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PRIVATE SECTOR LUNAR EXPLORATION

HEARING

BEFORE THE

SUBCOMMITTEE ON SPACE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

ONE HUNDRED FIFTEENTH CONGRESS

FIRST SESSION

SEPTEMBER 7, 2017

Serial No. 115–27

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



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

U.S. GOVERNMENT PUBLISHING OFFICE

27–174PDF WASHINGTON : 2017

For sale by the Superintendent of Documents, U.S. Government Publishing Office
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PRIVATE SECTOR LUNAR EXPLORATION

Thursday, September 7, 2017

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

The Subcommittee met, pursuant to call, at 10:05 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Brian Babin [Chairman of the Subcommittee] presiding.

LAMAR S. SMITH, Texas
CHAIRMAN

EDDIE BERNICE JOHNSON, Texas
RANKING MEMBER

Congress of the United States
House of Representatives
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
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Private Sector Lunar Exploration

Thursday, September 7, 2017
10:00 a.m.
2318 Rayburn House Office Building

Witnesses

Mr. Jason Crusan, Director, Advanced Exploration Systems, NASA

Mr. Bob Richards, Founder and CEO, Moon Express, Inc.

Mr. John Thornton, Chief Executive Officer, Astrobotic Technology, Inc.

Mr. Bretton Alexander, Director of Business Development and Strategy, Blue Origin

Dr. George Sowers, Professor, Space Resources, Colorado School of Mines

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

Charter

TO:	Members, Committee on Science, Space, and Technology
FROM:	Majority Staff, Committee on Science, Space, and Technology
DATE:	September 7th, 2017
SUBJECT:	Space Subcommittee Hearing: "Private Sector Lunar Exploration"

On Thursday, September 7th, 2017 at 10:00 a.m. in Room 2318 of the Rayburn House Office Building, the Committee on Science, Space, and Technology, Subcommittee on Space, will hold a hearing titled, "Private Sector Lunar Exploration."

Hearing Purpose

NASA is supporting private sector exploration of the Moon through various programs. The private sector is also investing their own funding in the hopes of serving a future market for transportation, cargo delivery, and surface operations (including in situ resource utilization). Moon Express plans to launch a mission to the Moon later this year or early next year. Astrobotic recently announced a mission in 2019. Blue Origin disclosed its "Blue Moon" concept last spring. The United Launch Alliance and SpaceX have also indicated plans to operate in cislunar space in the near-future. The Hearing will review these efforts, and NASA's role, in order to better understand the challenges and opportunities that they present.

Witnesses

- **Mr. Jason Crusan**, Director, Advanced Exploration Systems, NASA
- **Mr. Bob Richards**, Founder and CEO, Moon Express, Inc.
- **Mr. John Thornton**, Chief Executive Officer, Astrobotic Technology, Inc.
- **Mr. Bretton Alexander**, Director of Business Development and Strategy, Blue Origin
- **Dr. George Sowers**, Professor, Space Resources, Colorado School of Mines

Staff Contact

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

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

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

Welcome to today's hearing titled "Private Sector Lunar Exploration." I recognize myself for five minutes for an opening statement.

Exploration, particularly space exploration, is inherently and inescapably a matter of vital national strategic importance, both today and in years and decades to come. Because space exploration is so strongly linked to a wide range of current and future national interests, it is easy for us, as lawmakers, to fall into the habit of thinking of space as a strictly government operation and effort.

But not only can space involve the private sector, it must involve the private sector. Fully incorporating newly explored domains into our sphere of economic influence will ensure U.S. leadership in the future. Moreover, space is so vast and immense that it is foolish to propose that we can meaningfully plumb its depths without resources, talent, and drive that are so abundant in America's private sector.

There's no guarantee that the private sector will be successful. To the contrary, there will certainly be failures but the failures and successes should be determined by the free market. For this same reason, the private sector should not be artificially subsidized by the government. We should not leave our nation's space exploration future purely to the whims of market uncertainties, and we should not bet our nation's future in space on any one company. As we've seen so often in space, companies, and even entire sectors, come and they go. Our leadership in space is far too important to subject it to that kind of risk and uncertainty.

So while we will begin our discussion here today with NASA's testimony to provide context and help frame our deliberations, our intent is to understand not just how government-led exploration of space is proceeding, but where the private sector will take us and how these public and private actors will work together for their mutual benefit.

This hearing gives us an opportunity to understand what has worked well in the past, as well as what we could do better in the future. NASA has a vast array of tools at its disposal: traditional contracts, grants, cooperative research and development agreements, various funded and unfunded Space Act Agreements, and anchor tenancy agreements. All of these tools offer unique advantages and risks. Careful consideration should be given to which tool is used in order to ensure that the taxpayer is protected, and that the government does not corrupt the market. Ultimately, I hope that we can better understand if, how, and when the Moon can be integrated into human economic activity.

The Moon is the closest source of raw materials to Earth. In particular, the lunar poles may contain vast quantities of water, an invaluable resource for space exploration. Water is not only necessary to support the life of astronauts and crew; it can also be broken down into hydrogen and oxygen, which are excellent propellants.

Industrial, financial, and technical giants like Carnegie, Rockefeller, JP Morgan, and Edison dominated the economic and indus-

trial landscape of the late 19th century America. Advances in information technology in the late 20th century brought us Microsoft, Google, Apple, Facebook, and Amazon.

Will space be the next sector to lead economic growth? I don't know. If space becomes a home and workplace for humanity, if space can become part of our sphere of economic influence, then someday, perhaps in the far future, we will see those industries take root and grow.

But we cannot compel such an ambitious outcome, but by careful and thoughtful consideration we can, hopefully and humbly, enable it. At the very least we should not stifle it. I hope that today's discussion will help inform all of our thinking about the future of private sector exploration of space.

[The prepared statement of Chairman Babin follows:]

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

For Immediate Release
September 7, 2017

Media Contact: Thea McDonald
(202) 225-6371

Statement of Space Subcommittee Chairman Brian Babin (R-Texas)
Private Sector Lunar Exploration

Chairman Babin: Exploration, particularly space exploration, is inherently and inescapably a matter of vital national strategic importance, both today and in years and decades to come. Because space exploration is so strongly linked to a wide range of current and future national interests, it is easy for us, as lawmakers, to fall into the habit of thinking of space as a strictly government effort.

But not only can space involve the private sector, it must involve the private sector. Fully incorporating newly explored domains into our sphere of economic influence will ensure US leadership in the future. Moreover, space is so vast and immense that it is foolish to propose that we can meaningfully plumb its depths without the resources, talent, and drive that are so abundant in America's private sector. There is no guarantee that the private sector will be successful. To the contrary, there will certainly be failures. But the failures and successes should be determined by the free market. For this same reason, the private sector should not be artificially subsidized by the government. We should not leave our nation's space exploration future purely to the whims of market uncertainties, and we should not bet our nation's future in space on any one company. As we've seen so often in space, companies (and even entire sectors) come and go. Our leadership in space is too important to subject it to that kind of risk and uncertainty.

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an invaluable resource for space exploration. Water is not only necessary to support the life of astronauts and crew; it can also be broken down into hydrogen and oxygen, which are excellent propellants.

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We cannot compel such an ambitious outcome, but by careful and thoughtful consideration we can, hopefully and humbly, enable it. At the very least we should not stifle it. I hope that today's discussion will help inform all of our thinking about the future of private sector exploration of space.

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Chairman BABIN. And now at I'd like to turn to the gentlelady from—the gentleman from California, Dr. Bera.

Mr. BERA. Thank you, Mr. Chairman. And actually before I begin, I want to express my full support and sympathies to both you, your constituents in your district, and the employees at the NASA Johnson Space Center, and all those that were affected by Hurricane Harvey as well as those being affected by Hurricane Irma. Our thoughts and prayers go out to them, and they have our full support and you have our full support through the long recovery.

Chairman BABIN. Thank you.

Mr. BERA. It also does emphasize the important work of this Subcommittee as well as the Full Committee in better understanding Earth sciences, better understanding weather changes, and making sure that we do have the best forecasting equipment and satellites that are out there.

With that, I want to welcome the distinguished panel today, and thank you for calling this important hearing on lunar exploration plans and proposals.

Forty-eight years ago, Neil Armstrong and Buzz Aldrin touched down on the Moon, imprinting mankind's first footsteps on the Moon's surface. When astronauts Eugene Cernan and Harrison Schmitt lifted off the lunar surface on December 14, 1972, who would have imagined that they would be the last humans to visit the Moon for nearly a half-century and counting?

Now, we don't know exactly when humans will return to the lunar surface, but what is clear is that we're at the doorstep of a renaissance in Moon exploration. Soon, the Moon may entertain many visitors in the form of robotic spacecraft and rovers from many countries, and some, as we will hear today, will be owned and operated by commercial entities. Innovative technologies that will enable testing and demonstrations may one day lead to routine cargo and perhaps even routine human flights to and from the Moon and help promote increased economic activity in space. However, let's also not forget that the Moon remains an important scientific research center and the importance of finding that public-private nexus.

A 2007 National Academies report identified several scientific priorities for Moon exploration including the exploration of the lunar poles. According to the report, the South Pole Aitken Basin, in particular, is a priority for further scientific exploration because "it is the oldest and deepest observed impact structure on the Moon and the largest in the Solar System." And, you know, that exploration, as the Chairman touched on, you know, if in fact we confirm the presence of lunar ice there, can have huge impact, and certainly as we think about the Moon as a potential secondary launch site as we go and further explore into deep space, it's incredible important. But also as we look at this pristine laboratory, we want to make sure that, you know, we are balancing the research needs—if I think about Star Trek and the prime directive—and that we are not actually introducing other organisms or anything else, that may actually disrupt our science.

So, I look forward to hearing about the commercial entities, the potential of that nexus of the commercial sector, the scientific com-

munity, NASA all working together, and I think this is an incredibly important time for both lunar exploration but also for deep space exploration, and the importance of this Committee at this particular time I think is incredibly important.

A few questions that I hope to hear being addressed in today's hearing are, what are the market drivers for commercial efforts to explore the Moon? Who are the projected customers for planned private lunar exploration services and what services will be provided to those customers? How is NASA currently collaborating with the private sector on exploration of the Moon and are the current models of partnership working well? And are there opportunities for the private sector to collaborate with the science community on their exploration plans?

I'm looking forward to hearing, and I think it'll be very interesting.

With that, Mr. Chairman, I will yield back

[The prepared statement of Mr. Bera follows:]

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

House Committee on Science, Space, and Technology
Subcommittee on Space
"Private Sector Lunar Exploration"
September 7, 2017

Before I begin Mr. Chairman, I want to express my sympathies to you, to the constituents of your district, the employees of the NASA Johnson Space Center, and to all those affected by Hurricane Harvey. Our thoughts and prayers go out to them.

Good morning. And welcome to our distinguished panel. Thank you, Mr. Chairman, for calling this hearing to examine private sector lunar explorations plans and proposals.

Forty eight years ago, Neil Armstrong and Buzz Aldrin touched down on the Moon, imprinting mankind's first footsteps on the Moon's surface. When astronauts Eugene Cernan and Harrison Schmitt lifted off from the lunar surface on December 14, 1972, they couldn't imagine that they would be the last humans to visit the Moon for nearly a half-century and counting. Exactly when *humans* will return on the lunar surface is uncertain. However, what is clear is that we are on the doorstep of a renaissance in Moon exploration.

Soon, the Moon may entertain many visitors in the form of robotic spacecraft and rovers from many countries. And some, as we will hear today, will be owned and operated by commercial entities. Innovative technologies that will enable testing and demonstrations may one day lead to routine cargo—and perhaps even human—flights to and from the Moon and help promote increased economic activity in space. However, we should not forget that there remains important scientific research left to be done on the Moon.

A 2007 National Academies report identified several scientific priorities for moon exploration including the exploration of the lunar poles. According to the report, the South Pole Aitken Basin, in particular, is a priority for further scientific exploration because it is the *"oldest and deepest observed impact structure on the Moon and the largest in the Solar System"*. Determining a formation date of this impact basin is critical for understanding lunar chronology and the 2011 Academies' planetary science decadal survey also highlighted the need for research on the South Pole Aitken Basin.

I raise this point about scientific research in response to the possibility of commercial resource extraction and utilization on the Moon. In particular, we need to understand what ways, if any, commercial missions to the Moon may potentially impact future scientific investigations.

However, the aforementioned 2007 National Academies report noted the same data sets that are needed for exploration of lunar resources are also necessary for understanding the geochemical evolution of the Moon.

Mr. Chairman, there is a potential opportunity for commercial entities and the scientific community to collaborate on acquiring data and research that would support both their interests. This is a worthwhile collaboration for us to encourage.

Key questions I hope we will address at today's hearing include:

- What are the market drivers for commercial efforts to explore the Moon?
- Who are the projected customers for planned private lunar exploration services and what services will be provided to those customers?
- How is NASA currently collaborating with the private sector on exploration of the Moon? Are the current models of partnership working well?
- Are there opportunities for the private sector to collaborate with the science community on their exploration plans?

Mr. Chairman, we clearly have many things to discuss this morning. I look forward to hearing from our witnesses about the opportunities and challenges in establishing a sustainable space economy on the Moon.

Thank you and I yield back.

Chairman BABIN. Thank you.

And now I would like to recognize the Ranking Member of the Full Committee for a statement, Ms. Johnson.

Ms. JOHNSON. Thank you very much, Mr. Chairman. Good morning, and welcome to our witnesses. This hearing on private sector lunar exploration, I think is important.

While not a substitute for our governmental space programs, there are many innovative ideas for potential non-governmental roles in space emerging. Private sector innovation can capture the spirit of opportunity and engage and inspire the development of scientific and technical talent. It has the capacity to support commercial interests as well as governmental space activities, where appropriate.

This morning, we will hear about one example of potential commercial space activities—private sector lunar exploration. To date, only governmental entities have explored the Moon, but the private sector is getting interested in the Moon too.

It's no surprise that the Moon and its vicinity are of interest to a growing number of private sector entities and other nations. The Moon provides a potential testing ground for human exploration systems, operations, and activities. It harbors resources that could potentially be used to support lunar surface operations or exploration beyond the Moon, and some would argue that it even offers a destination for potential space tourists. I look forward to hearing from our witnesses about their plans for private sector lunar activities, NASA's current role in those efforts, and about both the opportunities and challenges that lie ahead for the private sector in carrying out their plans.

In addition, while not the focus of this hearing, it is important to note that the Moon has long been a body of scientific study, through U.S.-led and international lunar science missions, including from samples collected and returned on the Apollo missions. To that end Mr. Chairman, as we discuss private sector plans for lunar exploration, it is important that we understand the potential impacts of such activities on scientific priorities related to the Moon.

Before I close, I want to extend my thoughts and prayers to those in Houston and the surrounding areas and, especially, Mr. Chairman, to you for being a stalwart in an area that was devastated with the storm. I want to include the NASA employees, contractors, and partners of the Johnson Space Center. Their steadfast commitment to ensuring the safety of the ISS crew and continuation of the James Webb testing during Harvey's devastating rains exemplifies the professionalism and commitment they give our country's space program every day, even during times of extreme duress.

I thank you, and I yield back.

[The prepared statement of Ms. Johnson follows:]

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

House Committee on Science, Space, and Technology
Subcommittee on Space
"Private Sector Lunar Exploration"
September 7, 2017

Good morning, and welcome to our witnesses. Thank you, Mr. Chairman, for holding this hearing on "Private Sector Lunar Exploration". While not a substitute for our governmental space programs, there are many innovative ideas for potential non-governmental roles in space emerging. Private sector innovation can capture the spirit of opportunity and engage and inspire the development of scientific and technical talent. It has the capacity to support commercial interests as well as governmental space activities, where appropriate.

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I look forward to hearing from our witnesses about their plans for private sector lunar activities, NASA's current role in those efforts, and about both the opportunities and challenges that lie ahead for the private sector in carrying out their plans. In addition, while not the focus of this hearing, it is important to note that the Moon has long been a body of scientific study, through U.S.-led and international lunar science missions, including from samples collected and returned on the Apollo missions. To that end Mr. Chairman, as we discuss private sector plans for lunar exploration, it is important that we understand the potential impacts of such activities on scientific priorities related to the Moon.

Before I close, I want to extend my thoughts and prayers to those in Houston and the surrounding areas that were affected by Hurricane Harvey, including the NASA employees, contractors, and partners of the Johnson Space Center. Their steadfast commitment to ensuring the safety of the ISS crew and continuation of James Webb's testing during Harvey's devastating rains exemplifies the professionalism and commitment they give our country's space program every day, even during times of extreme duress.

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

Chairman BABIN. And we sure thank you for your comments there.

Now let me introduce our witnesses. Our first witness today is Mr. Jason Crusan, Director of Advanced Exploration Systems at NASA. He holds bachelor's degrees in electrical engineering and physics, a master's degree in computer information systems, and is currently a candidate for a doctorate in engineering management at George Washington University. Thank you for being here today.

Our second witness today is Mr. Bob Richards, Founder and CEO of Moon Express. He also chairs the Space Commerce Committee of the Commercial Spaceflight Federation and serves on the Board of the Space Foundation. Mr. Richards studied aerospace and industrial engineering at Ryerson University, physics and astronomy at the University of Toronto, and space science at Cornell University. Thank you for being here.

Our third witness today is Mr. John Thornton, CEO of Astrobotic Technology. Mr. Thornton led development of Astrobotic spacecraft including Red Rover, Polaris, and the Artemis lander, and the Griffin lander. He holds both a bachelor's of science and a master's of science degree in mechanical engineering from Carnegie Mellon University. Thank you for being here.

And then our fourth witness today is Mr. Bretton Alexander, Director of Business Development and Strategy at Blue Origin. He has served as a Senior Policy Analyst for Space Issues in the White House Office of Science and Technology Policy under both Presidents Bush and Clinton as well as President of the Commercial Spaceflight Federation. Mr. Alexander holds both a master's degree and a bachelor's of science degree in aerospace engineering from the University of Virginia. Good to see you this morning, too.

Our fifth witness today is Dr. George Sowers, Professor of Space Resources at Colorado School of Mines.

Mr. PERLMUTTER. Colorado. You heard that.

Chairman BABIN. Thank you, Ed, appreciate that. I think they heard that, though.

Dr. Sowers has also worked for Martin Marietta, Lockheed Martin, and the United Launch Alliance. Dr. Sowers holds a bachelor's of science in physics from Georgia Tech as well as a Ph.D. in physics from the University of Colorado. He is also a Fellow of the American Institute of Aeronautics and Astronautics.

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

TESTIMONY OF MR. JASON CRUSAN, DIRECTOR, ADVANCED EXPLORATION SYSTEMS, NASA

Mr. CRUSAN. Mr. Chairman and Members of the Subcommittee, thank you for the opportunity to appear today to discuss NASA's support of private sector exploration of the Moon.

NASA is working to foster commercial use of space and engagement with the broader domestic and international space community. This effort will build on the progress NASA commercial partnerships have been using to develop spacecraft and rockets capable of delivering cargo and soon astronauts to low-Earth orbit.

Its capabilities could also enable new science and exploration missions of interest to the larger scientific and academic commu-

nities and can fit well with concepts being discussed for human missions in cislunar space. In turn, they have the potential to provide important enabling competencies as NASA expands human presence into deep space.

NASA lunar science has helped map the Moon in incredible detail, determine the presence of water ice, and understand the Earth's satellite's irregular gravity field. NASA lunar missions are increasing global knowledge and understanding of the origins of our solar system, informing future exploration efforts of the Moon and other planetary bodies, and bringing the agency closer to having infrastructure and technologies needed to explore future destinations like Mars.

As part of the agency's overall strategy to conduct deep space exploration, NASA has been supporting the development of commercial lunar exploration. In 2014, NASA introduced an initiative called Lunar CATALYST, and the purpose of this initiative was to enable development of U.S. private sector robotic lunar landers that can deliver payloads to the lunar surface using U.S. commercial launch capabilities. Through CATALYST, NASA has provided partners with in-kind contributions including technical expertise, access to test facilities, software and loaning of equipment, and the initial flights of these commercial lunar landers may begin as early as 2018.

As a result, one or more of our partners would be able to market lunar payload delivery services for small instruments and technology demonstrations. Future commercial lunar transportation capabilities could also support science and exploration objectives such as sample return, geophysical network deployment, resource utilization, and technology advancements.

The agency is currently assessing possible robotic mission concepts, acquisition approaches, and associated payloads for a potential series of lunar cargo missions to the surface of the Moon starting as early as 2018.

In support of these objectives, NASA issued a Request for Information seeking ideas from industry for NASA participation in existing or future commercial missions to the Moon. The agency is interested in assessing the availability of commercial delivery services from Earth to the lunar surface as early as next fiscal year.

NASA continues to pursue other lunar exploration efforts as well. NASA's Lunar Reconnaissance Orbiter, or LRO, has produced the highest quality global topographic map of any planetary body and continues to share its data openly with the public. The Korea Pathfinder Lunar Orbiter mission, South Korea's first mission in exploration, will include NASA's ShadowCam, a highly sensitive optical camera that will peer into the regions that may hold volatiles, including water. NASA plans to include four Lunar Research CubeSats as part of the 13 CubeSats that are launching on Exploration Mission 1, the first launch of the Space Launch System. And lastly, NASA has been studying a potential Resource Prospector surface mission that would take the next step in understanding in the harvesting of resources and regolith, specifically volatiles, particularly in the lunar polar regions.

So NASA is committed to expanding partnerships with the U.S. government agencies as well as academic, industrial and entrepre-

neurial and international communities. NASA's collaborative efforts for fostering innovation in a growing space industry are continuing to transform capabilities and accelerate technologies to achieve national strategic goals.

Mr. Chairman, I'd be happy to respond to any questions you or the other Members of the Subcommittee have. Thank you.

[The prepared statement of Mr. Crusan follows:]

HOLD FOR RELEASE
UNTIL PRESENTED
BY WITNESS
Sept. 7, 2017

Statement of
Jason Crusan
Director, Advanced Exploration Systems Division
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 support of private sector exploration of the Moon. In support of its efforts to expand the frontiers of spaceflight capabilities in this new era of space exploration, NASA is working to foster the fullest possible commercial use of space and engagement with the broader community. Building on the progress of NASA's partnerships with the U.S. commercial space industry to develop new spacecraft and rockets capable of delivering cargo, and soon, astronauts, to low-Earth orbit, the Agency recognizes the U.S. industry's interest in reaching and exploring the Moon. Commercial robotic lunar lander capabilities could address emerging demand by private customers who wish to conduct activities on the Moon and could also enable new science and exploration missions of interest to the larger scientific and academic communities. These emerging commercial capabilities, in turn, have the potential of providing important enabling capabilities as NASA expands human presence into deep space, including to the surface of Mars.

NASA lunar science has helped to map the Moon, determine the presence of water ice, and understand Earth's satellite's irregular gravity field. NASA lunar missions are increasing global understanding of the origins of our solar system, informing future exploration efforts of the Moon and other planetary bodies, and bringing the Agency closer to having the infrastructure and technologies needed to explore future destinations like Mars. Future missions could help characterize the internal structure of the Moon and characterize ancient impact basins, in addition to demonstrating key technologies necessary to support future robotic and human exploration infrastructures.

Lunar CATALYST: Promoting Private Sector Robotic Exploration of the Moon

As part of the Agency's overall strategy to conduct deep space exploration, NASA is also supporting the development of commercial lunar exploration. In 2014, NASA introduced an initiative called Lunar Cargo Transportation and Landing by Soft Touchdown (CATALYST). The purpose of the initiative is to encourage the development of U.S. private-sector robotic lunar landers capable of successfully delivering payloads to the lunar surface using U.S. commercial launch capabilities.

In September 2014, NASA signed three-year Space Act Agreements (SAAs) with three U.S. firms: Astrobotic Technologies of Pittsburgh, PA; Masten Space Systems of Mojave, CA; and Moon Express Inc., of Cape Canaveral, FL. These companies were competitively selected on the basis of their proposed

technical approach, financial plan, and commercialization strategy. Through Lunar CATALYST, NASA has provided partners with in-kind contributions including technical expertise, access to test facilities, software, and the loaning of equipment. Initial flights of commercial lunar landers may begin as early as 2018, and as a result one or more of these companies will be able to market lunar payload delivery services for small instruments and technology demonstrations. Future commercial lunar transportation capabilities could support science and exploration objectives such as sample returns, geophysical network deployment, resource utilization, and technology advancements.

The Advanced Exploration Systems (AES) Division in NASA's Human Exploration and Operations Mission Directorate manages Lunar CATALYST. AES pioneers new approaches for rapidly developing prototype systems, demonstrating key capabilities and validating operational concepts for future human missions beyond Earth orbit, and Lunar CATALYST represents another step in the Agency's effort to spur growth in the commercial space sector. The NASA side of the Lunar CATALYST team is made up of lander development expertise from NASA's space science and human exploration communities, primarily from Marshall Space Flight Center and Johnson Space Center.

NASA recognizes that private-sector investment in technologies intended to enable commercial lunar activities, at least initially with respect to U.S. and other nations' exploration activities, has been increasing and anticipates that industry will eventually be able to provide commercial cargo transportation services to the lunar surface to both public and private customers. Commercial robotic lunar lander capabilities could address emerging demand by private customers who wish to conduct activities on the Moon, even while providing cost-effective transportation services for NASA's science and exploration missions, thereby benefitting the larger scientific and academic communities.

A Diversity of NASA Lunar Exploration Efforts

Along with our commercial and international partners, NASA has a continued interest in lunar exploration and is working to continue scientific investigations of our celestial neighbor that will also inform the Agency's deep space human exploration plans. The Science Mission Directorate, Space Technology Mission Directorate, and Human Exploration and Operations Mission Directorate (SMD, STMD, and HEOMD, respectively) are currently assessing possible robotic mission concepts, acquisition approaches, and associated payloads for a potential series of lunar cargo (i.e., uncrewed) missions to the surface of the Moon starting as early as 2018 and extending through at least 2024. NASA is considering a variety of objectives that could be addressed sending stand-alone instruments, experiments, or more complex payloads to the lunar surface. These would consist of NASA primary, secondary, or NASA hosted payloads and include the potential to gather data from commercial lunar surface missions and/or return payloads or samples to the Earth.

In support of these objectives, NASA issued a Request for Information (RFI) seeking ideas from industry for the Agency to possibly participate in existing or future commercial missions to the Moon. The Agency is interested in assessing the availability of a commercial launch from Earth to the lunar surface to provide landing services as early as Fiscal Year 2018, and through the next decade. This approach offers the Agency the potential to simultaneously address high-priority science, critical strategic objectives related to exploration, and technology demonstration, using commercially provided domestic space services and hardware.

Near-term robotic missions to the lunar surface offer an opportunity to achieve priority objectives for science and exploration. An early mission comprised of one or two instruments could reduce cost and risk for high priority science, and ensure the robustness of the lunar science community. A mission focused specifically on lunar polar volatiles may be the key to future exploration architectures, and

characterizing volatiles entrainment in regolith could be game-changing. Critical technologies can be demonstrated to enable improvements in precision landing, power generating, and low-temperature environments, to name a few areas. These missions might also serve as advance planning for Mars and other destinations or to enable deep-space architectures.

Other NASA lunar exploration efforts include:

- The selection of the Lunar Polar Hydrogen Mapper (LunaH-Map) through NASA's Small Innovative Missions for Planetary Exploration (SIMPLEx) program. LunaH-Map is a NASA Planetary Science Division CubeSat mission designed by Arizona State University to sense the presence of hydrogen in craters and other areas on the Moon using a neutron spectrometer. When completed, it will be one of 13 CubeSats set to launch on Exploration Mission 1 (EM-1) – the first integrated flight of NASA's Space Launch System (SLS) and Orion spacecraft. Upon arrival, the LunaH-Map spacecraft will produce the most detailed map to date of the Moon's water deposits, unveiling new details about the depth and distribution of the ice that has been identified from previous missions. Confirming and mapping those deposits in detail will help NASA understand how much water might be available and will help inform NASA's strategy for sending humans farther into the solar system.

- AES also selected three lunar research CubeSats set to be launched on EM-1:

    - Lunar Flashlight will map the lunar south pole for volatiles and demonstrate several technological firsts, including being the first CubeSat to reach the Moon, the first planetary CubeSat mission to use green propulsion, and the first mission to use lasers to look for water ice. It will shine light into the shaded polar regions with near-infrared lasers, while the on-board spectrometer measures surface reflection and composition. Lunar Flashlight is developed by NASA's Jet Propulsion Laboratory, with contributions from Marshall Space Flight Center.

    - Lunar IceCube will prospect for lunar volatiles and water during its six months in lunar orbit, investigating the distribution of water and other volatiles as a function of time of day, latitude, and regolith age and composition. IceCube's miniaturized Broadband InfraRed Compact High Resolution Explorer Spectrometer (BIRCHES) instrument will prospect for water in ice, liquid, and vapor forms from a highly inclined elliptical lunar orbit. Morehead State University in Kentucky is leading the mission, with contributions from the Busek Company and NASA's Goddard Space Flight Center.

    - Lockheed Martin's LunIR mission is hosting a mid-wave Infra-Red (MWIR) sensor LunIR will perform a lunar flyby to capture and downlink images of the lunar surface and its environment. It will help address strategic knowledge gaps related to surface characterization, remote sensing, and site selection observations. The data collected on thermal environments will add to the body of knowledge on the composition, structure, interaction with the space environment, and interaction with solar particles and the lunar regolith.

- AES has partnered with the Korea Aerospace Research Institute (KARI) on the Korea Pathfinder Lunar Orbiter (KPLO) – the country's first lunar exploration mission in 2020. Pursuant to a cooperative international SAA, NASA will provide Deep Space Network communication and lunar navigation and design expertise in exchange for flying one of AES's science instruments in development, the ShadowCam, on the KPLO mission. This instrument is a highly sensitive optical camera that will peer into the Moon's permanently shadowed areas at the lunar poles that

we suspect holds large amounts of volatiles, including water that may be useful for future exploration missions. KARI and NASA will also share data from KPLO's other instruments and, with support from the Planetary Science Division (PSD), are planning to add additional international scientific expertise to all the KPLO instrument teams.

- NASA Planetary Science Division's Lunar Reconnaissance Orbiter (LRO) is a mission whose seven different instruments are mapping the surface of the Moon and its surrounding environment. LRO has produced the highest quality, global topographic map of any planetary body and continues to share its data with the public through the Planetary Data System (PDS). Data is uploaded on a 3-month cadence and the public can suggest future targets for high-resolution imagery (which are prioritized by scientific objective or completed on a non-interference basis). Most recently, LRO has been acquiring imaging and topographic data for candidate Chandrayaan-2 landing sites, making these data available to the Indian Space Research Organisation (ISRO) through PDS. The PDS data has also been utilized by the Google Lunar X-Prize foundation for locating potential landing sites.

- NASA has also studied a potential Resource Prospector (RP) mission to provide information that could transform how the Agency approaches long-duration exploration. NASA's efforts to date have been focused on developing a suite of instruments to locate resources in regolith, specifically volatiles, particularly in the lunar polar regions. Building on the findings of the Lunar Crater Observation and Sensing Satellite (LCROSS), Gravity Recovery and Interior Laboratory (GRAIL), Lunar Atmosphere and Dust Environment Explorer (LADEE), LRO, and Chandrayaan-1 missions that proved the existence of water on the Moon, a potential future mission would take the next step in understanding how to harvest those resources. This potential "Resource Prospector" concept is being reviewed by the Agency to determine how and when the critical measurements should be pursued.

- The NASA Frontier Development Lab (FDL) is an Artificial Intelligence (AI) research and development (R&D) accelerator that tackles gaps in knowledge useful to the space program. NASA, in collaboration with SETI, established this public-private partnership with leading IT companies such as Intel, Nvidia, IBM Watson, Google, and others. FDL's industry partners provided hardware, software, subject matter experts, and funding while NASA provided modest stipends for the U.S.-based participants and subject matter experts. The 2017 FDL was an intense eight-week concentrated study on topics not only important to NASA, but also to humanity's future. This year, FDL focused on challenges within the fields of planetary defense, space resources, and space weather. The Space Resources challenge, funded in part by the Luxembourg Space Resources LLC, focused on developing algorithms to speed identification of craters and other hazards on the lunar surface. Working from data sets from NASA's LRO spacecraft, the team of lunar science and AI early-career scientists applied machine learning to removing artifacts from the imagery and altimeter data that yielded faster image resolution.

Conclusion

NASA is making advances to push the boundaries of human exploration farther into the solar system, and continues to spur development in the commercial space sector. Robotic missions to the Moon have revealed the existence of local resources including oxygen and water that may be highly valuable for exploration of the solar system. The potential to use the lunar surface in partnership with our commercial and international partners may allow these resources to be characterized and used to enable future exploration and pioneering. NASA is committed to expanding partnerships with other U.S. Government agencies, as well as the academic, industrial, entrepreneurial, and international

communities, recognizing them as indispensable contributors of skill and creativity to our missions. An important part of NASA's strategy is to partner with the commercial space industry to help the Agency achieve its strategic goals and objectives. NASA's collaborative efforts are fostering innovation and a growing commercial space industry, while transforming capabilities and accelerating technologies needed to achieve national strategic goals.

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

As director of the Advanced Exploration Systems (AES) Division within the Human Exploration and Operations Mission Directorate (HEOMD), Jason Crusan serves as NASA's senior executive, advisor and advocate on technology and innovation approaches leading to new flight and system capabilities for human exploration of space. He manages over 450 civil servant employees and 150 onsite contractors with an active portfolio of 20-30 technology, engineering and flight development projects. He leads integration with the agency's Space Technology Mission Directorate and programs within other HEOMD divisions including International Space Station and Exploration Systems Development.

Using an integrated approach that leverages public-private partnerships, industry, international partners, and academia, Mr. Crusan serves as the senior leader for AES across all NASA centers which involves: 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 effective 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.

Before becoming director of the agency's new Advanced Exploration Systems organization in 2012, Crusan fostered innovation at NASA in many key roles beginning in 2005. He served as chief technologist for space operations, and successfully directed various technical and strategic initiatives as program executive or project manager. He was part of the Miniature Radio Frequency Program (Mini-RF), 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 (CoECI) 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 degree in computer information systems, and is currently a candidate for a doctorate in Engineering Management at George Washington University. Mr. Crusan is married and has two children.

Chairman BABIN. Thank you very much, Mr. Crusan.

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

TESTIMONY OF MR. BOB RICHARDS,
FOUNDER AND CEO, MOON EXPRESS, INC.

Mr. RICHARDS. Thank you, Chairman Babin, Ranking Member Bera and Members of the Subcommittee. It is an honor to be invited to speak with you today about the efforts of U.S. commercial space industry in pioneering new business models for lunar exploration and development.

Only a few decades ago, Earth orbit was an economic frontier and the singular domain of government space agencies today. The private sector satellites generated billions of dollars of commerce annually in a mature, well-established economic sphere that impacts our everyday lives and has immeasurably improved life on Earth.

Now commerce looks beyond Earth orbit to a lunar frontier, which has also been the realm of governments but over the last decade, a combination of exponential technology and private sector investment has brought the Moon within reach of the commercial sector.

Today, I address you as Founder and CEO of Moon Express, a privately funded commercial space company created to seek and unlock the resources of the Moon through a progressive series of commercial robotic missions starting with our maiden voyage scheduled to launch next year.

I founded Moon Express with dotcom pioneers Naveen Jain and Barney Pell in 2010 as an enduring business, which starts with the creation of new space technologies and low-cost missions designed to capture and generate new markets for robotic lunar exploration. We are a Silicon Valley-born and -backed enterprise with investors ranging from billionaires to venture funds to celebrities. We began our life at the NASA Ames Research Park in Mountain View, California, and in 2015 we relocated the company to Cape Canaveral on Florida's Space Coast where we have licensed the historic Launch Complexes 17 and 18 from the U.S. Air Force and are currently refurbishing these facilities for our spacecraft, engineering tests, and our mission control.

Our vision is to open up the lunar frontier for everyone with turnkey payload data and mission surfaces to the Moon for a wide range of customers globally including governments, NGOs, commercial enterprises, universities, and consumers.

To do so, we have developed a flexible, scalable robotic explorer system that can reach the Moon and other destinations in the solar system from Earth orbit. After years of quiet development, we unveiled our robotic exploration architecture on July 12th just down the hall from this hearing room ranging from our MX–1E scout-class micro lander to our frontier-class MX–9 supporting lunar sample return. We have contracted for up to five launches from Rocket Lab USA aboard their electron rocket, which achieved a remarkable level of success during its maiden flight last May, and we expect to become operational later this year. Our first lunar scout mission in 2018 will utilize the electron together with our MX–1E

explorer to deliver a diverse manifest of scientific and commercial payloads to the lunar surface. This will be followed by expanded capabilities and ongoing missions. Our manifest is fully booked for our maiden mission, and we will be offering payload accommodations on our future ongoing missions planned at the rate of about one per year, but we are also prepared to scale up our systems and increase our flight rate to meet rising market demand and opportunity.

We have a big vision but it wouldn't be possible without the help we received from NASA. Moon Express has been honored to be partnered with NASA since the inception of our company through reimbursable Space Act agreements with both NASA Ames and Marshall Spaceflight Center. We were able to invest in and make use of NASA lunar lander test vehicles that allowed us to advance our own spacecraft control software. In 2014, we were selected as one of three industry partners with NASA for the Lunar CATALYST program established to spur commercial cargo transportation capabilities to the surface of the Moon. Supported by Lunar CATALYST and the Kennedy Space Center, we conducted test flights of our own lunar lander test vehicle at the shuttle landing facility, beginning a long-term collaboration with KFC, and that continues today. Thanks to our partnership with NASA, we're well on our way to building our maiden launch mission next year, which is in various stages of fabrication, assembly and test.

In the big picture, it's been 45 years since the United States left the surface of the Moon to the legacy of Apollo and a generation past. Moon Express is working to reopen the American frontier and the Moon and redefine what is possible for new generations.

The American flag is returning to the surface of the Moon next year, not because of a government program but because of private sector investments into low-cost rockets and smart robotic explorers that are collapsing the cost of lunar access. Together, we will begin a new democratized program to make the Moon accessible to entrepreneurs.

We are at the cusp of a glorious adventure. We aspire to the stars. Mars beckons as a second home for humanity, and the Moon is our gateway.

Thank you for the time and the opportunity to present this testimony.

[The prepared statement of Mr. Richards follows:]

Statement of Robert (Bob) Richards

Founder and CEO, Moon Express, Inc.

before the

United States House of Representatives'

Committee on Science, Space and Technology

Subcommittee on Space Hearing

on:

Private Sector Lunar Exploration

Thursday, September 7, 2017

Chairman Babin, Ranking Member Bera, and members of the Subcommittee: It is an honor to be invited to speak with you today about the efforts of U.S. commercial space industry in pioneering new business models for lunar exploration and development.

Only a few decades ago, Earth orbit was an economic frontier and the singular domain of government space agencies. Today, private sector satellites generate billions of dollars of commerce annually in a mature, well established economic sphere that impacts our everyday lives and has immeasurably improved life on Earth. Now commerce looks beyond Earth orbit to the lunar frontier, which has also been the realm of governments, but over the last decade, a combination of exponential technology advance and private space investment has brought the Moon within reach of the commercial sector.

The Moon is Earth's 8th continent, a new frontier for humanity with precious resources that can bring enormous benefits to life on Earth and our future in space. Private sector entrepreneurship will help expand our economic sphere to the Moon and create new opportunities for business markets to arise supporting science, exploration and discovery, but also horizons of infinite opportunity for creative entrepreneurs to unlock the energy and resources of a whole new world.

PERSONAL JOURNEY

My personal journey has been vested in creating international institutions and commercial space enterprises driven by the vision of a peaceful and prosperous spacefaring civilization. Along this journey, I co-founded the International Space University and more recently, Singularity University, to help inspire and educate new generations of leaders to take on bold new challenges of space exploration while caring for our home planet and each other.

I have also had the honor of working with NASA on the successful landing of a robotic spacecraft on the north pole of Mars, a scientific mission called Phoenix that added to our understanding of the Red Planet, and with the U.S. Air Force Advanced Research Lab on the demonstration of technologies in Earth orbit that enabled new capabilities in autonomous rendezvous and proximity maneuvers.

MOON EXPRESS

Today, I address you as Founder and CEO of Moon Express, a privately funded commercial space company created to seek and unlock the resources of the Moon through a progressive series of commercial robotic missions, starting with our maiden voyage scheduled to launch next year.

I founded Moon Express with "dotcom" pioneers Naveen Jain and Barney Pell in 2010. We are a Silicon Valley born and backed enterprise, with investors ranging from billionaires to venture funds to celebrities. We began our life at the NASA Ames Research Park in Mountain View, California, and in 2015 relocated to Cape Canaveral on Florida's Space Coast, where we are currently refurbishing the historic Launch Complexes 17 and 18 for our spacecraft engineering, test and mission control facilities.

THE MOON – OUR EIGHTH CONTINENT

The Moon is a new world with a total landmass approximating North and South America combined. The Moon has only been reached by government superpowers, but new advances in technology are bringing the Moon within reach of the private sector. Next year Moon Express' robotic explorers will set sail to Earth's 8th continent, seeking new opportunities for commerce, knowledge and adventure.

RESOURCES FOR HUMANITY

Like the Earth, the Moon has been enriched with vast resources through billions of years of bombardment by asteroids and comets. Unlike the Earth, these resources are largely on or near the lunar surface, and therefore relatively accessible. Moon Express is blazing a trail to the Moon to seek and harvest these resources to support a new space renaissance, where economic trade between countries will eventually become trade between worlds. All Moon Express expeditions will prospect for materials on the Moon as candidates for economic development and in-situ resource utilization.

WATER

One of the greatest practical space discoveries of our generation is the presence of vast quantities of water on the Moon, verified by NASA in 2009. Water (H_2O) not only supports life but its constituents, hydrogen and oxygen, are energetic and clean rocket fuel. The discovery of water on the Moon is a game changer, not just for the economic viability of lunar resources, but for the economics of humans reaching Mars and other deep space destinations. Water is the oil of the solar system, and the Moon can become a gas station in the sky to fuel human space exploration, development and settlement of the solar system. Moon Express will begin prospecting for water resources on the Moon with its very first expedition.

OUR LONG-TIME PARTNERSHIP WITH NASA

Moon Express has been honored to partner with NASA since the inception of our company. In 2010, we entered into a Reimbursable Space Act Agreement with NASA Ames Research Center that allowed us to invest private dollars into the refurbishment and recommissioning of NASA's Hover Test Vehicle (HTV) and test facility, where we got our lunar lander training wheels and advanced our spacecraft control software. That same year we won our first data purchase contract from NASA Headquarters under the Innovation Lunar Demonstrations Data program.

In 2012 we entered into a Reimbursable Space Act Agreement with NASA's Marshall Space Flight Center allowing us to invest in access to the 'Mighty Eagle' lander test vehicle. With NASA's support, we successfully conducted the first free flight demonstrations of our autonomous spacecraft software on the Mighty Eagle in Huntsville in 2013, validating our Guidance, Navigation and Control (GNC) flight software and proving the value of public-private partnerships for lunar capabilities. In 2014 we were selected as one of three industry partners for NASA's Lunar CATALYST program, established to spur commercial cargo transportation capabilities to the surface of the Moon. Later that year, supported by Lunar CATALYST, we conducted test flights of our own lander test vehicle at the Kennedy Space Center Shuttle Landing Facility, beginning a long-term collaboration with KSC, which continues today. In 2015, thanks to the welcoming support of Kennedy Space Center, Space Florida and the U.S. Air Force's 45th Space Wing, we relocated and consolidated our staff and company operations to the Space Coast, where we have licensed the historic Cape Canaveral launch complexes 17 and 18 from the U.S. Air Force as our new home. We are currently investing in the reconditioning and construction of these historic facilities to support our spacecraft development, test and mission operations.

CURRENT ACTIVITIES

We are currently building toward our maiden lunar mission next year, with our spacecraft systems in various stages of fabrication, assembly and test. Thanks to Lunar CATALYST, we have access to NASA facilities to test and validate our spacecraft propulsion, structures and avionics. We have contracted for up to five launches from Rocket Lab USA aboard their Electron rocket, which achieved a remarkable level of success during its maiden flight last May, and we expect to become operational later this year.

On July 12, just down the hall from this hearing room, we unveiled our spacecraft architecture and announced our first three lunar expeditions, beginning with an equatorial landing next year, a south pole flight in 2019, and a sample return in 2020, with a goal of proving out the technologies and legal premise of the first privately obtained lunar soil and rocks. Our MX family of robotic spacecraft are designed to collapse the cost of access to the Moon, introduce a new commercial paradigm for government missions, democratize lunar research and exploration, and blaze the trail for commercial space transportation and exploration beyond Earth's orbit.

Our first expedition will utilize our MX-1E robotic explorer to deliver a diverse manifest of scientific and commercial payloads to the lunar surface. Our customers for this mission include the International Lunar Observatory Association, the University of Maryland, The National Laboratories of Frascati, Celestis and Google.

'MISSION APPROVAL' FOR THE 1ST PRIVATE VENTURE TO THE MOON

On July 20, 2016, Moon Express become the first private company to receive authorization from the U.S. government for a private mission beyond Earth orbit and to the Moon, establishing a historic precedent of national and commercial compliance with the terms of the 1967 Outer Space Treaty (OST). This was in fact the first time in history that any government signatory to the OST exercised its rights and obligations to formally authorize and supervise a commercial entity to fly a mission beyond Earth orbit.

After recognizing the absence of any prescribed process or clarity of regulatory authority for our private lunar activities in 2015, we proposed a 'Mission Approval' framework to the U.S. government, intended as an interim 'patch' that built on the existing payload review process of the Federal Aviation Administration's Office of Commercial Space Transportation (FAA/AST) with a series of additional 'voluntary disclosures' intended to help satisfy U.S. obligations under the OST, including covenants of non-interference with domestic or foreign activities or heritage sites. After several months of socializing our proposal with the White House, Department of State, FAA, NASA, NOAA, Department of Defense, and other involved federal agencies, our proposal was accepted.

While thankful for the positive determination that allowed us to solidify our private financing and move forward with our plans, I note that our 'Mission Approval' was qualified as a "one-time only" authorization that does not extend to future missions by Moon Express or similar missions from other entities. For this reason, I am very pleased that this Committee has developed and marked up the American Space Commerce Free Enterprise Act, which provides an excellent "light touch" to OST Article VI compliance.

EXPANDING CAPABILITIES WITH MULTIPLE EXPEDITIONS

Following our initial "Lunar Scout" expedition next year, we will offer payload accommodations on future voyages, planned at the rate of one per year. But we can also scale up and increase the frequency of our lunar flights to meet market demand and opportunity.

Our second expedition in 2019, "Lunar Outpost", will enable the first commercial presence and exploration of the lunar South Pole. It may in fact be the first-ever soft-landing at a lunar pole. The primary goals of this mission are to set up the first lunar research outpost at a "peak of eternal light", prospect for water and useful minerals, and accommodate a variety of research instruments for our expedition partners.

Our third expedition, "Harvest Moon", will take place by 2020 and includes the first commercial sample return, beginning our business phase of lunar resource prospecting and harvesting. The samples brought back will be the only privately obtained lunar materials on Earth, and will be used to benefit science as well as commercial purposes.

OUR VISION: OPENING THE LUNAR FRONTIER – FOR ALL OF US

Our vision is to open the lunar frontier with turn-key payload, data and services for missions to the Moon for a wide range of customers globally, including governments, NGO's, commercial enterprises, universities, and consumers.

We have developed a family of flexible, scalable robotic explorers that can reach the Moon and other solar system destinations from Earth orbit. The MX spacecraft architecture supports multiple applications, including delivery of scientific and commercial payloads to the Moon at low cost using a rideshare model, or charter science or commercial expeditions to distant worlds.

Our MX robotic explorer spacecraft are optimized for launch on existing and emergent rocket systems:

MX-1: A single stage spacecraft capable of delivering up to 30kg to the lunar surface.

MX-2: A dual-stage spacecraft that doubles the capability of the MX-1 and can reach the moons of Mars.

MX-5: A cis-lunar workhorse spacecraft that can deliver up to 150kg to lunar orbit or 50kg to the surface.

MX-9: A lunar prospector/harvester that can deliver up to 500kg to the lunar surface, including an embedded MX-1R spacecraft that can launch from the lunar surface and return lunar samples to Earth.

WHAT CONGRESS CAN TO DO HELP

To assure freedom of enterprise beyond Earth orbit, industry needs a regulatory framework that meets U.S. obligations under the Outer Space Treaty with maximum certainty and minimal regulatory burden.

I would recommend that Congress support a process that focuses and streamlines the regulatory framework, limits the government's role to a light touch, promotes American innovation and investment, and satisfies international obligations. One possible approach is a "presumed authorization within boundary conditions", where U.S. policy would de facto allow non-traditional space activity in or beyond Earth orbit, provided there is:

1) no demonstrable meaningful negative impact on national security

2) no harmful interference with existing space infrastructure or activities

3) no breach to U.S. obligations under international treaties

I am hopeful that Congress and the Administration, in consultation with industry, can apply principles conducive to freedom of enterprise in space for companies like us whose success will result in the expansion of U.S. commercial space activity to the Moon and beyond. Enacting H.R. 2809, or something very like it, would go a long way to help business happen off-planet.

NEXT STEPS: A PUBLIC-PRIVATE PARTNERSHIP WITH NASA

As I have illustrated before, NASA has been an essential partner to Moon Express, providing access to expertise and technologies supporting our lunar lander development. We have benefitted from many Space Act Agreements with NASA centers that allowed us to learn from the agency and jointly develop new capabilities based on historic ones. Most of our early partnerships with NASA involved us paying NASA for access to technologies and facilities, but that has evolved in recent years into the use of no-exchange of funds Space Act Agreements that provide mutual value. In particular, NASA's Lunar Cargo Transportation and Landing by Soft Touchdown (Lunar CATALYST) program has provided us significant access to NASA technologies, facilities, and expertise which have accelerated our first few expeditions, offering exactly the kinds of capability NASA wanted to see arise.

As a next step, we would like to see NASA transition from a partner-technology developer to a partner-customer, beginning with the purchase of cargo services from us for delivery of science and exploration instruments to the Moon. Extending the public-private partnership model of commercial transportation services beyond Earth orbit will enable new growth in U.S. industrial capacity and capability while introducing the economics of private sector competitive innovation to deep space and planetary exploration.

Moon Express is flying spacecraft to the Moon next year. This means we can offer NASA an affordable way to carry small American experiments back to the Moon within this coming budget year. All of our development has been privately funded and we don't need a major public-private partnership program to fund our initial lander. Since we have a family of landers based on our core MX-1 spacecraft, we can offer NASA ongoing scalable capabilities on a fixed-price, milestone-based pay-for-services basis.

For NASA and U.S. lunar scientists to avail themselves of this near-term American return to the Moon, Congress would need to appropriate the money to fund experiments and purchase of cargo services from us. So our top priority request to enable the next step in our NASA lunar partnership would be for NASA to have the money set aside to actually buy lunar delivery services from the commercial marketplace.

If NASA wants Moon Express to accelerate the development of our family of landers, and perhaps grow our capabilities beyond our initial plans, we are ready and able to ramp up our current Lunar CATALYST partnership. Given how far we have come with private investments and no-exchange-of-funds Space Act Agreements, some competitively-awarded cost-sharing would help justify accelerating our investments into growing our capabilities to offer low cost lunar mission services that would advance NASA's interests and serve the taxpayers well.

Throughout history, varying forms of public private partnerships have been an effective approach to opening a new frontier. Recently, U.S. implementation of Commercial Orbital Transportation Services (COTS), Commercial Resupply Services (CRS), and Commercial Crew Development (CCDev) programs have demonstrated that private sector entrepreneurial approaches and investments can help NASA dollars go farther. Given similar program commitments for lunar mission and cargo delivery services, we can invest in solutions to fit NASA's needs. As NASA continues to flesh out its plans for human exploration of cis-lunar space and eventually Mars, commercial companies like Moon Express can complement mainstream NASA efforts like Orion and SLS and a Deep Space Gateway.

THE BIG PICTURE: Strategic commercial partnerships supporting deep space and NASA astronauts

The challenge of securing humanity's future through our expansion into space and ultimately becoming a multi-world species is both necessary and noble. But it's not just about boldly going; it's about boldly staying. To go to space to stay, it has to pay. While NASA pushes the boundaries of human knowledge and experience to new frontiers, partnerships with the private sector can help ensure that the engines of human imagination and discovery that drive forward those new frontiers are augmented by the engines of entrepreneurship and commerce that help make them permanent.

As a country built on the foundations of Earth's frontiers, the United States stands unique in all the world with the opportunity to focus the power of its entrepreneurial history and enterprising vision to open the lunar frontier to national, international and private sector interests, and in so doing, setting the standards of a freedom of enterprise supporting a peaceful, prosperous and boundless future for all humanity. Other countries have aggressive lunar programs underway with declared goals of resource exploitation and settlement that could eclipse American leadership, opportunity and security.

It's been 45 years since the United States left the surface of the Moon to the legacy of Apollo and a generation past. Moon Express is working to reopen the American frontier on the Moon and redefine what is possible for new generations.

The American flag is returning to the surface of the Moon next year, not because of a government program, but because of private sector investments into low cost rockets and smart, low cost robotic explorers that are collapsing the cost of lunar access. Together we will begin a new democratized paradigm of lunar exploration and make the Moon accessible to other entrepreneurs.

We are at the cusp of a glorious adventure, an epoch of evolution into space perhaps as significant as the evolution of life from the oceans onto land. One day, not long from now, a new generation will look up and see lights on the Moon, and know that they are members of a mutiworld species.

For the last half century, the United States has led the world in magnificent robotic and human achievements in space. The opportunity is at hand to continue that leadership with a focused and committed American return the Moon, this time to stay.

We aspire to the stars. Mars beckons as a second home for humanity. The Moon is our gateway.

Thank you for your time and the opportunity to present this testimony.

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MOON EXPRESS

COMMERCIAL LUNAR ROBOTIC EXPLORATION SYSTEMS

OVERVIEW

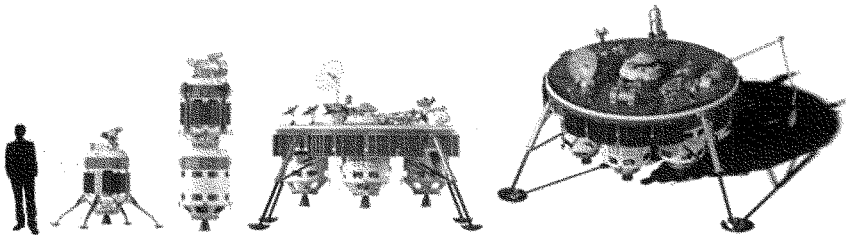
On July 12, 2017, Moon Express unveiled its exploration architecture, including plans to establish the world's first permanent lunar outpost at the South Pole of the Moon by 2020. The company's robotic explorers are flexible, scalable platforms that will help reopen the American frontier on the Moon, conduct prospecting and sample return operations, and support lunar science, exploration and commerce.

On July 20, 2016, Moon Express became the first company to receive U.S. government approval to send a robotic spacecraft beyond traditional Earth orbit and to the Moon. This was the first time in history that any government signatory to the Outer Space Treaty exercised its rights and obligations to formally authorize and supervise a commercial entity to fly a mission beyond Earth orbit.

MX FAMILY OF ROBOTIC EXPLORERS

Our MX family of flexible, scalable robotic explorers can reach the Moon and other solar system destinations from Earth orbit.

Configurable to existing and emerging launch systems, the MX spacecraft architecture supports multiple applications, including delivery of scientific and commercial payloads to the Moon at low cost using a rideshare model, or charter science expeditions to distant worlds.



MX-1 MX-2 MX-5 MX-9

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COMMERCIAL LUNAR EXPEDITIONS

Moon Express is working toward three maiden robotic missions to the Moon by 2020. Our on-going expeditions to the Moon with robotic explorers will collapse the cost of lunar access and enable new markets and opportunities to arise, bringing the Moon within reach by creating low cost frequent opportunities for democratized lunar exploration by scientists, researchers, students, and everyday people. Our goal is to open the lunar frontier for all of us, ultimately expanding Earth's economic and social spheres to our 8th continent, the Moon.

EXPEDITION ONE: LUNAR SCOUT (MX-2: 2018)
THE 1ST COMMERCIAL VOYAGE TO THE MOON

The Lunar Scout expedition will be the first commercial voyage to the Moon. This historic expedition will demonstrate the cost effectiveness of entrepreneurial approaches to space exploration, carrying a diverse manifest of payloads including the International Lunar Observatory, "MoonLight" by the INFN National Laboratories of Frascati and the University of Maryland, a Celestis memorial flight. Following completion of operations supporting our Lunar Scout expedition partners, we will attempt to win the $20M Google Lunar XPRIZE.

VIDEO: https://youtu.be/XJEkqpcu34U

EXPEDITION TWO: LUNAR OUTPOST (MX-2: 2019)
THE 1ST COMMERCIAL SOUTH POLE EXPEDITION

The Lunar Outpost expedition will enable the first commercial presence and exploration of the lunar South Pole. The poles of the Moon have concentrations of water and other valuable resources, as well as "peaks of eternal light" where permanent sunshine and direct continuous communication with Earth is possible. The primary goals of this mission are to set up the first lunar research outpost, prospect for water and useful minerals, and accommodate a variety of research instruments for our expedition partners.

VIDEO: https://youtu.be/KGWmDGqIIdk

EXPEDITION THREE: HARVEST MOON (MX-9: 2020)
THE 1ST COMMERCIAL LUNAR SAMPLE RETURN

The Harvest Moon expedition will take place by 2020 and includes the first commercial sample return mission, which also begins the business phase of lunar resource prospecting. The lunar samples brought back will be the only privately owned Moon materials on Earth, and will be used to benefit science as well as commercial purposes.

VIDEO: https://youtu.be/qXMr-P7KDuU

FOR MORE INFORMATION VISIT: www.moonexpress.com

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BIO – ROBERT (BOB) RICHARDS



Robert (Bob) Richards is a space entrepreneur and futurist. He is a Co-Founder of the International Space University, Singularity University, SEDS, the Space Generation Foundation and Moon Express, Inc. a space transportation and lunar resources company located at Cape Canaveral, where he is currently serves as President and CEO. Bob chairs the Space Commerce Committee of the Commercial Spaceflight Federation, serves on the board of the Space Foundation, and is a member of the International Institute of Space Law. As Director of the Optech Space Division from 2002-2009, Bob led the company's technology into orbit in 2004 and to the surface of Mars in 2007 aboard the NASA Phoenix Lander, making the first discovery of falling Martian snow. Bob studied aerospace and industrial engineering at Ryerson University; physics and astronomy at the University of Toronto; and space science at Cornell University where he became special assistant to Carl Sagan. Bob is an evangelist of the "NewSpace" movement and has been a catalyst for a number of commercial space ventures. He is the recipient of the K.E. Tsiolkovski Medal (Russia, 1995), the Space Frontier "Vision to Reality" Award (USA , 1994), the Arthur C. Clarke Commendation (Sri Lanka, 1990) and Aviation & Space Technology Laurel (USA, 1988). He is a contributing author of "Blueprint for Space" (Smithsonian Institution 1992); "Return to the Moon" (Apogee Books 2005) and "The Farthest Shore" (ISU Press 2009). In 2005 Bob received a Doctorate of Space Achievement (*honoris causa*) from the International Space University for "distinguished accomplishments in support of humanity's exploration and use of space."

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Chairman BABIN. Thank you, Mr. Richards.

I now recognize Mr. Thornton for five minutes to present your testimony.

TESTIMONY OF MR. JOHN THORNTON,
CHIEF EXECUTIVE OFFICER,
ASTROBOTIC TECHNOLOGY, INC.

Mr. THORNTON. Chairman Babin, Ranking Member Bera, and Members of the Subcommittee, thank you for the opportunity to discuss our nation's future on the Moon.

Incredibly, America has not returned to the lunar surface since the Apollo program ended in 1972. This has put our nation at a disadvantage as other nations like China have landed increasingly ambitious robotic missions on the surface of the Moon.

As we approach the 50th anniversary of Apollo 11 landing, our nation has a unique opportunity to answer a growing global demand for a reliable, proven means to access the lunar surface. Some nations are beginning to fly with the Chinese but it's not too late. By supporting our nation's entrepreneurs, America can once again lead the world back to the Moon.

Thankfully, with the strong technical support of NASA, especially through the leadership of Jason Crusan's AES Office, American industry is restoring access to the Moon with small robotic lunar landers.

Founded in the Rust Belt city of Pittsburgh in 2007, Astrobotic is leading the way to reestablish American access to the Moon with small-scale cargo delivery. We have assembled a world-class team of partners including NASA, United Launch Alliance, Airbus, and DHL. Together, we are building the Peregrine lunar lander, a privately developed spacecraft capable of delivering up to 265 kilograms of cargo to the Moon. In August, I celebrated ten years of building Astrobotic and the lunar market. Today, I am proud to say that Astrobotic is leading the world in lunar sales and market development with 11 deals representing six nations and a lunar pipeline of over 115 deals worth more than $1.8 billion. Astrobotic is flying its first mission to the Moon in 2019, the 50th anniversary of the Apollo 11 landing.

Peregrine is not a precursor or a demonstration. It is right-sized from the beginning to address the existing lunar market. At the historic price of $1.2 million per kilogram, Peregrine enables activities like resource development, scientific investigation, technology demonstration, and exploration.

The future is bright but tenuous for sustainable commercial lunar cargo delivery. The government would be wise to leverage and augment existing international lunar payload demand rather than overwhelm it with an oversupply of large landers that have no sustaining commercial demand for the foreseeable future.

Small landers like Peregrine stand ready to support upcoming NASA crewed exploration missions on SLS Orion to the deep space gateway by enabling telerobotic access to the surface. Small lander missions are our first step toward one day reestablishing human presence on the Moon and launching a cislunar off-world economy.

Much of Astrobotic's market progress is owed to a proven technical track record and world-class partnerships. For instance, Air-

bus is providing engineering support and expertise from ESA programs. Throughout partnership with United Launch Alliance, we will launch as a secondary payload from Cape Canaveral on America's reliable Atlas V launch vehicle, continuing a proud history of successful lunar missions including LRO, LCROSS and GRAIL.

NASA is providing access to their engineers and facilities through the highly successful Lunar CATALYST program, and we are encouraged by steps NASA has taken this year including issuing RFIs for small lunar payloads and lander services. With CATALYST insight into our service, Astrobotic believes now is the time for NASA to join our payload manifest.

We appreciate the leadership of House CJS Appropriations Subcommittee Chairman Culberson, Ranking Member Serrano, and Members of the Committee in providing $30 million in the fiscal year 2018 appropriations bill for a small robotic lunar lander demonstration mission. We are hopeful the Senate will follow the House's lead, and this funding will be included in a final omnibus, which could allow NASA to send payloads to the Moon. We encourage this Committee to lend its full support for this program in the appropriations process this fall.

As this Committee plans for the next NASA authorization, we urge you to authorize a frontier-class lander services program for small lunar landers within the launch services program similar to the Venture-class program. This would provide a contractual mechanism for NASA to easily purchase lunar payload services.

Mr. Chairman, we are proud to be leading the Moon shot from America's Rust Belt. This is a special moment for our company, our industry, our region, and our nation. Small lander services like Astrobotic have a proven market with sales, world-class partners, and credible spacecraft. With support from Congress, we can ensure American lunar market leadership and NASA's return to the Moon.

I look forward to any questions you may have.

[The prepared statement of Mr. Thornton follows:]

ASTROBOTIC

Statement of Mr. John Thornton,
Chief Executive Officer,
Astrobotic Technology, Inc.

before the

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

September 6, 2017

Chairman Babin, Ranking Member Bera, and Members of the Subcommittee: thank you for the opportunity to appear today to discuss our nation's future on the Moon. Incredibly, America has not had access to the lunar surface since the Apollo Program ended in 1972. This has put the nation at a disadvantage in science, exploration, and commercial activities, as other nations like China have landed increasingly ambitious robotic missions to the surface of the Moon. No doubt these developments weigh heavily in the minds of international governments, research institutions, and commercial customers as they decide whom to partner with to achieve their goals in space exploration and commerce.

As we approach the 50th anniversary of the Apollo 11 landing in 2019, it is imperative that we signal to the world that America intends to once again lead on the lunar surface. This is especially important as the world increasingly looks to new lunar frontiers like the Moon's far side and poles. Thankfully, American industry, with the strong technical support and cooperation of NASA, is restoring access to the lunar surface with affordable small robotic landers that provide significant capability for the government and other customers. American industry has taken the initiative to develop these small robotic lander capabilities with the majority of funding coming from non-NASA sources. In the case of our company, Astrobotic, we have stood as a private company for 10-years now, generating actual revenues from our 11-non-NASA deals. We have built a team of world-class partners, including Airbus DS and ULA, who have joined our mission because we have demonstrated a credible approach to building a spacecraft that can deliver for our customers.

Re-establishing American Access to the Moon with Small Landers

Founded in the Rust Belt in 2007, Astrobotic is one such company leading the way to re-establish American access to the Moon with small robotic lander capabilities. Astrobotic is building the *Peregrine Lunar Lander*, a privately developed spacecraft capable of delivering hundreds of kilograms to the Moon. Peregrine will enable robotic access to the Moon for companies, governments, and universities starting in 2019, for the historically low price of $1.2 million per kilogram.

Astrobotic is poised to provide a critical capability to the burgeoning lunar payload delivery market. The Moon offers untold opportunities for resource development, scientific investigation, technology demonstration, and exploration advancement. With Peregrine, Astrobotic offers a reliable, low-cost cargo delivery service that allows organizations around the world to

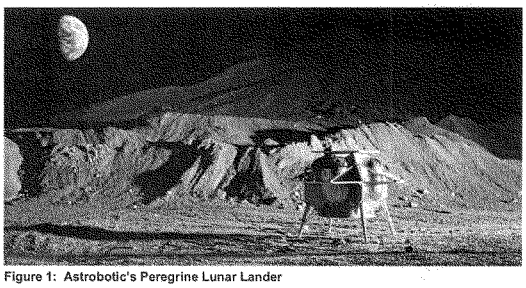


Figure 1: Astrobotic's Peregrine Lunar Lander

pursue these opportunities. Each Peregrine mission will deliver a diverse collection of payload types on a single flight to the Moon. With this end-to-end delivery service, payload customers are empowered to build their own payloads, and integrate them onto our lander using Astrobotic's standard interfaces. Once Peregrine lands on the Moon, the vehicle provides power and communications bandwidth to our payloads for the operation of their own missions on the surface.

With this approach, companies and governments are no longer required to build their own launch vehicles, landers, or other costly infrastructure to send and operate missions to the Moon, nor are they burdened with complicated bilateral or multilateral international agreements to make a mission possible. Instead, payload customers can buy just the service they need on Peregrine and make their lunar ambitions a reality faster and cheaper than ever before.

Astrobotic's first delivery mission will be a key demonstration of service for our payload customers. Peregrine will fly its first mission as a shared, secondary payload on the Atlas V launch vehicle, but on future missions two Peregrine landers could fly together as a primary payload to make deliveries at multiple lunar locations on a single flight. Astrobotic will launch a delivery mission to the Moon once per year, creating a regular cadence of low cost missions to the Moon for the world's space agencies and companies.

Serving the Market for Small Lander Services to the Moon

To date, Astrobotic has 11 deals in place from companies, governments, and nonprofits for Peregrine's first mission to the Moon. The manifest includes a payload reservation from the Agencia Espacial Mexicana, or AEM, the Mexican Space Agency. AEM will fly the first Latin American payload to the Moon on board Peregrine. They will join 6 other nations represented on our first mission: the United States, Japan, Mexico, the United Kingdom, Chile, Germany, and Hungary. The diverse international nature of Astrobotic's first mission manifest demonstrates a global pent up demand for lunar services. The AEM reservation to deliver a Mexican payload to the Moon is a model Astrobotic believes will be replicated repeatedly by other space agencies around the world. Many space agencies have the capability to build groundbreaking payloads that could advance the state of the art in a variety of fields; they just need a low cost transportation service to deliver them.



Figure 2: Astrobotic's Payload Manifest to fly on the Peregrine Lunar Lander

The current Mission One manifest includes contracts to carry small lunar rovers, marketing and time capsule artifacts, technology demonstrators, and memorial cremains. Astrobotic's most recent payload contract, which was signed with Atlas Space Operations at the 2017 Paris Air Show, will be a laser communications terminal that demonstrates the first optical communications capability on the lunar surface. Payload customers on board our mission will be able to take advantage of this breakthrough gigabit per second bandwidth, which will enable high definition streaming video. Laser communication services on the Moon is emblematic of the new era on the Moon made possible by small lander services like Astrobotic.

In addition to our existing payload deals, Astrobotic has developed a sales pipeline of 115 deals, valued at more than $1 billion. This pipeline exists today even before our first flight to the Moon, and reflects the



rapidly growing interest in the Moon. Our understanding of the Moon and the opportunities it holds for science, exploration, and commerce has changed dramatically since the Apollo landings. For instance, just a few years ago scientists from Japan discovered that the Moon has cave-like structures under the surface called lava tubes with entrances on the lunar surface known as skylights. Astrobotic has customers that plan to send autonomous rovers into these features to determine the suitability of lava tubes for future human habitation. With natural protection from radiation, meteorites, and thermal variance, lava tubes hold great potential as a location for long-term human settlements on the Moon. Rovers that peer inside lava tubes could also carry out scientific measurements of the cave walls that were at one time exposed to solar winds over billions of years. These measurements could lead to new insights in solar history.

Lava tubes are an exciting new destination for activity, and similarly the Moon's far side is also a previously untapped location for exploration and discovery. All of the Apollo missions landed at the "front side" of the Moon, and were never able to take advantage of the "radio quiet zone" of the Moon, which blocks interfering radio waves from Earth. Some Astrobotic customers seek to place the first-ever telescopes in cislunar space, which would allow for observations of deep space with almost no radio interference from Earth.

In addition to landing and operating at new lunar sites, some Astrobotic customers plan to build on the progress of past Apollo experiments. For instance, some plan to place retroreflector mirrors on the lunar surface to further triangulate the distance from the Earth to the Moon, and carry out experiments in relativity physics. Newly placed retroreflectors would compliment the ones left behind by Apollo. Others are looking to deploy seismometers and other geophysical instruments all over the surface to better understand the nature of the Moon as a planetary body, and augment instruments left behind in just a few locations by Apollo. Astrobotic also has payload customers that plan to trail blaze new experiments not previously seen during Apollo, such as the first plant growth experiments on a planetary body. Those experiments would be the first step toward growing food on other planets, and unlike anything done in the 1960s or 70s.

Making Use of Lunar Water Ice

When the Apollo program left the Moon for the final time, we thought the Moon was a dry and barren place. Today our understanding of the Moon is dramatically different, as more recent missions like NASA's LCROSS revealed the Moon to be a source of water ice. Thanks to LCROSS, we now know the Moon's polar cold traps have been collecting water from icy comet impacts for billions of years. In fact, some believe that there are 'Great Lakes' worth of water at the poles of the Moon. Water ice on the Moon holds enormous potential for deep space human exploration.

Currently the physics of the rocket equation makes it cost prohibitive for most public and private activities to take place beyond Earth orbit today. Anywhere between 80-95% of a rocket's mass is spent on just the propellant needed to reach Earth orbit.[1] This fuel problem in space breaks most business cases beyond Earth orbit, and cripples the plans of space agencies around the world. Hydrogen and oxygen are key propellants that can power missions beyond Earth orbit, and they can be extracted from water ice. Based on prior discoveries by spacecraft like LCROSS, significant quantities of water ice have been definitively shown to exist at the Moon's poles.[2] Thus it is possible to extract and utilize the fuel already at the lunar surface rather than ship it from Earth, which is costly.

[1] https://www.nasa.gov/mission_pages/station/expeditions/expedition30/tryanny.html
[2] https://www.space.com/7530-significant-amount-water-Moon.html



Utilizing fuel derived from lunar water ice, rather than shipping it from Earth could dramatically improve the economics of space activity at the Moon and beyond. For instance, one MIT study found the cost of a human mission to Mars could be reduced by as much as 68% if fuel from the Moon were used, rather than terrestrially-based fuel hauled from Earth.[3] All of this water ice exists at the poles of the Moon, which is why there is so much recent international interest in the lunar poles, including from the Chinese. Make no mistake; extracting water ice from the Moon will be a technically challenging endeavor that will require substantial research and development, technology demonstrations, and plain hard work and persistence over many years. Yet the promise of lunar water ice for our future in space is too exciting to ignore, and our customer pipeline shares this view.

With a capable lander like Peregrine, Astrobotic stands ready to serve the growing interest in the lunar poles with low cost lunar transportation. Small lander services like Astrobotic are well suited to begin the first step of landing and operating at the poles, obtaining ground truth of water ice in the Moon's cold traps, and demonstrating initial techniques to harvest water. Landing and successfully operating at these sites will be the first step toward realizing the promise of lunar water ice for deep space exploration.

It is important to recognize now that as space activities evolve, valuable resources at the Moon could be of strategic interest to the United States in just a few year short years, and U.S. commercial companies like Astrobotic will be best positioned to capture this value for the nation. Policymakers would be wise to recognize that our future plans for human exploration and other space activities beyond Earth could be substantially altered or supported by our access to this lunar water ice.

Building World Class Partnerships

Part of what makes Astrobotic's Peregrine Lander a credible and capable program is the world-class partners who have stood with us, and assisted our company as we progress toward flight. Not only are the following partners making irreplaceable contributions toward our mission, their statements of support indicate the maturity of our program and our approach. Several of them are pillars of the space community and do not lend the support of their brand lightly.

NASA has been an outstanding partner through the Lunar CATALYST program, which provides Astrobotic access to some of the best spacecraft engineers and facilities in the world, as part of NASA's effort to encourage the development of U.S. commercial robotic lunar lander capabilities. Astrobotic applauds the leadership of the Advanced Exploration Systems division within the Human Exploration and Operation (HEO) Mission Directorate for instituting and supporting CATALYST over the last three fiscal years. We also applaud NASA HEO's recent Request for Information (RFI) seeking information on the availability of small payloads that could be delivered to the Moon using U.S. commercial lunar cargo transportation service providers, as well as NASA's joint RFI seeking information on Lunar Surface Cargo Transportation Services from the Science Mission Directorate with support from the HEO Mission Directorate and the Space Technology Mission Directorate. Astrobotic believes the deep insights into programs like ours through the multi-year CATALYST experience now enable NASA to move beyond these RFIs, and make use of our services for their agency's goals in the immediate near term.

United Launch Alliance is partnering with Astrobotic to launch Peregrine as a secondary payload on an Atlas V launch in late 2019. ULA has been an excellent partner and the Atlas launch vehicle has a long history of successfully launching lunar missions, including Ranger, Lunar Orbiter, Surveyor, LRO/LCROSS and GRAIL. Astrobotic is proud to launch on a proven American launch vehicle from Cape Canaveral, Florida.

[3] http://news.mit.edu/2015/mars-mission-save-weight-fuel-on-Moon-1015

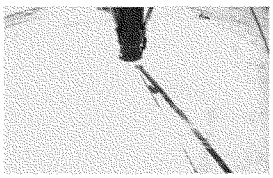
Airbus DS is providing systems engineering support and insight, along with irreplaceable wisdom from past ESA lunar lander experiences. Airbus DS has also provided crucial independent reviews for our spacecraft development milestones.

DHL, the world's largest logistics company, is bringing significant resources to bear for our mission, and is joining our effort as "The Official Logistics Provider to the Moon." Astrobotic's partnership with DHL is another example of the new opportunities that made possible with low cost lunar transportation. No longer is the Moon solely the domain of national governments.

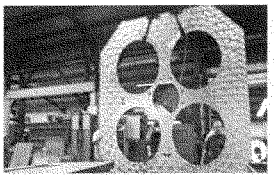
Demonstrating Credibility and Program Maturity

Astrobotic's progress in the lunar delivery market is made possible by the company's steadfast focus on developing a technically credible spacecraft. In fact, the Peregrine Lander recently completed a Preliminary Design Review, with support from Astrobotic's world-class partners, NASA Lunar CATALYST and Airbus DS. Astrobotic has also imported spaceflight talent from across the industry. In the case of our Mission Director, Astrobotic recruited a former 25-year Lockheed Martin veteran, who has put dozens of payloads into space on the Space Shuttle and the International Space Station. Our lead systems engineer is a veteran of 13 space missions including GRAIL, Mars Odyssey, Mars Reconnaissance Orbiter, MAVEN, and Orion. In all, Astrobotic has added more than 90-years of space experience to our team in the last 8-months. Astrobotic has been able to add these space industry veterans because of the reputation we have built over the past decade, delivering results across 23 past and ongoing NASA contracts, and developing actual hardware and technology for our mission.

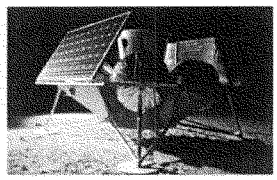
Across the years we have built and flight qualified a primary spacecraft structure for a Peregrine precursor lander, conducted numerous lunar surface mobility demonstrations at lunar analogue sites, and even demonstrated the world's first visually guided propulsive landing. In the case of our visually guided propulsive landing tests, we flew our Terrain Relative Navigation (TRN) technology three times on a Masten Lander in the Mojave Desert, and successfully demonstrated an autonomous guidance system in a GPS-denied environment that avoided mock ground hazards. TRN is exactly the kind of technology that will be needed to land at challenging environments like the lunar poles.



World's first visually guided propulsive landing



Lander prototype fabrication



Lunar analogue testing with lander & rover prototypes

Delivering NASA Payloads to the Moon

With NASA's deep insight into our program from the multi-year Lunar CATALYST experience, Astrobotic believes now is the right time for NASA to join our payload manifest with a payload reservation. Such a reservation would validate NASA's future use of private payload delivery services, and serve as a key demonstration for the rest of the payload market, which is made up of international space agencies, research institutions, and commercial customers.

We appreciate the leadership of House Commerce-Justice-Science Appropriations Subcommittee Chairman John Culberson (R-TX) and Ranking Member Jose Serrano (D-NY), as well as the members of



the committee for their leadership in providing $30 million in the FY 2018 Appropriations bill for a small robotic Lunar Lander demonstration mission. We are hopeful that the Senate will follow the House's lead and this funding will be included in a final Omnibus. Such funding would allow NASA to join our first mission with its own payload reservation, which would serve as a demonstration of service for the agency.

A NASA payload reservation would be a major step toward bringing small lander capabilities like Peregrine online, and would set up the lunar payload market to flourish. While Astrobotic has secured 11 deals to deliver payload on our first mission, it is no secret that the rest of the international space agency community looks closely to NASA's example for leadership. Such a demonstration of NASA payload delivery would enable the consideration of small landers for space exploration architectures and further help close new business cases in cislunar space.

A NASA demonstration mission would also aid in establishing a regular cadence of small to medium sized payload deliveries, and promote a vital logistics pipeline to the Moon that can be sustainably grown on a diverse market. The self-sustaining small to medium class service can help build the foundation for affordable large-scale lunar endeavors such as human surface missions, which would likely have an exclusive reliance on U.S. Government demand. Small robotic missions are a logical first step toward one day re-establishing a human presence on the lunar surface, and commercial services like Astrobotic exist today with a demonstrated market demand outside of the U.S. Government. The U.S. Government would be wise to ensure that the demand for the small to medium sized payload market is not quashed in a rush to develop larger capabilities that have no outside commercial demand for the foreseeable future.

It should also be noted that Astrobotic and American small lander services are competing with a half-dozen other private lunar payload delivery providers from the international community. A significant payload reservation on board a U.S. commercial provider from NASA would cement our status as the world leader in lunar delivery, and lead to the capture of a substantial portion of the international market by U.S. industry. Our sales pipeline currently has more than 100-deals that could also be won by our international competitors. In the event that one of these competitors captures a major portion of these eligible deals, American payload delivery providers could fall behind, and NASA could be left without a U.S.-domestic lunar payload delivery provider. Assuming that NASA is restricted to using domestic payload delivery providers (as is typically the case for launch vehicles), the agency could be shut out of getting its payloads to the lunar surface, while the rest of the international community is ramping up lunar surface activities. A NASA payload reservation on a small lander service like Peregrine would have a resounding effect toward ensuring American market share in this new lunar market.

Long Term Applications for Small Lander Services

With an imminent demonstration of lunar payload services, small lunar landers like Peregrine can now be leveraged for the purposes of NASA's near term exploration goals. Small robotic landers like Astrobotic's Peregrine stand ready to support upcoming NASA crewed Exploration Missions on SLS-Orion to the Deep Space Gateway by enabling telerobotic access to landers and rovers on the surface. In fact, SLS's unprecedented lift capability could carry multiple Peregrine landers along with crew, allowing access to multiple parts of the Moon during the same mission, while the crew operates from Orion and Deep Space Gateway in orbit. Small robotic lunar landers would be highly complimentary to the Deep Space Gateway. Their use in concert with the Gateway would be the first step toward an eco system of public-private activity around and on the Moon.

In addition to providing direct support to SLS-Orion crewed Exploration Missions at the Deep Space Gateway, there are dozens of small to medium sized NASA payloads that are ready to fly to the Moon on small robotic landers. These payloads run the gamut of science, exploration, and technology



demonstration, and many of them were identified in responses to a recent Request for Information issued by the Advanced Exploration Systems division at NASA in October 2016. As mentioned, it has been more than 40 years since NASA has soft landed payloads on the surface of the Moon. Small lander services have the potential to not just end this drought; they can afford NASA the ability to rapidly follow up an initial experiment with another one.

The value of this capability to science and exploration cannot be overstated. In the past, large sophisticated missions might visit the Moon, make a breakthrough, and then leave the science and exploration communities no ability to practically follow up their groundbreaking findings. Small to medium sized NASA payloads on landers like Peregrine fundamentally speed up the pace of discovery by allowing the agency to return to the Moon rapidly and regularly. The low cost of building and delivering payloads on small landers allows payload builders to experiment and try new approaches they never would have felt comfortable with on a mission that comes around once a decade and costs hundreds of millions of dollars. This rapid cadence of flights opens new horizons in our nation's space capabilities.

From a national policy perspective, small lander private missions to the Moon also provide an opportunity for the United States to help establish international norms for private activities at planetary destinations. For instance, retroreflectors might be carried on board Peregrine for a space agency as a payload to obtain new findings in the Earth-Moon system. At the same time, the permanent placement of these retroreflectors on the lunar surface could serve as physical navigation beacons for aiding and informing future missions to the Moon. Those beacons could also be used to assist in deconflicting interference and establishing keep out zones for future lunar activity in heavily congested areas on the surface. Perhaps most importantly, private small lander missions can establish norms and infrastructure like this retroreflectors example in just a couple of years.

With a commercial market already at hand for lunar payload services, small lander services can quickly ensure America is well represented in a new era of lunar activity, and international norms can be modeled by early American industry actors. In the most immediate term, Astrobotic has been glad to work with the FAA Office of Commercial Space Transportation (AST) to ensure our activities are in compliance with the Outer Space Treaty, and that we are well positioned to receive a mission authorization from the U.S. Government when the time is appropriate. Thanks to the FAA AST, we are confident there are no substantial regulatory barriers to our mission, and our customer base has demonstrated that they feel similarly. Based on our experience with FAA AST to date, we have been impressed with the professionalism, efficiency and responsiveness of their staff in facilitating this process, and commend their efforts to work with industry to enable non-traditional space activities.

NASA Authorization Recommendations

As this committee plans for the next NASA Authorization and conducts ongoing oversight, we urge you to consider authorizing a "Frontier Class Lander Services" program for small robotic landers and rovers to the lunar surface -- similar to the Venture Class Launch Services program for small launch vehicles -- within the NASA Launch Services Program. This would provide a contractual mechanism for NASA and international partners to easily purchase payload space for experiments and technology demonstrators.

Following the Venture Class Launch model would allow all mission directorates at NASA to take advantage of this new American capability. For example, the Human Exploration and Operations Mission Directorate could acquire payload service to the lunar surface for ongoing missions at the Deep Space Gateway. The Science Mission Directorate could opt to deliver science instruments on the Moon, and vastly increase the cadence of flight opportunities in cislunar space. The Space Technology Mission Directorate could increase the Technology Readiness Level of new space technology with actual



experience on the lunar surface. Ultimately a Frontier Class Lander Services program would enhance NASA's portfolio of capability across the agency.

We also encourage NASA to think creatively about how it can help bring international space agency partners to the table to think about opportunities to do science, technology and exploration experiments and missions using this new small lander capability. Many entities in the international space community have expressed a desire to operate missions on the Moon. Perhaps most notably, the head of the European Space Agency, Dr. Jan Woerner, has outlined a vision for a global Lunar Village, in which the next human outpost beyond the International Space Station (ISS) is on the Moon. As a leader of past international cooperative programs like the ISS, NASA would be well suited to aid in the facilitation of placing international space agency payloads on American small lander services.

Conclusion

Mr. Chairman, thank you again for the opportunity today to share our latest developments toward re-establishing American access to the lunar surface. Our team is proud to be leading a Moonshot from America's Rust Belt. We plan to source most of our supply chain from the region, and apply the manufacturing might of our area to reach the Moon. As a company based in Pittsburgh, we know that we stand on the shoulders of giants who helped make our region capable and strong. We also know that these new possibilities on the Moon are made possible thanks to the incredible pioneering spirit of those who came before us.

We now seek to advance these legacies toward a new era in American leadership on the Moon, and we believe this is a special moment in time for our company, our industry, and our country. Both the public and private sectors around the world have outlined plans for lunar activity in the near term. Small lander services to the Moon like Astrobotic now have a verified market demonstrated with real sales, world class partners, and a technically mature spacecraft design. With policy and appropriations support from Congress, American small lander services can capture a significant share of a nascent 21st century space market, while getting NASA back to the Moon. Astrobotic is ready to rise to this occasion, and chart a new course on the lunar surface for American explorers and entrepreneurs.

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

ASTROBOTIC

JOHN THORNTON
CHIEF EXECUTIVE OFFICER



John Thornton has grown Astrobotic's business of delivering affordable space robotics technology and planetary missions by attracting technology contracts, equity investment, and payload customers. Thornton was promoted to reboot the company 5 years ago. He established a new corporate structure, attracted key personnel and developed the company's payload business model. Thornton secured the company's first lunar delivery contract and led the company to an additional nine payload deals for the first mission. Thornton joined Astrobotic at its founding in 2007 as Mechanical Engineering Lead and soon thereafter was promoted to Chief Engineer. He led development of the program's spacecraft including Red Rover, Polaris, the Artemis lander and the Griffin lander.

Prior to Astrobotic, Thornton led the build of Scarab for Carnegie Mellon, a NASA concept robot for lunar drilling, and the first robot to carry a prototype of NASA's RESOLVE payload. He managed a research program that identified a battery that can survive the liquid nitrogen temperatures on the Moon. Thornton also founded Carnegie Mellon's Advanced Composites Lab, a research, training, design, and manufacturing lab specializing in high performance, lightweight composites for robotics. Thornton holds a MS and BS in Mechanical Engineering from Carnegie Mellon University.

Chairman BABIN. Thank you very much, Mr. Thornton.

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

TESTIMONY OF MR. BRETTON ALEXANDER,
DIRECTOR OF BUSINESS DEVELOPMENT AND STRATEGY,
BLUE ORIGIN

Mr. ALEXANDER. Chairman Babin, Ranking Member Bera, and Members of the Subcommittee, thank you for the opportunity to speak before you today about private sector lunar exploration, a topic that we're very excited about at Blue Origin.

Before I begin, I'd like to extend our thoughts and support to our friends at Johnson Space Center and the broader Texas community as they recover from Hurricane Harvey and to those at Kennedy and throughout Florida in the path of Hurricane Irma.

Blue Origin was founded to bring about a future where millions of people are living and working in space. We are committed to building the next generation of space transportation and are prepared to bring significant private capital to partner with NASA for return to the lunar surface.

It's time for America to return to the Moon, this time to stay. Enabling NASA and U.S. commercial activities on the Moon is a key step on the path to long-term exploration of the solar system.

Imagine driving from DC. to Los Angeles nonstop. You'd have to carry with you all of your fuel, food, and other necessities with you, which would make for a difficult trip. The Moon provides the resources and proximity to enable human exploration of deep space destinations like Mars, making it the ideal proving ground and first step.

For example, the lunar South Pole's Shackleton Crater contains critical resources for fuel and power generation while also offering a nearby proving ground for deep space exploration technologies.

All of this potential has not gone unnoticed. Many commercial entities and nations have plans for an ambitious decade of lunar exploration. The United States should be the leader in this worthy endeavor.

Blue Moon is a space transportation and lunar lander system that can cost-effectively deliver more than 10,000 pounds of cargo from Earth to the lunar surface. This equates to about five Mars Curiosity Rovers, or two Ford F–150 trucks. When you can cost-effectively and precisely soft land large amounts of cargo on the Moon, there are few limits on what you can do, everything from science rovers to resource discovery and utilization mission to surface habitats is made possible.

Blue Moon is scalable, repeatable, and based on proven technologies. Optimized to fly on NASA's Space Launch System, Blue Moon also scales to fly on many different launch vehicles. Just pick the launch vehicle and go. Smaller payloads, such as NASA's Resource Prospector, can use an Atlas V rocket, while larger payloads can use Blue Origin's New Glenn launch vehicle or NASA's SLS.

Blue Origin's proven technology provides a fast path to a U.S. lunar landing capability for medium to large payloads. Blue Origin's BE–3 is the first new liquid hydrogen-fueled rocket engine to be developed for production in over a decade. It has been proven

during five launches and landings of our New Shepard vertical landing booster. The BE–3's efficiency, deep throttling and relight capabilities all translate into more useful payload mass landed on the Moon.

Precision landing is also key, and Blue Origin has demonstrated this capability with the same New Shepard vehicle five times in less than a year. Both technologies reduce development time and risk.

Blue Origin has made and continues to make significant investments in the foundational technologies needed for Blue Moon. As part of a public-private partnership with NASA, we are willing to invest further in developing this capability. We invite NASA to partner with Blue Origin using innovative contracting mechanisms that require private sector investment and cost-sharing. NASA's Commercial Cargo and NextSTEP programs represent successful models that require partners to bring money and technologies toward achieving shared goals. These partnerships allow the country to meet big objectives more rapidly, while also promoting economic development and U.S. strategic leadership in space.

A NASA Reauthorization Act should include provisions that prioritize landing on the lunar surface in the near term. It should establish a regular cadence of cargo missions and include a strategy for the Moon as a stepping-stone for expanding human exploration in our solar system.

We are on the verge of a new space age, one defined by multiple international competitors focused on getting to the lunar surface. This Congress has the opportunity to ensure America's continued leadership in space. The Moon should be the near-term focus of human spaceflight beyond LEO as a necessary step toward exploration of the solar system, and Blue Origin is willing to significantly invest in partnership with NASA to accelerate America's return to the Moon.

Thank you, and I look forward to your questions.

[The prepared statement of Mr. Alexander follows:]

Testimony of Bretton Alexander
Director, Business Development & Strategy
Blue Origin
Before the House Subcommittee on Space
Hearing on Private Sector Lunar Exploration
September 7, 2017

Chairman Babin, Ranking Member Bera, and members of the Subcommittee, thank you for the opportunity to speak before you today about private sector lunar exploration – a topic that we're very excited about at Blue Origin.

Jeff Bezos founded Blue Origin to bring about a future where millions of people are living and working in space. Our team of over eleven hundred people across the nation works tirelessly each and every day to enable this future. We believe that the backbone of this vision is to achieve full operational reusability with our launch vehicles, which will lower the cost of access to space at higher flight rates and higher levels of safety and reliability. We will get there through practice, and we've recently made great progress flying our fully reusable *New Shepard* vehicle to space and back five times in less than 12 months. We are now developing *New Glenn*, our next-generation reusable rocket that will launch people and payloads to low Earth orbit and beyond.

We are committed to building the next generation of space transportation infrastructure, providing reliable, affordable, and frequent rides to space for everything from people and satellites to deep space exploration.

We recently entered into agreements with our first two commercial satellite launch customers for our *New Glenn* vehicle. We are ready to help end the nation's reliance on Russian engines for national security launches with our BE-4 engine. We are prepared to bring private capital to partner with NASA for a return to the lunar surface.

Why the Moon

It's time for America to return to the Moon – this time to stay. Enabling NASA and U.S. commercial activities on the Moon is a key step on the path to long-term exploration of the solar system. Imagine driving from D.C. to Los Angeles with no rest stop. You'd have to carry all of your fuel, food, and other necessities with you, which would make for a logistically-challenging trip. The same idea can be applied to space travel. Reaching destinations beyond low Earth orbit takes days, months, or even years, limiting human exploration due to the resource and logistics challenges necessary to sustain life. Fortunately, the Moon provides the resources and proximity to enable human exploration of deep space destinations like Mars, making it the ideal proving ground and rest stop for future exploration.

For example, the lunar South Pole's Shackleton Crater contains ice for fuel and logistics support, mineral compounds for developing structures, and near-continuous sunlight for power generation. Shackleton Crater, and other locations like it, offer a realistic proving ground for testing of critical deep space exploration technologies in close proximity to Earth.

All of this potential has not gone unnoticed. Multiple international commercial entities and nations have plans for an ambitious decade of lunar exploration. The United States should be the leader in this worthy endeavor.

Blue Moon

When you can cost effectively and precisely soft land large amounts of cargo on the Moon, there are few limits on what you can do. Cutting-edge science rovers, resource discovery and utilization missions, logistics support, and surface habitats are all made possible. The *Blue Moon* lunar lander can cost-effectively deliver over 10,000 pounds of useful payload to the lunar surface. *Blue Moon* is scalable, repeatable and based on proven technologies.

Scalable Payload Delivery

Blue Moon is optimized to fly on NASA's Space Launch System (SLS), providing the maximum payload to the lunar surface, but can also fly on many different launch vehicles, including Blue Origin's own *New Glenn.* The amount of cargo that can be delivered to the lunar surface depends on the launch vehicle, providing a flexible, scalable approach depending on the specific payload. For example, launch of a smaller payload, such as NASA's Resource Prospector, can use an Atlas V rocket, while much larger payloads can be launched on SLS.

Using SLS, *Blue Moon* can deliver over ten thousand pounds of cargo to the lunar surface, which equates to the weight of about five Mars Curiosity rovers or two Ford F-150 trucks. Delivering payloads of this size class facilitates many of the lunar exploration, science, and technology demonstration goals outlined in NASA's Planetary Science program, NASA Strategic Knowledge Gaps, and the NASA Strategic Space Technology Investment Plan. *Blue Moon*'s payload capacity can enable high-value missions from resource discovery and power generation to lunar sample return.

Repeatable Missions

Blue Moon is designed to be a repeatable transportation service, providing NASA with a commercial lunar cargo delivery solution. Just pick the launch vehicle and go. There is minimal customization of each lander. This repeatability ensures low cost and reliable access to the lunar surface for NASA as well as non-governmental activities.

With this cadence and substantial payload capacity, *Blue Moon* can conduct increasingly capable missions over time, such as ongoing pre-positioning of the comprehensive infrastructure needed for a human return. These repeatable missions will be the building blocks of a lunar economy and a key step on the path to millions of people living and working in space.

Proven Technologies

Blue Origin's proven technology, developed with private investment and enhanced by NASA's expertise, provides a fast path to a domestic U.S. lunar landing capability for medium to large payload delivery.

Precision landing is critical when transporting valuable payloads to the lunar surface, and Blue Origin has demonstrated this capability. We are developing the *New Shepard* suborbital system to take astronauts into space for tourism and science purposes. *New Shepard* has successfully flown five times in less than a year with the same rocket landing from space at our West Texas launch site. This accomplishment demonstrates the capability of the Blue Origin team to rapidly conduct breakthrough missions and powered precision vertical landings from space.

The *Blue Moon* architecture directly incorporates facets of *New Shepard*, including Vertical Takeoff/Vertical Landing (VTVL) technology and in-house tank development and tooling expertise. This technology, coupled with our extensive liquid propulsion capabilities, reduces development time and risk.

Blue Origin's 110,000-lbf BE-3 is the first new U.S. liquid hydrogen-fueled rocket engine to be developed for production in over a decade. The BE-3 engine has been proven for both launch and landing on the *New Shepard* program. The BE-3U, a 120,000-lbf in-space version of the engine, is an existing engine development program for Blue Origin's *New Glenn* that will be adapted for *Blue Moon*. The BE-3U's high specific impulse, deep throttling, and relight capabilities all translate into more useful payload mass landed on the Moon.

Public-Private Partnership

Blue Origin has made and continues to make significant investments in the foundational technologies needed for *Blue Moon*. As part of a public-private partnership with NASA, we are willing to invest further in developing this capability.

Specifically, NASA could partner with Blue Origin for medium to large lander development and services using innovative contracting mechanisms that require private sector investment and cost-share. Commercial Cargo and Next Space Technologies for Exploration (NextSTEP) represent successful programs that require partners to bring capital and existing technologies towards achieving shared goals with NASA. These mutually beneficial partnerships allow the country to meet ambitious lunar objectives more rapidly, while simultaneously facilitating economic development and U.S. strategic leadership in space.

Legislative Considerations

The U.S. regulatory environment needs to accommodate the new era of commercial activities in space and the technology developments that are on the horizon. As addressed in House Bill H.R. 2809, the American Space Commerce Free Enterprise Act of 2017, there remains a need for regulatory certainty and Congressional clarification on treaty interpretation before U.S. companies begin in-earnest activities on the Moon and other celestial bodies. This committee has an opportunity to steer commercial space activities through legislation authorizing NASA and the FAA Office of Commercial Space Transportation (AST).

As it relates to the Moon, a NASA Authorization Act should include provisions that prioritize landing on the lunar surface within a certain number of years, establish the requirements for a regular cadence of cargo missions, and a strategy that includes how the Moon can serve as a stepping-stone for expanding human exploration in our solar system. NASA partnerships with commercial companies will save taxpayer dollars, while enabling industry to expand the market for space transportation and research opportunities, supporting various missions to the lunar surface in the mid-to-late 2020s.

An updated Commercial Space Launch Act can address ongoing concerns with the FAA payload review process, as well as planetary protection, and non-interference provisions of the Outer Space Treaty. This committee can ensure that commercial space companies are able to pursue missions on the Moon and other on-orbit activities by directing that regulatory and executive agencies – including FAA, NOAA, FCC, NASA, and the State Department – may not attempt to, or in any way, deny access to space on the basis of Articles VI and IX of the Outer Space Treaty. The outlook is bright for commercial activities in space; however, U.S. regulatory

agencies could stifle industry at each step of advancement without clear guidance from the Congress.

There are strategic advantages to near-term U.S. lunar surface activities, as well as national security implications for establishing infrastructure in desirable locations. Despite the Moon's size, there are relatively few sites from which to begin looking for resources, which could lead to non-interference issues among countries. Many nation states and international commercial entities have plans to go to the Moon, including China, Russia, the European Space Agency, and more. The U.S. should not overlook the benefits of arriving on the Moon first, this is the very definition of American leadership in space.

Streamlining Launch Licensing

It is also important to streamline licensing of commercial launches as industry transitions from expendable to reusable rockets. In the case of expendable rockets, FAA and Air Force requirements are nearly identical. When launching from a federal range, a company can create a single set of deliverables for the Air Force and provide the same information to the FAA to satisfy launch license requirements. It is duplicative, but not onerous. In contrast, Air Force and FAA licensing requirements for reusable rockets are completely different from each other, necessitating two entirely different but equally rigorous sets of deliverables. This is duplicative and onerous, and will increase costs, delays, and uncertainty.

Instead, we seek streamlined licensing, irrespective of vehicle type, in alignment with the structure of 14 C.F.R. Part 431, "Launch and Reentry of a Reusable Launch Vehicle". We want FAA as the single point of contact for any commercial spaceflight company interactions with the government with sole authority over launches and reentries, without regard to location or type of launch, consistent with the National Space Transportation Policy. We encourage Congress to ensure that AST is prioritizing its existing, and any new resources, on its current statutory mission.

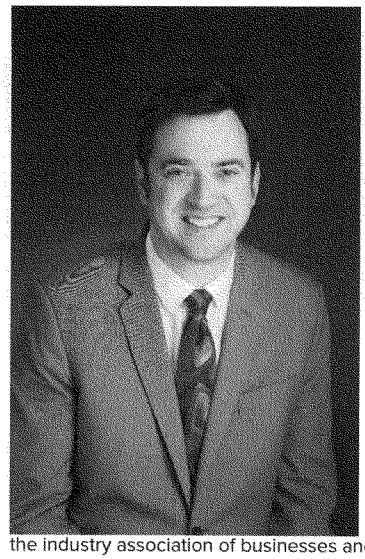
Conclusion

The leadership of the United States during the original space race and those first footsteps on the lunar surface are forever a part of our country's collective conscious. That unifying moment is part of what makes us who we are and inspires our shared desire for exploration even today. We are on the verge of a new space age, one defined by multiple international competitors that have renewed interest in the Moon.

This Congress has the opportunity to ensure America's continued leadership in space, which, in the near term, means leading the development of a lunar economy. Blue Origin's proven technology – developed through private investment and enhanced by NASA's expertise – enables long-term exploration and U.S. leadership in space. *Blue Moon* complements NASA's SLS launch system and is a natural addition to the country's overall exploration architecture. Long-term exploration plans of any kind will require precise delivery of large amounts of cargo and *Blue Moon* can provide that. Any credible first lunar settlement will require that capability.

Together, we can advance America's strategic interests in space. We are extending an offer of partnership that includes significant private investment and proven technology.

BLUE ORIGIN



Bretton (Brett) Alexander is Director of Business Development and Strategy for Blue Origin, LLC, a developer of vehicles and technologies to enable human space transportation. From October 2009 to October 2011, Brett was a member of the NASA Advisory Council (NAC), serving as the chair of the Commercial Space Committee, assessing NASA's partnership with industry to develop commercial crew and cargo capabilities to support the International Space Station and private spaceflight. Brett has served as a member of the FAA's Commercial Space Transportation Advisory Committee (COMSTAC) since 2008.

Brett previously served as a senior policy analyst for space issues in the White House Office of Science and Technology Policy where he served both Presidents Bush and Clinton. While at the White House, he played a central role in development of the Vision for Space Exploration, announced in January 2004.

From December 2006 to May 2011, Brett served as President of the Commercial Spaceflight Federation, the industry association of businesses and organizations working to make commercial human spaceflight a reality. From 2008 to 2011, Brett was also a consultant in the space industry, providing strategy and business development advice to launch service providers and vehicle developers, as well as assessment of international space activities to NASA.

From 2007 to 2008, Brett served as the executive director for Space and the X PRIZE Cup at the X PRIZE Foundation, responsible for overseeing all aspects of the Google Lunar X Prize, the Lunar Lander Challenge, and the X PRIZE Cup. He was also senior advisor to Transformational Space Corporation (t/Space) from 2005 to 2007. Prior to the White House, Brett held positions in the Federal Aviation Administration's Office of Commercial Space Transportation, The Aerospace Corporation, and ANSER Corporation.

Brett holds Master and Bachelor of Science degrees in aerospace engineering from the University of Virginia in Charlottesville, Virginia.

Chairman BABIN. Thank you, Mr. Alexander. I appreciate that.

I now recognize Dr. Sowers for five minutes to present his testimony.

TESTIMONY OF DR. GEORGE SOWERS, PROFESSOR, SPACE RESOURCES, COLORADO SCHOOL OF MINES

Dr. SOWERS. Mr. Chairman and Members of the Committee, thank you for the opportunity to appear today to discuss private sector lunar exploration.

The subject of today's hearing is of great interest to me. It's part of a larger topic, one that is truly revolutionary, that of bringing the resources of space into the economic sphere of humankind.

There have been two major economic revolutions in human history: the Agricultural Revolution of 10,000 years ago, which gave birth to human civilization, and the Industrial Revolution of 300 years ago, which gave rise to the tremendous increase in human well-being and prosperity we enjoy today.

Space resources will be the third major economic revolution and will usher in an era of unprecedented prosperity and flourishing. Furthermore, the development of space resources will enable us to save the Earth as we unchain human progress from the constraints of Earth's ever-diminishing resources.

Compared to Earth, the resources available in space are virtually infinite. Consider the power output of the Sun is 10 trillion times the power consumption of humans. Just one metallic asteroid 500 meters in diameter contains more platinum-group metals than have ever been mined.

Finally, we now know that the solar system contains abundant quantities of water. If you have water, you have hydrogen and oxygen, which are the most efficient chemical propellants known. Water is the oil of space.

We know these resources exist. Bringing them within the economic sphere of humankind requires the machinery of a robust space economy, and that means harnessing the power of the free market. Competition in the free market spurs innovation, leading to efficiency and growth. But the foundation of the free market is the consumer, the ordinary citizen, the taxpayer. The space economy must deliver value to consumers on Earth. Hence, the first place to begin is cislunar space.

The goal then of private sector exploration of the Moon is economic development. Extraction and utilization of lunar resources will be cornerstone of that development. The Moon is rich in resources that will drive the cislunar economy but the resource that would be most valuable in the near term is water processed into propellant. It happens that water is abundant at the lunar poles, billions of metric tons per pole by some estimates. A year ago, while at United Launch Alliance, I became the first person to offer to buy propellant in space. I set up price for propellant bought either at the lunar surface at $500 a kilogram or in high-Earth orbit like the first Earth-Moon Lagrange Point at $1,000 per kilogram. At these prices, the cost of any activity beyond low-Earth orbit becomes dramatically reduced. For example, the cost to deliver mass to the surface of the Moon will be reduced by a factor of three. The cost of a Mars mission will be similarly reduced. So you can see

that the water on the Moon is an immensely valuable resources. Strategically, we should view the poles of the Moon as the next Persian Gulf.

I've described the cislunar economy as a free market but the operation of a free market requires government to establish a framework of rights, enforce contracts, and to provide security. These things are part of the machinery of a robust space economy and are essential to reduce business uncertainty and enable private sector investment.

Beyond the minimal, there's much the government can do to stimulate the creation of the cislunar economy. First is to invest in the basic science to characterize the resources and develop the technologies to exploit them. One approach would be for NASA to establish a space resources institute, partnering with both academia and industry, domestic and international, to solve some of the basic problems common to all.

Second is to participate in the cislunar marketplace. I set a price for propellant based on purely commercial considerations, but having NASA as an additional customer purchasing propellant for, say, a Mars mission would significantly improve the business case and attract more competitors, driving more innovation and lowering costs even further. That's the virtuous circle of the free market.

Finally, NASA could invest through public-private partnerships in, for example, lunar water mining operations. This approach has proven successful with Commercial Crew and Cargo, and works well when the risks are too great for the private sector to take on by itself.

In conclusion, humankind is on the cusp of a third major economic revolution that promises to bring unprecedented prosperity and well-being for all. The first step is the creation of the cislunar economy with important roles for both the private sector and government.

Thank you again for inviting me to testify, and I look forward to your questions.

[The prepared statement of Dr. Sowers follows:]

Testimony of
Dr. George F. Sowers Jr.
Professor, Space Resources
Colorado School of Mines

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

Mr. Chairman and Members of the Subcommittee, thank you for the opportunity to appear today to discuss private sector lunar exploration. My name is George Sowers and I am a Professor of Practice at the Colorado School of Mines in Space Resources. Earlier this year, I retired from United Launch Alliance where I was Chief Scientist and Vice President of Advanced Programs.

Summary

- Space resources will be the third major economic revolution in human history.
  - Frees human progress from the resource constraints of Earth.
- Space resources are nearly infinite.
- Developing space resources will require a robust space economy.
  - Based on Free Market principles.
  - Must deliver value to consumers on Earth.
- Cislunar space, due to proximity with Earth, is the starting point.
- Economic development of the Moon will be critical to creating a robust cislunar economy.
- Propellant derived from water mined on the moon will be one of the first economically viable activities.
- Propellant from the Moon can dramatically reduce the cost of most space activities including missions to Mars.
- Government has several roles to play in developing the cislunar economy
  - Establishing a framework of rights, enforcing contracts and providing security.
  - Investing in basic science and technologies.
  - Participating in the cislunar economy as a customer.
  - Investing in infrastructure through public-private partnerships.

Introduction

The subject of today's hearing is of great interest to me. It is part of a larger topic—one that is truly revolutionary—that of bringing the resources of space into the economic sphere of humankind. There have been two major economic revolutions in human history: the agricultural revolution of 10,000 years ago which gave birth to human civilization and the industrial revolution of 300 years ago which gave rise to the tremendous increase in human well-being and prosperity we enjoy today. Space resources will be the third major economic revolution and will usher in an era of unprecedented prosperity and flourishing. Furthermore, the development of space resources will enable us to save the Earth as we unchain human progress from the constraints of Earth's ever diminishing resources. Table 1 shows the major economic revolution in human history.

Table 1. *Economic revolutions through human history.*

Revolution	Timeframe	Location	Energy Capture	Impact
Evolution of Modern Humans	~100,000 years ago	East Africa	4,000–5,000 kcal/cap/day	Spread throughout world
Agricultural	~10,000 years ago	Levant (hilly flanks)	10,000–30,000 kcal/cap/day	Increased population, empires, crowding, disease
Industrial	~300 years ago	England	50,000–230,000 kcal/cap/day	Manufacturing, mining, transportation, prosperity, pollution, climate change
Space Resources	10–50 years from now	Cislunar space	Hydrogen/oxygen propellants, solar power >>250,000 kcal/cap/day	Universal prosperity, green earth, reduce/eliminate scarcity

Compared to Earth, the resources available in space are virtually infinite. Consider. The power output of the sun is ten trillion times the entire world's power consumption. Just one metallic asteroid, 500 meters in diameter, contains more platinum group metals than have ever been mined. Finally, we now know, in large part through the efforts of NASA, that the inner solar system contains abundant quantities of water. If you have water, you have hydrogen and oxygen, which are the most efficient chemical propellants known. Water is the oil of space.

We know these resources exist. Bringing them within the economic sphere of humankind requires the machinery of a robust space economy. And that means harnessing the power of the free market. Competition in the free market spurs innovation leading to efficiency and growth. But the foundation of the free market is the consumer, the ordinary citizen—the taxpayer. The space economy must deliver value to consumers on Earth. Hence, the first place to begin is cislunar space: the Earth, the Moon and neighboring space to include near Earth objects (NEOs) or asteroids.

The geography of cislunar space determines the types of economic activities that might take place in various locations. The key locations are low Earth orbit (LEO), Geosynchronous orbit (GEO), Earth-Moon Lagrange point number one (EML1), low lunar orbit (LLO), the lunar surface or a near Earth object (NEO) or asteroid. Of critical

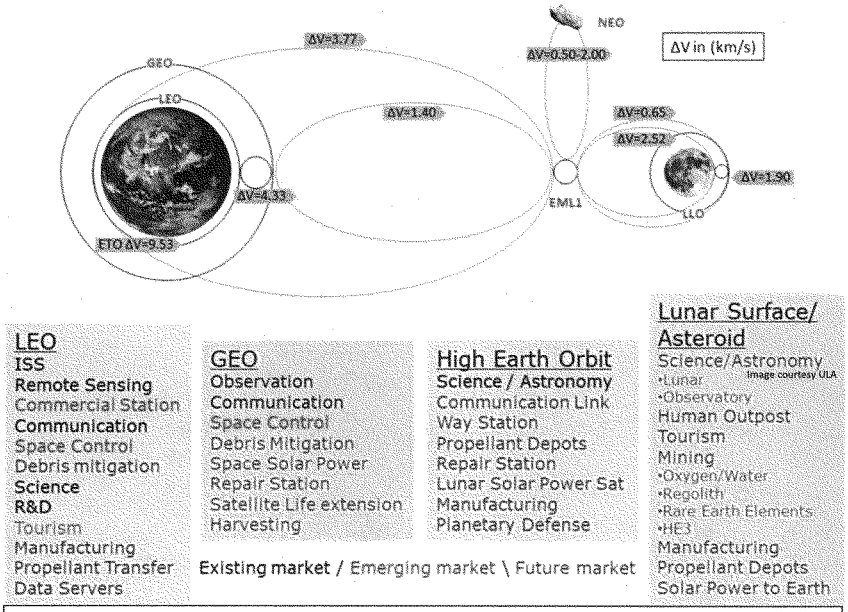


Figure 1. *The geography of cislunar space, the key locations, Delta V between them and potential economic activities.*

importance is the energy required to move from one location to another. A useful proxy for this energy is Delta V, the increment of velocity that must be added to a spacecraft to travel from one location to another. Figure 1 shows the relative locations in cislunar space, the delta V between the locations as well as some of the economic activities that might take place at key locations.

The Resource Potential of the Moon

The goal, then, of private sector exploration of the Moon is economic development. The extraction and utilization of lunar resources will be the cornerstone of that development.

The Moon is rich in resources that will drive the Cislunar Economy. The basic regolith can be used as raw material feeding manufacturing operations. Helium three, implanted by the solar wind, could be mined as fuel for fusion power plants. But the resource that will be most valuable in the near term is water processed into propellant. It happens that water is abundant at the lunar poles, billions of metric tons per pole by some estimates.

One year ago June, while at United Launch Alliance, I became the first person to offer to buy propellant in space. I set a price for propellant bought either on the lunar surface ($500/kg) or in a high Earth orbit like the first Earth-Moon Lagrange point ($1000/kg). It turns out that if you can buy propellant in orbit for less than it costs to ship it there from Earth, the business case can close. At these prices, the cost of any activity beyond low Earth orbit becomes dramatically reduced. For example, the cost to deliver mass to the surface of the Moon will be reduced by a factor of three. The cost of a Mars mission will be similarly reduced. So, you can see that the water on the Moon is an immensely valuable resource. Strategically we should view the poles of the Moon as the next Persian Gulf. Figure 2 shows the cost of propellant at various places within cislunar space.

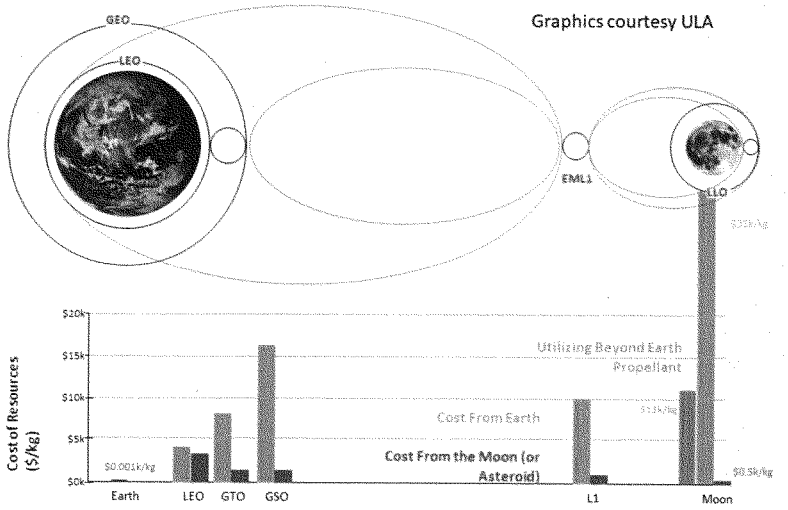


Figure 2. *The cost of propellant if shipped from earth (blue) or sourced in space (green).*

The Role of Government

I've described the Cislunar Economy as a free market and in general, a free market means commercial entities doing business with other commercial entities. But the operation of a free market requires government to establish a framework of rights, enforce contracts and provide security. These things are part of the machinery of a robust space economy and are essential to reduce business uncertainty and enable private sector investment.

Beyond the minimal, there is much the government can do to stimulate the creation of the Cislunar Economy. First is to invest in basic science to characterize the resources and develop the technologies to exploit them. One approach would be for NASA to establish a Space Resources Institute, partnering with both academia and industry, domestic and international, to solve some of the basic problems common to all.

Second is to *participate* in the cislunar marketplace. I set a price for propellant based on purely commercial considerations. But having NASA as an additional customer purchasing propellant for, say, a Mars mission would significantly improve the business case and attract more competitors driving more innovation and lowering costs even further. That is the virtuous circle of the free market.

Finally, NASA could invest through a public-private partnership in, for example, a water mining operation. This approach has proven successful with commercial crew and cargo and works well when the risks are too great for the private sector to take on by itself. Of course, a significant return on investment should accrue to both parties.

NASA has chartered a scientific analysis group to assess lunar exploration priorities. Called the Lunar Exploration Analysis Group (LEAG), this group has retained a Commercial Advisory Board (CAB) of which I am a member. The LEAG CAB conducted a workshop in June and developed several findings which are consistent with my testimony. The one-page summary of the workshop is included as Attachment 1.

Conclusion

In conclusion, humankind is on the cusp of a third major economic revolution that promises to bring unprecedented prosperity and well-being for all. The first step is the creation of the cislunar economy. The private sector is poised to begin. Government participation will only accelerate its realization. I close with a quote from John Marburger, the science advisor to President George W. Bush, from a 2006 address.

> *The Moon has unique significance for all space applications for a reason that to my amazement is hardly ever discussed in popular accounts of space policy. The Moon is the closest source of material that lies far up Earth's gravity well. Anything that can be made from Lunar material at costs comparable to Earth manufacture has an enormous overall cost advantage compared with objects lifted from Earth's surface. The greatest value of the Moon lies neither in science nor in exploration, but in its material.*

Thank you again for inviting me to testify. I look forward to your questions.

Attachments:

1. Back to the Moon Workshop Report

Back to the Moon Workshop Report

21-22 June 2017, Lunar & Planetary Institute, Houston.

Executive Summary

- There are many private sector companies that have aspirations to do things on and around the Moon. We heard from several of them at the meeting. No one has flight proven capability.....yet, but the first commercial expedition has regulatory approval for late this year.
- Many of these capabilities will enable real economic development of cislunar space and real wealth creation.
- We heard universal agreement that the following were the greatest challenges to further progress in commercial lunar missions:
  - not having a permanent regulatory framework for commercial lunar missions,
  - NASA transitioning to a customer.

Finding 1: A permanent regulatory framework for commercial lunar missions is part of a current Congressional discussion, embedded in the American Space Commerce Free Enterprise Act of 2017. The ASCFE framework builds on the 'Mission Approval' that Moon Express received from the USG in 2016. The meeting participants fully support these efforts as part of the ASCFE.

Finding 2: NASA can enable rapid development of the commercial lunar industry by offering to be a customer. The sooner NASA does this, the faster commercial capabilities will be developed. The range of capabilities offered would reflect the breadth of investigations that NASA could offer.

- There is a spectrum of services that NASA SMD and HEOMD could buy. For example, transportation services to lunar orbit, transportation to the lunar surface, rover services on the surface through buying samples or data.
- Commercial companies are already taking on scope and risk and will be able to attract more investments if they can show NASA as a customer. NASA can leverage that willingness, save time and dollars by crafting programs that take advantage of the new capabilities offered by commercial lunar companies.

Finding 3: In addition to paying for payload flights, NASA should strongly consider buying transportation services, samples and/or data. In order for this to succeed, the nature of the samples/data required must be adequately specified.

- The benefit of this approach is all the technical and financial risk is on the company. NASA's risk is that the company fails and the ride, data or samples are not available or obtained.
- NASA can mitigate some of this risk by partnering with the company by investing dollars or resources or expertise i.e., establish a public-private partnership.

Finding 4: NASA should consider public-private partnerships for particularly difficult or risky activities to share the risk, increase mission cadence and the probability of success, and enhance the business case for the commercial partner.

- **CONCLUSION**: There is a lot of enthusiasm for commercial lunar missions and capabilities of the private sector could enable a new era of lunar science and exploration.

Sowers Biography

Dr. George Sowers has 30 years of experience in the space transportation field. During a continuous span working for Martin Marietta, Lockheed Martin and the United Launch Alliance (ULA), Dr. Sowers helped develop over a dozen launch systems, including as the Chief Systems Engineer for Atlas V development. He recently retired from his position as VP and Chief Scientist of ULA where his team developed an architecture for fully reusable in-space stages fueled by propellant mined, refined and distributed in space. In 2016, Sowers became the first person to pubically set a price and business case for propellant delivered to a location in space. Dr. Sowers was the creator of the cislunar1000 vision being promoted by ULA. Dr. Sowers recently joined the faculty at the Colorado School of Mines where he will support the new Space Resources program. He holds a BS in Physics from GA Tech and a PhD in Physics from the University of Colorado. Dr. Sowers is a fellow of the American Institute of Aeronautics and Astronautics (AIAA).

Chairman BABIN. Thank you, Dr. Sowers.

I'd like to thank all the witnesses for your testimony. The Chair now recognizes himself for five minutes for questions.

Mr. Crusan, how could NASA leverage private sector technologies, products and services on future exploration concepts such as the potential deep space gateway or the hypothetical deep space transport? What elements are better suited to partnerships, and what aspects are more appropriate for a government-owned and operated effort?

Mr. CRUSAN. Mr. Chairman, we've been analyzing those exact cases that you've been asking about. We have our Next STEP initiative related to the gateway activities and how we construct and actually build that critical infrastructure, and we're trying to find that proper balance between government objectives and commercial objectives, both in the creation of that fundamental infrastructure but also in the utilization of that infrastructure as well.

Lunar CATALYST now with the potential to buy lunar landed services, are another extension of that instead of building technologies that are only for our own use here at NASA but building technologies that are fundamental to the industry demand that they need as well. So through CATALYST, we've been sharing the vast wealth of knowledge we have at NASA, sharing it with the U.S. industry openly to allow them to make the maximum best use of that. In every one of these endeavors, we have to tread carefully, though, to find that proper balance, and that's why we've been so deliberate about what we've been doing.

Chairman BABIN. Well, then that'll lead into the next thing I'd like to ask you about, the potential pitfalls of leveraging private sector investments in space. Are there any areas about which we should be cautious when it comes to partnerships for lunar exploration?

Mr. CRUSAN. Yes, so in a couple areas of alignment of incentives. So expanding the marketplace is a function of commercial demand and government use as well, so trying to get a proper balance and making sure that the government isn't expecting a higher level of performance that isn't commercially sustainable in the marketplace and getting that balance correct. So buying services at a rate which the industry is going to utilize for non-NASA use as well is one of the strong pitfalls that I would advise.

Chairman BABIN. Okay. And then to Mr. Richards, Thornton and Alexander, I'm pleased to see such a diversity of lunar landing capabilities being developed by your three companies, and it shows how the United States continues to lead the world in developing innovation and affordable solutions. Can each of our industry witnesses briefly explain what makes their lander unique and different from the others and so the Committee can better understand the differences and the capabilities between your services? We'll go with you, Mr. Richards, first.

Mr. RICHARDS. Thank you, Mr. Chairman. So Moon Express's approach has been to establish a family of vehicles that begins small and can grow with partnership with NASA, not presuming a dependency, but looking at the long tail of the market where we can do for lunar access what CubeSats did for access to low-Earth orbit. We believe there's a big market here. So we're starting with a

micro lander that can go in a very low-cost launch vehicle. When we started Moon Express, we were looking at missions that might cost $100 million or more to get to the Moon. With a combination of the current technology and the low-cost vehicles that are coming on the market, we can do initial precursor missions for under $10 million of our cost.

But those can scale up, and our modularity is key. So like rockets and especially being the manufacturer take advantage of modular systems and stages don't get changed over time, our basic propulsion model scales up into larger and larger lander systems that can reach the Moon and deliver materials back.

Chairman BABIN. Thank you. Mr. Thornton?

Mr. THORNTON. Thank you. So we are developing the Peregrine lunar lander. From the get-go, we are market-focused, so we say okay, what's the market out there for payloads, what sizes is necessary, and then we design a lander and the scale that's appropriate for that. So what we have determined is 265 kilograms of capacity serves the majority of the existing market for payload delivery. Our first mission to the Moon flies that commercially viable craft right from the get-go. It's a single-set secondary vehicle that flies on a United Launch Alliance launch vehicle to low-Earth orbit and then we fly the rest of the way to the Moon. Once on the surface of the Moon, we become the local utility so we provide power, we provide communications for payloads that come with us. Some payloads can stay attached to the lander. Some payloads can deploy and drive across the surface and use our WiFi on the surface to talk back to Earth. So the lander itself is designed to be a simple, robust system. It's single stage. There's no separations, very few mechanisms to actually move on the spacecraft, so we're all about simple reliability for robust delivery, and what we have found from our customers is that customers are very sensitive to any changes, substantial changes in spacecraft. The customers around the world tell us that if you change your spacecraft configuration mission to mission that they're going to think of that next launch as a demonstration launch and they want to make sure that it's a proven capability. So that's why we have a single spacecraft designed from the get-go to address the commercial market, and we believe that it's affordable enough to get that first flight demonstrated and to capture a large portion of the international market.

Chairman BABIN. Thank you.

Now we'll go to Mr. Alexander.

Mr. ALEXANDER. Thank you, Mr. Chairman. Blue Moon is designed as a large lander so it is designed to take more than 10,000 pounds to the lunar surface when launched on an SLS, a NASA SLS rocket. So that vehicle, that same spacecraft lunar lander can be flown on a variety of different launch vehicles ranging from 1,000 pounds of payload delivered to the surface all the way up to more than 10,000 pounds. So a single design does the in-space transfer as well as the landing down to the surface and carries with it that large payload capability. So it is designed to enable other missions. It's designed to enable NASA to preposition logistics for future human missions, to provide resource utilization missions, delivery and access to the surface, or to provide landers like

Resource Prospector, a way of actually getting to the surface. It's repeatable, scalable, and based on proven technologies.

Chairman BABIN. Okay. Thank you very much. I appreciate the witnesses.

Now I'd like to recognize the Ranking Member from California, Mr. Bera.

Mr. BERA. Thank you, Mr. Chairman.

So if I think about when I was a kid, probably six or seven years ago, and thinking about what I thought was the coolest Apollo mission when they sent up the lunar rover, the Moon buggy, and you think about how space was done then. It was NASA doing the launch vehicle, NASA doing the landing vehicle, in some ways NASA then doing the research vehicle, the Moon buggy. I want to make sure I'm thinking about this correctly. Let's—and maybe this is a question for Mr. Crusan. Let's say NASA is thinking about something like the Moon buggy or a research vehicle. They can now in this new world of space travel say okay, let's do some competitive bidding, see if Moon Express is the right landing vehicle or, you know, Astrobotic or Blue Moon is the landing vehicle we want to use. They can also then say okay, what launch vehicle do we want to use? Do we want to do an Aerojet Rocketdyne rocket or a Blue Origin rocket or a SpaceX rocket, or ULA rocket? And so we're creating this competitive marketplace where NASA in some ways could be the customer. Am I thinking about that correctly?

Mr. CRUSAN. Absolutely. So the Apollo reference is an interesting one in that during the development of Apollo and many times we were the entire—we were the user of the entire industrial base, and in fact, a lot of the industrial base didn't even exist at the time, and you think about that difference in that we had to pay the entire percentage of all the non-reoccurring costs in order to get a capability into an existence, and we were the only user of that at the end of the day so we also had to sustain it. What you now see are merging space economy activities, both launch vehicles and communication satellites and Earth observation work that's going on now where now we can be a leveraged buyer of those capabilities, especially in low-Earth orbit and geosynchronous-type environments that we have, and then we can then stretch those commercial capabilities to start applying towards exploration initiatives, and it comes down that there's—we have a mixed environment of traditional development with the high-risk, high-reliability needs that we have, and with commercial services and commercial technologies that we can apply into that environment that we need to execute the national mission. So at the same time, then we don't have to sustain the entire industrial base anymore either, and there's a very productive space sector that's growing.

Mr. BERA. And to the folks in the commercial sector, maybe Mr. Richards, Mr. Thornton, Mr. Alexander, are we looking at this—we're creating a competitive economy here where it could be NASA as a customer but it could also be academia or others as a customer. Is that how you're looking at your business model?

Mr. RICHARDS. For Moon Express—thank you—we certainly are. We love the idea of NASA as a customer. They've certainly been a great technology partner. We're building on the shoulders of giants and working shoulder to shoulder with giants, so that's great,

but we're looking at a global marketplace, and bringing the cost accessible to where university endorsements, I mean, we've got kids sending CubeSats into low-Earth orbit. We see the long tail of the market a great leverage for us to begin our lunar business and be able to scale up on the way, and I'm sure my friends will agree with me that competitiveness rocks, and we're very much in favor of it.

Mr. BERA. Same thing—same thoughts for Mr. Thornton and Mr. Alexander?

Mr. THORNTON. Yes, I'd agree with the sentiments. We think of the market for lunar services as global. We've identified 115 payloads worldwide that want to fly to the surface of the Moon, and that's a mix of government, international governments, domestic, small and big. We think of the smaller space agencies as the nonvertical space agencies. They need a little help because they don't have their own spacecraft, they don't have their own launch vehicles. We can enable that. One of our customers is the Mexican space agency, a perfect example how we are enabling their access to the surface of the Moon, and then we also see a mix of commercial interests as well.

Mr. BERA. And same thing with Blue Origin?

Mr. ALEXANDER. Yeah, absolutely. I think there's a large market out there of international, government and commercial activities, but I do also think that NASA should be leading this effort. The United States should be leading the world in returning to the Moon in terms of utilizing the Moon's resources and so there's a large role for NASA to play in that.

Mr. BERA. Great. Excellent.

Dr. Sowers, in your opening testimony you raised some interesting questions. Obviously there's a value of that water on the Moon and that ice on the Moon, and I think, you know, it raises questions. Is this going to be the Wild West? Whoever gets to that water first, do they own that water? I mean, we're talking about another planetary body. So, who owns that water? What country can claim that water, or is it our entire planet Earth? And then I would imagine there's some urgency that this body ought to be thinking about those questions. You know, certainly how do you create the framework that addresses and creates some certainty for folks that are going to go out there and explore, creates that market but then also doesn't stifle innovation. And I'd just be curious as you're thinking through those questions, what things we ought to be thinking about as a body.

Dr. SOWERS. That's a very important question. You know, I view the space economy as a free market but the free market has to have constraints and controls. There also has to be a system of rights. So you raise the question, who owns it. You know, there needs to be the establishment of a framework of, if you will, property rights for space so that if a company invests in, you know, developing a resources that they can return—reap a return on that investment. You know, those are important. Enforcement of contracts, you know, how do we make sure that, you know, if some company buys something from a country, you know, that those contracts can be enforced. Then you have also the issue of physical security. You know, if there's wealth in space, eventually there's

going to be pirates in space, and so kind of have to have a way of ensuring the security of the enterprises that take place out there.

Mr. BERA. Great. Thank you.

Mr. Chairman, it looks like we might have some work ahead of us.

Chairman BABIN. Absolutely. We'll have another Texas oil boom out there but it'll be water this time. Thank you very much.

I now recognize the gentleman from Florida, Mr. Posey, who is trying to get out of here to get his district ready.

Mr. POSEY. Thank you very much, Mr. Chairman.

Chairman BABIN. Yes, sir.

Mr. POSEY. Mr. Richards, Thornton and Alexander, you mentioned that you got help and encouragement from NASA. I wonder in 30 seconds or less each if you can briefly tell me what kind of assistance you got from NASA.

Mr. RICHARDS. We've been partnering with NASA since the beginning with technology development so we've been given access. Sometimes we—most of the time we have to pay for that access but more recently with Lunar CATALYST, based on a mutual exchange, access to technology, test facilities, expertise, software, things that have displaced otherwise capital costs that we would've had to use investment money for.

Mr. POSEY. Okay. Thank you.

Mr. THORNTON. NASA has been a great partner of Astrobotic for a very long time. Most notably, the CATALYST program has been fantastic for us. It's taking NASA's best spacecraft engineers and landing engineers and fusing together with our technology to create a great vehicle. We just had our preliminary design review. We had 20 NASA people in the room including another dozen people on the phone looking over our whole system and helping us out. It's a first time for us so it's great to have the best in the business part of the mission.

Mr. POSEY. Thank you.

Mr. ALEXANDER. Blue Origin does not currently have a partnership with NASA on lunar lander activities. However, we do have a long history of cooperating with NASA on propulsion and other technologies. We've worked very well with NASA, and we appreciate their technical expertise and look forward to a partnership with NASA on the Blue Moon lunar lander.

Mr. POSEY. Okay. Mr. Crusan, I appreciate that NASA is trying to privatize what it can here and keep a long-term, I hope, focus on Mars. We've kind of helped incubate, move along, assist and encourage these companies. Have we made any agreements with them yet? I mean, how are we going to utilize them?

Mr. CRUSAN. Yes. To date, we've done a no-exchange-of-funds Space Act Agreement where we haven't exchanged any funds for that but just providing, as we said, the support services that you heard from the partners here, and what we are now looking at doing is actually buying landed delivery services in the next fiscal year here of actually buying the first ability to land small payloads, and that's in our plans and our budget submit that we did this year.

Mr. POSEY. Okay. And tell me a little bit more about those.

Mr. CRUSAN. Yeah, so we're talking initially about small landed services so small payloads of everything from scientific context to instruments to do single-point measurement related to volatiles to small technology demonstrations. This is a sign of our confidence of—growing confidence in the commercial industry, and managing a risk without getting too large or too costly payloads for us on the first maiden flights. So it's that balanced risk approach of us giving confidence in them but also not risking large endeavors at this point at NASA. So it's that balancing act that we're doing with them as we've done with Commercial Cargo and such when were in the development phases for those.

Mr. POSEY. Okay. Have you signed any contracts yet?

Mr. CRUSAN. No, we've not. The RFI was the first step towards that.

Mr. POSEY. Okay. And when do you anticipate we would be doing contractual agreements?

Mr. CRUSAN. We're preparing for the solicitation as we speak, basically was informed by the Request for Information that was done only a couple months ago.

Mr. POSEY. Okay. That's good.

Thank you, Mr. Chairman. I yield back.

Chairman BABIN. Yes, sir. Thank you.

Now I'd like to recognize the Ranking Member of the full Committee from Texas, the gentlewoman, Ms. Johnson.

Ms. JOHNSON. Thank you very much.

Let me express my appreciation for your interest, motivation and enthusiasm for what you are doing, and hope that it'll inspire the next generation of thinkers for the future.

I want to ask you who you anticipate or do you have any ideas of who your customers will be from the private sector service for vacationing or whatever? How do you anticipate seeking them?

Mr. RICHARDS. So that's—thank you for that question. We already have customers so we've been marketing for a number of years now. An example is, we'll be delivering a lunar telescope for a private customer starting with a precursor, then a large system to the south pole of the Moon in 2019, and this is a nice nexus of science, of commerce, of private investment capabilities with a global scientific foundation, but led by a U.S. entrepreneur. So that's one of the examples of how science and commerce can intertwine. Our maiden mission has a full manifest, and we're marketing into our future missions now.

Ms. JOHNSON. How do you anticipate determining the cost for services?

Mr. THORNTON. So first for us, it starts with the customer. We have customers the world over that are interested in flying, and I think that's a really notable important thing because we started ten years ago, and 7, eight years ago, there were no customers. It was too new. People thought it was a little crazy, frankly, but all good ideas start as crazy ideas and then they become reality. So we have 115 customers interested, everything from space agencies to commercial organizations, even down to universities and people that are just looking to inspire folks. We have a time capsule from Japan that is collecting the dreams of children from Asia, and they

have more than 100,000 kids signed up sending their dreams. So we have all sorts, shapes and sizes of payloads attached.

In terms of the pricing and how to address that, it's about what can cover our costs fundamentally. The majority of our cost is the launch cost, so as the costs of the launch vehicles come down, that will drive our prices down as well. Part of the reason that we build the same spacecraft again and again is we're looking to get that cost efficiency improved even more, but so far our price at $1.2 million per kilogram is accepted by the market and we already have numerous deals at that price point.

Ms. JOHNSON. That sounds good. You know before now, there's been lots of thought of attempting to retrieve or save artifacts from the Moon. Have you considered retrieving any of the artifacts or have you given that any thought?

Mr. THORNTON. So we haven't started looking at retrieving artifacts. We think of what's on the Moon is memorials, permanent memorials, and one day, museums and potentially even national parks to go visit on the service of the Moon. Each one of our missions that landed a man on the Moon and all the precursors that led up to it, that's a really important part of history. So we intend to certainly have a keep-out zone and make sure that we don't land too close to it because it is possible to damage those if you land too close, but we think about it as a memorial for all time, and we think of our early landers the same way. We're essentially sending a snapshot of humanity for our first mission, and it's going to be a sampling of people all over the world. We have six nations flying with us on our first mission and many more that are interested in coming with us. So we're all about making the Moon accessible to the world, and I think those first landings will be monuments to just that.

Ms. JOHNSON. You know, several years ago I was trying to find a vehicle to try to preserve some of the debris and artifacts, and the only place I could find was under the Parks Act. And so when I introduced the resolution, the news had it that I was attempting to establish a park on the Moon. I was a little embarrassed, but young people in high schools were very concerned and very enthusiastic about the possibility of establishing a park on the Moon, which I didn't have in mind at all. But what it reminded me of is how we do stimulate the young mind to think forward. So I encourage you to continue to think forward. Just don't send us the bill. Thank you.

Chairman BABIN. Yes, ma'am. Thank you.

Now I'd like to recognize the gentleman from Florida, Dr. Dunn.

Mr. DUNN. Thank you very much, Mr. Chairman. It's certainly exciting to have such an august panel and talking about a space economy that's genuinely prosperous. That's just so exciting to be in space.

Let's start with a lightning round of questions real quick if I can. What is the number one thing that you think is the most important to the United States as a whole, number one thing, just sort of a lightning round and we'll go right down the panel. We'll start with Mr. Crusan.

Mr. CRUSAN. For me, it's continued human presence in space.

Mr. RICHARDS. And expanding human presence in space with the United States in the lead of it.

Mr. THORNTON. It's making the Moon accessible to the world and U.S. leadership in doing so.

Mr. ALEXANDER. I would agree that it's U.S. leadership in space, and I think the Moon is the right focus for the near term.

Dr. SOWERS. It's creating that space economy and developing the propellant resources on the Moon.

Mr. DUNN. Outstanding. So great answers.

Again, just because we're, you know, the Congress of the United States, Mr. Crusan, how do you think this affects national security?

Mr. CRUSAN. So with space, you have resources. With resources come different demands and different agendas. So I think from a national security point of view, the understanding of fundamental resources that exist in our nearest neighbor is incredibly important for us. It can help influence our human spaceflight architectures for sending humans further out into space. So first order of understanding what is there and what is its value to us as the United States.

Mr. DUNN. Great, great.

Mr. Thornton, you mentioned you had 115 customers? Okay. So what's the difference between your commercial customers and your government customers?

Mr. THORNTON. Sure. Just to clarify, we have 115 payloads in our pipeline, so it's our sales pipeline, but the difference that we have, about half of that is government, big and small around the world. Half of that is commercial. About half of the commercial part is new startups, and then the other half are established organizations. DHL, who is a partner and sponsor of ours, is an example of that commercial side. They see the innovative shipping to the Moon is an extension of their global shipping service and they're happy to be a part of our mission.

On the small size, people are seeing the capability of flying to the surface of the Moon as a means to potentially open their own businesses. We're seeing that with human ashes. We're seeing that—there's groups that are interested in having races on the surface of the Moon, create like a NASCAR experience from the Moon. We've got groups that—we just signed a payload that wants to create a first laser communication node from the surface of the Moon, and that's a huge step because that is two orders of magnitude more bandwidth than we would have otherwise. So radio is about 100, 200 KBPS so it's like a little bit more than a 56K modem, and then a gigabit per second, that's faster than most home internet connections. So you could have virtual reality experiences and HD video and pictures streaming back from the Moon. So it really stands to have a fascinating and immersive experience for people back here on Earth.

Mr. DUNN. Outstanding. Anything to add to that, Mr. Richards or Mr. Alexander?

Mr. RICHARDS. Well, the excitement is genuine about the potential for the markets. We've got our heads down in the hard job right now of actually proving we can land on the Moon, and getting the technology right, it's a very hard thing to do, and only three superpowers have ever done it. So while having great confidence

that these amazing markets are going to open up, we're focused right now on getting it right, and not having all our eggs in one basket. We have purchased several launches. Although we look across the spectrum of emergent and existing launchers agnostically, anybody going our way to Earth orbit, we'd be happy to buy a ride if it's at the right price, but we're after collapsing the cost of access to the Moon and other destinations after Earth orbit.

Mr. ALEXANDER. I would just add that, you know, returning to the Moon is a worthy endeavor. There are a lot of resources there as we talked about to bring into the economic sphere of humanity, and to do that, we need to go back in a fairly big way. So we have designed a lander that can take a lot of those capabilities to the surface of the Moon and eventually support human return to the Moon. It's important to do from a U.S. leadership perspective. It's important to do from an economic perspective but it requires a concerted effort.

Mr. DUNN. We're going to run out of time here. I have more questions than I could possibly ask in half an hour, but let me go back to Mr. Bera's question because I thought that was a great one, and I didn't really hear an answer.

I'm going to ask Dr. Sowers, who owns the water, or who should own the water? You got around that when he asked you last time.

Dr. SOWERS. Yeah, I think the people that discover it and develop it should own it. I mean, that's a "should." You know, I think we need to make sure that we can establish a framework, you know, regulatory or legal framework that makes that the case.

Mr. DUNN. So pirates in space. I love that.

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

Chairman BABIN. Yes, sir. Thank you.

Now we're going to go to the gentleman from Virginia, Mr. Beyer.

Mr. BEYER. Mr. Chairman, thank you, and Mr. Chairman, I'd like to start with an announcement, talking about pirates in space, that we had Andy Weir here, who wrote The Martian, last year, who's a rock star. He was sitting right where Dr. Sowers it. And yesterday they announced his new book, Artemis, which is about a smuggler on the Moon, and it comes out November 14th, so that'll be fun.

First question really is for Mr. Crusan. In Mr. Thornton's testimony, he talks about NASA authorization, Congress and NASA on authorizing Frontier class lander services similar to the Venture class launch services. What's your perspective on that, and how does that fit in with NASA's vision?

Mr. CRUSAN. So it's actually right in line with what we were thinking about doing here now is we're proceeding towards actually buying landed services. That is in essence what he's suggesting. It's just a fundamental of what scale do you go to at what time, and we want to make sure that we're buying services that are kind of on the same scale as industry is growing, so just matching that growth rate and having the government as a customer, not the sole provider or purchaser of services. That's the balance that we've been seeking from the NASA side.

Mr. BEYER. Great. Thank you.

Mr. Crusan, Ranking Member Johnson asked a question about artifacts. As you develop the Lunar CATALYST program, has there

been discussion of the U.S. government artifacts on the Moon and any steps to protect and preserve them?

Mr. CRUSAN. Yeah, in fact, actually, we did develop a standard and published it about interaction effects for any of the Apollo landing sites, and we worked collaboratively with the Google Lunar XPRIZE and actually many of the industry folks that are here at the table, and agreed on those standards and stand backs from those locations, making sure we don't have things like plume interactions of dust settling and covering up footprints, and we publically posted those standards out there, and industry has accepted those as guidance for their future missions that they want to conduct.

Mr. BEYER. Great. Thank you.

Mr. Richards, you've clearly been a visionary in this for a long time. One of the big debates in this Committee, we talked to the previous NASA Administrator and said what's the big picture, what's the constancy of purpose with NASA, and he said very simply, "Mars." So one of the debates here has been, do we go directly to Mars or do we go to the Moon first, and there's a big division obviously within the space community about this. Is this development of the private sector Moon stuff a way to have our cake and eat it too?

Mr. RICHARDS. So it's all of the above. The Moon is not an off ramp to Mars, it's an on ramp to Mars, and by building—you know, to go to space to stay, it has to pay, so by building out infrastructure and capabilities in a cislunar economy, we can assure that a balanced partnership between the government and the private sector will learn how to live off-planet, we'll learn how to use the resources that are out there and that will dramatically lower the cost of going to Mars, and we'll learn a lot about our human condition, things that humans have never experienced being that far from Planet Earth. We can practice those things and learn a lot by practicing at the Moon.

But it's not just the way to get to Mars. It's also a definitive destination of itself. I look forward to the generation of kids that'll look up and see lights on the Moon. You know, there'll be a completely different perspective of humanity as a spacefaring and a multi-world civilization.

And I would like to comment on, you know, a number of questions and who owns the Moon and who owns the water. So the United States Congress—thank you—answered that question for us in 2015. We will talk about that, but what you said was, those who go peacefully under the auspices and with due regard to the international treaties will own what we peacefully obtain, and this is not an appropriation question, but also with Moon Express. Before I could assure our investors that we could blaze a trail to the Moon, I had to blaze a trail through the regulatory framework that would allow us to go there. So Moon Express in 2016, thank you to a number of members in this room, achieved the first ever U.S. authorization for private sector missions beyond Earth orbit and to the Moon under the terms of the Outer Space Treaty.

Mr. BEYER. Great. Thank you very much.

Mr. Alexander, I only have 30 seconds. One of the things you recommended was streamlining the licensing of commercial launches. How do we go about that process?

Mr. ALEXANDER. I think there's a couple of different issues. We have an issue with licensing of commercial launches, which currently the expendable launch vehicle framework that's been used for the last 20 years is sort of duplicated between the Air Force and the FAA, and those of us developing reusable launch vehicles like New Glenn are being licensed under an FAA regime and so there's reusable launch vehicles and so there's a little bit of duplicative work that has to be done with the FAA and the Air Force.

I think separately to Bob Richards' comments there about licensing activities beyond launch and beyond Earth orbit that clarity that he responded or reflected in getting the first license for an activity on the Moon, finding a home for that within the U.S. government is also an important matter.

Mr. BEYER. Thank you, Mr. Chairman.

Chairman BABIN. Yes, sir. Thank you.

And now I'd like to recognize the gentleman from California, Mr. Rohrabacher.

Mr. ROHRABACHER. Thank you very much, Mr. Chairman, and I can't tell you how great it is to be here listening to people talk about a mission that we can accomplish. We sit here listening about people wanting to spend billions and billions of dollars on mission impossible, which is Mars, and I take it that right now we actually have the capability if we actually commit the resources to accomplish the mission to the Moon now. Isn't that correct? Yes or no?

Mr. CRUSAN. Technically no objections.

Mr. RICHARDS. Absolutely the capability, and we would love to partner.

Mr. THORNTON. Absolutely. All systems go.

Mr. ALEXANDER. Yes, absolutely.

Dr. SOWERS. Yes.

Mr. ROHRABACHER. Okay. Now, if we did that same question to people about well, are if we spend the billions of dollars for the Mars mission, are you sure we're going to be able to accomplish this? I don't think we would have anywhere near the same answers that we just got.

And, you know, sometimes it is really difficult to get our country and our government and our bureaucracy even when it's at NASA to sort of focus on what we can do even though we're not doing it now, and I remember that when I first got here, which was a long time ago now in this very same Committee, that we had to force NASA into trying to do its mission around the Moon instead of around the equator of the Moon that we had to convince them maybe doing the orbit would be really important, and we actually had to force them to do it, and I will tell you because there were some visionaries who said there might be ice at the polar areas which we could use then as a very important component of future travel in space but also things we could do with hydrogen, et cetera. Let me note the person who made that argument to me originally is sitting right over there. His name is Jim Muncy, who is one of the real pioneers of—there you go, Jim. You get the credit,

and he should get the credit because he was a visionary and could see the importance of making sure whether there was water there or not, and why always, always go around the equator and not around the polar areas to find out what was going on in the Moon.

So let me just suggest that this is a very exciting potential and, you know, a lot of people—you know, half the world—I don't know if you know this—half the world when they look at the Moon, they see a man on the Moon, but the other half of the world sees what? A rabbit in the Moon. So when you look at the Moon next time, half the world doesn't even seen a man in the Moon. One thing that really worked for us when we were leading the world when it came to the Moon and space projects is what the world looked up and they looked at the Moon and they say there are Americans on the Moon. That impressed the entire world. It's time for us to impress the world again, the young people of the world and their own young people, and the potentials that you've talked about today are very exciting.

Let me ask this. One of the things that I have advocated over the years when it comes to commercial space activities is, we should be encouraging them. Instead of giving them subsidies, we could give them tax breaks, and I have a piece of legislation that suggests commercial activity in space, zero gravity should be zero taxed. Would that type of approach be helpful to any of your operations in terms of making sure that the tax load that you wouldn't have to be carrying the burden of a tax load up to space with you, and just your thoughts on zero gravity, zero tax, right down the line.

Mr. RICHARDS. So quickly, as an interim measure, that certainly sounds attractive. You know, I believe that the first companies—the first trillionaire companies will be created through investments in space resources, so eventually that will be a tax base, but zero G, zero tax is great. You might also think about things like R&D tax credits for companies that typically invest in resource development, and it's that type of money that we're going to have to invest in space.

Mr. ROHRABACHER. But of course, if you think you're going to be successful and you're saying there's not going to be a capital gains tax on someone who invests in your company, that's pretty powerful.

Mr. THORNTON. I'd echo that it's certainly an interesting idea and certainly could help. The space is really hard. It's a very, very challenging environment, and building a business around space is doubly hard. So anything that can support that is certainly something we would support ourselves.

Mr. ROHRABACHER. Okay.

Mr. ALEXANDER. I would echo what both of the gentlemen said, that, you know, revenue-based tax credits are helpful or tax rates, low tax rates, but also the R&D tax credits as well.

Dr. SOWERS. You know, I think all of these guys are going to say that, you know, tax breaks look good to them. I think if we're going to invest, I think, you know, maybe perhaps better leverage in our investment is some of the basic science and R&D. For example, you know, we need the guys with the mules and the picks on the Moon to see, you know, where the real motherlode of the ice is, and in-

vestment in some of those kinds of things which actually, you know, lowers investment risk for commercial operation maybe also something to consider.

Mr. ROHRABACHER. Well, tax breaks as compared to subsidies give greater decision-making to the entrepreneur, and when you were talking about subsidies, which have to be approved from government officials, you have more bureaucratic decision-making, and I would just suggest, Mr. Chairman, that we unleash our entrepreneurs and we will be very pleased with what—our future generations will be very pleased with our accomplishments. Thank you very much.

Chairman BABIN. Yes, sir. Thank you.

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

Mr. PERLMUTTER. Thank you, Dr. Babin.

Thank you all for your testimony today. I want to say to Dr. Sowers, I have my Colorado School of Mines tie on today, and I want to applaud you for leading the space resources department at the college, so thank you very much.

I have two themes I'd like to talk about. One is property rights and the other is Mars. To my friend, Mr. Rohrabacher, we're going to get there by 2033.

So let's start with property rights. Mr. Richards, I'd like to talk to you about that. And I think you're right. I think in 2015, we gave a lot of comfort to entrepreneurs such as yourself and the other companies to get out there, but I would ask you so the section I think you're referring to is 51303, Asteroid Resource and Space Resource Rights, and it says "shall be entitled to any asteroid resource or space resource obtained including to possess, own, transport, use and sell the asteroid resource or space resource obtained in accordance with applicable law including international obligations." So what is the applicable law? I mean, I don't want to be like a judge sitting up here but I think we need to—personally, I think we've got more work to do to provide the framework that Dr. Sowers was talking about.

Mr. RICHARDS. There's a lot more work to do. It's a global conversation, and I applaud the United States for taking the step forward of explicitly saying what I think was implicit in the Outer Space Treaty. There are a number of treaties but the Outer Space Treaty is the predominant one that dictates how humans are going to behave in space and to each other in space.

So saying that, staying away from the question of property rights and that term, although I think we know what it means in this chamber, internationally is incendiary at this point, and in Moon Express's case, none of our investors said hey, make sure you have those property rights down or we can't invest. That wasn't the case. I believe that there will be an ongoing conversation. We don't have to answer all the questions today but the step that was taken was a very forward step that was very much appreciated.

The next step for us of getting the authorization under that law and in due regard to the Outer Space Treaty, even though there wasn't a regulatory framework for us to even apply for a Moon Express mission, we created one out of thin air and with the support of many agencies received a one-time permission to do so. So this is still evolving, and it's—the onus is on private sector individuals

and companies to behave properly and do things responsibly and think about them because it will be a global conversation.

Mr. PERLMUTTER. And I guess my concern, and Mr. Thornton and Mr. Alexander, if you guys want to chime in, is just, Dr. Sowers talked about pirates, but we're talking about mining, we're talking about taking resources, so, is there title? Is somebody jumping somebody else's claim? Exactly how do you see this working? Because I think from our point of view as legislators, we need some help trying to beef this up a little bit so that we don't have jumping claims or piracy or whatever.

Mr. RICHARDS. It would be nice not to be in a reactive mode forever.

Mr. PERLMUTTER. All right. So let me ask Mr. Thornton.

Mr. THORNTON. So in our view, the Commercial Space Launch Competitiveness Act of 2015, currently that's sufficient for where we're at. We don't view that as a barrier for development or investment or partners to even invest or send payloads in the resources realm. So currently, we don't see the strong push for additional change at the moment.

It's also reassuring that the government of Luxembourg recently had a similar thing where they could say that Luxembourg companies could own the rights for resources. So we're starting to see international——

Mr. PERLMUTTER. Activity?

Mr. THORNTON. — activity, and then also agreement with the norms that the United States is creating.

Mr. PERLMUTTER. Mr. Alexander?

Mr. ALEXANDER. I think it's important for the U.S. government through the State Department to be talking internationally with its counterparts, particularly in the U.N. Committee on Peaceful Uses of Outer Space about what the Space Treaty, Outer Space Treaty, allows and how we're interpreting that. It's important for us as an industry to have the certainty that comes with, like you said, with the 2015 law but also that it's founded in the Outer Space Treaty, which basically say that those resources are available to everybody so that when we go, let's say, to the Moon and discover water ice there, we're not saying now we own every piece of resource on the Moon and every bit of water ice on the Moon; we're saying, you know, we are able to utilize what we are able to extract and be able to sell that and have property rights over that but not rights to the entire Moon. So I think it's important from a government perspective that we go out and explain what our interpretation of the treaty is and the framework that we're establishing and lead by example.

Mr. PERLMUTTER. Thank you. If you would indulge me with one more minute of questions?

Chairman BABIN. Can I make one——

Mr. PERLMUTTER. Yes.

Chairman BABIN. —just say one thing? And what you guys are talking about demonstrates the importance of why the House and the Senate need to get this American Space Free Enterprise Act completed. Go ahead.

Mr. PERLMUTTER. So to Dr. Sowers and Mr. Crusan on the Mars theme I'd like to talk about. How do you see us working with the

private sector or international partners and going to the Moon and developing some commercial activities up there? How does that help us in your opinions to get us to Mars? Dr. Sowers?

Dr. SOWERS. Well, I'll just give you one example. If you can develop the water resource on the Moon into propellant, there's studies that have been done, there was a recent one done out of MIT that suggested that you could reduce the cost of a Mars mission by about a factor of three. You know, clearly there's assumptions in there, you know, and you have to assume things about the nature of the resource and the cost to extract it and refine it but with reasonable assumptions, you know, a factor of three seems quite doable. So, you know, the resources on the Moon could be immensely valuable in helping us get to Mars.

Mr. PERLMUTTER. Mr. Crusan?

Mr. CRUSAN. Yeah, these are not mutually exclusive activities. Our human spaceflight plans right now, we're working on concepts of deep space gateway and transport-type architecture that then also working with the commercial industry on landed and surfaces, we can conduct tests of technologies, advancement of understanding of the resources, if the resources are there, is there a means by which to get them from there to a staging point that we can use for deep space transportation in addition to that. So these activities don't need to be mutually exclusive.

Mr. PERLMUTTER. All right. Thank you, and thanks, Mr. Chair. I yield back.

Chairman BABIN. Yes, sir. Thank you.

I want to thank the witnesses for their very valuable and exciting testimony today and your answers, and the Members for the questions that we've asked. The record will remain open for two weeks for additional comments and written questions from Members, because I know I have one that I would like to ask as well, but I want to say this: Thank you for being here.

This meeting is adjourned.

[Whereupon, at 11:32 a.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

"Private Sector Lunar Exploration"

Mr. Jason Crusan, Director, Advanced Exploration Systems, NASA

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

1. In their written statements, Mr. Thornton, Mr. Richards, and Dr. Sowers discuss private sector plans to extract water from the Moon's water ice. The results from previous lunar probes indicate that a significant amount of water ice is likely to bepresent at the lunar poles. The scientific community has placed a priority on investigating the South Pole Aitken Basin of the Moon to investigate the early stages of the Earth-Moon system and to help understand how and when volatiles were delivered to Earth?

    a. What impact would potential private sector resource extractions at the lunar poles have on the science community's research activities at those locations?

    Answer: Located on the Moon's far side southern polar region, the South Pole-Aitken (SPA) basin is the largest and oldest recognized basin on the Moon and is likely to contain some fraction of the mineralogy of the Moon's lower crust. Because of this, scientists are interested in closer study of the basin and mission concepts to return a sample of material from the SPA basin terrain have been proposed in order to provide critical information to understand the history of Earth's Moon. At this time, no such mission has been initiated, however, it is included in the list of potential missions under the current New Frontiers 4 solicitation. It is possible that future lunar commercial transportation capabilities could support analogous science objectives, and NASA will continue to seek opportunities to work with the private sector to enhance and complement our own lunar science and research plans.

    b. How would NASA balance its involvement with the private sector activities and those of the scientific community?

    Answer: NASA is continuing the scientific investigation of the Moon through a variety of spacecraft, including the Lunar Reconnaissance Orbiter, as well as several CubeSats to be launched as secondary payloads on Exploration Mission-1 (Lunar Polar Hydrogen Mapper, Lunar Flashlight, Lunar IceCube, and Lockheed Martin's LunIR mission). At the same time, the Agency is supporting the development of private sector lunar capabilities that can be utilized for both commercial and scientific benefit.

    The National Aeronautics and Space Act of 1958 (as amended) assigns NASA the mission to "seek and encourage, to the maximum extent possible, the fullest commercial use of space". NASA recognizes that private sector activities in space

have the potential to improve access to the Moon and other destinations by both NASA and non-NASA customers. Through initiatives such as Lunar Cargo Transportation and Landing by Soft Touchdown (CATALYST), NASA continues to encourage private ventures to develop both the space capabilities and the associated business plans that could expand the opportunities to send NASA science, exploration, or technology demonstration payloads to the Moon or other destinations in space. To the extent that private investments can help lower the cost of space access and increase the frequency of missions, NASA will seek ways to work with the private sector to enhance and complement our own plans for space science and exploration.

In 2014, NASA introduced Lunar CATALYST. The purpose of the initiative is to encourage the development of U.S. private-sector robotic lunar landers capable of successfully delivering payloads to the lunar surface using U.S. commercial launch capabilities. Commercial robotic lunar lander capabilities could address emerging demand by private customers who wish to conduct activities on the Moon and could also enable new science and exploration missions of interest to the larger scientific and academic communities. These emerging commercial capabilities, in turn, have the potential to make space exploration more affordable and sustainable as NASA expands human presence into deep space.

Future commercial lunar transportation capabilities could support science and exploration objectives such as sample returns, geophysical network deployment, resource utilization, and technology advancements.

In the longer term, commercial development of lunar resources (a stated goal of many nascent commercial lunar companies) requires scientific understanding of the Moon. For example, data about lunar geology, volatiles, and regolith trafficability etc., is knowledge required to benefit commercial interests and is also of interest to the broader scientific communities. Therefore, NASA believes both sectors could benefit.

c. What can be done now to ensure that the Moon is explored for the mutual benefit of the science community and the private sector?

Answer: Please see response to Question #1b, above. NASA's support for the development of commercial lunar capabilities is intended to also benefit the Agency's own science and exploration missions.

2. Does NASA require that partnerships with industry on lunar exploration contribute in some way to advancing NASA's mission? If not, why not? To what extent are the current partnerships between NASA and the private sector primarily serving NASA's objectives and to what extent are they primarily serving private sector interests?

Answer: An important part of NASA's strategy is to partner with the commercial space industry to assist the Agency in achieving its strategic goals and objectives. NASA's collaborative efforts are fostering innovation and a growing commercial space industry,

while transforming capabilities and accelerating technologies needed to achieve national strategic goals.

As noted above, NASA's Lunar CATALYST was designed to encourage the development of U.S. private-sector robotic lunar landers capable of successfully delivering payloads to the lunar surface using U.S. commercial launch capabilities. NASA's collaboration with industry through CATALYST, such as providing technical expertise and access to NASA's testing facilities, is a modest investment that has increased the private sector's rate of progress. Future commercial lunar transportation capabilities could make new science and exploration missions more affordable and viable, such as sample returns, geophysical network deployment, resource utilization, and technology advancements.

Earlier this year, NASA issued a Request for Information (RFI) seeking ideas from industry for the Agency to possibly participate in existing or future commercial missions to the Moon. The Agency is interested in assessing the availability of a commercial launch from Earth to the lunar surface to provide landing services as early as Fiscal Year 2018, and through the next decade. This approach offers the Agency the potential to simultaneously address high-priority science, critical strategic objectives related to exploration, and technology demonstration, using commercially-provided domestic space services and hardware.

3. NASA has experience partnering with the private sector in space activities. Two companies are flying resupply missions to the ISS. NASA is also collaborating with U.S. companies to develop systems for transporting astronauts to the ISS to end our reliance on Russian rockets. How do the goals of the Lunar CATALYST program compare with the goals of the other public-private partnerships NASA has been carrying out, and are there any "lessons learned" that should be applied to the lunar partnerships?

   Answer: The Agency employs several kinds of mechanisms to work with the commercial sector to advance U.S. space capabilities, including – but not limited to – Federal Acquisition Regulation (FAR)-based contracts to fulfill Agency requirements, and partnerships using Space Act Agreements (SAAs), just two one of the mechanisms NASA uses to support and encourage commercial innovation. The Commercial Resupply Service (CRS) contracts, under which Space Exploration Technologies (SpaceX) and Orbital ATK have been providing cargo resupply to the International Space Station (ISS), are examples of the former. NASA's Commercial Orbital Transportation Services (COTS) and NASA's Lunar CATALYST initiatives both represent examples of NASA using Space Act Agreements to provide support to industry partners developing commercial space capabilities that could eventually support both government and commercial users. Both initiatives required industry to focus on the commercial market by keeping "skin in the game." While COTS provided for payments to industry, Lunar CATALYST is a no-funds-exchanged activity and provides only in-kind contributions in the form of NASA expertise and access to NASA facilities. NASA is pleased with the progress being made by our three Lunar CATALYST commercial partners. The particular approaches to be employed in future lunar partnerships – as well as applicable lessons learned from previous partnerships – will be dependent on a variety of factors.

4. The House Appropriations Committee singled out the Lunar CATALYST program in the legislative report accompanying its FY 2018 Appropriations bill. The Committee proposed up to $30 million be provided for Lunar CATALYST activities, including a lunar lander demonstration.

    a. What is the current funding level for the Lunar CATALYST program?

    Answer: NASA's Lunar CATALYST initiative is currently supporting three companies through no-exchange-of-funds Space Act Agreements. NASA is providing engineering expertise, hardware and software, and test facilities to these companies. NASA Advanced Exploration Systems (AES) lander technology activities planned in FY 2018 include $20 million for both Lunar CATALYST Partner and general Lander Support along with beginning the funding required to support commercial landed services.

    b. Based on the plans of some companies and the Google Lunar XPRIZE competition under which participant teams are required to land on the Moon, would lunar lander demonstrations happen anyway regardless of additional NASA investment? Is there any benefit to conducting an additional demonstration in which NASA is involved? If so, what?

    Answer: NASA defers to private sector organizations for details about their business plans and levels of investment in lunar missions. As noted above, the Agency is supporting the development of commercial lunar capabilities through efforts such as Lunar CATALYST. NASA believes such capabilities can benefit both commercial and Government-sector space exploration.

    c. If the provision for a NASA lunar lander demonstration was included, how would NASA ensure that the demonstration provider is competitively selected?

    Answer: NASA's Lunar CATALYST partners were competitively selected. The Agency is considering issuing a solicitation for commercial landed services along with solicitation(s) for small payloads (<10 kg) that could be available for commercial transportation to the Moon as early as FY 2018. Should NASA issue such a lunar cargo transportation solicitation, the provider(s) would be selected on a competitive basis.

5. Under Lunar CATALYST agreements between NASA and the partners, what milestones do partners need to meet and what is the nature of those milestones? To date, have Lunar CATALYST partners met their agreed upon milestones, including financial milestones? If not, which milestones are proving to be the most challenging? What will NASA do if milestones are not met?

    Answer: The Lunar CATALYST partners must achieve technical as well as financial milestones under their no-funds-exchanged Space Act Agreements. The technical milestones include major events, such as completing design reviews, assembly and environmental testing of lander subsystems, and rocket engine tests. The financial

milestones ensure that the companies are developing viable business plans and raising sufficient funds from private investors and payload customers.

- Astrobotic has completed 7 of 20 milestones, including the Preliminary Design Review for their Peregrine lander. Astrobotic has also booked nine payload customers for their first flight.

- Masten Space Systems has completed 14 of 22 milestones, including testing of the main engine for their terrestrial demonstrator vehicle and all of their financial milestones.

- Moon Express has completed 7 of 16 milestones, including detailed design of their MX-1E lander, tethered flight testing, full funding for their first lunar mission, and signing a launch contract with Rocket Lab.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Private Sector Lunar Exploration"

Mr. Jason Crusan, Director, Advanced Exploration Systems, NASA

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

1. A number of companies that aspire to reach the Moon have discussed sending their vehicles and personnel to areas of the lunar surface where artifacts remain from prior U.S. government landings and activities on the Moon, including from the Apollo program. Some of these companies have also expressed interest in bringing back artifacts from prior lunar landings. Do you believe that prior landing sites and artifacts, such as those from the Apollo missions, should be accessible to commercial interests or should the sites be protected for historical and scientific reasons?

   Answer: In 2011, NASA established guidelines to protect lunar historic sites and preserve ongoing and future science on the Moon. NASA recognized that many spacefaring nations and commercial entities were making plans to send spacecraft to the Moon, with some even planning to land near and/or visit historic sites with rovers or hopping spacecraft. The Agency, in consultation with industry, historians, scientists and other stakeholders, assembled the guidelines using, for example, data from previous lunar studies and analysis of the unmanned lander Surveyor 3's samples after Apollo 12 landed nearby in 1969. Experts from the historic, scientific, flight-planning communities as well as representatives from the Google Lunar X-Prize contestants also contributed to the technical recommendations. The guidelines do allow for rovers and hoppers to safely access many sites and provide suggested areas of scientific or technical interest. The guidelines do not represent mandatory U.S. or international requirements, rather NASA provided them to help the lunar mission planners preserve and protect historic lunar artifacts and potential science opportunities for future missions.

   Please see the following link to access the guidelines noted above:

   https://www.nasa.gov/pdf/617743main_NASA-USG_LUNAR_HISTORIC_SITES_RevA-508.pdf

   a. If you believe that the Apollo sites should be accessible to commercial interests what do you envision as being an acceptable level of access?

      Answer: Yes, NASA believes that Apollo and other lunar heritage and scientific sites should be accessible to commercial interests; hence Agency efforts to establish the voluntary guidelines outlined in the response to Question #1, above. In addition, NASA can provide additional guidance to mission planners as needed.

b. If you believe that the Apollo sites should be protected for historical and scientific reasons, how do you think we should best protect those artifacts from being disturbed by future missions to the Moon?

Answer: Please see response to Question #1, above. The guidelines established by NASA do not represent mandatory U.S. or international requirements, they are intended to help lunar mission planners preserve and protect historic lunar artifacts and potential science opportunities for future missions (NASA, as the current primary customer for many of the companies planning lunar exploration missions, does not plan to fund landed missions that would impinge upon or otherwise negatively impact these sites).

Responses by Mr. Bob Richards

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Private Sector Lunar Exploration"

Mr. Bob Richards, Founder and CEO, Moon Express, Inc.

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

1. Is your company capable of carrying out missions to the Moon without a NASA financial contribution, i.e., are you depending on NASA partnerships and/or funding to implement your plans, at least in the near-term? How do you foresee that evolving over time?

   Answer: Our business model does not depend on NASA for financial contributions to development, though we have, of course, benefitted tremendously from the in-kind assistance provided by NASA through the Lunar CATALYST program as described in my testimony. We have the private investment and non-NASA customers necessary to support at least our first mission to the Moon and do not intend to be reliant on NASA for our maiden flight. We also have a primary commercial customer for our second mission to the Lunar South Pole, planned for 2019.

   That being said, having NASA as a customer and partner would be extremely beneficial and enable us to undertake more ambitious missions more quickly. We are not asking for charity, however. By buying services from Moon Express [and other commercial providers], NASA will be able to scout the Moon for scientific and exploration purposes at a fraction of the cost of a traditional mission.

   With leadership from NASA, we can start a virtuous cycle. As NASA procures more commercial services in this fashion, the more affordable such services will become. As prices drop, new players, such as universities and philanthropic organizations, will be able to afford to conduct missions of their own, and that will improve efficiencies and capabilities even further. To us, this is the "long tail of the market" that could be very lucrative as a business, and very beneficial to enabling new generation of lunar and planetary scientists. The next decade could see space science flourish as never before, despite the tight fiscal environment.

2. Last August, Moon Express became the first commercial entity to receive a favorable payload determination from the FAA for a mission to land on the Moon. That is a major milestone for the commercial space industry. Can you describe the process your company went through to get this determination from the FAA?

   Answer: Moon Express proposed to leverage FAA's existing payload review process for the company's maiden lunar mission. In addition to the usual requirements for a payload review, Moon Express offered a series of "voluntary disclosures" to assure FAA and other interested Federal agencies that the mission would not violate the United States' obligations under international law, implicate national security concerns, or interfere with

domestic or foreign activities in space. Moon Express called the proposed ad-hoc framework a "Mission Approval". These disclosures were incorporated into the company's payload review application and were thus considered by the Federal government to be binding enough to satisfy the U.S. government's obligation, under Article VI of the Outer Space Treaty, to "authorize and supervise" American private sector activity in space. This led to Moon Express receiving the first federal authorization for a commercial lunar mission, in 2016.

While we greatly appreciate the work of all of the Federal agencies involved in authorizing our mission, we strongly support this committee's efforts to provide a clearer pathway through which the Federal government can "authorize and supervise" non-traditional space activities that are not obviously covered by the existing regulatory structures.

3. A 2007 National Academies report, "The Scientific Context for the Exploration of the Moon", found that data sets that are needed to facilitate resource utilization on the Moon are the same as those needed for research to understand the geochemistry of the Moon. To what extent, if at all, have you explored the potential for partnering with the scientific community to obtain such data?

   Answer: An important part of the Moon Express business case is to enable low cost scientific investigations of the Moon through commercial robotic spacecraft. NASA is very interested in this model. Moon Express engages regularly with the lunar scientific community to better understand its needs, and we employ a world renowned lunar scientist, Dr. Paul Spudis as our chief scientist through the Lunar & Planetary Institute. We believe that there may be excellent opportunities for commercial companies such as ours to partner with NASA's Science Mission Directorate (SMD), Human Exploration and Operations Mission Directorate (HEOMD) and Space Technology Mission Directorate (STMD) to conduct low-cost lunar missions that can conduct important scientific research, answer questions about lunar resources available for exploration use, and test out exciting new technologies. In November 2016, NASA released a Request for Information seeking information from potential partners to gather data on small payloads that could be delivered to the surface of the moon as early as the 2017-2020 timeframe using emerging U.S. commercial lunar cargo transportation service providers. [https://www.nasa.gov/feature/nasa-seeks-additional-information-on-small-lunar-surface-payloads].

4. The Google Lunar XPRIZE competition was announced almost exactly one decade ago.

   a. How important has the Google Lunar XPRIZE been to spurring private sector interest in lunar exploration over that time period?

      Answer: The Google Lunar XPRIZE played a pivotal role in inspiring entrepreneurs to examine commercial opportunities for lunar exploration. A new generation of commercial companies were founded in part because of the incentive provided by the large prize values at stake.

b. In what ways has the Lunar XPRIZE spurred Moon Express to be where it is today, to be, as you state, "building toward our maiden lunar mission next year."

Answer: The Google Lunar XPRIZE (GLXP) competition has inspirational roots and legacies dating back to heroic efforts in the 1990's at commercial lunar business cases. In turn, the competition has inspired a number of aspects of today's emerging commercial lunar industry. I was proud to be at the launch event of the prize on September 13, 2007, joining in the enthusiasm and optimism of the unveiling of this incredible new challenge. Soon afterwards, I was the first official registrant in the competition with a precursor company to Moon Express.

I applaud XPRIZE and Google for issuing a bold challenge with a big prize attached, and the GLXP is an important element in the landscape. That being said, Moon Express's; business model predates the competition and the company has never been dependent on, or primarily driven by, the opportunity to win the GLXP.

c. Do you anticipate that industry will continue to take on unique and challenging problems in space even after the XPRIZE competition concludes?

Answer: There is no doubt in my mind that the amazing amount of entrepreneurial energy unleashed by that the Google Lunar XPRIZE will continue to take on unique and challenges problems in space even after the competition is over, whether or not any prize is won. The genie will not go back in the bottle. It should also be noted that the GLXP has spurred international competitors to enter the commercial lunar industry, so from the perspective of Moon Express the prize is a double-edged sword.

Thus, leadership from the Federal government, and NASA in particular, is crucial. If NASA continues to build on and expand successful initiatives such Lunar CATALYST, NextSTEP, and the commercial cargo and crew programs, progress will be much more rapid than if the agency turns inward and returns to more traditional ways of doing business.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Private Sector Lunar Exploration"

Mr. Bob Richards, Founder and CEO, Moon Express, Inc.

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

1. A number of companies that aspire to reach the Moon have discussed sending their vehicles and personnel to areas of the lunar surface where artifacts remain from prior U.S. government landings and activities on the Moon, including from the Apollo program. Some of these companies have also expressed interest in bringing back artifacts from prior lunar landings. Do you believe that prior landing sites and artifacts, such as those from the Apollo missions, should be accessible to commercial interests or should the sites be protected for historical and scientific reasons?

    a. If you believe that the Apollo sites should be accessible to commercial interests what do you envision as being an acceptable level of access?

    Answer: The Apollo program inspired me and millions of others of space enthusiasts to reach for the stars. I would never want to jeopardize the historical legacy of my heroes - the brave astronauts who landed on the Moon and the thousands of scientists, engineers, and other ground-based personnel who supported them. At Moon Express, we look forward to working with Congress and NASA to ensure that any proposed activities of ours that could potentially affect lunar heritage sites appropriately balance historical, scientific, educational, and commercial interests. The determination of what is an "acceptable level of access" for such missions will probably be very fact-specific. For example, a mission to collect an artifact or document a landing site for educational or scientific purposes might deserve a higher level of access than one with purely economic motivations.

    In our 'Mission Approval' application, discussed above, we consulted with NASA and provided covenants to respect and not interfere with any U.S. artifacts or heritage sites. The application referenced as our guideline NASA's 2011 white paper on "Recommendations to Space-Faring Entities: How to Protect and Preserve the Historic and Scientific Value of U.S. Government Lunar Artifacts" [https://www.nasa.gov/directorates/heo/library/reports/lunar-artifacts.html].

b. If you believe that the Apollo sites should be protected for historical and scientific reasons, how do you think we should best protect those artifacts from being disturbed by future missions to the Moon?

Answer: As noted above, this will likely be a very mission-specific inquiry. I suspect that a company planning on undertaking a mission in the vicinity of these sites would, at the very least, want to consult with NASA on proper prophylactic measures. I believe that the recent NASA authorization act requested a study from the Executive Branch on this issue and I look forward to reading that study and its recommendations.

Responses by Mr. John Thornton

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Private Sector Lunar Exploration"

Mr. John Thornton, Chief Executive Officer, Astrobotic Technology, Inc.

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

1. Is your company capable of carrying out missions to the Moon without a NASA financial contribution, i.e., are you depending on NASA partnerships and/or funding to implement your plans, at least in the near-term? How do you foresee that evolving over time?

   Answer: Astrobotic is capable of carrying out missions to the Moon without a NASA financial contribution in the form of a payload reservation; however, the schedule risk for Mission One reaching the Moon in 2019 is significantly increased without a commitment from NASA in FY 2018 to purchase payloads. Many of our customers are waiting to see what NASA's payload commitment will be on commercial delivery providers to help calibrate their own commitment decisions. This is especially true for international space agencies that take cues from NASA's leadership. Many will use NASA's purchase of service as a confidence gauge and an evaluation of our service.

   At the same time, it should be noted that lunar delivery is a nascent market with multiple international competitors, many of whom are subsidized by their local governments. Should NASA not move forward now with an imminent payload commitment that helps to complete our manifest, the risk increases that our competitors can capture a significant portion of market share during the time period in which Mission One is delayed, and potentially leave NASA without a U.S. domestic payload delivery service provider that has a substantial market outside of U.S. government customers. Swift action by NASA to purchase payload services will help ensure American market share for lunar delivery, and provide the agency much needed access to the Moon going forward.

   In addition to a NASA payload buy, Astrobotic continues to rely on the expertise and assistance of our partners at NASA through the NASA Lunar CATALYST program and the Advanced Exploration Systems (AES) program. Astrobotic is planning to continue utilizing CATALYST for the next 3-fiscal years based on NASA's current plans to extend the program beyond its current term. Should that change, our ability to complete Mission One would be severely hindered. Following Mission One, Astrobotic intends to no longer rely on CATALYST/AES assistance, and instead would seek to carry NASA payloads to the Moon on a regular basis much like the Launch Services Program at procures launches for NASA payloads. This model was outlined in our testimony as the "Frontier Class Lander Services" program for small robotic landers and rovers to the lunar surface -- similar to the Venture Class Launch Services program for small launch vehicles -- within the NASA Launch Services Program.

2. In your prepared statement, you state that Astrobotic has entered into 11 non-NASA deals as well as a sales pipeline of 115 deals valued at over $1 billion. Have financial commitments been made with respect to the 11 deals? Given the level of customer interest that you have described, to what extent does your business case rely on NASA investments, either in financially contributing to demonstrations or as a regular customer of lunar lander services?

   Answer: Nearly all of our 11-payload deals involve financial commitments, which is a requirement for payloads to sign up for Astrobotic's first mission. The only exception would be a payload called MoonArk, which Astrobotic is carrying as a philanthropic arrangement in-kind. All other payloads on the manifest require significant financial commitment upfront and over time. To be clear, Astrobotic has received significant revenue from commercial and international payload delivery sales to the Moon for years several years. Our service does not rely on NASA investments, however the company does lean heavily on in-kind technical advice and access to agency testing capabilities provided through the NASA Lunar CATALYST Program, which has been a successful public-private partnership that transfers expertise and allows Astrobotic to utilize NASA's world-class facilities for the development of our first mission.

3. A 2007 National Academies report, "The Scientific Context for the Exploration of the Moon", found that data sets that are needed to facilitate resource utilization on the Moon are the same as those needed for research to understand the geochemistry of the Moon. To what extent, if at all, have you explored the potential for partnering with the scientific community to obtain such data?

   Answer: Astrobotic regularly engages in dialogue with the scientific community to help them understand how their instruments and payloads would best integrate with the Peregrine Lunar Lander. Given that Peregrine is a modular delivery vehicle, the lander alone will likely not be adequate for obtaining data that advances lunar science; rather instruments and payloads built and provided by the scientific community and placed on Peregrine will allow them to obtain the data they need.

   Realistically, a funding source and mechanism are still required by the scientific community to get these payloads built and then sent to the Moon on commercial providers like Astrobotic. A payload buy by NASA would ideally involve a call for payload ideas from the science and exploration community, (building on the RFI for Lunar payloads issued by NASA last year) which would allow the scientific community to put forth its best ideas to obtain much needed data sets. NASA would then be in a position to prioritize and fund those payload concepts, and make judgments on which should fly first on commercial providers.

4. In your written testimony you state that "extracting water ice from the Moon will be a technically challenging endeavor that will require substantial research and development, technology demonstrations, and plain hard work and persistence over many years."

a. Do you have a sense of how far along we are in that process today and how much farther we need to be?

Answer: NASA's LRO/LCROSS mission was an important first step in obtaining data on lunar water ice. What is needed now is to ground truth the data with a suface resource-prospecting mission to the lunar poles to obtain precise measurement of the volatiles and carry out the first ISRU experiments of water extraction from the surface of the Moon. Prospecting is a key first step before significant investments can be made toward utilizing resources.

With that in mind, Astrobotic enthusiastically supports NASA's proposed Resource Prospector mission, which would obtain this much-needed first demonstration sometime in the early 2020s. Resource Prospector would answer many important questions, like where the water is located, how much is there, and how difficult is it to extract? With these insights in hand, the private sector can begin to take steps toward making this resource available as a commodity through extraction, harvesting, storage, and transfer of water ice for propellants and life support.

b. When do you believe we will have the technical and operational capability to extract water ice from the Moon?

Answer: The first step is to establish low cost lunar transportation services, which is the intent of Astrobotic's Mission One. Astrobotic's first mission will demonstrate the delivery of payloads to the Moon using Peregrine, and begin a regular cadence of low cost flights to the Moon of about once a year following the first flight in 2019. With the establishment of a regular pipeline of delivery missions in place, and a successful resource prospecting mission, Astrobotic forecasts that an aggressive program to extract and utilize water ice could begin seeing revenue as a business in under 10-years.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Private Sector Lunar Exploration"

Mr. John Thornton, Chief Executive Officer, Astrobotic Technology, Inc.

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

1. A number of companies that aspire to reach the Moon have discussed sending their vehicles and personnel to areas of the lunar surface where artifacts remain from prior U.S. government landings and activities on the Moon, including from the Apollo program. Some of these companies have also expressed interest in bringing back artifacts from prior lunar landings. Do you believe that prior landing sites and artifacts, such as those from the Apollo missions, should be accessible to commercial interests or should the sites be protected for historical and scientific reasons?

   Answer: Astrobotic believes the landing site and artifacts from the Apollo missions should be strictly off limits to commercial entities, and be carefully preserved for future generations. Astrobotic intends to adhere to the guidelines drafted by NASA to protect historic sites on the Moon. We commend you and other members of the committee for your efforts to send a clear signal that these sites should be protected as historical monuments, and not disturbed for commercial or private benefit.

   a. If you believe that the Apollo sites should be accessible to commercial interests what do you envision as being an acceptable level of access?

      Answer: Not applicable.

   b. If you believe that the Apollo sites should be protected for historical and scientific reasons, how do you think we should best protect those artifacts from being disturbed by future missions to the Moon?

      Answer: Astrobotic recommends the U.S. Government lead the formation of any formal regime to protect Apollo sites given that these sites contain hardware that is the property of the U.S. Government. Astrobotic recommends the U.S. Government work closely with international partners on any such potential regimes, given the international nature of space activities at destinations like the Moon.

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