravity as well?

Mr. WEIR. Yes.

Mr. ROHRABACHER. Okay. So we've got these threats that's called space debris floating around there. Don't you think that perhaps it would be a better use of our money right now to help clean up that space debris and perhaps even protecting the world from an asteroid or a meteorite that could destroy the whole world? Shouldn't we actually be getting those jobs done before we spend billions of dollars to try to get to Mars to plant our flag and come back?

Mr. WEIR. Well, we already are protecting the world from asteroids.

Mr. ROHRABACHER. We are?

Mr. WEIR. It's called Planetary Defense.

Mr. ROHRABACHER. Yes?

Mr. WEIR. And the main way it's done is that we track all asteroids that are large enough to be any significant threat to Earth, and that's already being done, and so we know——

Mr. ROHRABACHER. We can track, but frankly, it's being tracked but we don't know what to do after that.

Mr. WEIR. Well, we do know that for at least the next 50 years, we have no dangerous asteroids heading our way. But yes, if we detected something that was a significant threat, I'm pretty sure this body and your colleagues on the other side of the building would be willing to, you know, put together some funding or something to shoot it down. So I feel confident that that could be taken care of.

As for space debris, people often underestimate how big Earth orbit is. To give you an idea of how big it is, it's bigger than the whole world. It's the entire surface of Earth but bigger. So when people say hey, let's clean up the space debris, that's like saying hey, can we get rid of all the gum wrappers in the Pacific Ocean. There are few, they are far between. They are hard to find, and it's just not viable for us to track them all down.

What we should be doing is putting in place policies that prevent people from leaving stuff up in space for very long, put it into orbit so that it will eventually decay, and if parts break off, that they will eventually decay and come into the safety of Earth's atmosphere, and of course, protecting Earth from anything that we've launched is a non-issue because we haven't launched anything that's big enough to survive reentry and hit the ground.

Mr. ROHRABACHER. Thank you. I do disagree with you on a couple of things but let me note that's good. That's what these hearings are all about is to get different points of view out. I wonder if the panel agrees with our witness that it's impossible that there would be a rock headed toward the Earth enough to do great damage to our Earth that we wouldn't see for 50 years out. I think that there could possibly be something that might emerge on the radar screen like the one that I think just recently went by a couple days ago.

Mr. CULBERTSON. Yes, sir. There's always a possibility that something could emerge, and as Congressman Bridenstine knows, if a target's coming right at you in the air, you sometimes don't see it until it's right on top of you, and that could be the case. I participated in a study with the National Science Foundation a few years ago where we did look at the observational capabilities both on the surface of the Earth and in space to track the objects that are out there, and he's right. We haven't detected anything yet that we can track that is a threat to the Earth. I also agree with him that if we did detect something and we had time to do something about it, we would do something about it.

Mr. ROHRABACHER. If we had time. That's the big "if."

Mr. CULBERTSON. Right, but right now if you were to say I want to do a specific thing to protect the Earth against a specific asteroid or any other object, there are so many different types of objects out there, settling on only one solution probably would not be cost-effective. You'd need to know the threat.

Mr. ROHRABACHER. Well, let's put it this way. It would have to be one solution but at this point I would like to know, rather than spending billions of dollars to go to Mars when they might turn around to take a look at the Earth and see a big blip because all of a sudden something had hit the planet, we don't have the plan—I'm not talking about one option. We don't have a plan that has several options if something big is spotted headed toward the Earth, and to spend billions of dollars on what we can't do now, which is what's been outlined in testimony, and giving up those things we could do, we could put a plan in place to protect us, and we could put a plan in place that would actually deal with the—and I would disagree with—I think it's a little more risky than just bubblegum wrappers in the Pacific Ocean. And so I think we should do that.

One last question. You were talking about space habitat. Is Bigelow—you know, Bigelow put a lot of money, its own money, into developing new technology for space habitat. Is that part of the equation is what he's done and what he offers? Is that going to be part of the equation of what we're talking about here?

Mr. CRUSAN. We have contracts right now under NextSTEP with four commercial firms: Lockheed Martin, Boeing, Orbital ATK and Bigelow Aerospace. So all four are currently under our phase I activities, and they had an opportunity to move to phase II just like the others and an ability to on-ramp also other organizations beyond the four that we are currently working with.

Mr. ROHRABACHER. Well, there's lots of things that we can do in space. I hope that we make sure that we don't waste dollars on things that we don't accomplish anything with, and on that, the witness—see, I'm an author too. I'm a writer too. We're both writers. And I agree with you totally.

So thank you very much, Mr. Chairman, for this hearing.

Chairman BABIN. Yes, sir. Thank you.

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

And by the way, we are going to go back through a second round of questions if that's okay with everyone.

Mr. BRIDENSTINE. I approve.

Chairman BABIN. Okay.

Mr. BRIDENSTINE. Thank you, Mr. Chairman.

I wanted to bring up a couple of things that I want to make sure people understand my philosophy on, primarily because of some of the testimony we just heard.

The Interagency Space Debris Coordination Committee put out a study not too long ago. It included five other space agencies from throughout the world and then NASA is the sixth, and it indicated that in that critical orbital regime from 700 kilometers to 900 kilometers, given the current regulatory environment, we will continue to see space debris grow. It's not going to go away. It will continue to grow, and that's if everything stays the same as far as launch frequency and the satellites that are launched right now, and we know that that is not the case. Launch frequencies are going to continue to increase. We've got constellations that are hundreds and in many cases—in some cases now thousands of satellites going into low-Earth orbit, and this is not going to be sustainable for the long term. We've got to make sure we're doing the right things on this Committee so that we can mitigate the debris, as you talked about, but eventually there's going to come a day when remediation is going to be necessary, and we need to be very serious and methodical about how we go about that.

I wanted to ask you a question, Mr. Crusan, about one of the reasons to do the Asteroid Redirect Mission is for propulsion. Why is it necessary to do an asteroid redirect mission to create the propulsion capabilities necessary for a Mars mission?

Mr. CRUSAN. So there are two aspects that are important, the actual funding of large-scale solar electric propulsion systems from the arrays to the power management systems to the actual thrusters. The other aspect is actually operating a large-scale system such as that in deep space for a prolonged period of time to get a good understanding.

Mr. BRIDENSTINE. So why is an asteroid redirect mission necessary for that?

Mr. CRUSAN. It's an opportunity to test those critical systems.

Mr. BRIDENSTINE. So it's not necessary, it's just something that would be a good idea because it gives us a reason to do what is necessary?

Mr. CRUSAN. Yes.

Mr. BRIDENSTINE. Okay. I wanted to ask you a question regarding the fiscal year 2016 Omnibus. It directed NASA to have a cislunar habitat prototype ready by 2018 and directed NASA to spend no less than $55 million specifically on a habitation module. However, NASA's operations plan for fiscal year 2016 only allocates $25 million, not the total $55 million, to NextSTEP activities. According to the NextSTEP 2 announcement, "The initial solicitation is seeking ground prototype habitation systems." It seems as if NASA is only spending $25 million explicitly on the development of a ground prototype. Can you explain how NASA's other expenditures meet the Omnibus directive of $55 million specifically on the prototype? So $25 million, $55 million. Where's the other $30 million?

Mr. CRUSAN. So there's two aspects that we're looking at. You have the habitation systems, the things that which you put inside the habitat—the life support systems, the radiation mitigation, things like logistics and the outfitting. Those are all core systems. And then you have the integrated habitat itself, the actual module or modules that you would like. Both of those are needed to go forward. In fiscal year 2016, we're actually spending in excess of $70 million on habitat systems at the total level, part of that in the integrated capability with industry and part of that also with industry on the habitat systems that are actually going to be inside of that overall capsule or module that we'll be actually building. So we believe we're meeting the intent of that by spending in excess of $70 million on habitat systems and the integrated habitat capability.

Mr. BRIDENSTINE. Are you guys going to be able to achieve a prototype habitat for cislunar by 2018?

Mr. CRUSAN. In our current budget profile? Yes.

Mr. BRIDENSTINE. Now, when you think about—and this is just because I don't know. I'm asking you, when you think about having a prototype, what does that mean? Does that mean it's going to be on the ground? Does that mean it's going to be in space?

Mr. CRUSAN. No. So it'll absolutely be a ground prototype, and we look at form, fit and function. Form and fit, obviously we believe we can have high fidelity of those. The level of function is a level of ability to actually build all the various systems, either in a computer model mode or actual physical hardware. So it will have high-fidelity form and fit, and variable fidelity of function, depending on what we see in our proposals actually on phase II.

Mr. BRIDENSTINE. Awesome.

Mr. Chairman, I'm out of time. Thank you.

Chairman BABIN. Yes, sir. Thank you.

Now I think we will go back through one more time if that's okay, and my next question would be for Mr. Crusan first but if anyone else would like to answer, I certainly would appreciate it.

NASA must ensure its investments in and acquisition strategies for deep space habitats are in the taxpayers' best interests. At the same time, a legitimate part of NASA's strategy for deep space habitats is to make investments that facilitate private-sector habitats in low-Earth orbit and beyond. In phase III of NextSTEP, NASA will determine its acquisition approach for deep space habitats. What types of acquisition mechanisms should NASA be considering, and what are the benefits and challenges of these respectively and how should NASA balance the interests of the taxpayers fostering commercial markets?

Mr. CRUSAN. So as you note, there are multiple strategies that we could go with the final acquisition. In NextSTEP phase II, we require a corporate resource contribution of 30 percent at a minimum eligibility requirement on that procurement, on that solicitation. That is to foster the dual use of whatever habitation systems for deep space are meant for low-Earth orbit for that kind of skin in the game of those procurements. That also allows us the ability for intellectual property related to commercial endeavors in low-Earth orbit to reside with the commercial entities as well.

So going forward into the final acquisition, it could be that one choice we go to a standard cost-plus-type contract or it could be more of a fixed price in certain elements of the contract where there's high alignment with commercial needs. When we talk about a habitat, it could be a subsystem, the entirety of the system. You could think about service modules or small propulsion buses that have high alignment, say, with commercial satellite buses, or the habitat structure be on a fixed-price basis. So it's much more granular when you start dividing the various systems that we could approach. So you wouldn't have to have a single contract methodology for the entirety of the system end to end. You could actually have customized acquisition pieces that match best with the commercial potential of those subsystems, and that's what we're looking at trying to achieve you of this phase II effort is looking at how do you divide a system up in such a way that optimizes the LEO use of components while getting at the deep space needs that we have, and we know there will be incompatibility in a few of those areas, and that's what we're trying to find during the studies.

Chairman BABIN. Okay. Thank you, Mr. Crusan. Would anybody else like to add anything there?

Mr. ELBON. I would like to add——

Chairman BABIN. Mr. Elbon, yes, sir.

Mr. ELBON. —a couple of points. You know, the public-private partnership has worked really well for Commercial Cargo, and I think we'll find that it'll work really well for Commercial Crew. It's important, I think, to remember that that mission is a mission we've been doing since we put John Glenn in orbit over 50 years ago, well understood the risk postures, understood the technologies there to do it, and so companies were able with some very top-level NASA requirements to develop solutions to do that mission.

We're now going beyond low-Earth orbit into deep space, the area around the Moon, and we haven't done as much there. The requirements aren't understood. I think NASA needs to stay in the middle of those requirements because this thing is going to evolve into what goes to Mars. And so it's real important that we look at the differences in the mission and the whole situation and not look at everything as a nail because we've got a hammer here.

Chairman BABIN. Exactly. Thank you.

And one more question for Mr. Weir. As a writer, you've inspired many with the possibility of science, technology, engineering, mathematics, and let's not forget botany. We certainly need young people devoted to STEM fields if we are going to Mars. What recommendations do you have for this Committee and for NASA as to how we can continue to inspire people with space exploration and the possibilities of STEM? And these four young ladies sitting in the back I think are perfect examples of people who are being inspired, and if you could elaborate on that, I would appreciate it.

Mr. WEIR. Well, I would recommend you keep doing cool stuff. I mean, basically——

Chairman BABIN. I've been trying to do that all my life.

Mr. WEIR. Yeah. Well, basically people, especially kids, are motivated by results, by what they see. So ideologies or concepts or things we might do at some point in the future, those are less interesting to kids choosing potential careers than the things that are actually being done. So if you want to see more kids in STEM, do more cool stuff in space.

Chairman BABIN. Good answer. Okay. All right. Thank you so much.

And now I'd like to recognize the gentlewoman from Maryland, Ms. Edwards.

Ms. EDWARDS. Thank you, Mr. Chairman, and again, thanks to the witnesses.

I have a couple of questions actually for the companies who are here because you have decades of work in space systems, and I'm just trying to figure out what it is that NASA needs to do now in conjunction with our elected leadership to make sure that we're really on pace to get this done, and my concern rests with the fact that we continue to have this kind of push and pull with the Administration and the Committee over what platform we're going to use as the springboard to Mars. Is it going to be an asteroid retrieval mission? Is it going to be on the Moon? I mean, all of those different considerations. And I want to know from your perspective when we need to resolve this so that we have the ability to move forward in a way that allows us to put the resources that are necessary to get the job done. Because I think as long as the Executive Branch and the Congress are in slightly different places, it's very confusing, and it's unpredictable, and we don't have the resources that we need, and in fact, we could be just wasting money because we'll come up on another Administration starting from scratch. And so I would just like your opinions of that. Mr. Elbon?

Mr. ELBON. Yeah, I'll start. I was asked in the Human to Mars panel this morning what the biggest tent pole was for us getting to Mars, and my response was just about what you said, and that is, we need to get on a path and stay on that path, and it has to survive several Administrations, you know, in a couple decades here. So I think we have to be careful not to be distracted by other ideas, not to invest in one path and then switch to another path. So the answer I would give is as soon as we can we need to nail down the architecture and the approach and then stay on that path, keep it funded, and that will allow us to get to Mars at lower cost and a lower schedule than switching back and forth.

Ms. EDWARDS. Thank you.

Ms. Sigur?

Ms. SIGUR. And my comment is much along the same lines. A level of commitment and vision I think are mandatory. NASA has a great vision to establish certain types of capability. What we can't afford to do is to start and stop and start and stop and start and stop. The questions and the issues are very hard. Multiyear funding would be beneficial, and that once we establish that there's a vision that we're going to go after, let's commit.

There's a difference when we're trying to get a commitment for someone to make a one-off and something that feels like a business. So having that vision, establishing it for multiple years and sticking to it I think would be a real benefit.

Ms. EDWARDS. Mr. Culbertson?

Mr. CULBERTSON. Yes, ma'am, pretty much along the same lines. We need a vision. We need leadership. We need decisions out of the government, both branches of the government, and we need everybody to be pretty much on the same page. So in my view, it needs to be as non-partisan as possible, bipartisan where necessary, but we need decisions and we need the right level of funding, and also you need to know that as industry, you're investing in this, it will eventually pay off for you too, and so if we're going to have to have skin in the game, we need to understand how NASA or other agencies will allow us to commercialize that. For example, if we had an X percentage investment in it, we ought to be able to sell X percentage of that capability while we are providing that kind of service and support. Services are a good way to start in this, and we're doing that with Cargo and Crew and other ways of continuing those kind of operations in space, and of course, communications is a great example of how that can evolve into a standalone industry. Whether we can establish an industry like that around the Moon, I think that's a long way off but it certainly could happen, depending on what we discover there.

I also think, to address some of the earlier discussion, developing the capabilities to do these kind of things will allow us to address some of the other really hard problems such as protection of the planet and detecting things further out and sooner so that if we need to take action, we can do that. That comes as a byproduct of doing really hard things like this as we saw going to the Moon.

Ms. EDWARDS. Thank you. And we don't have time for it here today but I do think that there's value in providing information to the Committee about what you perceive as the job creation and technology creation capabilities that would lend itself to the way that we begin to think about the value of investing in this really long-term and quite expensive endeavor, and the question is, will it pay off in the kind of way that the space program has over these last almost six decades. So thank you very much for your consideration.

Chairman BABIN. Thank you.

Now I'd like to recognize the gentleman from Oklahoma, Mr. Bridenstine.

Mr. BRIDENSTINE. Well, thank you, Mr. Chairman.

Ms. Sigur, I wanted to second your comments about, we need to have a vision and we need to have something that we can stick to, and I think all of us on this Committee on both sides of the aisle agree with that 100 percent, and I agree with you especially because you're a graduate of Rice University, which everybody knows is the preeminent engineering school in the country. Although I was not an engineer there, I highly respect those who were.

I want to go back for a second. I'm going to sound like a broken record here but when you think about the space debris challenge that we have, it is very real, and I know Orbital ATK, you guys are working on doing some mitigation by extending the life of satellites that currently exist in space so that we don't have to continue launching new, but I'm on the Armed Services Committee, Subcommittee on Strategic Forces, and I can tell you, you go back to 2007, the Chinese shot down a weather satellite, created 5,000 pieces of orbital debris. A couple years later you had an Iridium satellite collide with a Cosmos satellite, created thousands of more pieces of orbital debris, all in these critical orbital regimes, and this Interagency Committee on Space Debris Coordination said that those kind of collisions, Iridium and Cosmos, will continue to happen on average every five to nine years, which means they're going to continue to grow. So these are absolutely necessary.

I believe by making the right investments today, not only are we protecting low-Earth orbit but we're protecting our ability to do what's necessary to get to Mars one day. That's what we're doing.

On the Mars issue going back for a second, the Mitch Daniel report that came out, the National Research Council put out a report, said, you know, our budgets, the money we are spending today and our missions and our strategy absolutely will not get us to Mars. It wasn't that it was going to be delayed ten years or delayed 20 years. They flat-out said we're not going to get there. That should have sounded an alarm for all of us on this Committee. What is we're doing wrong? And we need to get real assessments over what we're doing wrong on this Committee so that we can actually go home and tell our constituents that we are not investing their money in vain. I mean, that should have infuriated all of us on this Committee. And so we have those issues.

Now, when you talk about SLS and you think about specific mission plans beyond EM–1, I believe we need an increased launch frequency. I don't think that, you know, launching every four years is going to get done what we need to get done and have it be safe. But barring that we're going to increase launch frequency given the budgets that we have, we need to increase the utility of every launch that we do, and I wanted to ask if when it comes to EM–2, Mr. Crusan, do you know, is there going to be a secondary payload that might be a habitat that could go out to cislunar or beyond low-Earth orbit?

Mr. CRUSAN. So one of the things we're looking at is how do you do that sequence of habitation buildout. So part of the NextSTEP analysis with industry here is looking at the ability to co-manifest on SLS and looking at the crew and the ability for habitation elements or habitation modules per se and how would you put those on. Consideration for the EM sequence will have a direct impact on what cargo and what capabilities fly on each of the exploration missions on SLS. That's what we're studying actually with industry.

Mr. BRIDENSTINE. So when we think about—and I know I just asked you the question about the Asteroid Redirect and why is that necessary, is it possible that we could launch a habitat on EM–2 and then have that be the target, in essence, for follow-on SLS missions?

Mr. CRUSAN. Depending on the size of the habitat, yes. Technically, there is no reason why you wouldn't put on there. It's an ability of, is that the right first element or do you want to split apart your elements of station-keeping capability or a node or habitat. That's one of the things that we're working with industry, which pieces of those do you sequence first.

Mr. BRIDENSTINE. So is it possible, could we use a Delta IV to put a habitat where it needs to go to make that a target for the follow-on EM missions?

Mr. CRUSAN. So under the NextSTEP phase II, we have the co-manifested option with SLS that people can study and give us options for that. We also have the ability for industry to propose alternative launch vehicle options as well including Delta IV and others, and where we stage that is in deep space, so as long as those vehicles or whatever proposed vehicle that they're talking about can throw a reasonable size volume to cislunar space, then yes, that's an open consideration.

Mr. BRIDENSTINE. Mr. Chairman, if it's all right—I know I'm out of time. We need to make sure that Congress is aware and understands what the objective here is and ultimately the direction we're going to go because I don't want to get another report in ten years that says under no circumstances will we ever get to Mars and between now and ten years from now we will have made all these investments believing one thing and being told later something else.

So with that, Mr. Chairman, I yield back.

Chairman BABIN. Thank you. Well stated.

I now recognize the gentleman from Virginia, Mr. Beyer.

Mr. BEYER. Thank you, Mr. Chairman.

Ms. Sigur, we—my understanding through this is that we've been taking about habitats in orbit around Moon and later obviously the habitat that takes us through the thousand-day journey. And then you've written about the habitats in a Mars orbit and stationing it there instead, and suggested, at least in the written testimony, that you might be able to do that by 2028, which is, you know, 4 or five years earlier than we planned with NASA. Is this built into NASA time frame? And what are the necessary steps to move to essentially a Mars orbit rather than something cislunar?

Ms. SIGUR. Let me add a couple of points of clarification. The proposed mission would be one that would be in Mars orbit, not supplanting a mission to the surface of Mars, which is still planned as scheduled for the 2030s. The concept is that at Mars orbit, we'd be able to get smarter, we'd be able to get information and data, and it would allow for us to have real information about the planet and make real-time decisions and accelerate some of the milestones that would be forthcoming, and again, could happen a lot faster because we're in close proximity. The steps that we propose are taking advantage of existing committed missions that we have for Orion SLS with a view towards leaning forward as was just recently suggested by Congressman Bridenstine to say let's look to see what's happening in EM–1, 2, 3 and beyond to see if there are ways for us to do prepositioning, to see if we can work early tests with a target towards having before we get to 2024 a habitat system around the Moon, which does take advantage of using that as a testing ground for the deep space systems that we have before we go even further beyond.

So nothing that I've said is intended to preclude those milestones as steppingstones but really push towards how we can bring things forward to the left by doing some of the hard tests earlier.

Mr. BEYER. Thank you.

Mr. Culbertson, you mentioned that Orbital ATK's cislunar habitat design incorporates lessons that you've learned from delivering cargo to ISS. Can you talk about what some of those lessons are?

Mr. CULBERTSON. Yes, sir. Many of them have to do with acquisition process in terms of how we built this as an orbital investment with NASA co-investing but we own the system basically and we provide the service, and they pay for the service. You can take that same principle almost anywhere in the local vicinity—by that, I mean the Moon—by providing cargo services, crew services, power, other things that you could provide to any NASA activity that was happening around the Moon. But a lot of it has to do with how the hardware's developed, what the level of oversight versus insight is that NASA would have to have. As long as they set the goals and the standards and we can meet them, then you can provide the service and they can get what they need without investing in a whole lot of hardware. But the commercial industry, of course, has to show a return for shareholders in order to be able to do that.

On the technical side, of course, the spacecraft has performed very well autonomously going to the Space Station, achieving its rendezvous, stopping at 10 meters and being grappled by the crew. That kind of autonomy certainly can apply to any activities in cislunar space. The redundancy that we have, the spacecraft was based on our 15-year life geocoms that have a lot of resiliency and reliability in their systems, and we can fly a lot longer than the 90 days that we currently do on a Space Station mission. So we think we've got the basics available to us to move to low-Earth— I mean to cislunar.

Mr. BEYER. Thank you very much.

Mr. Elbon, you talked and wrote about the challenges of in-space propulsion, which obviously is very different from blasting off at Wallops Island. You also wrote about the solar electric tug using the power of the sun to do the propulsion. Is that what's generally established as the way we're going to move from, say, a cislunar station all the way to Mars?

Mr. ELBON. Yeah, one of the building blocks of the architecture is a solar electric capability that would be used to accelerate on the way to Mars and then after you're halfway there you can decelerate, and that is a very efficient kind of propulsion system from a mass perspective, and as Mr. Crusan was talking, it's a big part of what will come out of the Asteroid Retrieval Mission, so we'll have that capability. It's important for us to be able to do the mission.

Mr. BEYER. And is that really the only form of in-space propulsion that's being considered?

Mr. ELBON. Well, it will take a lot of—not a lot. In addition to that, we'll need cryopropulsion, and that gets into technologies of being able to store the cryo, maybe not just cry but at least chemical propulsion to allow us to make the initial increase in Delta V to get away from the Moon and on the way back from Mars as well.

Mr. BEYER. One last short question.

Mr. Weir, did you pick Matt Damon to play you or——

Mr. WEIR. No. My main job on the film was to cash the check.

Chairman BABIN. That is not a bad job, I can tell you that.

This concludes our hearing, and I want to thank each and every one of you, Mr. Crusan, Mr. Elbon, Ms. Sigur, Mr. Culbertson and Mr. Weir. It's been a fascinating hearing and I really have enjoyed it, and we've learned a lot, and I want to also announce that the record will remain open for two weeks for additional written comments and written questions from members who perhaps were not able to make it.

So with that, this hearing is adjourned.

[Whereupon, at 4:32 p.m., the Subcommittee was adjourned.]

Appendix I

ANSWERS TO POST-HEARING QUESTIONS

ANSWERS TO POST-HEARING QUESTIONS

Responses by Mr. Jason Crusan

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON SPACE

"Next Steps to Mars: Deep Space Habitats"

Mr. Jason Crusan, Director, Advanced Exploration Systems, Human Exploration and Operations Mission Directorate, NASA

Questions submitted by Rep. Brian Babin, Chairman,
Subcommittee on Space

Question 1:

NASA's solicitation for the first round of NextSTEP awards had a one-to-one cost sharing requirement for funds awarded and according to a NASA press release, "Because capabilities and technologies developed through these awards will have significant potential commercial applications, NASA expects partners to contribute significant resources." Testimony before the Committee highlights that the Commercial Cargo program was able to attract a roughly 50-50 cost share for the development of cargo capabilities, while the Commercial Crew program was only been able to attract round 10 percent of development costs. What percentage of development costs does NASA expect partners to contribute towards habitat development in phase 2, phase 3, and beyond? What markets does NASA expect to emerge that would close a business case for deep space habitats? Will NASA relinquish intellectual property derived from this taxpayer investment?

Answer 1:

Offerors were required to show a minimum of 50 percent corporate contribution for Phase 1, made within the five years prior to the release of the Next Space Technologies for Exploration Partnerships (NextSTEP) Broad Agency Announcement (BAA) or during the duration of the proposed period of performance that was directly relevant to the proposed effort, and 30 percent for Phase 2 made within one year prior to the release of the NextSTEP BAA or during the period of the contract performance. Corporate contribution could be in the form of direct labor, travel, consumables or other in-kind contributions. Also, other reasonable forms of corporate contribution could include investments in special facilities or equipment, tooling or other prior private investment, including Independent Research and Development (IRAD). For this BAA, state and local government contributions could be included with private corporate resources. Partner contributions for Phase 3 are to be determined.

NASA defers to commercial entities for information on their business plans for deep space, or low Earth orbit (LEO), habitats, but the Agency intends to transition LEO to private platforms and capabilities enabled by commercial markets, academia and government agencies, including NASA, with interest in LEO research and activities.

Please see below regarding intellectual property in the NextSTEP BAA.

- Data Rights: The objective of a contract awarded under this [NextSTEP] BAA is to provide recipients with the incentive to develop commercial applications of technologies developed through the partnership. Data exchanged between NASA and a recipient will generally be freely exchanged without restriction as to its disclosure, use or duplication. However, a recipient's proprietary data that is exchanged or developed will be protected from disclosure provided it is clearly marked as such. Further, data produced by NASA that would be a trade secret or commercial or financial information that would be privileged or confidential had the data been obtained from the nongovernmental partner, may be protected from disclosure for up to 5 years.

- Invention Rights: Recipients that are Small Businesses or nonprofit organizations may elect to retain title to their inventions pursuant to the Bayh-Dole Act (35 U.S.C. § 202). Large business recipients are subject to section 20135 of the National Aeronautics and Space Act (51 U.S.C. § 20135) relating to property rights in inventions. Title to inventions made under an agreement by a large business recipient initially vests with NASA. However, these recipients may request a waiver to obtain title to inventions made under the agreement. Such a request may be made in advance of the agreement or within 30 days thereafter. Even if a waiver request is not made, or denied, a large business recipient may request a waiver on individual inventions made during the course of the agreement.

Question 2a:

You testified that the NextSTEP program has three phases, with NASA determining the acquisition approach for deep space habitats in phase three.

a. What types of acquisition mechanisms (FAR based contracts such as cost-plus and firm fixed price, Space Act Agreements, or Cooperative Research and Development Agreements) is NASA considering and what are the benefits and challenges of these, respectively?

Answer 2a:

The multiple phases of NextSTEP are informing NASA's acquisition strategy for its deep space, long duration habitation capability. As part of this process, NASA will consider a variety of acquisition mechanisms, and consider potential domestic and international partnerships. NASA is committed to determining the most appropriate procurement mechanism that stimulates optimum competition for future space infrastructure. Such determination will be dependent on a number of factors and will be consistent with Federal laws and regulations as well as Agency guidance. NASA uses Federal Acquisition Requirement (FAR) based contracts when the primary purpose of the activity is to obtain goods or services for the direct benefit of the Agency. FAR-based contracts can support research and development activities as well as more traditional procurements where requirements are well understood. Space Act Agreements are a useful tool for activities which are of mutual benefit, or when a specialized capability is requested by a partner on a reimbursable basis. NASA most often uses Cooperative Research and Development Agreements (CRADAs) to support the Agency's technology transfer efforts because a commercial partner is able to employ the resulting system or design for its own commercial purposes.

Question 2b:

Does NASA plan to use the NextSTEP, phase three, competition to procure a cis-lunar habitat, or could NASA procure that cis-lunar habitat in phase two? If so, which elements and how and when will that decision get made? How does NextSTEP fit within the plans of NASA's international partners?

Answer 2b:

In NextSTEP Phase 2, NASA plans to define a reference habitat architecture based on contractor concepts and identified Government-furnished equipment in preparation for Phase 3. There is no intent to develop flight units in Phase 2. As noted above, as NASA moves forward with the development of a deep space habitation capability, the Agency will consider potential international partnerships. A hab capability in cislunar space could potentially support commercial and international lunar activities. The combination of commercial, international, and in-house activity that will comprise the acquisition strategy for deep space habitation will be informed by Phase 2 which extends into mid-2018.

Question 3:

NASA has been developing the Space Launch System and Orion Crew Vehicle for several years and only now beginning efforts to build habitation modules for our astronauts to carry out deep space missions. How do you see these deep space habitation capabilities complementing the Orion and SLS efforts?

Answer 3:

The Space Launch System (SLS) and Orion will carry us into the Proving Ground of cislunar space. The next capabilities needed beyond SLS and Orion for human exploration are deep space, long duration habitation and in-space propulsion. Validation of these and related capabilities in cislunar space will mark our readiness to begin Earth-independent exploration beyond the Earth-Moon system. All these capabilities are necessary elements of NASA's planned deep space exploration architecture. A deep space habitation capability is the foundation of human space missions beyond low-Earth orbit (LEO), supporting our plans for Mars-class mission distances and durations.

Question 4:

The Orion Crew Vehicle is currently being developed and is expected to launch aboard the Space Launch System in late 2018. Many of the technologies involved in developing a crew vehicle are also important to the development of bigger habitation technologies. How is NASA leveraging the lessons learned in Orion's development to help create deep space habitats?

Answer 4:

Development of the Orion crew systems, which is expected launch as a fully-capable system in the early 2020s, will inform the development of NASA's deep space hab capability, but it is important to note that groundwork for this latter capability is already being laid aboard the International Space Station (ISS), which is currently serving as a testbed for technology development, including in the areas of environmental control and life support system technology for long duration deep space missions that will require capabilities beyond Orion's. This critical work will continue throughout the operating life of the Station. Orion's modern avionics, crew systems, and long-duration capability are all features that will inform deep space habitation development.

Question 5:

NASA has taken steps to develop deep space habitation technologies with the commercial industry with its Next Space Technologies for Exploration Partnerships (NextSTEP) program. Can you talk about the lessons you've learned from the NextSTEP program so far? Any surprises in what you learned from industry?

Answer 5:

One of the significant lessons learned to date is that spacecraft functions can be carried out by different components. This will make the development of common interfaces and standards very important as we move forward to ensure the different elements can work with one another. This finding is the basis of the requirement for Phase 2 efforts to support the development of standards and common interfaces. Another significant finding is that there is interest in using LEO to develop Mars-class habitation systems while at the same time using those systems for commercial applications. This includes elements such as habitats, logistics modules, and power and propulsion buses that leverage commercial satellite bus capabilities.

Question 6:

What rockets do you expect will launch the deep space habitation modules? Does the size of the habitation module for journeys to Mars drive you to using a Space Launch System rocket? Can other, smaller rockets carry habitation modules to low-Earth orbit or around the Moon, or does that also require the throw-weight of an SLS heavy-lift rocket? Should the habitat be designed for an SLS launch from the beginning?

Answer 6:

The Space Launch System offers significant mass and volumetric advantages when considering options for launching habitation modules into cislunar space. Depending on the specifics of the hab capabilities developed, however, NASA could also launch some components of a habitat system using other launch vehicles, particularly when doing so would maximize cost-effectiveness. NASA complies with the National Space Transportation Policy which, among other provisions, requires that departments and agencies "Refrain from conducting United States Government space transportation activities that preclude, discourage, or compete with U.S. commercial space transportation activities, unless required by national security or public safety." As such, NASA will use commercial launch capabilities when those meet its requirements. Some of the habitat system concepts being explored incorporate flexibility for using multiple launch vehicles, depending upon the deployment concept for the various modules. Commercial launch vehicles will have an important role in logistics resupply of a deep space habitat, but deployment of very large habitation and related elements to cislunar space and on to Mars will require the capabilities of SLS. NASA continually monitors trends in the commercial space transportation industry to evaluate which current and future vehicles can meet its requirements.

Question 7:

As the ultimate goal is to put American boots on Mars, there are several other components necessary to complete that mission. In Mr. Elbon's testimony, he pointed out that we still need vehicles such as a solar-electric tug, and a Mars lander and ascent vehicle if we are to conduct a Mars mission: A habitat is just one piece of the puzzle. How does knowing (or not knowing) how the other pieces of the puzzle fit together for that eventual Mars mission impact the design efforts going on now for the deep space habitation systems? Since NASA has yet to lay out the phasing of developments, budgets, and schedules for a mission to Mars, how can you know that NASA's approach to its habitat development is the most efficient way forward?

Answer 7:

The ultimate goal is not just to put American boots on Mars but also, as the President has stated, to push out into the solar system not just to visit, but to stay. NASA's evolvable exploration architecture is predicated on the idea that the Agency will learn from each new phase of spacecraft development and operations and apply that new knowledge to subsequent phases of development and operations. While NASA understands the basic conceptual components that will be required to carry out a crewed Mars mission, specific technologies, spacecraft configurations, integration, and operations concepts are being developed as we press forward from the Earth-reliant phase in LEO to the proving ground of cislunar space. For example, at this point, whether NASA eventually uses multiple, smaller hab modules for a Mars mission or a single, large module is to be determined. It is important to retain the flexibility to incorporate the results of early exploration missions in subsequent vehicle development.

Question 8:

The European Space Agency is the only international partner who has not yet committed to extending the life of the International Space Station through 2024. ESA Director General Johann Woerner has shown interest in developing a human presence on the moon, a 'lunar village.' If the United States were to plan to return to the Moon, would the habitation capabilities on the Moon be applicable to future missions on Mars?

Answer 8:

Per the NASA Authorization Act of 2010 and Administration policy, NASA is executing an integrated human and robotic exploration strategy leading to the human exploration of Mars. NASA's exploration strategy is to move from today's Earth-reliant posture through the proving ground of cislunar space to an Earth-independent capability needed to extend human presence into the solar system and to the surface of Mars. Given the substantial technical differences between the entry, descent, and landing, and ascent environments of Mars and the Moon, a costly human landing on the lunar surface would provide limited applicability to a landing on Mars.

NASA's exploration strategy is consistent with the Global Exploration Roadmap (GER), released in August 2013, with 11 other international space agencies participating in the International Space Exploration Coordination Group (ISECG). The GER defines common goals for missions to the Moon, cislunar space, and Mars. There is common agreement among these agencies that cislunar space is the next best destination given the resources available in these countries to commit to space exploration. The GER also reflects that NASA and our international partners share a common interest in advancing a unified strategy toward deep-space exploration, with robotic and human missions to destinations that include near-Earth asteroids, the Moon and Mars. Orion and SLS have the potential to support international partner activities in the vicinity of the Moon.

Question 9a:

I do not see our European counterparts or any other countries interested in the Administration's Asteroid Retrieval Mission. Further, U.S. law states that NASA Administrator "shall establish a program to develop a sustained human presence on the Moon."[1]

a. Given that, how will NASA's habitation development efforts facilitate cis-lunar exploration, as well as lunar surface exploration, as a way to prepare for an eventual mission to Mars?

Answer 9a:

Please see the response to Question #8, above, regarding NASA's exploration strategy and its goal of the human exploration of Mars, and the potential for

[1] 51 U.S.C. §20302

SLS/Orion to support international partner activities on the Moon.

Regarding international interest in the Asteroid Redirect Mission, NASA is in discussions with several interested key stakeholders toward partnership agreements. NASA and the Italian Space Agency (ASI) have an ongoing study regarding ARM, specifically covering areas in which ASI is interested in participating. Interest was also expressed by the Canadian Space Agency and the Japan Aerospace Exploration Agency, leading to ongoing discussions with these agencies.

NASA has identified a number of areas where international collaboration on the ARM could provide mutual benefit. Examples could include:

- Data sharing and lessons learned analysis involving other asteroid/small body missions;
- Near Earth Asteroid identification and characterization, both near term as NASA works to down-select candidate asteroid targets, and longer term to support detailed study of the selected asteroid, as well as contribute to the overall survey and characterization objectives of planetary defense;
- Systems that could be helpful during the capture phase, including cameras and autonomous robotics and tools;
- Rendezvous sensor contributions that could be used for a wide range of mission applications including automated rendezvous and docking and asteroid characterization and proximity operations; and,
- Additional payload contributions to the robotic mission that could advance either science, *in situ* resource utilization, planetary defense or other partner goals.

Question 9b:

Numerous experts have testified before this Committee that a crewed mission to Mars should be preceded by an independent six month mission on ISS, a 13 month stay on the lunar surface, and another six month stay on ISS before returning to the Earth. This "shakeout" mission would test the systems and protocols necessary for a Mars mission within the proximity of the Earth. How will NASA's habitation development efforts take into account the logical needs to both cis-lunar capabilities as well as lunar surface capabilities?

Answer 9b:

NASA's habitation development efforts are focused on meeting the goals in cislunar space that will pave the way for a future human Mars mission. This includes a one-year "shakedown cruise" in cislunar space by the end of the 2020s. The specifics of the validation approach are still under consideration.

Question 10:

The U.S. government currently operates the International Space Station with a variety of international partners. Given that NASA intends to extend its human exploration activities into cis-lunar space in orbit around the Moon, how do you recommend we weave international and commercial partners into this phase of the journey? Are there good lessons learned from the international partnership onboard the Space Station?

Answer 10:

As NASA moves forward into cislunar space, the Agency is strongly encouraging potential commercial and international partnerships. The top-level ISS agreements – the multilateral Intergovernmental Agreement (IGA) and bilateral Memoranda of Understanding (MOU) between NASA and each of the four other partners – that have provided a framework for cooperation on the ISS Program among these international partners, have provided an excellent example of how multiple nations can contribute to ambitious space endeavors. The ongoing successful operation and conduct of international and commercial research aboard ISS serves as a validation of this approach. The NextSTEP BAA for habitat systems has engaged commercial partners early in the concept development phase to provide opportunities to incorporate their concepts and provide opportunities for their participation in these exploration activities. NASA is also pursuing, through a Request For Information (RFI) and other programmatic activities, commercial interest in using unique ISS capabilities, such as available docking ports and attachment sites, for companies to perform research and potentially develop new systems that will help in the commercialization of LEO and inform NASA cislunar plans. NASA will take the lessons learned from ISS, as well as other international and commercial partnerships, to bring the best the world has to offer in achieving sustainable human exploration of deep space.

Question 11:

The recent Commercial Space Launch Competitiveness act extended the life of the International Space Station through 2024. While it is at least eight years away from us today, do you think there is capability and interest in the private sector to take ownership of the International Space Station after 2024? If so, are there some issues that NASA should begin exploring in the coming years to set up a transition of operations and maintenance? What questions would you like to see addressed?

Answer 11:

The ISS represents an international partnership among NASA and four international space agencies. Beyond this, given the significant technical complexity and resource requirements of operating the ISS, NASA does not plan to transfer ownership of the entire Station to the private sector after the end of ISS operations. NASA would consider future proposals to transition specific elements or components of the ISS to the private sector for use in commercial LEO platforms and services apart from the ISS. NASA is also considering proposals for working with commercial partners prior to 2024 to facilitate transition of LEO operations to commercial platforms.

Question 12:

NASA's Inspector General conducted a study in 2014 that identified several hardware challenges to keeping the International Space Station running through 2024. As industry and NASA work together to build new habitat technologies, is there any way to update the Station's hardware with these new technologies to prevent damage from micrometeoroid and orbital debris, fires, or other dangers?

Answer 12:

NASA is taking advantage of lessons learned over almost 16 years of continuously crewed ISS operations to improve hardware aboard the Station and future spacecraft. In the area of micrometeoroid and orbital debris (MMOD) shielding, enhanced shielding has been added to the Russian segment of ISS. In order to better understand fire in space, in June 2016, NASA conducted the Spacecraft Fire Experiment (Saffire-1), which intentionally lit a large-scale fire inside an empty Cygnus cargo vehicle after it left the Station, but before re-entering Earth's atmosphere. Instruments and cameras measured flame growth, oxygen use, heat generated, and more, improving understanding of fire growth in microgravity and safeguarding future space missions. Subsequent Saffire missions will test improved fire detection, suppression, and cleanup technologies that will benefit both the ISS and future exploration spacecraft. Other habitation system improvements, such as those that will improve the reliability of the Environmental Control and Life Support Systems, will also be incorporated into and tested on the ISS to improve its robustness through its remaining operating life.

Question 13:

In his testimony, Mr. Weir made the case for a large rotating habitat that could essentially eliminate the physiological problems (muscle and bone loss) for our astronauts from living in zero gravity. What are the pros and cons of such a design? Should NASA or industry consider such a habitat for a journey to Mars?

Answer 13:

Although NASA's Human Research Program (HRP) continues to seek answers in this area, the human spaceflight research community does not have enough data to suggest whether partial-gravity or a full 1-gravity environment is necessary to maintain proper human health. Therefore, NASA is not currently assessing the implementation of artificial-g as a design parameter in cislunar or Mars spacecraft concepts. Should use of artificial gravity be shown to be an important countermeasure for protecting crew health and safety, NASA would adapt its countermeasure plans accordingly. While a habitat with artificial gravity could potentially help mitigate some risks to crew health and safety, it could also generate additional challenges.

Question 14:

NASA intends to develop its deep space habitat capabilities with extensive cislunar flight testing. How accurately will this be able to simulate a journey to Mars? What, if any, are the major differences?

Answer 14:

NASA's primary human spaceflight goal in the Proving Ground of cislunar space is to prepare, develop, and test all the crew-related capabilities for long duration transit missions to Mars, culminating in a long-duration crewed validation expedition in cislunar space or beyond by the end of the 2020s. This will involve the development and deployment of an integrated habitat in cislunar space, aboard which crews will perform integration and final validation of research and technologies tested in LEO, including on the ISS. Missions in the Proving Ground will also simulate Mars transit operations through limited interaction with Mission Control (again, based on pathfinder experiments conducted in LEO), limited cargo resupply, and no crew exchanges.

While certain systems will be unique to a Mars mission (see response to Question #8, above, noting the limited applicability of a landing on the Moon to a Mars mission), NASA anticipates validating the following capabilities/technologies in cislunar space in support of a crewed Mars mission:

- Advanced countermeasures against deconditioning (bone, muscle, cardiovascular);
- Crew performance, psychological well-being, and intervention for Mars flight operations;
- Integrated medical capabilities (autonomous medical diagnosis and treatment)
- Human and environmental health in a closed Mars spacecraft (immune system, microbiome);
- Mars mission food system
- Space radiation protection/monitoring systems;
- Crew habitation systems (human computer/robotic/vehicle interfaces); and
- Robustness/reliability of crew exercise systems.

Question 15:

It goes without saying that our astronauts will need to eat on long duration missions. Currently, food is provided to astronauts aboard the International Space Station through regular resupply missions. Any mission to Mars will not have a convenient re-supply method. Can you describe some of the challenges NASA is facing when it comes to food systems? Will future explorers grow their own food like Mark Watney did in *The Martian?* Will growing food using *in situ* resources reduce cargo mass requirements?

Answer 15:

Storing food for long durations on deep space mission poses a major challenge. In addition to the many years the food will have to be stored, mission planners have to take into consideration the lack of resupply capability, potential lack of refrigerators or freezers, and the need to minimize packaging in order to save mass. All of these factors contribute to a food system that may provide greatly reduced nutritional value for exploration crewmembers. In the near term, NASA is addressing these challenges through an advanced food technology project that is developing capabilities in the following areas:

- Nutritional and food fortification studies to protect crew health
- Long-term food stabilization research to maximize shelf life
- Advanced food packaging to reduce mass and volume requirements
- Bio-regenerative food processing to provide a fresh food source with critical nutrients
- Advanced food preparation techniques to enable optimal balance of calories and nutrition in collaboration with DOD combat feeding program

In the long term, future explorers may grow their own food, once growing techniques can be proven to be safe and reliable. Once such techniques have been established, there is the potential to reduce cargo mass requirements through the use of bio-regenerative food processing.

Question 16:

What will the BEAM module be used for over the next two years? Are there any plans to use the habitable volume for storage, experiments, or other purposes? Who will be using the habitat for such activities, what will they be doing, and how will that be determined? Will NASA allow commercial activities within the module? If so, who will control and manage those activities? How is NASA planning on making use of habitable volume that may become available during NextSTEP 2?

Answer 16:

NASA is investigating concepts for habitats that can keep astronauts healthy during space exploration. Expandable habitats are one such concept under consideration – they require less payload volume on the rocket than traditional rigid structures, and expand after being deployed in space to provide additional room for astronauts to live and work inside. The Bigelow Expandable Activity Module (BEAM) is the first test of such a module attached to the space station. It will allow investigators to gauge how well it performs overall, and how it protects against space radiation, space debris and the temperature extremes of space.

In late May, BEAM was filled with air and expanded. Astronauts will enter BEAM on an occasional basis to conduct tests to validate the module's overall performance and the capability of expandable habitats. After the testing period is completed, BEAM will be released from the space station to eventually burn up harmlessly in the Earth's atmosphere. The BEAM contract stipulates that the module remains the property of Bigelow Aerospace during its two-year mission.

Through the Next Space Technologies for Exploration Partnerships (NextSTEP) effort, NASA and industry will identify commercial capability development for LEO that intersects with the Agency's long duration, deep space habitation requirements, along with any potential options to leverage commercial LEO advancements towards meeting NASA long duration, deep space habitation needs while promoting commercial activity in LEO. NextSTEP Phase 2 could include ISS demonstrations, though NASA's strategy for evolving habitation systems using the ISS is not dependent on these potential habitable volumes and demonstrations at this point in time. The multiple phases of NextSTEP are informing NASA's acquisition strategy for its deep space, long duration habitation capability.

Question 17:

Does NASA plan to transfer any component of the ISS to a private sector entity? If so, what legal mechanism would NASA use to effectuate that transaction? Would such a transfer require an open, transparent, and competitive process?

Answer 17:

NASA does not currently have plans to transfer ISS components to the private sector but has not ruled out that possibility in the future. Please see response to Question #11, above.

Question 18:

Does anything prevent NASA from leasing habitation services from the private sector? If such an option was available to NASA, and was cost competitive and technically sound, would anything prohibit NASA from leasing habitat services?

Answer 18:

NASA is not prohibited from leasing habitation services from the private sector.

Responses by Mr. John Elbon

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON SPACE

Next Steps to Mars: Deep Space Habitats

Mr. John Elbon, Vice President and General Manager, Space Exploration, Boeing Defense, Space, and Security , the Boeing Company

Questions submitted by Rep. Brian Babin, Chairman, Subcommittee on Space

1. NASA certainly has an interest in developing deep space habitation capabilities, but private industry, too, has shown interest in developing habitats for commercial purposes. As people in the business world who report to your shareholders, what questions do you think need to be answered before NASA makes decisions on its acquisition approach for a deep space habitation module?

   Is it a national program? Is it part of our international policy or diplomacy? Who will pay the preponderance of the cost for the system? Who will own and operate the system? How much oversight or insight does the government want? What market is there other than the government? How suitable are the current commercial designs for low-Earth orbit habitats for use in the more demanding space environments outside of the Van Allen belts?

   - How do you think NASA might be able to encourage commercial or philanthropic investment in space exploration?

     A desire to invest is typically tied to a future return on that investment. In order to drive investment, there needs to be a defined market that will allow the investor to recoup their investment and earn additional profit equal or better than their cost of capital. At the present time, commercial use of the ISS is heavily subsidized by NASA. Given the current commercial demand, it is unlikely commercial activity would be able to create a profitable business case to cover the fixed and operating costs of a space platform without some level of government investment/subsidy.

   - Given the synergies of various interests, what types of acquisition strategies should NASA consider? What makes procurement of a cislunar habitat different than existing partnerships like commercial crew and cargo?

     Note that NASA provided the preponderance of funding for development of the commercial crew and cargo systems, but the contractors retain the intellectual property. Commercial Crew and Cargo are based on known technologies and demonstrated capabilities dating back to the Mercury, Gemini, and Apollo programs. In addition, NASA has provided a demand model that allows the companies to recoup their investments through the service contracts. The Cis-lunar habitat will be part of an international partnership and a national program, and as such, NASA should consider a government cost-plus contract. NASA will require full oversight and function as the integrator of the cis-lunar system, coordinating requirements between the international partners. In addition, there is not a demand to produce habitats on an annual basis as is the case for commercial crew and cargo program that enables the business case to close for a commercial company.

2. NASA and the US government are currently working with industry on a variety of projects that promote the development of commercial habitat technologies. Bigelow Aerospace recently had its BEAM module installed on the International Space Station and a variety of companies are working with NASA's NextSTEP to advance deep space exploration technologies. Given this, what government policies are helping or hindering the development of commercial space habitats?

   By providing access (launch and crew time) to the International Space Station as a National Laboratory, the government is attracting commercial users in the area of biological science, material science, and Earth observation. Also, in the case of commercial crew and cargo, by providing a demand that allows the parties to recoup their investment in the development, the government is fostering a commercial services approach for both crew and cargo. In the case of cis-lunar habitats, there is not a commercial demand to justify significant investment which will push the preponderance or all of the investment on the government. Investments associated with deep space exploration program will likely require the stability provided by international governmental partners as with the ISS. Introducing commercial market uncertainties for critical architectural elements such as habitats, pose additional schedule, technical compliance, and sustainability risks to what is expected to be an extremely interrelated architectural undertaking.

   - One of the problems that Bigelow Aerospace cites is that "NASA is over focused on transportation systems to the International Space Station...and additional destinations are vital." He recommends that America return to the Moon and then on to Mars. What are your thoughts about this?

     The problem is that there is not enough demand in low Earth orbit, other than the government, to sustain a commercial destination without significant government support and involvement. Commercial demand on the International Space Station is possible due to the high level of government subsidy on the launch and crew time to support microgravity research.

     The current path that NASA is on with a cis-lunar system would enable both a return to the Moon, by the US, international partners or commercial interests, as well as prepare us for the journey to Mars. The SLS and Orion are the first two enabling systems for deep space exploration, with subsequent elements reliant upon the availability of these systems. Within NASA's constrained budget, priority has been placed on completing the SLS and Orion developments. With those elements moving out of design and into test and production, habitats are the next critical architecture element. NASA has been performing the necessary predevelopment exercises to fully inform a habitat development is fully compatible with SLS and Orion, and other future envisioned interfaces.

3. Many academic and commercial organizations currently use the International Space Station as a platform for conducting activities in microgravity.
   - If the ISS program were ended in 2024, would demand for those organizations be enough for industry to step in and provide their own habitats in low Earth orbit?

Current commercial use on the ISS does not generate the required revenue to sustain a habitat in low Earth orbit. Today, the majority of launch cost and crew time are provided by the US government.

- Is a commercial habitat market in low Earth orbit possible without government support? Are there any regulatory issues that are inhibiting the development of commercial habitats?

  Today it cost the US government $3B a year to sustain the International Space Station with the majority of that cost being crew and cargo logistics (~$1.5-2.0B). Our estimates are that a commercial destination would cost roughly $2B a year to operate with crew and cargo logistics being the majority of the cost. There has not yet materialized a commercial market that would sustain that annual revenue stream without a significant government role. Commercial markets may offset some costs, but not the majority of the costs. Over time and as valuable research becomes public, the amount of commercial revenue will likely grow, but it will not fully replace the government investment.

4. Companies like Bigelow Aerospace are proposing to send up their own habitats for commercial purposes to low Earth orbit. Some proposals call for non-NASA/private sector astronauts to live and work on these commercial stations. What is the commercial industry doing to prepare private sector astronauts?

   To date, 7 private citizens have flown 8 times to the International Space Station through contracts with Space Adventures and flights on Soyuz. Space Adventures continues to contract with parties interested in flying to the International Space Station. As part of the Commercial Crew program, Boeing is planning on sending a Boeing astronaut on the Crewed Flight Test scheduled for 2018 and is working with Space Adventures on potential use of a 5th seat on NASA missions for private spaceflight participants.

5. The International Space Station, as the name suggests, provides a low Earth orbiting platform for many different countries. After the ISS, those countries that may want to continue human operations in space. Is there an international market for habitat volume or services in low Earth orbit or beyond if those countries want to continue?

   The ISS exists today because of the international agreements between the countries. There may be interest in continuing operations in low Earth orbit on a commercial destination, but it will be driven by other priorities as it would not be tied directly to international policy. Given today's priorities, the international partners would likely turn their investment towards cis-lunar, Moon and Mars.

6. There are some that are worried about the influence that foreign-subsidized launch is having on the US commercial launch market. As US companies look to develop their own commercial habitats, is there any worry that other countries like China might come in and compete with their own low-Earth orbit habitats? What should the US do to prevent this?

   China has publically offered access to their Space Station, which is planned to be operational in 2020-2021. In addition, the European Space Agency has made agreements with China to fly crew to the Chinese space station. As such, there will be competition between a Chinese (national) space station and a commercial destination for international partners and commercial industry. US policy can only deny US company/citizen access to the Chinese Space Station. By the US government retaining a leadership role in low Earth orbit (on ISS) and tying it to international policy/agreements, the US can retain international and commercial participation.

7. As private industry continues to work on habitation technologies, what challenges are you encountering? What are the greatest obstacles to building habitation technologies that will protect our astronauts in cis-lunar space or carry our astronauts to Mars?

   The primary structure of a habitat is well understood based on the experience with the International Space Station. The habitation technologies are focused on areas where deep space will be different that low Earth orbit, which are highly reliable environmental control systems and radiation protection for the electronics and the crew. When we travel beyond low Earth orbit, the ability to return to Earth is measured in weeks or months, not hours. As such, the systems have to be much more autonomous and reliable than they are today on the ISS. One specific system, which NASA is focused on, is the environmental control system (water and air purification/filtration). NASA is working on developing a system for deep space that they plan to launch and demonstrate on the ISS before implementing into the deep space habitat. The electronics systems used today on the ISS are not subject to the cosmic radiation environment that they will experience in deep space. As such, NASA is working to mature these electronics systems to survive a long-duration mission in deep space.

8. NASA is working with industry to develop habitation technologies through programs like NextSTEP. As NASA and the private industry continue to work together, what do you think the role of NASA should be moving forward? How would you shape the private-public relationship? What is the appropriate level of cost-sharing? Who should retain intellectual property rights? What structure is the best of the U.S. taxpayer?

   NASA needs to lead the development and integration effort for the cis-lunar system given its tie to international policy and partnerships. Assuming that cis-lunar (and the journey to Mars) is a national program, government should fund, have full oversight, and retain the intellectual property rights. Any private-public partnerships should be aligned with logistics, similar to low Earth orbit, and leverage capabilities already developed to increase flight rate and improve commercial business models.

9. NASA has been developing the Space Launch System and Orion Crew Vehicle for several years and only now beginning efforts to build habitation modules for our astronauts to carry out deep space missions. How do you see these deep space habitation capabilities complementing the Orion and SLS efforts?

   A deep space habitat will likely be the first to launch on the Space Launch System co-manifested with Orion. By co-manifesting, you leverage the capability of the Space Launch System and allow for every launch to be leveraged for a human spaceflight mission. Each launch allows augmentation of capability and logistics to continually demonstrate critical systems to support the journey to Mars.

10. NASA recently sent out its second Next Step Technologies for Exploration Partnerships broad area announcement. Given industry's experience with the first iteration of the NextSTEP program, what advice would you give to NASA as they consider further developments in space habitation and the NextSTEP program?

    Look for opportunities to increase mission duration and capability as early and quickly as possible to accelerate learning in preparation for the journey to Mars. Leverage ISS to advance technologies, such as ECLSS, with a plan to onramp to cis-lunar. Limit or eliminate "throw-away" systems that are one time use and focus on evolvable systems that add capability and fully leverage the government investment. Set high level architecture decisions, such as destination and objectives, as soon as possible to allow industry to more closely focus its efforts.

11. NASA is not only working with industry teams to develop deep space habitation technology. It is also working with colleges and universities through the X-Hab Academic Innovation Challenge. Can you discuss what work, if any, is being done between industry and academia to foster the development of this technology? What are the primary goals for the X-Hab Academic Innovation Challenge?

    Boeing is not currently teamed with colleges or universities on the X-Hab Academic Innovation Challenge.

12. What rockets do you expect to launch the deep space habitation modules from? Does the size of the habitation module for journeys to Mars dive you to using Space Launch System rocket? Can other, smaller rockets carry habitation modules to low-Earth orbit or around the Moon, or does that also require the throw-weight of an SLS heavy-lift rocket? Should the habitat be designed for an SLS launch from the beginning?

    The optimum solution is design the habitat for an SLS from the beginning to leverage the co-manifested capability to align with crewed missions, expand mission duration and accelerate learning in preparation for the journey to Mars. Smaller rockets could launch each system independently, but would significantly increase logistics, in-space transportation systems, and total cost. The International Space Station required forty four launches to transport the sub-elements to low-Earth Orbit for assembly. The payload mass and volume associated with the SLS could have delivered that in five launches. This would have significantly reduced complexity and cost of the ISS. A significant lesson learned from the ISS program is to minimize on-orbit assembly and design complexity by launching larger pre-integrated elements.

13. As the ultimate goal is to put American boots on Mars, there are several other components necessary to complete that mission. In Mr. Elbon's testimony, he pointed out that we still need vehicles such as a solar-electric tug, and a Mars lander and ascent vehicle if we are to conduct a Mars mission. A habitat is just one piece of the puzzle. How does knowing (or not knowing) how the pieces of the puzzle fit together for the eventual Mars mission impact the design efforts going on now for the deep space habitation systems?

    There are six critical capabilities that are required to get humans to Mars. The first pieces of the puzzle, SLS and Orion will be demonstrated through missions to cis-lunar space. The second pieces of the puzzle, the habitat and in-space propulsion systems will be developed, evolved and demonstrated in cis-lunar space prior to the journey to Mars. Ultimately the final pieces of the puzzle, descent and ascent from Mars will be developed and demonstrated when we travel to Mars. By phasing the pieces of the puzzle, you are able to not only incrementally demonstrate capability and retire risk, but you are able to fund the journey to Mars within the projected NASA human spaceflight budget.

14. The European Space Agency is the only international partner who has not yet committed to extending the life of the International Space Station through 2024. ESA Director General Johann Woerner has shown interest in developing a human presence on the moon, a 'lunar village.' If the United States were to plan to return to the Moon, would the habitation capabilities on the Moon be applicable to future missions on Mars, or completely different? How difficult will it be to adapt your habitat design for surface operations on the Moon, Mars, or both?

Our understanding is that ESA will extend ISS through 2024 at the next ministerial meeting in this fall. There are many common systems when comparing uses of habitats. The primary structure developed for the International Space Station can be directly applied to any pressured habitat system whether it be in orbit or on the surface of the Moon or Mars. The differences are tied to the systems within the habitats. In low Earth orbit, with the ability to return to Earth in hours, systems do not have to be highly autonomous or redundant. In addition, the astronauts and the electronics are protected from cosmic rays and radiation. When the habitat is moved to cis-lunar space, it takes days for astronuats to return to Earth, so systems need to be more autonomous and redundant. Also, in cis-lunar space you are subject to cosmic radiation which impacts crew health and electronics systems. On the surface of the Moon or Mars, you have some relief from cosmic radiation, but you have to deal with other environmental events and dust.

15. I do not see our European counterparts or any other countries interested in the Administrations' Asteroid Retrieval Mission. Further, U.S. law states that NASA Administrator "shall establish a program to develop a sustained human presence on the Moon."[1]

    Solar electric propulsion (SEP) capability is a critical element to future exploration programs independent of whether it is developed in support of the Asteroid Retrieval Mission (ARM) or journey to Mars. The spacecraft bus and propulsion technologies being developed in support of ARM can be directly applied to early cis-lunar systems to support station keeping and vehicle translation between orbits (Lagrange points) in cis-lunar space. Ultimately, evolved SEP systems can pre-position logistics in Mars orbit and transport crew to Mars.

    - Given that, how should NASA's habitation development efforts facilitate cis-lunar exploration, as well as lunar surface exploration, as a way to prepare for an eventual mission to Mars?

      By initiating development of a cis-lunar platform, NASA enables demonstration of key technologies and capabilities, including crew health, in an environment similar to a Mars mission. In addition, it enables a flexible path to support missions to the surface of the Moon as well as a staging ground for the journey to Mars. Once a habitat exists in cis-lunar, it also opens opportunities for commercial logistics missions, asteroid mining, insitu-resource utilization studies, and lunar colonization.
    - Numerous experts have testified before this Committee that a crewed mission to Mars should be preceded by an independent six month mission on ISS, a 13 month stay on the lunar surface, and another six month stay on ISS before returning to Earth. This "shakeout" mission would test the systems and protocols necessary for a Mars mission within the proximity of the Earth. How should NASA's habitation development efforts take into account he logical needs to both cis-lunar capabilities as well as lunar surface capabilities?

      Cis-lunar space is a better location for a "shakeout" cruise as it represents the environment (cosmic radiation and proximity to Earth) that our astronauts will experience on their journey to Mars. The key is to demonstrate the performance of the transportation systems and crew to survive an 800 to 1100 day journey. A stay on the surface of the Moon could help demonstrate surface systems and crew operations, but is not required to support the journey to Mars.

16. The U.S. government currently operates the International Space Station with a variety of international partners. Given that NASA intends to extend its human exploration activities into cis-lunar space in orbit around the Moon, how do you recommend we weave international and

commercial partners into this phase of the journey? Are there good lessons learned from the international partnership onboard the Space Station?

The journey to Mars, which starts in cis-lunar space, will be a global endeavor. The partnership forged in the development and on-going operations of the International Space Station is a perfect example of how to cooperate and collaborate in cis-lunar and the journey to Mars. Similar to the ISS, governments can look for opportunities to engage the commercial market and transition logistics to commercial service providers.

17. The recent Commercial Space Launch Competitiveness act extended the life of the International Space Station through 2024. While it is at least 8 years away from us today, do you think there is capability and interest in the private sector to take ownership of the International Space Station after 2024? If so, are there some issues that NASA should begin exploring in the coming years to set up a transition of operations and maintenance? What questions would you like to see addressed?

The key to fostering a commercial market is to provide enough runway to support experiments in their infancy today. Typically this has been 10 years, which was the purpose behind extending the ISS to 2024 in 2014. By stating an end date to ISS, potential investigators are driven away from leveraging ISS and for terrestrial alternatives for fear that they will invest their time and energy and not have ISS when they are ready. The key is to keep a low Earth orbit destination going whether that be by extending the ISS, turning over operations of ISS to a commercial entity, or a new, commercial destination. Commercial interest in operating a destination in low Earth orbit will be driven by the ability to close a business case, which will likely rely heavily on continued government investment. There are parties expressing interest, but none have found a model as yet that closes without significant government investment.

18. NASA's Inspector General conducted a study in 2014 that identified several hardware challenges to keeping the International Space Station running through 2024. As industry and NASA work together to build new habitat technologies, is there any way to update the Station's hardware with these new technologies to prevent damage from micrometeoroid and orbital debris, fires, or other dangers?

Boeing has assessed the ability to extend the life of ISS at NASA's request. The ISS is capable of operating until 2028 and beyond. However, there are a couple of key systems that will require repair or replacement, such as the solar arrays. Systems being developed today to support future exploration programs, such as the DSS and ATK solar arrays, are being looked at as systems that can extend the life of ISS. In addition, ISS is being used as a test-bed for key technologies, such as ECLSS, to support deep space exploration. These systems will further enhance capabilities and extend the life of ISS.

19. In his testimony, Mr. Weir made the case for a large rotating habitat that could essentially eliminate the physiological problems (muscle and bone loss) for our astronauts from living in zero gravity. What are the pros and cons of such a design? Should NASA or industry consider such a habitat for a journey to Mars?

While artificial gravity creates advantages for long duration missions, it is technically challenging and costly. To introduce artificial gravity concepts would require significant budget increases and would likely delay the current path to Mars due to lessons learned as we mature that technology.

20. The U.S. has two commercial cargo resupply providers with a third on the way in addition to international capabilities to supply the ISS and a crew of six or seven.
    - How many crew members are you initially planning in your cis-lunar habitat designs around the Moon?

      The baseline mission today is 4 crew members on an Orion mission.

    - How often would you need to resupply this crew in cis-lunar orbit using current cargo-lifting capabilities?

      The current plan is annual missions with increased durations each mission enabled by a co-manifest SLS (Orion + cis-lunar system/logistics). Additional logistics missions can be provided to further extend mission duration.

21. What bodies of standards (interfaces, ergonomic, power, data, docking, etc.) are being used to inform your habitat design?

    Today, the international docking system standard is informing our design for docking and berthing interfaces as well as resource transfer, including power, data, and fluids.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON SPACE

Next Steps to Mars: Deep Space Habitats

Mr. John Elbon, Vice President and General Manager, Space Exploration, Boeing Defense, Space, and Security , the Boeing Company

Questions submitted by Rep. Donna Edwards, Ranking Member, Subcommittee on Space

1. Based on Boeing's decades of work on space systems, what in your view is the most efficient way to obtain an operational deep space habitat?

   If cis-lunar is an international endeavor, the most efficient way is to have NASA lead the development and function as the lead integrator between the international parties. It is important that NASA leads the development of the first element in cis-lunar to ensure that integration and operations of the cis-lunar system is in the US.

   - If we are to send humans to Mars in the 2030s as the NASA Administrator suggests, what are some of the technological challenges and risks that must be addressed in order to acquire operations habitat(s) ready for use to transit to, orbit, and operate on the surface of Mars?

     Mars is challenging. First, with missions as long as 800 to 1,100 days, the systems (especially the environmental control system – water and air filtration) need to be highly reliable and capable of operating in the deep space (cosmic radiation) environment. We have been continually enhance the environmental control system on the ISS as we learn how to improve reliability. In addition, with communication delays of up to 45 minutes and black out period as long as two week (when Mars is behind the Sun), the crew has to be able to operate the system autonomously.

   - At what pace must these risk-mitigation activities be undertaken if we are to land humans on Mars by the early 2030s?

     Environmental control systems are being developed and will be tested on the ISS this decade. The cis-lunar habitats will help demonstrate systems in deep space in the early/mid 2020's. A "shakedown" cruise in the late 2020's allows full demonstration of the systems required to transport astronauts to Mars.

   - Is the FY2016 appropriation timeline for having a ground-based prototype of a habitation system by 2018 reasonable?

     Yes, a ground-based demonstrator/prototype can be developed by 2018 within existing budget. Key is define an architecture that is flexible enough to adopt to changing NASA requirements and the role of the international partners as we develop these prototypes.

2. Does NASA have final requirements for a deep space habitat that it has provided you? If so, what are they? If not, what is your perspective on how those requirements should be established?

   No, the purpose of NextSTEP-2 is for industry to share architecture approaches and concepts to help NASA, along with discussions with their international partners, develop requirements for the deep space habitat. NASA should use the NextSTEP inputs to iteratively create and improve habitat requirements.

3. What are the most significant cost drivers for deep space habitats? Are there technologies under development that would help lower the costs of developing habitats?

   The most significant driver to cost is point solutions that single mission purposed and not leveraged for future missions. The key is to use of common hardware and continue to leverage development as the systems evolve to support the journey to Mars.

4. Your prepared statement noted that from ISS operations, you have learned that we need an environmental control and life support system that is more efficient at recycling air and water in deep space applications. How did you come to that conclusion and what technology advances are necessary to enable the greater efficiency desired?

   Based on our experiences on the International Space Station, environmental control systems are not reliable enough to support long-duration missions. We also learned that environmental controls systems (specifically bearings and valves) do not operate the same when tested on Earth as they do in microgravity. Current systems in use require continuous maintenance and repair. Based on what we have learned on ISS, NASA is working on the next generation environmental control systems that will be launched and demonstrated on the ISS before transitioning to support deep space missions.

5. How is NASA carrying out oversight of your NextSTEP work and what lessons have been learned that can be applied to the oversight of future NextSTEP work, including on habitats?

   Our NextSTEP experience with NASA has been positive. NASA has monitored our progress closely and rapidly responded to questions while maintaining an objective distance with respect to direction to avoid injecting their concepts and thoughts into our efforts. This approach has allowed NASA to gain fresh, outside input on cislunar habitats from Boeing and presumably the other NextSTEP contractors. This oversight approach has worked well for the concept development phase. A similar approach during habitat procurement could potentially likewise improve cost and efficiency by streamlining interfaces and project decisions.

Responses by Ms. Wanda Sigur

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON SPACE

Next Steps to Mars: Deep Space Habitats

Ms. Wanda Sigur, Vice President and General Manager, Civil Space, Lockheed Martin Corporation

Questions submitted by Rep. Brian Babin, Chairman, Subcommittee on Space

1. NASA certainly has an interest in developing deep space habitation capabilities, but private industry, too, has shown interest in developing habitats for commercial purpose. As people in the business world who report to your shareholders, what questions do you think need to be answered before NASA makes decisions on its acquisition approach for a deep space habitation module?

The acquisition approach for habitats should consider technical development complexity and end-user markets, critically examining commercial market viability or, conversely, intended government use. The questions should include: what is the long-term outlook for sustainable economic activity in space? Specifically, are there resources that can realistically be monetized or services which would have paying customers other than the government? For instance, can precious metals from asteroids be extracted at a scale large enough to overcome the recurring cost of mining them? Will fusion technology ever be able to capitalize on the helium-3 presumed to be at the Moon? Are there enough private citizens able to afford the cost of a flight to establish tourism as an ongoing activity to more than just the ultra-wealthy? Will there ever be a destination other than a government-funded outpost for cargo deliveries? Can such an outpost ever be self-sustaining so that it creates both a supply of products to trade for the things it demands?

- **How do you think NASA might be able to encourage commercial or philanthropic investments in space exploration?**

If the long-term business case closes, the government could encourage commercial investments through direct or indirect subsidies of space activities, such as the currently provided access to the International Space Station (ISS).

Philanthropic investments can be encouraged by appealing to two notions: the "need to explore," which NASA has discussed for quite some time, or the "need for humans to survive," which appeals to the same impulse as eco-tourism.

- **Given the synergies of various interests, what types of acquisition strategies should NASA consider? What makes the procurement of a cis-lunar habitat different than existing partnerships like commercial crew and cargo?**

NASA should utilize acquisition strategies that emphasize stability and adoption of modern design, manufacturing, and operations techniques. Stability provides confidence for real or human capital investments and modern industrial practices allow companies efficiencies through process commonality across their customer base.

Cis-lunar habitats are currently needed by the exact same number of customers (one) as the existing crew and cargo partnerships, i.e., the government. The rate and the time horizon of a stable "demand" is slower and longer for destinations beyond low Earth orbit, however, due to the distance to the Moon and the resulting higher energy and cost requirements, the Moon presents a more difficult business case. Additionally, the barrier to participation is much higher, as seen by the limited number of parties which have visited the Moon (governments of developed countries) compared to the number of parties that have visited low Earth orbit (viable communications and imaging businesses, entrepreneurs, hobbyists).

2. NASA and the U.S. government are currently working with industry on a variety of projects that promote the development of commercial habitat technologies. Bigelow Aerospace recently had its BEAM module installed on the ISS and a variety of companies are working with NASA's NextSTEP to advance deep space exploration technologies. Given this, what government policies are helping or hindering the development of commercial space habitats?

- **One of the problems that Bob Bigelow cites is that "NASA is over focused on transportation systems to the International Space Station. . .and additional destinations are vital." He recommends that America return to the Moon and then on to Mars. What are your thoughts about this?**

It seems wise that cis-lunar space be used as a proving ground for the human exploration of Mars – consistent with NASA's plans. What is important is to map these cis-lunar missions (whether orbital or surface) to the achievement of objectives that directly reduce the risk and enable human Mars exploration missions. From these missions will naturally come opportunities for private industry to provide various mission elements, either as purely commercial endeavors or in one of the variants of public-private partnerships. This will be true of the habitat element of these deep space missions. Commercial cargo and crew are examples of these kind of partnerships and can be applied to elements of the exploration architecture when the essential risks have been retired (like long-duration, highly-closed life support systems for 1000-day missions), or if the mission is carefully architected to separate the higher risk from low risk technologies. As for policies that help or hinder, Space Act Agreements are a good example of one that gives private organizations and academia access to NASA-developed technologies and NASA subject matter experts.

3. Many academic and commercial organizations currently use the ISS as a platform for conducting activities in microgravity.

- **If the ISS program were ended in 2024, would demand from those organizations be enough for industry to step in and provide their own habitats in low Earth orbit?**

At this point, probably not. The current use of the ISS as a platform is nearly completely subsidized. To date, the returns on activities performed on the ISS have been niche research results (e.g., bone loss, crystal growth) rather than breakthroughs enabling large commercial successes. Without demonstration of significant commercial success from a subsidized platform, the chances of industry investing billions of dollars to provide their own spacefaring infrastructure is small. However, as discussed in question 5, an existing and emerging international market in addition to ongoing microgravity research may eventually change the current demand.

- **Is a commercial habitat market in low Earth orbit possible without government support? Are there any regulatory issues that are inhibiting the development of commercial habitats?**

Again, likely not at this point. The best industry studies have concluded that space tourism for the ultra-wealthy is the only viable market for space habitats. Both supply and demand are currently many years behind the projections in these studies.

Regulatory frameworks typically adapt after the fact to technological innovations. For instance, the music industry was greatly disrupted by file sharing and the regulation of that industry was undertaken *after* a consistent supply and demand was established. As a "trailing indicator," government regulations (or lack thereof) have little value in stimulating an industry.

4. Companies like Bigelow Aerospace are proposing to send their own habitats for commercial purposes to low Earth orbit. Some proposals call for non-NASA/private sector astronauts to live and work on these commercial stations. What is the commercial industry doing to prepare private sector astronauts?

Any large efforts have not been publicly identified and programs that were started seem to be placed on hold. At the academic level, Embry-Riddle has recently been in the news celebrating the graduation of their first class of a training program. For an orbiting laboratory or hotel, a fair assumption is that the astronauts, in order to ensure their own safety, should know about the engineering and assembly of the systems - at least until many developments in error-proofing space travel have been achieved. Scientists and hotel guests on Earth tend to know very little about the engineering of a facility but have the ability to walk out if there is a problem. Maritime passengers have limited control, so a higher standard on commercial ventures is applied. Passengers on commercial flights additionally lack that ability but count on a well-trained crew of pilots and flight attendants to keep them safe. The Russians currently use a similar model for the right-seat in the Soyuz with both their commercial customers and their government customers. The solution to all of these concerns is additional investment, further challenging the already limited business case.

5. The ISS, as the name suggests, provides a low Earth orbiting platform for many different countries. After the ISS, those countries that want to continue human operations in space. Is there an international market for habitat volume or services in low Earth orbit or beyond if those countries want to continue?

Recent entrepreneurial trends suggest that there is an existing and emerging international market for low Earth orbit pressurized volume and special services. While many envision that space tourism will eventually be an important market, there are serious research advantages in the biological and material sciences that can be best accomplished in a zero-g environment requiring long duration exposure (i.e., greater than minutes). One such example is a start-up company (The Space Research Company) spun off from CU-Boulder that is developing pressurized volume CubeSats that serve to test biological organism reactions to new drugs and treatments. The zero-g environment allows them to accelerate biological metabolism activity providing a distinct advantage to Earth-bound experiments. The Canadian company, Urthecast, has developed a viable imaging business on ISS. There is a reasonable expectation that this ISS-enabled technology market will continue to grow; however, it may be some time before any of these companies could afford the overhead costs of maintaining the ISS human presence without government subsidies.

6. There are some that are worried about the influence that foreign-subsidized launch is having on the US commercial launch market. As US companies look to develop their own commercial habitats, is there any worry that other countries like China might come in and compete with their own low Earth orbit habitats? What should the U.S. do to prevent this?

At this point, it is hard to envision a scenario where countries like China could compete with their own low Earth habitats, particularly since a market supporting a commercial business case for low Earth orbit habitats has yet to emerge.

7. As private industry continues to work on habitation technologies, what challenges are you encountering? What are the greatest obstacles to building habitation technologies that will protect our astronauts in cis-lunar space or carry our astronauts to Mars?

Creating a modular and evolvable infrastructure will require a significant amount of up front work on standards and interfaces. In addition, creating a habitat that will allow us to move into deep space will require us to operate differently than we do with ISS. We will need to get comfortable with allowing astronauts to operate more autonomously without continual ground support. Astronauts will have to be trained to "stay and fight" in emergency situations. We will also have to create systems that can operate for long periods of time without astronauts or ground crews. This will require a significant amount of built in automation and self-maintenance.

8. NASA is working with industry to develop habitation technologies through programs like NextSTEP. As NASA and the private industry continue to work together, what do you think the role of NASA should be moving forward? How would you shape the private-public relationship?

Public-private partnerships allow for risk sharing on leading edge technology programs. NASA is currently working with industry to try to identify commercial opportunities in low Earth orbit and cis-lunar space. Commercial activities enabled by exploration will have a range of risks to the NASA hardware and missions. As the risk to NASA and other government agencies decreases, so will the amount of NASA participation and oversight in those activities.

Partnerships should be built on an open architecture that allows each customer to create a unique business arrangement. These arrangements range from new developments under cost-plus type contracts to simple government licensing for launch. In between, government purchase of services through FAR part 12 or Space Act Agreements are possible. Blending of different business approaches provide maximum benefit for both NASA and private industry.

Slow habitat development, un-materialized demand, and low flight rate all present potential risks to a commercialization plan.

9. NASA has been developing the Space Launch System and Orion Crew Vehicle for several years and only now beginning efforts to build habitation modules for our astronauts to carry out deep space missions. How do you see these deep space habitation capabilities complementing the Orion and SLS efforts?

As America's deep space human-rated spacecraft, Orion is capable of supporting multi-year missions for everything from initial flights in cis-lunar space (~30 days) to a one year "shakedown" flight to demonstrate long-duration, deep space capability, to a round trip to Mars likely to last around 1,000 days (3 years). The two features Orion needs to fulfill these missions are increased habitable volume for crew living and sufficient consumables to support a specific mission duration with appropriate margins.

10. The Orion Crew Vehicle is currently being developed and is expected to launch aboard the Space Launch System in late 2018. Many of the technologies involved in developing a crew vehicle are also important to the development of bigger habitation technologies. How is industry leveraging the lessons learned in Orion's development to help create deep space habitats?

Orion is designed with everything needed for a deep space mission, including radiation hardened, redundant avionics, deep space navigation and communication. We are looking for all possible ways to leverage these existing Orion capabilities to make deep space habitat development more capable and affordable.

11. NASA recently sent out its second Next Space Technologies for Exploration Partnerships broad area announcement. Given industry's experience with the first iteration of the NEXTSTEP program, what advice would you give to NASA as they consider further developments in space habitation and the NextSTEP program?

We look forward to having the chance to continue to work with NASA under Phase 2. There are significant decisions that will need to be made to get to a cis-lunar habitat in the early 2020s. NASA will need to define the modules and elements that will be a part of the architecture and reference missions that the habitat will support. NASA will need to continue to define key driving requirements. Understanding the rolls for domestic versus international participation is also key.

12. NASA is not only working with industry teams to develop deep space habitation technology. It is also working with colleges and universities through the X-Hab Academic Innovation Challenge. Can you discuss what work, if any, is being done between industry and academia to foster the development of this technology? What are the primary goals for the X-Hab Academic Innovation Challenge?

The primary goals of the X-Hab challenge are to foster innovation and collaboration by students and professors using strategic partnerships between universities and NASA. Administered as grants of $10-20K through the National Space Grant Foundation from NASA's Advanced Exploration Systems Division, the awards are expected to produce studies or even prototypes that NASA can consider for use on its Exploration Systems. These results can pertain to space habitation or other technologies beneficial to the exploration program. This is an excellent way to tap the creativity of engineers and scientists in training and their professors. In addition to this NASA program, Lockheed Martin is a regular sponsor of senior design projects and research projects with major universities across the country. Our engineers and managers serve as reviewers and mentors to hundreds of students, both graduate and undergraduate, in exploration technologies that include space habitation and a variety of other critical areas.

13. What rockets do you expect to launch the deep space habitation modules from? Does the size of the habitation module for journeys to Mars drive you to using a Space Launch System rocket? Can other, smaller rockets carry habitation modules to low-Earth orbit or around the Moon, or does that also require the throw-weight of an SLS heavy-lift rocket? Should the habitat be designed for an SLS launch from the beginning?

The plan is to launch the deep space habitation modules on an SLS for maximum on orbit mass. Round trips to Mars are on the order of three years, so the required pressurized volume for crew living and consumables is extensive. With any reasonably achievable launch success rate, there has to be a rocket with not just large throw weight to low Earth orbit, but considerable throw weight to the velocities required for deep space exploration.

14. As the ultimate goal is to put American boots on Mars, there are several other components necessary to complete that mission. In Mr. Elbon's testimony, he pointed out that we still need

vehicles such as a solar-electric tug, and a Mars lander and ascent vehicle if we are to conduct a Mars mission. A habitat is just one piece of the puzzle. How does knowing (or not knowing) how the other pieces of the puzzle fit together for that eventual Mars mission impact the design efforts going on now for the deep space habitation systems? Since NASA has yet to lay out the phasing of developments, budgets, and schedules for a mission to Mars, how does this uncertainty impact industry's ability to provide technologies necessary to carry out NASA's plans?

While more certainty in future budgets would allow for optimization of the overall design of a human Mars mission resulting in both greater performance and reduced costs, we cannot afford to wait for that day to come. Today, with our best understanding of what is to come, we are looking to leverage Orion's capabilities as well as some of the unique mission requirements coming out of the Science Mission Directorate, for example solar electric propulsion, as mentioned. To make the goal of humans to Mars achievable, we demand the most stringent requirements for safety and also examine opportunities to leverage existing capabilities to drive affordability. Imagine if the Mars ascent and decent vehicle had the same avionics as Orion, which are deep space human-rated to include redundant radiation hardened fault tolerance. We are looking to do the same with deep space communication and navigation, as well as other major systems.

15. The European Space Agency is the only international partner who has not yet committed to extending the life of the ISS through 2024. ESA Director General Johann Woerner has shown interest in developing a human presence on the Moon, a "lunar village." If the United States were to plan to return to the Moon, would the habitation capabilities on the Moon be applicable to future missions on Mars, or completely different? How difficult will it be to adapt your habitat design for surface operations on the Moon, Mars, or both?

A cis-lunar habitat can be a great asset for both lunar surface operations and preparing for Mars. In fact, under Phase 2, we will be working with and funding Airbus (with internal funding) to study concepts where the habitat provides an orbiting "waystation" for outposts on the lunar surface. Essentially, this would allow astronauts to have an orbiting platform they would launch to and transfer to a lander to get to the surface. This could be very analogous to the way we eventually do Mars missions. In addition, we believe there are ways to reduce cost by creating habitats that all have common structures (e.g., the orbiting habitat has the same basic structure as the landed habitat or even the lander). We are looking into ways to provide provisions for such features right now.

16. I do not see our European counterparts of any other countries interested in the Administration's Asteroid Retrieval Mission. Further, U.S. law states that NASA Administrator "shall establish a program to develop a sustained human presence on the Moon."

- **Given that, how should NASA's habitation development efforts facilitate cis-lunar exploration, as well as lunar surface exploration, as a way to prepare for an eventual mission to Mars?**
- **Numerous experts have testified before this Committee that a crewed mission to Mars should be preceded by an independent six month mission on ISS, a 13 month stay on the lunar surface, and another six month stay on ISS before returning to Earth. This "shakeout" mission would test the systems and protocols necessary for a Mars mission within the proximity of the Earth. How should NASA's habitation development efforts take into account the logical needs to both cis-lunar capabilities as well as lunar surface capabilities?**

The cis-lunar and near Earth space environments represent incredible opportunities to test out or "shakedown" the system necessary to carry out human exploration beyond the Earth and Moon, and specifically to Mars. The deep space habitat is one essential element in the system, the others being Orion, SLS, solar electric propulsion tugs, in-space propulsion, and landers. The key method to understanding what missions in cis-lunar or near Earth space are the right ones to accomplish is to map backwards from the first human missions to Mars and determine the necessary flight test objectives for the precursor missions closer to home. In our proposed Mars Base Camp architecture, in addition to important cis-lunar missions that check off these objectives, we propose a "shakeout" mission to a near Earth object that would last one year, conduct serious science, and test all the interplanetary and surface exploration systems necessary to do the same at Mars a few years later. This year-long mission is an extension of an important concept learned over 50 years of space vehicle and human mission development – that you should "test like you fly." So before heading out to Mars with the full up system, we should test it in near Earth space like we will fly it to Mars. This is far superior to stitching together a series of shorter flight test flights in lieu of a shakedown.

17. The U.S. Government currently operates the ISS with a variety of international partners. Given that NASA intends to extend its human exploration activities into cis-lunar space in orbit around the Moon, how do you recommend we weave international and commercial partners into this phase of the journey? Are there good lessons learned from the international partnership onboard the ISS?

The ISS is a stunning example of international cooperation. As one considers NASA's Journey to Mars and their concept of the cis-lunar proving ground, there are enormous opportunities and needs for international contributions and partners. The key to garnering their support is for the U.S. to lead the way. The international partners should rally behind a coherent vision that is affordable and has a timeline that does not extend too far into the future. It is important to establish nearer-term achievable missions to cis-lunar space that are directly tied to nearer-term achievable missions to Mars. Establishing a goal of the first mission to Mars as early as 2028, an orbital mission that explores the moons of Mars – Deimos and Phobos – with astronauts , and the surface of Mars with astronaut-controlled robots, is the right starting point. We have proposed Mars Base Camp as an example architecture that does just this with a compelling science mission to galvanize international support and bring clarity to the kinds of missions that should be conducted as precursors and shakedowns in cis-lunar space.

18. NASA's Orion crew vehicle is being developed with both domestic and international partners. For example, our partners at the European Space Agency are building the vehicle's service module, which regulates temperature and provides power, water, oxygen, and nitrogen. These are vital functions for a habitat. Do you feel that the existing international participation in Orion sets the stage for future collaboration? How does industry work across the international boundaries?

Just as ISS has set a standard for international collaboration, deep space exploration will ultimately be a multi-nation, multi-partner endeavor. The current arrangement on Orion between NASA and the European Space Agency (ESA) provides an opportunity for regular interaction with Airbus, the industry partner on the ESA side. Within the bounds of current export law, Lockheed Martin has nearly daily interactions with the Airbus team. In order to facilitate the engineering and programmatic discussions, Lockheed Martin has located an engineer with the Airbus team in Bremen, Germany. We are also in the process of adding a software and avionics engineer with the Airbus team in LeMureaux, France. Likewise, Airbus has an engineer located with the Lockheed Martin team in Denver. We are able to quickly support the program by working interface issues across the two companies.

Lockheed Martin also developed and leads an International Industry Collaboration Team that develops concepts that meet respective national objectives. In turn, this helps the space agencies define their goals/objectives and inputs to the Global Exploration Roadmap of the International Space Exploration Coordination Group and, ultimately, their contributions to a joint international exploration program.

19. The recent Commercial Space Launch Competitiveness Act extended the life of the ISS through 2024. While it is at least 8 years away from us today, do you think there is capability and interest in the private sector to take ownership of the ISS after 2024? If so, are there some issues that NASA should begin exploring in the coming years to set up a transition of operations and maintenance? What questions would you like to see addressed?

NASA should develop a list of the items required to operate and maintain the ISS prior to a potential transition to the private sector regardless of the transition date and, additionally, a list of ISS services/needs NASA would require following a potential transition to the private sector.

20. NASA's Inspector General conducted a study in 2014 that identified several hardware challenges to keeping the ISS running through 2024. As industry and NASA work together to build new habitat technologies, is there any way to update the Station's hardware with these new technologies to prevent damage from micrometeoroid and orbital debris, fires, or other dangers?

Updating the current ISS hardware is certainly possible, for instance, with new and higher efficiency (29% vs 14%) solar cells. Many of these updates would derive from other satellite technologies, such as communication or imaging satellites, in addition to improvements seen in the specialized human space flight design community.

Any new habitat systems will take advantage of lessons learned from the ISS experience, both to prevent failure and also to reduce overdesign. Because the cis-lunar environment is different (little orbital debris, higher radiation, longer return times) and because much of the ISS technology is vintage 1990, ISS hardware would not be used "off the shelf" for cis-lunar habitat missions. The new hardware provides elements of robust design.

It is entirely possible that some elements of the new habitat technologies could be used to update station hardware, but it is not clear that the incremental improvements to the ISS would be justified. Extending the life of ISS beyond 2024 will require much more than repurposing cis-lunar habitat technologies which begs the question of return on investment.

21. In his testimony, Mr. Weir made the case for a large rotating habitat that could essentially eliminate the physiological problems (muscle and bone loss) for our astronauts from living in zero gravity. What are the pros and cons of such a design? Should NASA or industry consider such a habitat for a journey to Mars?

It is too early to assess Mr. Weir's notional design with certainty. We have learned a lot from experience on the ISS, for example, with proper diet and vigorous exercise, data show that we can maintain both muscle mass and bone density. However, NASA is still continuing to learn about vision impairment and intracranial pressure and proper countermeasures have yet to be developed and validated.

Upon early examination, Mr. Weir's proposal also introduces new risks that need to be addressed. Introducing gravity changes on-orbit execution and requires assessment of new challenges, such as trauma and engineering complexity. It is difficult to develop systems that operate reliably in zero-g. The complexity gets magnified if the systems have to operate across a range of g, especially including start-up and shut-down transients and resulting falling bodies at various velocities. Although his concept involving tethered rotating bodies is intriguing, the effects and associated risk reduction of the high velocity debris on the wire rope and potential sling shot effects merit investigation.

22. The U.S. has two commercial cargo resupply providers with a third on the way in addition to international capabilities to supply the ISS and crew of six or seven.

- **How many crew members are you initially planning in your cis-lunar habitat designs around the Moon?**

Four crew members are planned in our initial design, analysis, and tests.

- **How often would you need to resupply this crew in cis-lunar orbit using current cargo-lifting capabilities?**

Right now, we are planning one cargo flight per year because we only have one crewed flight per year. If the number of crew or missions increases, the required number of cargo flights will also increase.

23. What bodies of standards (interface, ergonomic, power, data, docking, etc.) are being used to inform your habitat design?

We are performing human factors engineering to the same standards employed by ISS and Orion. We also conform to the International Docking System Standards for docking interfaces. We will be architecting the avionics system to conform to NASA's open avionics architecture. We employ several other standards developed by NASA's human spacecraft.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON SPACE

Next Steps to Mars: Deep Space Habitats

Ms. Wanda Sigur, Vice President and General Manager, Civil Space, Lockheed Martin Corporation

Questions submitted by Rep. Donna Edwards, Ranking Member, Subcommittee on Space

1. Based on LM's decades of work on space systems, what in your view is the most efficient way to obtain an operational deep space habitat?

- **If we are to send humans to Mars in the 2030s as the NASA Administrator suggests, what are some of the technological challenges and risks that must be addressed in order to acquire operational habitat(s) ready for use to transit to, orbit, and operate on the surface of Mars?**

Mars is achievable. Radiation protection for the crew will need to be further evaluated, as well as long duration exposure to microgravity. Combining Orion's radiation storm shelter designed to protect the crew from a solar storm with a habitat that provides increased protection from galactic radiation should make these risks tolerable. High reliability, regenerative life support systems will be required for long-duration trips into deep space. Keys to achieving this may be to combine the expertise of the onboard crew with advances in additive manufacturing.

- **At what pace must these risk-mitigation activities be undertaken if we are to land humans on Mars by the early 2030s?**

Landing humans on the surface of Mars in the early 2030s is achievable but requires constancy of purpose. With both crew safety and affordability in mind, we have put forward our Mars Base Camp vision of how to achieve a human mission to Mars orbit in 2028. Orion and SLS have laid the foundation and now is the time to begin in earnest the development of the habitation module.

- **Is the FY 2016 appropriation timeline for having a ground-based prototype of a habitation system by 2018 reasonable?**

Yes.

2. Does NASA have final requirements for a deep space habitat that it has provided to you? If so, what are they? If not, what is your perspective on how those requirements should be established?

No. NASA has given us a few key driving requirements (see below) to guide our study but are saving the in depth requirements derivation for Phase 2 and 3. Right now, Lockheed Martin is developing a baseline set of system level and subsystem level requirements that will be delivered to NASA at the end of the study. NASA may reveal additional requirements at the start of Phase 2. We believe NASA should use the study results they are paying for to inform the baseline requirements set and that appears to be the track they are on.

- Shall support a crew of four on missions of 30-60 days;
- Shall support the Asteroid Redirect Robotic Mission;

- The co-manifest performance of the SLS 1B is 6,000 kg initially, including a payload adapter;
- Shall have an operational lifetime of at least 10 years;
- Shall support a cadence of one crewed mission per year; and
- Shall support 8-hour EVA's for two crew members.

3. Space radiation is a significant risk for human exploration of deep space. How will the Orion crew vehicle mitigate against this risk? What further research and technology development work will be needed to inform the design of deep space habitats to provide the maximum protection against space radiation?

Orion mitigates the risk of space radiation through five primary avenues: 1) Development Flight Instrumentation and Recording, 2) Remote Detection and Advanced Notification, 3) Radiation Safe Haven Design, 4) Human Mission Local Monitoring, and 5) Technology Insertion.

Most importantly, Orion is designed with specific internal locations with extra shielding for the crew. In addition, our EFT-1 sensors have provided excellent information of the environment and these sensors will also be included for future flights.

We continue to investigate new technologies particularly in the areas of radiation shielding in habitation areas and possibly crew clothing.

4. What are the most significant cost drivers for deep space habitats? Are there technologies under development that would help lower the costs of developing habitats?

- Advanced life support: for Mars missions, we need environmental control and life support systems (ECLSS) capable of recycling water and oxygen. While ISS has tested some of these systems, we need systems that are more reliable and take less volume and mass. ISS can continue to path find solutions.
- Solar electric propulsion: SEP is currently under development across industry but not much experience on the scales required. Commonality with other systems currently being developed may provide opportunities for cost savings.
- Automated systems: we need to increase crew and system autonomy. LM and others in industry are currently investing in this technology. LM has experience in automated interplanetary vehicles. ISS can help us start to work through crew operational autonomy issues.
- Software and avionics: typically large expenses for programs. We believe we can take advantage of existing Orion and planetary heritage systems to reduce costs.

Early heavy reliance on Orion's advanced capabilities can reduce cost and complexity in the early stages of the habitat (i.e., power, ECLSS, radiation, propulsion, crew systems, etc.)

5. Regarding Lockheed Martin's approach to sending humans to Mars, you stated in your prepared statement that an orbiting Mars Base Camp could get us closer to doing real-time scientific exploration as early as 2028.

- **What would be the necessary steps leading to such a Mars-orbiting space station?**

The first two steps are Exploration Mission-1 and 2 where Orion's ability to perform deep space missions will be demonstrated. Following EM-2, Orion and a deep space habitat will demonstrate increasing mission durations and building up the required elements for a one-year shakedown cruise in cis-lunar space. Following the successful completion of the shakedown cruise, crews should be ready to push out on a round trip mission to orbit Mars.

- **What level of funding for NASA was assumed in deriving the 2028 date?**

Consistent funding of deep space human exploration at current levels plus inflation was assumed. In addition, the full commitment to the program would allow for higher rate production across the supply base, driving down costs, encouraging investment and attracting international partners.

- **What are the key technology challenges associated with developing and building such a base camp?**

Long duration, high reliability life support systems with limited access to spare parts in addition to the items mentioned above.

- **Have you shared your ideas with NASA? What has been their reaction?**

We have shared our plan with several organizations within NASA and received positive feedback and some helpful suggestions for improvement.

6. How is NASA carrying out oversight of your NextSTEP work and what lessons have been learned that can be applied to the oversight of future NextSTEP work, including on habitats?

At this stage, NASA is trying not to influence the outcome of the contractor studies in progress. They want an untainted, honest evaluation of potential architectures. We still have quarterly reviews of our work where NASA can check in on status. We also have periodic meetings with NASA subject matter experts if it is needed. Looking forward, NASA plans to continue the same structure but will be standing up their own parallel efforts that will also draw on results coming from the contractors.

Responses by Mr. Frank Culbertson

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON SPACE

Next Steps to Mars: Deep Space Habitats

Mr. Frank Culbertson, President, Space Systems Group, Orbital ATK

Questions submitted by Rep. Brian Babin, Chairman, Subcommittee on Space

1. *NASA certainly has an interest in developing deep space habitation capabilities, but private industry, too, has shown interest in developing habitats for commercial purpose. As people in the business world who report to your shareholders, what questions do you think need to be answered before NASA makes decisions on its acquisition approach for a deep space habitation module?*

NASA has a need for a deep space habitation capability that is scalable in capability over time. Initial visits to cislunar space will be relatively short in duration (approximately 60 days) and will focus on proving out the basic systems necessary to survive in deep space. The other primary focus will be human performance operating in the deep space environment. NASA wants to increase the size and capability of the habitat over time to prove the technology developments to enable our next steps for a mission to Mars. One critical technology to enable a multiyear stay in the habitat is the development of closed loop Environmental Control and Life Support System(ECLSS) system. Long duration missions require significant "recycling" or "closed loop" of the environmental control. Currently, only the government is investing in advanced closed loop environmental control.

Our vision for a near term habitat is based on our Cygnus spacecraft. The Cygnus derived habitat is designed to have a 15 year lifetime, and would be man tended on multiple missions of increasing duration. This first element of the habitat would provide a toe-hold in deep space, augmenting the capability of the Orion vehicle. With every SLS launch, the volume and capability of the habitat will increase.

We believe there is a spectrum of acquisition approaches that could be used to efficiently procure a deep space habitat. Some aspects of the deep space habitat are so unique, that a pure commercial approach is probably not likely. However, application of commercial development standards and commercial contracting methodology can still provide cost savings. The logistics system that will resupply the cislunar station is probably the first place to look for the potential for commercial capital to be applied. This would be similar to the approach used to procure cargo resupply services to the International Space Station.

In addition to commercial acquisition approaches, NASA should consider inviting international space agencies that may be willing to contribute elements to the deep space habitat. Any NASA acquisition plan should accommodate international partner and commercial participation.

- *How do you think NASA might be able to encourage commercial or philanthropic investments in space exploration?*

Commercial investment is encouraged by long term service procurements that allow a favorable Industry return on investment and long term stable policy and funding commitments.

- *Given the synergies of various interests, what types of acquisition strategies should NASA consider? What makes procurement of a cislunar habitat different than existing partnerships like commercial crew and cargo?*

  The amount of private funding available for the development of various cislunar habitats or a cislunar logistics system would be gated by the technical risk of the development, the lifetime of the habitat, and the projected NASA and non-NASA use of the habitat. Currently the business case for cislunar commercial activity appears to be much more limited than the business case in Low Earth Orbit. This means that the private investment during the cislunar development phase is likely to be more limited.

2. *NASA and the US government are currently working with industry on a variety of projects that promote the development of commercial habitat technologies. Bigelow Aerospace recently had its BEAM module installed on the International Space Station and a variety of companies are working with NASA's NextSTEP to advance deep space exploration technologies.*

- *Given this, what government policies are helping or hindering the development of commercial space habitats?*

  There are multiple policy and contractual agreements between the International Partners concerning joint operation on the ISS. All of these policies should be examined for applicability to a cislunar habitat. For example, indemnification and cross waivers currently in place at the International Space Station may be necessary in a cislunar habitat.

- *One of the problems that Bigelow Aerospace cites is that "NASA is over focused on transportation systems to the International Space Station...and additional destinations are vital." He recommends that America return to the Moon and then on to Mars. What are your thoughts about this?*

  A continuous manned presence in space coupled with a commitment by the government is necessary. The International Space Station currently meets that need, and provides a good testing area for technologies needed to go beyond Low Earth Orbit and for continued research on the impacts on humans living in the space environment. We support an approach that makes early progress from Low Earth Orbit, to cislunar orbit, possibly to the moon and ultimately to Mars. Lunar surface capability may not be necessary for the minimum road map to the Martian Surface, but in some mission scenarios, lunar surface missions are useful. It is important not to sunset the ISS capability until a viable alternative capability exists in either low earth orbit or cislunar space. Cygnus can be evolved from supporting ISS to becoming an element in a cislunar orbit habitat or on the lunar surface. This is the most cost effective approach to achieving beyond Low Earth Orbit goals.

3. *Many academic and commercial organizations currently use the International Space Station as a platform for conducting activities in microgravity.*

- *If the ISS program were ended in 2024, would demand from those organizations be enough for industry to step in and provide their own habitats in low Earth orbit?*

  The business case for a purely commercial habitat in low earth orbit is still uncertain. Much of the science research, technology development and operations at ISS are subsidized by the ISS partner governments and NASA. A more prudent approach would be to use a single commercial module attached to the ISS in conjunction with continued government operation of the ISS. This module could be a pathfinder to assess follow-on full commercial operations. Cost sharing between government and commercial elements may help the business case as well.

- *Is a commercial habitat market in Low Earth Orbit [LEO] possible without government support?*

  No. Our business analysis does not show a commercial market sufficient to support the ISS without NASA funding. The government is still needed as an anchor tenant and to provide support to a commercial LEO habitat.

- *Are there any regulatory issues that are inhibiting the development of commercial habitats?*

  There are still some uncertainties concerning regulatory jurisdiction in space. Third party liability and indemnification are potentially unsolved problems and may be greater than the ability of private insurance regimes to support.

4. *Companies like Bigelow Aerospace are proposing to send up their own habitats for commercial purposes to low Earth orbit. Some proposals call for non-NASA/private sector astronauts to live and work on these commercial stations. What is the commercial industry doing to prepare private sector astronauts?*

   Orbital ATK is not involved in developing commercial/private sector astronauts.

5. *The International Space Station (ISS), as the name suggests, provides a low Earth orbiting platform for many different countries. After the ISS, those countries may want to continue human operations in space. Is there an international market for habitat volume or services in Low Earth Orbit or beyond if those countries want to continue?*

   We are not able to address the space policy and budget plans of foreign governments. We think there may be a market for "sovereign government" astronauts from a variety of countries around the world interested in doing research in space. Many second and third world countries might be interested in rides to a commercial module if such a capability existed. Affordable space transportation and facilities could develop such a market.

6. *There are some that are worried about the influence that foreign-subsidized launch is having on the US commercial launch market. As U.S. companies look to develop their own commercial habitats, is there any worry that other countries like China might come in and compete with their own Low-Earth Orbit (LEO) habitats? What should the US do to prevent this?*

   The U.S. should continue to lead human space exploration, encouraging the current ISS Partners to work with the U.S., not China, to explore and develop space beyond Low Earth Orbit. We believe the U.S. government should maintain current ITAR rules that prohibit collaboration with China. We also remain concerned about unfair launch vehicle competition coming from Russia and India.

7. *As private industry continues to work on habitation technologies, what challenges are you encountering? What are the greatest obstacles to building habitation technologies that will protect our astronauts in cislunar space or carry our astronauts to Mars?*

A cislunar habitat poses many engineering and operational challenges. The necessary level of reliability must be very high since return to from cislunar space to the earth can take up to a week. We must address the impact of the radiation environment in cislunar space on the astronauts.

8. *NASA is working with industry to develop habitation technologies through programs like NextSTEP. As NASA and the private industry continue to work together, what do you think the role of NASA should be moving forward?*

NASA should provide funding and oversight for the development of an initial cislunar habitat. Such an arrangement would provide much higher science, technology, and operational results to retire and mitigate risk for future missions to Mars. NASA should manage the role of the International Partners as it does today in the ISS Program.

- *How would you shape the private- public relationship?*

  NASA does not need to fund and develop everything, and can benefit from the participation of private sector, academia, and international partners. However, the private-public partnership will not succeed unless there is significant commercial demand for habitat services. In the early phase of cislunar exploration, we believe the logistics resupply system is the best opportunity for a private-public relationship. We believe it is possible to extend the successful commercial ISS Cargo Resupply model to deep space cargo resupply.

- *What is the appropriate level of cost-sharing?*

  It is premature to identify the appropriate split between public and private funding for the development of deep space habitats and logistics.

- *Who should retain intellectual property rights?*

  Intellectual Property should be retained by Industry as part of the commercial model. This allows private industry to accomplish other commercial business in adjacent markets and improve the return on investment.

- *What structure is the best for the U.S. taxpayer?*

  The U.S. taxpayer will benefit if commercial investment augments the NASA investment. This will only occur if there are stable funding and policy commitments.

9. *NASA has been developing the Space Launch System and Orion Crew Vehicle for several years and only now beginning efforts to build habitation modules for our astronauts to carry out deep space missions. How do you see these deep space habitation capabilities complementing the Orion and SLS efforts?*

A deep space habitat is very complementary and essential to the full utilization of the Orion and SLS. In addition to extending the mission duration of Orion through the addition of logistic supplies, a habitat would also increase the science and technology demonstration return significantly. Finally, the habitat provides improved safety for the astronauts, as a redundant element and safe haven against a wide range of contingencies. Our approach also provides an incremental growth path to longer duration habitat elements, which are targeted for Mars missions.

10. *NASA recently sent out its second Next Space Technologies for Exploration Partnerships broad area announcement. Given industry's experience with the first iteration of the NextSTEP program, what advice would you give to NASA as they consider further developments in space habitation and the NextSTEP program?*

We strongly support the acceleration of flight testing of the NextSTEP initial cislunar habitat. We believe that using a derivative of Cygnus as a near term habitat is the best approach to demonstrate deep space habitation technologies and mitigate risks to human health. The results of the near term habitat missions will inform the development of longer duration habitation to support Mars exploration.

11. NASA is not only working with industry teams to develop deep space habitation technology. It is also working with colleges and universities through the X-Hab Academic Innovation Challenge. Can you discuss what work, if any, is being done between industry and academia to foster the development of this technology?

Orbital ATK is working with Colorado University (CU) in Boulder. Colorado on our NextSTEP Phase 1 study. CU provided input on Orbital ATK habitat design and human factors assessments.

- *What are the primary goals for the X-Hab Academic Innovation Challenge?*

  Orbital ATK is not engaged in the X-HAB Challenge.

12. What rockets do you expect to launch the deep space habitation modules from?

Our plan is to use the Space Launch System to launch our Cygnus habitat. We will continue to maintain backup compatibility with EELV as we have done for our Cargo Resupply Missions.

- *Does the size of the habitation module for journeys to Mars drive you to using a Space Launch System rocket?*

  Yes, the launch capacity of the SLS makes it the best rocket for all exploration missions beyond Low Earth Orbit (LEO).

- *Can other, smaller rockets carry habitation modules to low-Earth orbit or around the Moon, or does that also require the throw-weight of an SLS heavy-lift rocket? Should the habitat be designed for an SLS launch from the beginning?*

  The size and mass of habitat modules varies between different modules and will drive the capability of the transportation system used. Long duration missions to Mars require the largest and heaviest modules. SLS, is required for the long duration habitats and generally provides additional flexibility for the launch of any of the modules.

- *As the ultimate goal is to put American boots on Mars, there are several other components necessary to complete that mission. In Mr. Elbon's testimony, he pointed out that we still need vehicles such as a solar-electric tug, and a Mars lander and ascent vehicle if we are to conduct a Mars mission. A habitat is just one piece of the puzzle. How does knowing (or not knowing) how the other pieces of the puzzle fit together for that eventual Mars mission impact the design efforts going on now for the deep space habitation systems?*

  Early Deep Space Habitats can be designed to be evolvable and capable of supporting cislunar, lunar and beyond without resolution of the total Mars architecture. We support NASA's desire for common interfaces and open standards. We support the inclusion of the international and commercial involvement in a deep space habitat.

- *Since NASA has yet to lay out the phasing of developments, budgets, and schedules for a mission to Mars, how does this uncertainty impact industry's ability to provide technologies necessary to carry out NASA's plans?*

  NASA's Beyond Low Earth Orbit planning is driven by capabilities not dates or budgets. Technologies needed to support cislunar, lunar, Mars, Europa and other deep space destinations are the initial targets for development.

13. *The European Space Agency is the only international partner who has not yet committed to extending the life of the International Space Station through 2024. ESA Director General Johann Woerner has shown interest in developing a human presence on the moon, a 'lunar village.' If the United States were to plan to return to the Moon, would the habitation capabilities on the Moon be applicable to future missions on Mars, or completely different? How difficult will it be to adapt your habitat design for surface operations on the Moon, Mars, or both?*

    Our Cygnus based LEO and cislunar habitat designs could be easily adapted to operations on the Moon or Mars.

14. *I do not see our European counterparts or any other countries interested in the Administration's Asteroid Retrieval Mission. Further, U.S. law states that NASA Administrator "shall establish a program to develop a sustained human presence on the Moon."*[1]

    - *Given that, how should NASA's habitation development efforts facilitate cis lunar exploration, as well as lunar surface exploration, as a way to prepare for an eventual mission to Mars?*

      A cislunar habitat is a good place to test and demonstrate capabilities and the right starting point for cislunar exploration as well as lunar surface exploration and Mars missions. We recommend that NASA continue with NextSTEP Phase 2 plans leading toward the earliest flight opportunity possible.

[1] 5J U.S.C. §20302

- *Numerous experts have testified before this Committee that a crewed mission to Mars should be preceded by an independent six month mission on ISS, a 13 month stay on the lunar surface, and another six month stay on ISS before returning to the Earth. This "shakeout" mission would test the systems and protocols necessary for a Mars mission within the proximity of the Earth. How should NASA's habitation development efforts take into account the logical needs to both cis-lunar capabilities as well as lunar surface capabilities?*

  We believe NASA's NextSTEP habitation program is capability driven and supports which ever ultimate destination is selected.

15. *The U.S. government currently operates the International Space Station with a variety of international partners. Given that NASA intends to extend its human exploration activities into cis-lunar space in orbit around the Moon, how do you recommend we weave international and commercial partners into this phase of the journey ?*

The U.S. should leverage its successful relationships on the ISS to extend human exploration capabilities into cislunar space beyond low earth orbit. The current ISS team includes government to government as well as industry to industry relationships. For example, Orbital ATK has a strategic relationship with Thales Alenia Space in Turino Italy which builds the Cygnus Pressurized Cargo Module. We have been able to execute strategic developments using commercial terms that support bigger picture goals within NASA, ESA, and the Italian Space Agency. We think the ISS model of international and commercial partners is worth extending to future exploration missions.

- *Are there good lessons learned from the international partnership onboard the Space Station?*

  There are many technical, programmatic, and operational lessons learned from the ISS. Many of these would apply to operations in cislunar space, the lunar surface and beyond to MARS, Europa and elsewhere.

16. *The recent Commercial Space Launch Competitiveness act extended the life of the International Space Station through 2024. While it is at least 8 years away from us today, do you think there is capability and interest in the private sector to take ownership of the International Space Station after 2024?*

Current commercial market assessment shows the ISS is too expensive to maintain solely through commercial sales. If the total operating cost could be reduced through the introduction of lower cost commercial modules or lower cost transportation, the private sector might be able to operate the ISS under commercial terms.

- *If so, are there some issues that NASA should begin exploring in the coming years to set up a transition of operations and maintenance? What questions would you like to see addressed?*

  Third party liability insurance, indemnification and possibly Intellectual Property (IP) rights needs to be addressed. In the commercial launch world, specific legislation was made to provide indemnification to private launch companies but such indemnification was not provided for the SLS or Orion. The current International

Space Station has many cross waiver agreements in place to cover the interaction of the International Partners at ISS. A commercially run ISS would have to develop similar agreements and protections.

17. *NASA's Inspector General conducted a study in 2014 that identified several hardware challenges to keeping the International Space Station running through 2024. As industry and NASA work together to build new habitat technologies, is there any way to update the Station's hardware with these new technologies to prevent damage from micrometeoroid and orbital debris, fires, or other dangers?*

NASA continually assesses ISS hardware and new technologies to prevent the damage defined above. Recently Cygnus flew a hosted payload that conducted research for NASA on fire propagation in space. The results will inform the development of new technologies. This is just one example of the use of Cygnus to demonstrate new technology.

18. *In his testimony, Mr. Weir made the case for a large rotating habitat that could essentially eliminate the physiological problems (muscle and bone loss) for our astronauts from living in zero gravity. What are the pros and cons of such a design?*

We respect and appreciate Mr. Weirs' contributions to our industry, space exploration, and the public support for NASA but respectfully do not agree with Mr. Weir's assessment. We do not believe that artificial gravity is needed.

- *Should NASA or industry consider such a habitat for a journey to Mars?*

  No

19. *The U.S. has two commercial cargo resupply providers with a third on the way in addition to international capabilities to supply the ISS and a crew of six or seven. How many crew members are you initially planning in your cis-lunar habitat designs around the Moon?*

Four

- *How often would you need to resupply this crew in cis-lunar orbit using current cargo-lifting capabilities?*

  NASA's current SLS design can launch the Orion and a co-manifested module on the same mission. This co-manifested capability is believed to be sufficient for both cargo and habitat module delivery. NASA's NextSTEP Phase 2 will further refine the number of cargo launches required.

20. *Being a former astronaut, when you lived aboard the ISS, did you conduct or participate in any tests that were designed to help to reduce risks to future astronauts living aboard a cis-lunar habitat?*

While living and working on-board the International Space Station, I participated in many experiments to help us understand the effects of long duration microgravity on the human body. Each of these tests added to our knowledge of the effects of living in space.

- *What additional tests would you recommend before you'd be willing to go on a mission to Mars?*

I would like to see a better understanding of the effects of radiation, especially galactic radiation, on the crew before embarking on a long duration trip to Mars.

21. *What bodies of standards (interface, ergonomic, power, data, docking, etc.) are being used to inform your habitat design?*

A detailed answer would include many elements that Orbital ATK considers proprietary the habitat must support compatibility with Orion, a fifteen year lifetime, capable of operating crewed and uncrewed.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON SPACE
Next Steps to Mars: Deep Space Habitats
Mr. Frank Culbertson, President , Space Systems Group, Orbital ATK
Questions submitted by Rep. Donna Edwards, Ranking Member, Subcommittee on Space

1. *Based on Orbital ATK's decades of work on space systems, what in your view is the most efficient way to obtain an operational deep space habitat?*

   - *If we are to send humans to Mars in the 2030s as the NASA Administrator suggests, what are some of the technological challenges and risks that must be addressed in order to acquire an operational habitat ready for use to transit to, orbit, and operate on the surface of Mars?*

     The risks associated with a mission to the Mars surface are substantial. The largest risk and biggest challenge is the development of the transportation capable of reaching Mars. Mars entry, descent and landing technologies are immature and will require time and investment to achieve. Long duration closed loop life support is also considered a technological challenge that must be mitigated.

   - *At what pace must these risk-mitigation activities be undertaken if we are to land humans on Mars by the early 2030s?*

     We support NASA's approach for the cislunar "proving ground". We believe this capabilities driven, stepping stone approach will prove the technologies necessary for a Mars landing by the 2030s. The launch of the initial Cygnus derived habitat into cislunar space is the first step in this plan.

   - *Is the FY 2016 appropriation timeline for having a ground-based prototype of a habitation system by 2018 reasonable?*

     Yes, because we are leveraging many existing designs from our flight proven Cygnus.

2. *Does NASA have final requirements for a deep space habitat that it has provided to you? If so, what are they? If not, what is your perspective on how those requirements should be established?*

   We have a good understanding of the requirements for the initial cislunar habitat. This habitat will grow in size and capability over time. Early missions will develop the operational experience for long duration missions. At this time, the requirements for future long duration habitat configurations are less well known. We believe NASA is on the correct path to develop these more detailed requirements.

3. *What are the most significant cost drivers for deep space habitats?*

   The most significant cost driver for a deep space habitat is the transportation cost to get the habitat into cislunar space. The next tier of cost drivers include safety critical systems such as a closed loop life support and the overall avionics and software to operate the habitat.

- *Are there technologies under development that would help lower the costs of developing habitats?*

  The best approach to lowering the cost of a deep space habitat is modify an operational man rated spacecraft for the differences between low earth orbit and deep space. That is exactly the approach that we have taken with the Cygnus derived habitat. Cygnus is qualified to take cargo to the International Space Station in low earth orbit. It is man rated when attached to ISS and autonomous when not attached to ISS. A Cygnus derived habitat would have similar functionality but in deep space with the Orion Spacecraft replacing the ISS. This approach is best for the earlier, less capable habitats of short to medium duration. As the manned mission duration increases, consumables become a bigger issue. For very long duration missions to Mars, it will be important to recycle air and water. This technology is not well demonstrated and will take time to prove out in the space environment.

4. *How is NASA carrying out oversight of your NextSTEP work and what lessons have been learned that can be applied to the oversight of future NextSTEP work, including on habitats?*

   NASA has contractual and technical leads for each NextSTEP team. NASA subject matter experts are assigned to assist in maximizing the NASA lessons learned. Reviews and milestones are evaluated against a NASA approved contractor plan. NASA only "pays for performance" after a milestone is achieved.

5. *You noted that Cygnus could be developed to go beyond low-Earth orbit. What would be required to enable that capability?*

   The primary differences between a Low Earth Orbit Cygnus and a deep space or cislunar orbit Cygnus involve differences in local environment. The thermal environment is much colder in cislunar space than in low earth orbit. GPS navigation and Tracking and Data Relay Satellite System communication is not available in cislunar space and needs to be replaced with deep space alternatives.

6. *You stated in your prepared remarks that a cislunar habitat is a good opportunity to apply commercial acquisition practices and commercial development standards. In particular, you highlighted the NASA Commercial Resupply Services contract and underlined the emphasis of services instead of hardware. Do you view this services approach as being applicable to habitats, and if so why?*

   A services based approach is possible for an operational phase after the basic transportation and technology is demonstrated. The service based approach could be used for repetitive cargo resupply to the habitat. Because the cislunar commercial market is much more speculative compared with low earth orbit, it is likely that NASA will have to fund a greater share of development and operations costs than occurred under the ISS Cargo Resupply Service. A service based approach makes it easier to use commercial contracting and commercial development standards that typically save two thirds of the cost compared with a typical cost plus approach.

- *What would be the necessary prerequisites NASA would need to do and know before a services contract could be considered?*

  The NASA funded habitat development would need to be completed and operational before a commercial resupply service contract would be possible.

- *Are you proposing that NASA lease a privately owned habitat, or would the services contract just apply to its resupply?*

  We are currently considering commercial resupply services to the habitat.

Responses by Mr. Andy Weir
Response from Andy Weir

Questions submitted by Rep. Brian Babin, Chairman, Subcommittee on Space:

Q: In your science fiction writing about the possible future in space exploration, have you "envisioned" how NASA and private companies as well as other countries might live and work together in exploration space? There are different roles and responsibilities between government and business actors. Do you mostly see common interests or any conflicting goals?

I strongly believe that the best way to press forward with space exploration is for the private sector to take it up, which they will absolutely do once there's a market demand for it. The market demand will come when the price point gets low enough for middleclass Americans to afford.

So I believe the best interaction of private industry and government is two-fold. First off, the government should fund research in the direction of affordable space travel. Instead of being result focused (like getting to the Moon) it should be process focused (like getting to space for under a certain dollar amount). Competitive contracts for space launches are the best approach here. Allocations for launches should be "We're setting aside $X for commercial space launches. And we'll go with whichever company will give us the most mass to orbit for that money". That's obviously over-simplified, but you get the idea.

The other way government can help is with policy changes. Right now, policy is one of the main impediments to commercial space development. Congress needs to be very clear on how US laws interact with space research. And, more importantly, we need an update to the Outer Space Treaty. It's hopelessly out of date. With the commercial space boom looming on the horizon, I'm sure the other signatories of the OST will be happy to discuss changes.

In your testimony, you describe a large, rotating habitat that would be able to negate the negative effects of microgravity. Could you describe some of the benefits and risks associated with such a vehicle?

The benefits are enormous. This approach would eliminate *all* negative effects of microgravity because the astronauts would no longer be in microgravity. No more muscle degradation. No more vision impairment. No more bone loss. No more heart weakness. And most importantly: Astronauts would be fully-functional when they return to Earth (or set foot on Mars).

It would also free up enormous resources in the form of work-hours. Present day astronauts have to spend two hours a day exercising just to counteract the negative effects of microgravity. That's $1/8^{th}$ of their waking hours. We spend far more time and energy on this one task than anything else in space travel. With a centripetal space station, those hours would be freed up for research tasks or just more rest for the crew, making them more efficient.

The risks are few, though the difficulties in designing such a station are non-trivial. Having constant force on the extremities of the station presents engineering challenges. But there is no new technology needed to solve them.

The biggest risk would come from the rotation of the station itself. It would surely be two sections connected by strong cables. If the cables were to break, the station would fly apart. This is not so terrible as you might suspect. The velocity that the compartments would be separating is trivial compared to the velocity of the station orbiting Earth. The astronauts would simply board the return craft and go home.

We talk a great deal about how it is important to encourage students to study science and engineering, but it seems that books, movies and TV shows like Star Trek and Star Wars ignite the imagination. Scientists and engineers want to build the technologies from science fiction.

- **What lessons have you learned from writing *The Martian* when it comes to inspiring young scientists and engineers to build the future you envision?**
    - I was very surprised at how much the book inspired kids and young adults about space technology. I had no idea that was going to happen. I thought I was just writing a space adventure book with accurate science. I'm thrilled that it had this effect. I guess the lesson I learned was anything can be inspiring as long as it's cool.
- **As a noted visionary, what do you think of the progress America has made in space exploration over the past 59 years since Sputnik? Is the lack of progress perhaps because it is harder than we thought during the Apollo missions?**
    - I feel that no industry will significantly advance without a market demand. The lack of progress over these past few decades is directly tied to that lack of demand. If we can create the demand we'll be set. I don't believe the challenges are anything we can't beat. We just need to do it the American way – by making sure people know that figuring out how to get up there cheaply will make them a lot of money.

Questions submitted by Rep. Donna Edwards, Ranking Member, Subcommittee on Space:

As a NASA website states, *The Martian* merges the fictional and factual narratives about Mars. In the movie adaptation of your book, the realism of Mark Watney's journey is heightened by images of hardware and systems like the Mars Rover he traveled in, the Hermes nuclear powered spacecraft, and the Mars Ascent Vehicle. But the reality is that NASA and its supporting contractors are just starting to initiate design of these future vehicles. So how do we keep the public from minimizing the difficulty and level of effort needed to send humans to Mars?

I don't believe those challenges are that difficult. The biggest challenge NASA faces is a lack of focus. Political realities have forced them to branch out into environmental sciences, booster research that isn't needed, external requirements to use outdated technology, repeated changes in directives as administrations come and go, and unpredictable variations in funding.

If NASA were given a clear directive, non-discretionary funding to get it done, and permission to back-burner or cancel other projects, they could do anything we wanted.

Appendix II

Additional Material for the Record

STATEMENT SUBMITTED BY THE FULL COMMITTEE RANKING MEMBER EDDIE BERNICE JOHNSON

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

House Committee on Science, Space, and Technology
Subcommittee on Space
"Next Steps to Mars: Deep Space Habitats"
May 18, 2016

Thank you, Mr. Chairman, for holding today's hearing on "*Next Steps to Mars: Deep Space Habitats*". I have long been a strong supporter of NASA, including NASA's human spaceflight program. Having a bold and inspiring goal to send humans beyond low-Earth orbit, as we did with Apollo, inspired a generation of scientists and engineers and led to countless technological advances and benefits to our nation.

A few years ago, the National Academies issued a Congressionally-mandated report citing the importance of Mars as the horizon goal for human space exploration. Other advisory bodies and reports have reached similar conclusions. And, the House has passed policy provisions on the goal of sending humans to Mars.

Discussions within this Subcommittee and the full Committee have focused on strategies for how to get there. Now it is time to do the hard work that must be accomplished if we are to make measurable progress toward sending humans to Mars.

Today, we will hear about the initial work on one critical element needed for a human mission to Mars—namely, habitats.

There are many other critical capabilities needed, as well, before we can send humans to explore Mars. Advances in propulsion, the ability to land large payloads on Mars, and development of a Mars ascent vehicle that can safely return crew from the surface of Mars back to Earth are just a few of the technological challenges that I hope the Subcommittee will explore in future hearings.

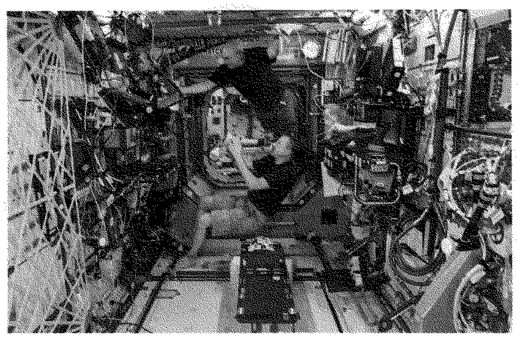
I'd like to thank our very distinguished panel for being here and I look forward to your testimony.

Thank you, and I yield back.

DOCUMENTS SUBMITTED FOR THE RECORD

OPINION

Houston, we have an opportunity — it's called Mars



In this April 9, 2015 photo made available by NASA, astronauts Terry Virts, bottom, and Scott Kelly perform experiments on the International Space Station. Kelly sees his recently completed one-year mission as a "steppingstone" to Mars. (NASA)

By **THE DENVER POST** | newsroom@denverpost.com
PUBLISHED: March 8, 2016 at 8:50 am | UPDATED: April 14, 2016 at 6:32 pm

Last week, Astronaut Scott Kelly returned from an almost one-year mission to test the effects of space travel on the human body. Kelly's experiment directly contributes to our understanding of the challenges NASA must overcome to send astronauts to deep-space destinations like Mars. And one of our best opportunities to go there is right around the corner.

Seventeen years from now, Earth and Mars will be aligned for what could be the most significant and inspirational journey in human history.

A mission such as this — the first human space flight to another planet in our solar system — requires careful planning and persistence of purpose. So what is needed to get there from where we are today?

This is not merely a science fiction movie starring Matt Damon. This is a goal that is within the reach of NASA's technological capability. NASA and American industry are already building the most critical elements for journeys to deep space, the Orion crew vehicle and Space Launch System rocket. With those systems ready for missions within the next five years, NASA can begin taking critical steps to prepare for that rare planetary alignment in 2033.

If we launch humans from the Earth to the Red Planet in 2033, it would only take a year-and-a-half round trip instead of the normal journey of two or three years. A shorter mission like this greatly improves the likelihood of success, as our astronauts would not need to spend as much time exposed to solar flares, cosmic radiation, or the effects of zero gravity on the human body. A shorter duration mission also means less possibility of a mechanical or life-support problem.

For the past 15 years, astronauts have been preparing for deep space exploration onboard the International Space Station. Larger in size than a football field, the Space Station is considered by many to be the greatest engineering achievement in the history of the world. And it has served as the laboratory in which Kelly and other astronauts have spent long stretches in space, providing valuable information for longer human missions.

The Space Station is also becoming a technology incubator for several commercial products and ventures. The technology spinoffs from America's space program have significantly added to our economy and improved our way of life — from the microchips in our computers, to lightweight metal alloys used in our cars, touchpad screens on our iPads and GPS devices.

Congress — on a bipartisan basis — has shown its support for NASA's deep space exploration endeavors. Year after year, Congress has provided the necessary funding for Orion and the Space Launch System. We believe it is a priority for America to remain a pioneering nation on the frontier of space. We have committed to maintaining American leadership in space now and in the future, across presidential administrations and Congresses.

A Mars journey requires a long-term plan from NASA. Just as the Apollo missions in the 1960s required Mercury and Gemini precursor missions, we need a mission statement from NASA laying out when we are going to Mars, what technologies and research we need to get there, and how we as a nation will get it done.

We need a detailed plan to put an end to the uncertainties that could delay a mission to Mars. NASA and American space companies must focus their engineering and scientific expertise on the great task before them. Americans will feel a renewed sense of pride and curiosity about their space program. And they will be able to celebrate another historic first as we plant the American flag on Mars.

This could be a turning point in the history of our great space-faring nation. We can do this.

Rep. Lamar Smith is a Republican from Texas. Rep. Ed Perlmutter is a Democrat from Colorado. Smith is chair of the House Committee on Science, Space, and Technology. Perlmutter is a member of the committee.

To send a letter to the editor about this article, submit online or check out our guidelines for how to submit by e-mail or mail.

ExploreMars.org

May 18, 2016

The Honorable Lamar Smith
The Honorable Eddie Bernice Johnson
The Honorable Brian Babin
The Honorable Donna Edwards
Committee on Science, Space, & Technology
Rayburn House Office Building
Washington, DC 20515

The Human Exploration of Mars: A Congressional Opportunity

Dear Committee Chairman Smith, Committee Ranking Member Johnson, Space Subcommittee Chairman Babin, and Space Subcommittee Ranking Member Edwards:

Explore Mars, Inc. respectfully submits this letter to the Committee with reference to the hearing, *Next Steps to Mars: Deep Space Habitats*, which has been scheduled for Wednesday, May 18, 2016. We thank you and the rest of the members of the Committee for scheduling this hearing and for allowing us to express our views on this critically important topic.

Explore Mars, Inc. is a non-profit advocacy group dedicated to the goal of sending humans to Mars within the next two decades. We believe that achieving this goal is important to our nation for many reasons, including maintaining America's world leadership, for our nation's economy, for advancing STEM education, and for our nation's overall prosperity and security.

Sending humans to explore Mars is not a new goal for the United States space program. It has been a priority since the days of the Apollo Program, and it has been NASA's official goal under multiple Administrations, as reflected in the NASA Authorization Acts of 2005, 2008, and 2010. Most recently, the U.S. House of Representatives, in Section 202 of the NASA Authorization Act of 2015 [H.R. 810 – (2015-2016)] stated that, "Human exploration deeper into the Solar System shall be a core mission of the Administration. It is the policy of the United States that the goal of the Administration's exploration program shall be to successfully conduct a crewed mission to the surface of Mars to begin human exploration of that planet...".

Yet, until recently, political and technological progress toward achieving this goal has remained elusive. However, thanks to sustained bi-partisan support by Congress, engineering and technology solutions to the challenges of travelling to Mars may soon be at hand. Moreover, both NASA and the private sector, working together, have been developing increasingly credible, affordable, and sustainable scenarios that lay out substantive plans for initial human missions to Mars in the early to mid-2030s.

Explore Mars, Inc. applauds Congress for taking a significant step forward at the end of 2015, when, reversing a recent trend of NASA funding shortfalls, Congress approved an increase of nearly $800 million in the overall NASA budget, over and above the Administration's FY2016 budget request. Nevertheless, even with this increase in FY2016, NASA's budget is still significantly below what is necessary to accomplish all that NASA has been tasked with by Congress and the Administration. We respectfully urge Congress to take further action to close this shortfall by increasing NASA's FY2017 budget by $1 billion above the FY2016 enacted level, to a total of $20.3 billion.

There has been undeniable progress in the development of the capabilities necessary for long-duration human exploration beyond Low-Earth Orbit (LEO), thanks to work on the International Space Station (ISS). There has also been great progress in developing the Space Launch System (SLS) and Orion, with hardware now actually being built and tested. However, current scenarios under study by industry that are aimed at getting humans to Mars by the 2030s, which include cost estimates, demonstrate a shortfall in several key technology areas.

These scenarios all are converging on the same essential technology capabilities, each of which is time-sensitive and critical for achieving the goal of human exploration of Mars:

Long-Duration Human Operations Beyond LEO, especially Environmental Control and Life Support Systems (ECLSS): Keeping astronauts safe and active on the trip to Mars, on its surface, and on the return journey to Earth, is a major challenge. Enormous advances in our capabilities for safe operation in deep space have been made in recent years, thanks to the ISS. Necessary next-generation capabilities include ECLSS systems that are more power-efficient, robust, lower-mass, and serviceable, in addition to spacecraft power management systems, radiation protection, and capabilities for autonomous operation. Testing the habitation systems in the actual deep-space environment, such as in cis-lunar space, which is accessible by the SLS and Orion spacecraft, is necessary to demonstrate the systems for long-duration missions to Mars.

Additionally, we need to aggressively utilize our robotic missions to Mars to enable human missions to the Red Planet. Two such critical areas are Entry, Descent, Landing, and Ascent, and In-Situ Resource Utilization:

Mars atmospheric Entry, Descent, Landing, and Ascent (EDLA): EDLA may be the single greatest technical hurdle to overcome in order to successfully land and return humans from the surface of Mars. Development of these capabilities will take some time and in the mid-term enable high priority scientific exploration of the Red Planet that is not otherwise possible. Unfortunately, EDLA funding – for human missions and major science goals – has stalled in recent years, and more recently has seen significant budget cuts.

There is significant work that can be done at Earth to enable Martian EDLA, but ultimately we need to be flying progressively heavier spacecraft/landers at Mars to test and validate these EDLA systems to ensure that they will be safe for humans. These missions would not be standalone EDLA missions but rather would be included with other key science and "humans to Mars" enabling engineering objectives.

In Situ Resource Utilization (ISRU): For sustained operations on the Martian surface, use of local resources will be essential for significantly reducing the amount of mass that must be carried to Mars and thus the overall cost of these missions. Water and oxygen are the most critical resources. Oxygen can be extracted anywhere on the planet from the rarified CO2 atmosphere, and a prototype extraction device, called the Mars Oxygen ISRU Experiment (MOXIE), will be flown on the Mars 2020 Rover. Recent discoveries have shown that there are also significant quantities of water on Mars near the surface. Water is exciting for all the reasons that water is critical on Earth; it will also allow for self-sufficiency in terms of the local production of propellant for the Mars Ascent Vehicle (MAV). Unfortunately, while we know that water exists on Mars, the orbital reconnaissance instruments flown to date were not designed to find water that is easily accessible for ISRU. A next-generation reconnaissance orbiter will be needed to precisely identify where these feed stocks are located. Access to this water will probably determine where the initial human base on Mars is located, and for this reason the *First Landing Site/Exploration Zone Workshop for Human Missions to the Surface of Mars*, held in October 2015, strongly recommended that a next-generation reconnaissance orbiter be made an immediate priority. Workshop participants also saw a strong synergy in the ISRU and science objectives that such an orbiter would make possible. In time, it will be necessary to validate on the planet's surface what was learned from orbital measurements about these water feed stocks and to verify production techniques, but orbital reconnaissance is the critical next step.

Coordination Within NASA and With the Private Sector, Academia, and our International Partners

Essential to successful human and scientific exploration of Mars will be expanded coordination among the three relevant mission directorates at NASA: human space flight, science, and technology. Moreover, new approaches for stimulating private/entrepreneurial activities must be encouraged, as the private sector, along with academia, both enthusiastic about and committed to the exploration of Mars, are two of the greatest strengths of this nation. We must also fully encourage and engage our international partners so that they can develop their contributions to a multi-national program of exploration. Indeed, these were among the findings and observations that were made by the recent *Mars Affordability and Sustainability Workshops*, three of which have been held to date (2013, 2014, and 2015), the reports of which can be found on the Explore Mars website at www.exploremars.org/affording-mars .

The Critical Next Ten Years

NASA needs a clear budget picture to enable timely decisions on and commitment to the necessary courses of action. In addition to a prioritized increase in the NASA budget, advances toward human missions to Mars will not be possible if some key decisions are delayed much longer. As indicated earlier in this letter, human missions to Mars in the 2030s will rely on some key capabilities being developed and demonstrated in the 2020s, which is fast approaching. Fortunately, we have a Mars program that is far more integrated than ever before, and which is the beneficiary of broad bi-partisan support as well as widespread support among the general public. But we need a long-duration habitat to carry humans to deep space, and then to Mars, and we need that habitat as soon, as safe, and as affordable as possible. We also need to develop increasingly capable EDLA systems. Furthermore, we also need a new class of robotic reconnaissance for Mars that, while advancing science, also ties directly to human exploration needs such as ISRU.

Conclusion

Scientific exploration of Mars continues to reveal an intriguing world, rich with mysteries yet to be revealed, as well as a potential site for long-duration human habitation. Such exploration, when committed to and properly funded, will contribute to improving the quality of life for our country. As NASA Administrator Charles Bolden has frequently observed, "We are closer to sending humans to Mars than at any time in the past".

Explore Mars, Inc. believes, however, that we should no longer refer to Mars as the 'ultimate destination' or the 'horizon goal'. In 2016 and beyond, such phrases just solidify the perception that Mars is a far-off goal that never seems to get any closer. With continued Congressional support, and in partnership with the private sector and the scientific communities, as well as the international community, human missions to Mars starting in the early to mid-2030s are now a goal that is achievable in the near-term; but such will require sufficient budgets and policy sustainability. Mars needs to be humanity's next great destination, with intermediate stops and the establishment of infrastructure along the way, but all on a clear path outward and into the solar system.

Thank you, again, for allowing us the opportunity to provide this input to the Committee. Explore Mars, Inc. stands ready to provide further input and recommendations on the importance of sending humans to Mars, and we look forward to working with the Committee and its staff on ways in which we can all help to bring us closer to that goal.

Sincerely,

Chris Carberry, CEO

Artemis Westenberg, President

Rick Zucker, Director of Political Outreach

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Chairman Brian Babin
316 Cannon House Office Building
Washington, D.C.

Ranking Member Donna Edwards
2445 Rayburn House Office Building
Washington, D.C.

Dear Chairman Babin, Ranking Member Edwards, and members of the Space Subcommittee:

Last spring, The Planetary Society convened a workshop to examine an intriguing concept to send humans to Mars which leverages existing hardware and programs, works within constrained budgets, and provides a long-term guide for human exploration in space. This plan, developed for NASA by engineers at the Jet Propulsion Laboratory, would send humans to orbit Mars in 2033 and to land on the surface of Mars in 2039. Subsequent missions would develop a sustained, long-term presence on the surface beginning in the early 2040s.

Our workshop report, Humans Orbiting Mars: A Critical Step Toward the Red Planet, explores the orbit-first concept from the perspective of cost, public engagement, scientific value, and coalition-building potential. Independent cost estimates by the Aerospace Corporation demonstrate that this plan could fit within NASA's human spaceflight budget increasing only at the rate of inflation. The plan relies on the Space Launch System and Orion crew vehicle, and identifies clear technology development needs, particularly a deep space habitat. We have included our report for your review.

As a predicate to the first Mars missions in the 2030s, the orbit-first concept proposes several long-duration human missions in cis-lunar space in the late 2020s in order to validate closed-loop life support and other critical technology required for the deep space habitat.

Though NASA has yet to coalesce around a clear, executable plan for its Journey to Mars ambitions, it has proposed a similar set of tests and projected the need for a deep space habitat in cis-lunar space. Congress wisely provided initial funding for this project its FY 2016 omnibus appropriation, and NASA rightly requested a new start for the program in its FY 2017 budget request. We believe that developing this critical hardware should be a higher priority within the human spaceflight program, and we are encouraged by the support and interest demonstrated by Congress thus far.

Sincerely,

Casey Dreier

Casey Dreier
Director of Space Policy
The Planetary Society

BIGELOW General Contractor providing design, engineering & assembly of space complexes.

Hon. Lamar Smith
Chairman, House Committee on Science, Space, and Technology
2321 Rayburn House Office Building
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Hon. Eddie Bernice Johnson
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Hon. Donna Edwards
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May 18, 2016

Dear Chairmen and Ranking Members,

Thank you for this opportunity to express my views to the Committee on the subject of expandable habitats and their future uses. The leadership you have all shown in your respective positions on the Committee to address the nation's needs not only for a coherent space policy, but also for supporting the private sector's ability to compete and make America a leader in human spaceflight once again, has proven invaluable. I believe that on this point we share a common understanding of the difficulties that the United States faces not only internally but externally as well. I worry that our country has drifted for far too long and has lost its spirit to seek out new opportunities throughout the Solar System. I hope that you and the other Members of this Committee will understand my frustrations with regard to the failures of leadership I see in Washington, DC in establishing destinations for expandable habitats. I look forward to working with the Committee to ensure that the United States remains a leader in human spaceflight and expandable habitat development.

As you may be aware, I have personally funded the development of expandable habitats at Bigelow Aerospace for over fifteen years. I am proud of the accomplishments my company has made in the development and commercialization of expandable habitat systems, architecture abandoned by NASA in the 1990's. I have spent almost $300 million designing, manufacturing, testing, and flying hardware because I believe that my company can offer superior habitat systems at dramatically lower cost to NASA or any other customer. Moreover, I have never received any money for development costs. In fact, I have paid NASA for the right to develop expandable habitat systems through patent royalties. While the success of the Bigelow Expandable Activity Module ("BEAM") will certainly provide the International Space Station ("ISS") with more volume as well as enable opportunities for various entities to utilize that volume, I have worked with NASA in good faith to establish the foundation of a relationship centered on the viability of expandable habitat systems on the ISS and as standalone space stations. But I have to admit that I consider the BEAM a distraction from the main goal of Bigelow Aerospace, which is to provide any customer with an affordable and safe expandable habitat that can be augmented to go almost anywhere in the Solar System as well as outfitted for

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almost any type of mission. That is why I continue to develop the company's main product, the B330, which offers 330 cubic meters of volume; volume that traditional metallic structures – including the ISS – cannot match in terms of less mass, better radiation and micro-meteorite protection, and lower cost.

I have had many discussions about the future of space exploration with dozens of American and foreign officials. We agree that NASA is over focused on transportation systems to the ISS. Additional destinations besides the ISS are vital to sustain a viable space taxi enterprise with new markets that eventually replace the ISS. I therefore urge the Committee to acknowledge that developing new habitat systems that can carry humans, experiments, cargo, and other technologies for the exploration of the Moon, Mars, and other destinations must begin in low Earth orbit and then proceed to cislunar space. If we truly commit to an initial destination in low Earth orbit then following quickly to cislunar space, I believe that expandable habitats can offer NASA and others the ability to test and gain experience for future missions to Mars and deep space.

I write to you today in the hopes that we can find a common path forward from low Earth orbit to Mars. From my position as Founder and President of Bigelow Aerospace, I see the development of great new launch vehicles, capsules that can support transit from and to the Earth, and what I can offer by way of affordable and safe expandable habitats for use in low Earth orbit, deep space, and on planetary bodies like the Moon and Mars. However, I see all these innovate and enabling technologies, but no destinations besides the ISS. Where shall NASA and this nation go once the ISS is no longer available? We should not repeat the mistakes of the past to move on without a plan. We should not move ahead by allowing others to lead. This nation should recommit itself to returning to the Moon and then on to Mars because it is the only practical way to guarantee that future space activities will have a foundational infrastructure capable of growing and maintaining stable economies to ensure our nation and our species can continue to explore space.

I believe Bigelow Aerospace can continue to play a vital role to make sure that there is no "space station" gap. Bigelow Aerospace continues to develop partnerships with launch providers and other companies to ensure that NASA and other potential customers have alternatives and choices for the utilization of expandable habitats. My company is ready to provide the market the means to achieve the twin goals of exploration and the development of a sustainable space economy. I have worked tirelessly to guarantee that expandable habitat manufacturing is ready to go once a destination is chosen. Bigelow Aerospace is ready to take the next step in human spaceflight and help the United States regain its leadership role in the exploration of space.

I wish to thank the Committee for its time and am happy to discuss these matters further in subsequent discussions.

Sincerely,

Robert T. Bigelow

Robert T. Bigelow
Founder & President
Bigelow Aerospace, LLC