S. HRG. 115–283

REOPENING THE AMERICAN FRONTIER: PROMOTING PARTNERSHIPS BETWEEN COMMERCIAL SPACE AND THE U.S. GOVERNMENT TO ADVANCE EXPLORATION AND SETTLEMENT

HEARING

BEFORE THE

SUBCOMMITTEE ON SPACE, SCIENCE, AND COMPETITIVENESS

OF THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION
UNITED STATES SENATE

ONE HUNDRED FIFTEENTH CONGRESS

FIRST SESSION

JULY 13, 2017

Printed for the use of the Committee on Commerce, Science, and Transportation

Available online: http://www.govinfo.gov

U.S. GOVERNMENT PUBLISHING OFFICE
30–770 PDF WASHINGTON : 2018

SENATE COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION

ONE HUNDRED FIFTEENTH CONGRESS

FIRST SESSION

JOHN THUNE, South Dakota, *Chairman*

ROGER F. WICKER, Mississippi	BILL NELSON, Florida, *Ranking*
ROY BLUNT, Missouri	MARIA CANTWELL, Washington
TED CRUZ, Texas	AMY KLOBUCHAR, Minnesota
DEB FISCHER, Nebraska	RICHARD BLUMENTHAL, Connecticut
JERRY MORAN, Kansas	BRIAN SCHATZ, Hawaii
DAN SULLIVAN, Alaska	EDWARD MARKEY, Massachusetts
DEAN HELLER, Nevada	CORY BOOKER, New Jersey
JAMES INHOFE, Oklahoma	TOM UDALL, New Mexico
MIKE LEE, Utah	GARY PETERS, Michigan
RON JOHNSON, Wisconsin	TAMMY BALDWIN, Wisconsin
SHELLEY MOORE CAPITO, West Virginia	TAMMY DUCKWORTH, Illinois
CORY GARDNER, Colorado	MAGGIE HASSAN, New Hampshire
TODD YOUNG, Indiana	CATHERINE CORTEZ MASTO, Nevada

NICK ROSSI, *Staff Director*
ADRIAN ARNAKIS, *Deputy Staff Director*
JASON VAN BEEK, *General Counsel*
KIM LIPSKY, *Democratic Staff Director*
CHRIS DAY, *Democratic Deputy Staff Director*
RENAE BLACK, *Senior Counsel*

SUBCOMMITTEE ON SPACE, SCIENCE, AND COMPETITIVENESS

TED CRUZ, Texas, *Chairman*	EDWARD MARKEY, Massachusetts, *Ranking*
JERRY MORAN, Kansas	BRIAN SCHATZ, Hawaii
DAN SULLIVAN, Alaska	TOM UDALL, New Mexico
MIKE LEE, Utah	GARY PETERS, Michigan
RON JOHNSON, Wisconsin	TAMMY BALDWIN, Wisconsin
SHELLEY MOORE CAPITO, West Virginia	MAGGIE HASSAN, New Hampshire
CORY GARDNER, Colorado	

CONTENTS

	Page
Hearing held on July 13, 2017	1
Statement of Senator Cruz	1
Statement from The Center for Advancement of Science in Space (CASIS)	2
Statement of Senator Markey	5
Statement of Senator Nelson	6
Statement of Senator Sullivan	53

WITNESSES

Jeffrey Manber, Chief Executive Officer, NanoRacks LLC	9
Prepared statement	10
Tim Ellis, CEO and Co-Founder, Relativity Space, Inc.	15
Prepared statement	16
Tim Hughes, Senior Vice President, Global Business and Government Affairs, Space Exploration Technologies Corp. (SpaceX)	22
Prepared statement	24
Dr. Moriba K. Jah, Associate Professor, Aerospace Engineering and Engineering Mechanics, Cockell School of Engineering, The University of Texas at Austin	31
Prepared statement	32
Robert D. Cabana, Director, John F. Kennedy Space Center, National Aeronautics and Space Administration	40
Prepared statement	41

APPENDIX

Response to written questions submitted by Hon. Dan Sullivan to:	
Jeffrey Manber	59
Tim Ellis	60
Tim Hughes	61
Dr. Moriba K. Jah	62
Robert D. Cabana	64

REOPENING THE AMERICAN FRONTIER: PROMOTING PARTNERSHIPS BETWEEN COMMERCIAL SPACE AND THE U.S. GOVERNMENT TO ADVANCE EXPLORATION AND SETTLEMENT

THURSDAY, JULY 13, 2017

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

The subcommittee met, pursuant to notice, at 9 a.m. in Room SR–253, Russell Senate Office Building, Hon. Ted Cruz, Chairman of the Subcommittee, presiding.

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

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

Senator CRUZ. Good morning, everyone. Welcome to this hearing.

Here's to the crazy ones, the misfits, the rebels, the troublemakers, the round pegs in the square holes, the ones who see things differently. They're not fond of rules, and they have no respect for the status quo. You can quote them, disagree with them, glorify or vilify them. About the only thing you can't do is ignore them because they change things. They push the human race forward, and while some may see them as the crazy ones, we see genius, because the people who are crazy enough to think they can change the world are the ones who do. That quote, of course, was made famous by Apple in the company's 1997 television commercial, "Think Different."

Nearly 3 months ago, this subcommittee began a series of hearings looking at the reopening of the American frontier. These hearings are in a way dedicated to the crazy ones who not only think differently, but who take risks and are looking to push the human race forward by expanding American commerce and settlement throughout the universe.

Our national space program is on the verge of a renaissance. This renaissance is being driven by innovators who don't accept the status quo and who are changing the very nature of space flight. This renaissance is also being driven by public-private partnerships between NASA and commercial space companies.

In the last few years, we have witnessed the test flights and success of reusable rockets, which will lower the cost for Americans to

access space. We've seen the deployment of Cube Satellites from the International Space Station, which are not only helping maximize the utilization of the International Space Station, but are expanding research opportunities for Federal agencies, industry, and even high schools.

As our previous hearings have showcased, we also have seen an interest for American companies who are looking to expand a commercial presence to the surface of the Moon and beyond.

Space exploration is rapidly expanding, and both commercial companies and NASA are complementing one another. A survey by the Department of Commerce found that U.S. companies had $62.9 billion in space-related sales in 2012. While U.S. Government programs provided much of this market, about one-quarter of the sales were within the commercial sector. Public-private partnerships have become the backbone of core NASA programs, such as the Commercial Orbiter Transportation Services, the COTS program, and the Commercial Crew program, which will finally end our dependence on Russia to transport American astronauts to and from the International Space Station.

However, we shouldn't be content to rest on the laurels of recent success. There is still a lot of work left that needs to be completed to ensure continued U.S. competitiveness in space. Congress needs to work to ensure that investment and innovation within the commercial space sector isn't effectively chilled by obsolete regulations or overly burdensome requirements that may not naturally apply to new business models.

We must also continue to challenge NASA and the commercial space community to find new ways to partner to advance our national space policy goals, as Congress will never be able to fully fund every priority within the space community.

And in preparation of an expansion of commercial space activity, we will also need to examine orbital debris and how it impacts exploration and space traffic management.

There are people who are crazy enough to think that they can change the very nature of space exploration, and if they keep pressing forward, they just might.

If there are no objections, I want to enter into the hearing record a statement provided by the Center for the Advancement of Science in Space.

[The information referred to follows:]

STATEMENT OF THE CENTER FOR ADVANCEMENT OF SCIENCE IN SPACE (CASIS)

Public-Private Partnerships in Space: Examples from the ISS National Laboratory Model

Public private partnerships are a key component to driving innovation and national leadership. With the potential to address a wide array of modern challenges from technology development to infrastructure modernization, and from education to the economic development of space, public private partnerships unlock new possibilities unavailable when we rely solely on public or private investment.

The International Space Station (ISS) National laboratory is a great example of a public private partnership model that is working in space. The ISS National Lab opens up the incredible possibilities of the space station research environment to a diverse range of researchers, entrepreneurs and innovators that could create entirely new markets in space.

The International Space Station offers a unique research and development platform, unlike any on Earth, enabling research that benefits both exploration and life

on Earth. In an effort to expand the research opportunities this unparalleled platform provides to the nation, the International Space Station United States Orbital Segment, through bipartisan legislation, was designated as a U.S. National Laboratory in 2005, enabling research and development access to a broad range of commercial, academic and government users. After final assembly of the ISS in 2011, the Center for the Advancement of Science in Space (CASIS), a (501)(c)(3) organization, was selected by NASA to manage the International Space Station United States National Laboratory. CASIS fulfills its mission to accelerate space-based research by engaging a variety of non-traditional space users, operating in the fields of life science, physical science, technology development, and remote sensing. CASIS engages primarily with organizations that pay toward the value obtained on the International Space Station National Laboratory, as well as with other organizations addressing national science and research priorities. This research serves commercial, and entrepreneurial needs and other important goals such as the pursuit of new knowledge or education. Since 2011, CASIS has stewarded more than 200 International Space Station research projects, ranging from developing new drug therapies, to monitoring tropical cyclones, to improving equipment for first-responders, to producing unique fiber-optics materials in space. Working together with NASA, CASIS aims to advance the Nation's leadership in commercial space, pursue groundbreaking science not possible on Earth, and leverage the space station to inspire the next generation.

Prior to the ISS National Lab Model, NASA traditionally funded all aspects of International Space Station research, whether it was research needed to further exploration, or discovery-based space research that expanded upon its scientific agenda. As the International Space Station evolved into a National Laboratory, CASIS has increased the diversity of users by accelerating utilization of the International Space Station National Laboratory as an innovation platform for a wide variety of partners. These include Fortune 500 Organizations, small businesses, educational institutions, philanthropic and research Foundations, Federal and state government agencies, and other thought leaders in pursuit of groundbreaking technology and innovation who are interested in leveraging microgravity to solve complex research problems on Earth. CASIS plays a role in not only attracting a diverse set of users, including private companies, to utilize the International Space Station National Laboratory, but also in engaging the private sector through various research and cost-sharing arrangements.

CASIS has developed a successful sponsored program model that attracts third party funding from private industry and other government agencies to solve big problems or address target challenges. These programs translate into projects on the International Space Station National Laboratory. The sponsored program enables an organization to ask new questions and explore key variables, using the International Space Station National Laboratory environment as a tool in their innovation portfolio. In return, the organization creates opportunities for targeted research and development projects, STEM projects or fosters novel ideas of startup companies. Fortune 500 companies, government agencies and regional incubators have successfully used the International Space Station National Lab sponsored program model. This unique research and development model is flexible to meet the needs and budget of a partnering organization. Successful sponsored programs include Boeing Mass Challenge, Massachusetts Life Sciences Center, National Space Foundation (NSF) fluid dynamics and combustion and NIH's National Center for Advancing Translational Sciences (NCATS) organ on chip technologies that total more than $20 million in third party funding over the last two years. Additional sponsored programs totaling close to $5 million in 2017 with Fortune 500 organizations are imminent and will target major challenges to humankind as well as STEM education initiatives.

Much of the CASIS International Space Station National Laboratory portfolio consists of organizations starting new space commercial activities. Over the last 5 years CASIS has made concerted efforts to educate a wide variety of organizations about the opportunity that the International Space Station National Laboratory represents. Many of these organizations are now using the International Space Station National Laboratory as part of their research and technology development process for the first time. Demand for space projects is being seen in the following areas:

- Better targeting and quick to fail models in *drug development* that can lead to breakthroughs in curing disease and better *drug delivery* systems that can lead to increased access of therapies throughout the world
- *Accelerated Disease Modeling* associated with aging and chronic disease

- *Regenerative Medicine* breakthroughs that can repair, restore or replace damaged tissues and organs due to creating ways to expand and grow cells in a three dimensional environment
- Crop Science breakthroughs that can lead to ways to *feed the growing world population* with less land, water, etc.
- Understanding of fundamental material properties that can lead to *novel materials* and *better manufacturing* processes on earth
- Creation of commercially relevant *microgravity enabled materials* that may transform many U.S. industries including telecommunication *semi-conductor manufacturing*
- 3D-Metal printing and other *additive manufacturing* capacity in space
- Quantum satellite technology that could benefit national security
- Remote sensing capability that can impact a variety of downstream applications including maritime security (jamming, spoofing), weather, agriculture productivity, energy and urban development

As the demand for space research and development projects increases, the supply of access to space, and research and development facilities will need to be augmented. In space private sector commercial research and development facility operators are on the forefront of a new era of space research on the International Space Station and future space platforms. These organizations operate their facilities internally and externally on the International Space Station. They provide users with more choices to address unique research needs and are the pathfinders for a marketplace in low-Earth orbit. Many of these companies have used their own resources to invest in on-orbit research and development facilities, reducing the risk for the Federal sector to develop these facilities and services. In its first five years of International Space Station National Laboratory management, CASIS has supported growth in the number of these research and development facility operators from one in FY12 to five in FY16—with four additional facilities expected to begin in-orbit operations by FY18. CASIS fosters healthy competition between these supply partners by allowing them to bid on each commercial customer projects, seeking the best solution for the customer. The current commercial facility operators are:

- *NanoRacks*—Since 2009, NanoRacks has provided hardware and services for the International Space Station National Laboratory. Three internal research platforms can house plug-and-play NanoLabs and provide critical capabilities such as centrifugation and microscopy. Additionally, the NanoRacks External Platform was launched in FY15 and provides capabilities for Earth and deep space observation, sensor development, and testing for advanced electronics and materials.
- *BioServe*—In-orbit offerings from BioServe include multiple life sciences facilities and kits, including the multi-purpose Space Automated Bioproduct Laboratory (SABL), launched in FY15. SABL supports myriad initiatives for commercial life sciences research as well as physical and material science experiments.
- *TechShot*—Launched in FY15, the TechShot Bone Densitometer is a commercial bone-density scanner for use in spaceflight rodent research. In just one year, the successful operation of this facility has already demonstrated its utility as a catalyst for disease modeling research and commercial biomedical initiatives in space.
- *Made In Space*—In FY16, the Additive Manufacturing Facility developed by Made In Space launched to the International Space Station, enabling 3D printing projects from commercial, educational, and government entities interested in the development of objects for experiments and technology demonstrations. These objects will be produced onboard the International Space Station in a fraction of the time currently required to have such objects manifested and delivered to the station using traditional ground preparation and launch.
- *Space Tango*—TangoLab-1 is a general research platform launched in FY16. This facility from Space Tango allows multiple automated experiments in the life and physical sciences to run simultaneously. This architecture minimizes crewmember interaction and reduces complexity while increasing scalability, enabling improved throughput for users.

In addition to currently available capabilities, a growing pipeline of commercial International Space Station National Laboratory facilities in preparation (from Teledyne Brown, AlphaSpace, STaArS, and HNu Photonics) will advance research in remote sensing, materials testing, molecular biology, and tissue culture. Companies are exploring how these capabilities might transition onto future low-Earth

orbit platforms, from free-flying spacecraft to expandable modules. Through support of such companies, CASIS and NASA is enabling the International Space Station National Laboratory to serve as an incubator for the low-Earth orbit market and U.S. private sector spaceflight interests, and using public private partnership funding models to share the risk and benefits of these emerging human space flight activities.

CASIS is executing congressional intent by leveraging public private partnerships to get the most out of the International Space Station and its national lab. With the active involvement of our partners, CASIS is helping deliver advances of scientific and economic value to the Nation. As our outreach leads more organizations to form public private partnerships to use the national lab, the Nation's return on its investment in the ISS will continue to increase. And as the ISS approaches the end of its planned service life, Congress will have an opportunity to consider the value of maintaining a national laboratory on another platform in space.

Senator CRUZ. I now recognize the Committee's Ranking Member, Senator Ed Markey, for an opening statement.

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

Senator MARKEY. Thank you, Mr. Chairman, very much. And thank you for this distinguished panel of witnesses. I think it's going to be a great hearing.

When President Ulysses S. Grant hammered in the Golden Spike on the Transcontinental Railroad, he was connecting not only the eastern and western United States, but completing a project made possible by a public-private partnership. We were able to complete this historic achievement of connecting the United States by way of rail by connecting government with private industry.

As we now further look toward the stars, we should continue to look to maximize these sorts of collaborative partnerships between government and business, but we need to ensure that these sorts of partnerships continue to benefit both the public and the private partners. So we need to identify the ways in which the public benefits from projects in space, including those projects undertaken by private and commercial entities will participate.

Every day we benefit from the transformational advancements made possible due to space exploration. From GPS to cancer research and everything in between, our activities in space and the knowledge we develop there make life on Earth better. As NASA increasingly turns its gaze further from Earth, we need to ensure that we protect our capabilities to continue to conduct the basic scientific research to conduct in space that has driven so much innovation. The responsibility to continue pursuing science closer to home needs to continue to be mission critical and cannot simply be jettisoned.

The International Space Station orbiting the planet is the successful result of partnerships between 15 countries and five international space agencies, including NASA. The Space Station is an example of international cooperation, but also of successful public-private partnerships, which combine the government's ability to invest in infrastructure and basic research with the private sector's ability to innovate and commercialize.

The National Laboratory located on the International Space Station is managed by the Center for the Advancement of Science in Space, which is tasked with promoting public-private partnerships with the goals of fostering scientific breakthroughs to benefit all of

humankind and delivering a commercial return on the investment that the United States has made.

This collaboration has made it possible for private entities across the United States to take advantage of this incredibly important laboratory.

For example, Visidyne, a company based in Burlington, Massachusetts, has conducted three major projects on the International Space Station National Laboratory, developing algorithms and imagery from the Station that can better predict tropical cyclones and save lives. This work was only made possible due to the public-private partnerships encouraged as a part of the National Lab.

When we pursue these sorts of public-private partnerships in the right way, the public interest will benefit. The Outer Space Treaty states that the use of outer space, quote, should be carried on for the benefit of all peoples. Therefore, we need to make sure that we are continuing to structure our priorities in space to maximize the scientific and other benefits to all people.

We should also ensure that our space policies promote the inclusion of small businesses and protect our ability to conduct scientific and nonprofit activities as well as promoting for-profit activities in the new frontier.

The United States continues to be a pioneer in space activities, and our policies should support the continued innovation that has been the key to America's economic success. While space may be the final frontier, this is not the first time that we have looked to innovate by allowing government and industry to partner together. There may not be a golden spike to symbolically connect Earth to space, but the same successful collaboration between governments and business that fueled the achievements of centuries past can drive the innovation in this century and beyond. I look forward to working with this Subcommittee and stakeholders to ensure American scientists and American companies continue to be leaders in space.

Thank you, Mr. Chairman.

Senator CRUZ. Thank you, Senator Markey.

I would now like to recognize Senator Nelson, the Ranking Member of the Full Committee, if he would care to make an opening statement.

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

Senator NELSON. Thank you, Mr. Chairman.

And good morning. And we have an exciting topic here. We are right on the cusp of a major breakthrough and a reengagement of the American people in America's space program.

Now, we have certainly witnessed the gee-whiz stuff as we see rovers on Mars and as we understand greater information about the depths of the universe through the Hubble. And next year we're going to launch the James Webb, which is going to look back in time almost to the beginning of the universe.

We set upon the manned space program a new course with the NASA bill back in 2010. It set a dual course. It set one course—the commercial operations, as described by my two colleagues—bringing new vitality into the space program with creativity and in-

geniousness, and that obviously is paying off in the gee-whiz stuff that we see. We set off on the other dual track with getting NASA out of low-Earth orbit and exploring the cosmos, deep into the cosmos, and with the goal as set by our President three years ago, followed by this President, to go to Mars, followed by another NASA authorization bill that sets that as its course, Mars with human beings, with American boots on the surface of Mars.

In the course of that, there have been enormous changes. The very launch pads that were created for the Apollo program to take us to the Moon? Those launch pads, under the able leadership of Bob Cabana, have been transformed: one for a commercial operation that can handle all sizes of rockets; the other, reconfigured.

And one of the things that we've got to tend to is to make sure appropriators get us the $600 million requested to—since this new launch vehicle, the monster rocket, the largest rocket ever, called the SLS, with its spacecraft on top, Orion—it's going to grow over time. It's going to evolve. It's going to get up to where it is launching an unbelievable 260,000 pounds. The Space Shuttle cargo bay, for example, would carry about 45,000.

And so that launch tower has to be capable, not for the first of the SLS rockets, which is going to be smaller, but to handle, as it evolves, when we put crew on it in 2021 or 2022. And then we start doing the deep space missions and taking up huge components that in lunar orbit will be assembled, and then we will go off with humans to Mars and return.

That is an exciting future, and it couldn't be done had we not had the leadership of Bob Cabana, who you will hear from today. It couldn't have been done either if we hadn't had finally the U.S. Air Force, NASA, and the FAA all getting in a room and agreeing that we can use all of that unused real estate down there at the Cape Canaveral Air Force Station for a lot of this activity.

And now we're going to be—within a year and a half, 2 years—sending Americans on American rockets again. You will see the American public reengage like you've never seen, once Americans are flying on American rockets again. And that is the excitement of the future. Right now, in what's called the Operations and Checkout Building, named after Neil Armstrong, Bob Cabana took the Vice President of the United States there last week and showed him the spacecraft that is going to go—Orion—on the top of the SLS next—in about a year and a half, 2 years. And so that's why I say we are right on the cusp.

I want to thank General Monteith, the Commander, the two-star, that is the Commander of the Cape Canaveral Air Force Station because we've never seen the cooperation of the Air Force with NASA and the FAA like we are now seeing. And I'm happy to report in last year's—actually, it's this year's defense authorization that you and I have helped Chairman McCain get out, there are provisions that we inserted to improve the launch infrastructure at the range, at the Air Force Eastern Test Range, and to accelerate the Air Force's adaptation to reusable launch vehicles like SpaceX's Falcon 9.

And, Mr. Ellis, I want to add that I want you to know we have a spot for you at what we generically call the Cape for you to launch your rockets. I would love for Relativity Space to become a

part of the community of the folks as this exciting business is being built there.

So thanks to all of you. Thanks to Senator Cruz and Senator Markey for holding this hearing.

Thank you.

Senator CRUZ. Thank you, Senator Nelson.

And I will note when the Vice President was down in Florida, he promptly reached out and touched the display right next to the "Do Not Touch" sign.

[Laughter.]

Senator CRUZ. And then he had the presence of mind and quick wit to blame the junior Senator from Florida for enticing him to do so.

Senator NELSON. And thank goodness I wasn't there, or he would have blamed me.

[Laughter.]

Senator CRUZ. Well, we appreciate this very distinguished panel coming and testifying this morning. We have five witnesses.

The first is Mr. Jeffrey Manber, who has served as the CEO of NanoRacks since 2009, and is the Chairman of the XO Markets Board. He has steered the growth of NanoRacks from a garage space in Webster, Texas, to where NanoRacks is today, a pioneer and leader in the commercial market for low-Earth orbit utilization.

Our second witness is Mr. Tim Ellis, who is Co-Founder and CEO of Relativity, based in Los Angeles, California. Relativity is using 3D printing to build orbital rockets with zero human labor. Prior to Relativity, he worked at Blue Origin as a propulsion development engineer, and was involved in the initial development of Blue Origin's BE–4 rocket engine.

Mr. Tim Hughes is Senior Vice President of Global Business and Government Affairs at SpaceX. Prior to joining SpaceX, Mr. Hughes served as majority counsel to the Committee on Science and Technology in the United States House of Representatives. He was the principal attorney responsible for helping draft and shepherd the passage of groundbreaking commercial human spaceflight legislation, the Commercial Space Launch Amendments Act of 2004.

Dr. Moriba K. Jah is an Assistant Professor of Aerospace Engineering and Engineering Mechanics at the University of Texas at Austin. "Hook 'Em."

Dr. JAH. "Hook 'Em."

Senator CRUZ. Prior to beginning at UT Austin, Dr. Jah was the Director of the University of Arizona's Space Object Behavioral Sciences with applications to space domain awareness, space protection, space traffic monitoring, and space debris research. Preceding that, Dr. Jah was the lead for the Air Force Research Laboratory's Advanced Sciences and Technology Research Institute for Astronautics and a principal investigator for the Detect/Track/ID/Characterize Program at the Air Force Research Laboratory's Space Vehicles Directorate.

And, finally, Mr. Robert Cabana is a former NASA astronaut currently serving as Director of NASA's John F. Kennedy Space Center in Florida. In his current role, Mr. Cabana manages all NASA

facilities and activities at the spaceport, including a team of civil service and contractor employees who operate and support numerous space programs and projects. A veteran of four space flights, Mr. Cabana has logged 38 days in space.

Thank you, gentlemen, for joining us.

Mr. Manber, we'll begin with you.

STATEMENT OF JEFFREY MANBER,
CHIEF EXECUTIVE OFFICER, NANORACKS LLC

Mr. MANBER. Thank you, Chairman Cruz, Ranking Member Markey, and other distinguished members of the Subcommittee. I'm delighted to discuss with you today the challenges we face in developing an American-style marketplace in space.

Since my last visit before this Subcommittee in 2014, my company, NanoRacks, has continued to grow into a commercial space station company. We have taken on dozens of new customers and have brought over 550 research projects to the Space Station, including over 180 satellites, as you mentioned, all with no direct NASA funding.

How is this possible? Through a growing number of public-private partnerships between us and NASA, each one more commercial in nature. Each partnership allows the creativity of the private sector to further utilize the public investments made by you and Congress for the Space Station.

NanoRacks has self-funded over $10 million in hardware to date. Moving forward, we have partnered with Boeing Aerospace and we are co-investing $15 million to manufacture the world's first commercial space station airlock, we call it the Gateway to Space, to further grow our business. These investments will develop the technical expertise and hardware base to own and operate our own space stations, a realistic goal we have set for ourselves as U.S. policy has matured.

But why am I not seeking NASA money up front? Because that's not how the commercial marketplace works. I want to make sure there is no Space Station gap, just as there was with Shuttle and transportation. For a seamless transition, I believe we need the agility of the private sector to be involved. I want to squeeze efficiencies where none existed before, efficiencies in cost, efficiencies in use. This is how you build a customer base, and this is how you expand markets, even in outer space. This is called capitalism.

So how best to work with NASA to realize these efficiencies? Or to put it another way, what is the optimal partnership? The short answer is we don't know that answer yet. But the good news is that our partnerships are getting more and more productive, and the proof is our growing customer base.

In our partnerships, NASA has always been the safety regulator, the launch provider, and station resource provider. NanoRacks is the designer and developer of the hardware, provides the funding, and builds the customer base.

Sometimes NASA is a customer to us at NanoRacks, but there is no guarantee. To my understanding, this is how our partnerships with NASA are unique, no guarantee of NASA use, no preoperational funding. We invest our own capital and pray there's a market.

More recently, we have agreed to pay the space agency for use of Space Station resources via pricing discounts and other tangible advantages to the taxpayer. Our station satellite deployment service is a great example. We, at NanoRacks, were the program originator and the operator. In other words, it was our idea and our capital and our hardware to deploy satellites from the Station. NASA provided the existing Station resources.

The result? Today, we are one of the leading American providers of CubeSat deployment opportunities. We have shown that Space Station has a unique role in satellite deployment, such as our Stash and Deploy program, where we store satellites on the Station for months at a time before timely deployment. You can't do that with a launch vehicle.

However, an even larger success is that we, NASA and NanoRacks, have accelerated the growth of the small satellite market on behalf of customers like Spire, Planet Labs, universities, and other agencies of the U.S. Government now using the Station for satellite deployment. Better use of Station; again, no direct NASA funding.

What's next? We are proud to be part of the NASA NextSTEP program. Specifically, NanoRacks, along with Space Systems Loral, is studying the reuse of upper stages, including that of the ULA Atlas 5, for use as a low-Earth orbit commercial habitat. This pathway is made possible because of the growing maturity of the partnership between NASA and NanoRacks.

Let me add one key point necessary for continued commercial growth, if I may. I respectfully ask that by 2019, we know the end date for Station services, whether it's 2024, whether it's 2028, the date to me is not as critical as the certainty. This will help us attract investment capital.

Additionally, let me compliment this committee's work on the ISS Transition Plan and specifically addressing this issue in the NASA Transition Authorization Act of 2017.

In summation, we have a range of partnerships today, each with greater commitments by NanoRacks. And I applaud the NASA Space Station folks for more and more venturing out of their own comfort zone in forging new relationships with companies like NanoRacks. And I thank Congress and I thank you gentlemen here today for the leadership you've shown on allowing us to go down the commercial pathway.

I know we will continue to be successful because creating new markets and tapping the next frontier is what America does best, whether on the Earth or for the benefit of those of us on Earth.

I look forward to answering your questions. And please accept my written testimony as part of the record. Thank you.

[The prepared statement of Mr. Manber follows:]

PREPARED STATEMENT OF JEFFREY MANBER, CHIEF EXECUTIVE OFFICER, NANORACKS LLC

Chairman Cruz, Ranking Member Markey, and other distinguished members of the Space, Science, and Competitiveness subcommittee, thank you for giving me the opportunity to return to this room to testify before Congress once again. I look forward to discussing with you the challenges we face at my company NanoRacks, and within the larger commercial space industry, in seeking to develop a robust, American-style, service-based economy in space. We seek a marketplace that will realize

multiple commercial space stations, in multiple orbits—within near and deep space, serving both traditional and unique customers from around the world.

Since my visit before this subcommittee in April of 2014, NanoRacks has continued to grow into a commercial space station company via greater utilization of the International Space Station and other platforms. In the past three years we have taken on dozens of new customers, ranging from high schools you represent, to multiple U.S. agencies, other members of the commercial space industry and even foreign governments. To date, NanoRacks has brought over 550 research projects to the Space Station, including approximately 180 satellites, many of which are educational-based experiments representing schools throughout the country. All of this has been done with no direct NASA funding. We are a company that lives on our customers and the revenue generated from our ability to bring payloads and provide services to the Space Station.

How is this all possible? Through a growing number of non-traditional public-private partnerships between my company and NASA. These relationships have grown in time to be more robust, as both organizations learn what works and what doesn't for industry and for government.

As I discussed three years ago before this subcommittee, we at NanoRacks have chosen a business model that is quite normal here on the Earth, but far less common in our space program. Fundamentally, we pay for our own hardware. For example, we have invested $5 million in our External Platform, over $4 million in our satellite deployment program, and close to $1 million in our internal research frames. We are now partnered with Boeing Aerospace and investing $15 million to manufacture the world's first commercial space station airlock. This expenditure of at least $30 million from one company, one small company I would emphasize, has made the International Space Station more robust, asserted American leadership and spurred the growth of new markets.

Why am I not seeking upfront NASA money? Because that's not how the commercial marketplace works. I want to make sure there is no space station gap as there was with shuttle. For a seamless transition, we need the agility of the private sector. I want to squeeze efficiencies where none existed before: efficiencies in cost and efficiencies in use. This is how you build a customer base, and this is how you expand markets—whether on the Earth or in space. This is called capitalism.

For my company, these investments are intended to develop the technical expertise and hardware base to eventually own and operate our own space stations—a realistic goal we've set for ourselves as U.S. policy has matured. Why does this work? Because the growth and development of our public private partnership with NASA allows each of our customers—whether NASA, the European Union, pharmaceutical companies, schools, or industry, to pay fees to use our services—just like any other business here on Earth.

When last here, I ended my talk by stating how we have forged a new, and constantly evolving relationship with NASA. NASA is our landlord, and NASA is our safety official. But every day the agency has become less and less of a competitor. Still true! And today, we work with NASA, not without challenges, but focused on establishing the agency as a facilitator for the private sector building a space economy in low-Earth orbit, and eventually, beyond LEO, that will make all Americans proud.

This is what I would like to briefly talk with you more about today: The changing relationship between NASA, NanoRacks and other members of the industry—and how we together are working to fulfill the wishes of you, in Congress, to inject more commercial practices in the conduct of the American space program. The growing partnership between NASA and NanoRacks adds value to each new program on the space station, and, if utilized to its fullest potential, it can bring about a future in which we can only dream today.

Our Evolving Partnership with NASA

Seven years ago when I first approached NASA, I told the space agency I didn't want their funding. Boy that got their attention. Instead, I wanted the right to put research hardware on the International Space Station and offer services to the public, including NASA, for a fee.

Some at NASA were shocked. How could we charge money for a service onboard the station? Others asked so many questions from their public-sector perspective: Who would set the price? What if there were no customers? What would be the relationship between NASA and the company? Would astronauts work on a commercial service? What services would we offer? How would NASA know if we were successful? By the way, I told them if we were still in business in five years with customers, we would have been successful!

Both sides survived those initial days. And I applaud the Space Station Program Office for more than once leaving their comfort zone to meet our objectives at least half-way. Today, it is more accepted that companies can utilize the space station for commercial gain. That's great. And NanoRacks has competition—some offering very similar services. That's a sign of policy success. Now comes the hard part. What is the optimal partnership and policy between NASA and private companies to assure a robust commercial marketplace in low-Earth orbit? And, at the same time, is their one type of partnership that is optimal or do different commercial programs, customers, and sectors require differing partnerships?

Permit me to illustrate the landscape as we see it at NanoRacks.

For the past seven years, NanoRacks and NASA have worked together in what has become the first public-private partnership that demonstrates a true path to a commercial marketplace in orbit. Our partnership serves two goals:

1. To unleash the power of the private sector in space services;
2. To assure U.S. leadership and new programs including commercial space station platforms during a time of difficult Federal budgets.

In our partnerships, NASA is the safety regulator, launch provider, and station resource provider. NanoRacks is the designer and developer of chosen hardware, the funding source for the hardware, and chief marketer of on-orbit services.

Our relationship works because this program is voluntary. The private sector (NanoRacks) can choose which hardware it wishes to develop and market. Consequently, the government can choose if to utilize the hardware. In plain language, NASA acts sometimes as a customer to NanoRacks to use our services, but there is no guarantee they will. And we should perform the service to be paid by customers. And, in a growing number of cases we "pay" the space agency for use of space station resources via pricing discounts and other tangible advantages.

There is one other implicit understanding: the private sector program can fail—and there may not be customers. NanoRacks assumes this risk.

One of our largest demonstrated successes with this partnership has been the development of our space station satellite deployment program. NanoRacks recognized that American industry wanted to develop sophisticated small satellites, but was stymied by the fact that the only real small satellites launch opportunities were non-domestic. NanoRacks believed the International Space Station could play a pivotal role.

Today, our responsibilities in the public-private partnership have expanded: we are the program originator and program operator related to launching the small satellites of our customers. The government risk remains confined to the safety of the hardware. And we use the NASA-Japanese space agency (JAXA) barter relationship to utilize the Japanese airlock to deploy the satellites, until the NanoRacks Airlock Module, now under development, is on station in 2019.

As such, I believe this is as pure an example that has ever existed of a public-private partnership between NASA and the private sector. Unlike the Commercial Resupply Mission program (CRS), NASA did not institute our program. NASA did not fund our program, and there was no guarantee that NASA would even use our program. Let me add, however, that CRS has proven to be everything we hoped in allowing a company like SpaceX to leverage NASA as a customer, and truly change space transportation today.

But look at what the NASA-NanoRacks partnership has provided: American leadership in a marketplace for small satellite services.

Today, we are one of the leading American providers of small satellite deployment opportunities in low-Earth orbit. Our experiment has been a wonderful success: our satellite customers range from NASA and other government agencies, the European Commission, private companies, startups, universities, high schools—and yes, even elementary schools. Over 180 small satellites have been deployed from the station. Just as importantly, we have shown that space stations can have several unique roles in satellite deployment. To cite just one example, we have customers who store satellites on the space station to deploy on demand, when necessary. That can't be done from a launch vehicle!

So industry (NanoRacks) suggested a commercial space station program (satellite deployments) to NASA. We fully funded the hardware. We made use of NASA resources. NASA is "paid" via defined deployment opportunities. And the U.S. Government has become growing customer as well.

However, an even larger success is that we—NASA and NanoRacks—accelerated the growth of the small satellite market. Without a doubt. Because of our demonstrated success, private capital exists for non-ISS launch services. Companies around the world are able to tap private capital because there is an existing market.

There are (literally!) dozens of companies that offer low-cost, efficient CubeSats and SmallSats.

For example, our customer Spire is changing the way we track ship movements and weather from space through their CubeSat constellation. The leadership at Spire tells me that this is causing NOAA to re-look at public-private partnerships for the availability of commercial weather data.

Clearly, our initiative and willingness to take the risk worked. The market is growing and the number of customers is increasing, but the ISS share of the marketplace is dropping, as it should, in a growing competitive marketplace. This is a public-private partnership at its best, whether on the ground or in low-Earth orbit.

Partnership Stage Two: Commercial Airlock on Space Station

As I previously mentioned, NanoRacks is currently manufacturing the world's first commercial Airlock Module onboard the International Space Station. The NanoRacks Airlock Module, which we call our "Gateway to Space," will be on the station in 2019. We solicited NASA for the right to build and operate the Airlock. We did not seek NASA funding. We saw a market need and are willing to invest our own capital to increase the capacity of the station as a deployment platform for smaller satellites and for moving larger cargo out of the station.

The advantages for the program are many: the NanoRacks Airlock Module will be five times larger in volume than the current airlock owned and operated by our friends at JAXA. It will be commercially operated, efficient, allow NASA capabilities not possible today, and best of all, at the proper time, the hardware can be removed and mated onto our own future commercial platform. NASA is not funding the Airlock Module. Rather, in an exciting and unique partnership with Boeing, our two organizations are privately funding the hardware. Yet we are aware that the Airlock Module is also utilizing valuable NASA resources, and we have voluntarily entered into negotiations with the space agency to forge a partnership that makes smart sense for both parties.

In this regard, NanoRacks is a commercial space market pioneer. Together with NASA we are forging an even larger partnership than that for the satellite deployment program. At the same time, we have made clear to the Space Station Program Office officials that we expect other companies will also enter into such partnerships. And not just for space station use. Use of taxpayer resources for commercial services should either be at no-cost for all, or some sort of barter arrangement for all.

For us, our Airlock Module is a stepping-stone to the goal of working with NASA on commercial habitats in an equitable manner.

From Airlock to Commercial Space Stations beyond ISS

NASA has a unique opportunity, one previously only dreamed about: fostering U.S. leadership in opening the door for commercial space stations in low-Earth orbit and beyond. I have spent the last three decades working to bring about a more commercial space marketplace, including helping set up the first investment fund for commercial space ventures on Wall Street and commercially marketing the Russian space station *Mir*.

My time at NanoRacks has been focused on our long-term goal: owning and operating commercial space stations, all while democratizing access to space. One where NASA is a customer; where the capital is commercial, and the operating system onboard the station is one based on American-style free markets.

There are a number of approaches companies can take as we look to a future beyond the International Space Station. Some of our colleagues in the industry seek to realize the commercial habitats after the ISS by constructing new platforms and stations on the ground, and launching them into orbit. That's one way. And that's the expensive way.

Let's consider another strategy: the re-use of in-space hardware. We have seen recently the value of re-using the first stage of launch vehicles, as shown by both Elon Musk's SpaceX and Jeff Bezos' Blue Origin. At NanoRacks, we are focused on re-using the second stage, not for use in another rocket, but as the shells of commercial habitats. I'm pleased to report that NASA has given us a chance to prove the value of using re-purposed in-space hardware for commercial habitats in low-Earth orbit.

Over fifty years ago, NASA's Marshall Space Flight Director Werner von Braun proposed the idea of re-using the spent upper stage of a rocket and converting it into an orbiting platform. From this concept came America's first space station, Skylab, which was a re-purposed second stage of a Saturn 5—the vehicle that took America to the Moon.

We are "back to the future" now at NanoRacks. We have been awarded funding through the NASA NextSTEP Phase II program for the "Ixion Initiative," a concept

study for re-using in-space hardware and converting upper stages of rockets into commercial habitats in low-Earth orbit and deep space. Specifically, NanoRacks, along with Space Systems Loral (SSL), is studying the re-use of upper stages, including that of United Launch Alliance's (ULA) Atlas 5, for use as a low-Earth commercial habitat.

This pathway is made possible because of the growing maturity of the partnership between NASA and NanoRacks. From NASA's acceptance of our first self-funded research platforms to our satellite deployers to the commercial Airlock, we together have paved a partnership where the gravity pull is mutual: both sides contribute what it does best. In NASA's case, that is resources and hardware already paid for by the taxpayer and available for further utilization. In NanoRacks' case, that is capital and the expertise in attracting and working with customers in a cost-efficient manner.

Let me add, if I may, one key point necessary to make our program a success: The announcement of a firm date for the end of the current mode of ISS operations. I respectfully ask that by 2019 we know the end date for station services. Additionally, let me compliment this committee's work on the ISS Transition Plan and specifically addressing this issue in the NASA Transition Authorization Act of 2017.

No matter the end of operations date, the private sector needs to hear what that date is, rather than keeping it ambiguous—and we seek for this committee to emphasize this with the next NASA Administrator. Also key is to understand the requirements of the U.S. Federal Government as a customer, post-ISS. Keep in mind, this is not only about creating a robust economy in space, but also assuring we do not leave this territory to foreign governments.

The Ixion Initiative team and NanoRacks look forward to being part of this discussion on the proper ISS transition.

However, some key questions still remain: How does NASA determine the merits of a commercially funded program? How much should a company be expected to contribute? How does NASA protect this emerging marketplace from foreign government competition dumping at arbitrary prices or zero cost? And how do we assure America's continued leadership in near space in the event of commercial setbacks?

In short, what is the policy that will enable flexible, optimal, public private partnerships between NASA and industry? We are far closer than three years ago, and I'm confident with your continued leadership we are close enough to imagine commercial habitats and commercial in-space servicing in partnership with NASA. Close enough for us to be confident enough to continue investing private capital.

Conclusion

We are in a new space race, one where to the winner belongs the most robust use of the new frontier by all segments of our society. NASA is ready, industry is ready, and I'm ready, to focus on our return to the Moon and the human exploration of Mars. But I am sure that this can only be done once we have freed up our national resources from low-Earth orbit by creating a sustainable market economy in near space.

Whether we're reaching for Mars, returning humans to the Moon, exploring asteroids, or conducting science and business on commercial platforms, flexible partnerships constitute the direction we should be heading, and the methodology we should be using. The International Space Station has served as a powerful management and policy test bed for how the government and private sector can undertake space exploration together—and that has been proven by seven years (and counting) of customer growth at NanoRacks.

I'm confident we are on the right pathway even though there is no precedent to guide us. There is no proven formula to understand how to make space just another place to do business, one where America will excel. We are venturing into the unknown.

However, we will be successful in this venture because creating new markets and tapping the next frontier is what America does best, whether on the Earth, or for the benefit of those of us on Earth.

Thank you. I will look forward to answering your questions.

Senator CRUZ. Thank you, Mr. Manber.

Mr. Ellis.

STATEMENT OF TIM ELLIS, CEO AND CO-FOUNDER, RELATIVITY SPACE, INC.

Mr. ELLIS. Chairman Cruz, Ranking Member Markey, members of the Committee, thank you for this opportunity to testify.

My name is Tim Ellis. I'm a native of Plano, Texas, and the CEO and Co-Founder of Relativity. We're a stealth-mode startup creating a new launch service for orbital payloads, allowing for enhanced launch certainty at significantly reduced cost. Relativity's rockets are 100 percent designed, built, and flown in the United States. We are based in Los Angeles with current testing operations in Mississippi, and we are looking to expand operations into Florida, Texas, and beyond.

We're a 2016 graduate of the prestigious startup accelerator Y Combinator, whose alumni include Dropbox and Airbnb. We then raised an eight-figure funding round led by top Silicon Valley firm, Social Capital. As an entirely privately funded startup, I believe Relativity offers a unique perspective on building a space business.

The VC funding model is fantastic for creating innovation in a short timeframe, but the reality is that startups often operate on 12- to 24-month do-or-die funding cycles during which we must hit aggressive growth goals or risk not being able to raise more money to survive. This environment creates both challenges and opportunities for time- and capital-intensive efforts, like developing space infrastructure. This reality is what led Relativity to first explore public-private partnerships.

For the past 10 months, Relativity has worked with NASA Stennis Space Center via a Reimbursable Space Act Agreement. We are actively testing our liquid oxygen/liquid methane engines with over six dozen hot fires in the past 6 months of testing. Due to this partnership with NASA, we are able to spend more of our precious time and investment capital on Relativity's other never before seen technology innovations rather than commodity infrastructure buildup for engine testing, and as a result, we're a much more attractive opportunity for investors.

We believe the U.S. Government has an historic opportunity to act as an accelerator for space startups, much like President Eisenhower catalyzed the American automobile industry when he created the interstate highway system.

I think progress would be made by addressing the four following challenges.

First, the current incarnations of the Space Act Agreement and Commercial Space Launch Act Agreement frameworks are not ideal instruments for providing startups access to infrastructure due to their limited applicability and certainty. Relativity proposes a Commercial Space Lease Agreement, a new framework similar to SAA or CSLA, but with standardized provisions for greater access to leasing engine test, rocket stage launch, or satellite development infrastructure at direct cost, much like LC–39A and LC–13 at Kennedy Space Center.

Second, currently there are lack of ideal launch sites in the U.S. for small-class launch vehicles to meet polar, retrograde, and sun synchronous orbits. Consequently, many small satellite customers look to foreign launches from India, Russia, and Europe. The use of an offshore drone ship launch platform operating under an FAA

license could potentially alleviate this problem by allowing for launches in international waters. The concept we envision is more like the reverse of the drone ships and barges SpaceX and Blue Origin pioneered for landing recovered boost stages versus the expensive Sea Launch platform. Creating an open access West Coast launch site similar to Kennedy's 39C could be another alternative.

Third, for our potential customers, issues such as orbital debris reduction and spectrum rights need to be tackled in a way that do not limit the potential revenues of satellite companies or the launchers that fly them. A large addressable market needs to exist to attract private investment on both sides.

Fourth, we also encourage NASA to explore a modulated version of the Venture Class Launch Services program that provides for larger recurring contracts.

In closing, Relativity is but one example of the hundreds of dynamic space startups hard at work in suburban garages and repurposed airplane hangars all across America. I believe we are united by a vision for America that is predicated on pushing the limit of what is possible, both in technology and in spirit. We are all convinced that an incredible future waits for us among the stars and that America will lead it.

Space is the ultimate stage for exploring our humanity. What could be more human or more American than aspiring to do something in the face of the impossible and succeeding?

I thank our team at Relativity for embarking on this journey. And, Chairman Cruz, Ranking Member Markey, and members of the Committee, thank you.

[The prepared statement of Mr. Ellis follows:]

PREPARED STATEMENT OF TIM ELLIS, CEO AND CO-FOUNDER, RELATIVITY SPACE, INC.

Chairman Cruz, Ranking Member Markey, Members of the Committee—thank you for the opportunity to testify here today, and for your leadership in guiding America's ambitions in space. I firmly believe that this Committee's work in the weeks and months ahead has the potential to inspire and empower the next generation of space entrepreneurs.

Relativity is a stealth-mode startup reimagining the way orbital rockets are built and flown. We are creating a new launch service for orbital payloads enabled by never-seen-before technologies, allowing for a high degree of launch schedule certainty at significantly reduced cost. The ability to get back and forth from space inexpensively and on a reliable launch schedule will unleash not only economic opportunities on Earth and beyond, but also push forward humankind's desire to explore the heavens we have gazed at in wonder for thousands of years. At the moment, however, there is a paucity of affordable launch options capable of addressing emerging market demands. Satellite and other payload customers increasingly require new models to access space on short lead-times, at lower cost, with high frequency, and with scalable services. From India to China and Russia to Europe, other countries are racing to address these market needs, and at Relativity, we intend to help preserve and expand U.S. dominance in commercial space.

When Dwight D. Eisenhower created the interstate highway system he helped to catalyze the American automobile industry. I believe that this Committee finds itself at a moment of similar opportunity. Smart and aggressive updates to our national space infrastructure and regulatory framework have the potential to unleash a new generation of American ingenuity in space. Public-private partnerships will be critical to continuing this tradition of bold innovation. Partnerships build upon the enabling foundations NASA and other U.S. Government agencies have created for private companies. They act as accelerators that open doors of opportunity which might otherwise remain closed.

Today, due to a confluence of private investment, emerging markets, the continued strong support of the United States Government, and the maturation of revolu-

tionary new technologies, commercial space is on the cusp of changing forever. My testimony will reflect our company's unique perspective from the intersection of these exciting trends. I am hopeful that our conversation here today will help us develop a deeper understanding of the challenges facing the next generation of commercial space companies and the ways in which new legislation could address these challenges.

Company Introduction

I co-founded Relativity in December 2015 with Jordan Noone. We are alumni of Blue Origin and SpaceX, where we were both propulsion development engineers and worked on programs such as BE–4, New Glenn, Crew Dragon, and Cargo Dragon.

I proudly spent my first eighteen years as a resident of Plano, Texas, with both sides of my family residing among the great aerospace states of Texas, Florida, Colorado, and Alaska for generations. Relativity is based in Los Angeles, California, with testing operations in Mississippi, and we are exploring potential test facility expansion and launch opportunities in Florida, Alaska, Georgia, Texas, California, and Hawaii. As cofounders, Jordan and I originally met seven years ago as students at the University of Southern California in the Rocket Propulsion Laboratory. We led the first student group in the United States to attain FAA clearance to launch a suborbital rocket above the Von Karman line of 100 km, a project that ambitiously involved us designing and building our own rockets from scratch as young students. We were inspired by the long and storied history of the great American innovators who were willing to dream big and boldly claim: Impossible is nothing.

In January 2016, Relativity joined Y Combinator, a Silicon Valley-based startup accelerator that is widely recognized as the most prestigious accelerator in the world and whose notable alumni include Airbnb, Dropbox, Stripe, and others among its combined $80 billion company portfolio valuation. In March 2016, Relativity graduated from the Y Combinator program and shortly afterwards, we raised an eight-figure funding round led by Silicon Valley venture firm Social Capital, with participation by Y Combinator Continuity, Phillip Spector (formerly of Intelsat), the University of Southern California, Stanford University, and other private investors. Still just two cofounders, we expanded to our current Los Angeles facility in July 2016, and worked to scale up a bigger and extraordinarily talented core team.

Relativity has begun testing of our liquid oxygen/liquid methane engine with over six dozen hot fires across multiple test articles at NASA Stennis Space Center, with plans for continued routine testing. Additionally, we are hard at work developing a series of novel, never-seen-before technologies for creating our own orbital launch service and changing the way things get to space. Altogether, we made significant progress in the last ten months and achieved dramatic results that we will begin sharing publicly once out of stealth. We are happy to discuss more details of our progress specifically with government policy makers and regulators to ensure there is early awareness of development plans for Relativity's capabilities, and form public-private partnerships that will help get us there.

The Venture Perspective

Relativity is an entirely privately funded company and, as such, we believe we have a rather unique perspective on building a successful private space business.

As first-time founders, Social Capital, Y Combinator, and our other investors and advisors taught Jordan and me some fundamental lessons about how to run a successful startup. This advice may best be distilled by the proverbial motto: "Make something people want." Relativity was founded on the belief that people crave a fantastic future, a future that pushes the boundaries of what we dream to be possible and then brings those dreams to life. The very idea of America is predicated on pushing the limit of what is possible, both in technology and in spirit. Space is the ultimate stage for exploring our humanity. We are convinced that an incredible future waits for us among the stars, and that America will lead it. We believe this is "something people want."

But to help make this vision a reality Relativity must first build a thriving business and, while Relativity's investors share our conviction and ambition to build an iconic company, they also have very real financial targets that we must reach, together, to be successful. Working alongside some of the top venture capitalists (VC's) in Silicon Valley, we have learned that investors generally focus on the following key criteria when deciding whether or not to fund a company:

- *Potential for Outsized Returns:* small capital investments create large company value increases, normally in a 5–10 year return on investment (ROI) timeframe
- *Large Total Addressable Market:* the target market needs to be $1B+, growing quickly, or emerging and highly disruptive

The VC funding model is fantastic for creating industry-disrupting innovation in a relatively short timeframe, but it comes with some non-intuitive quirks. Venture capital is predicated on the financial model that approximately one-third of companies funded will fail, one-third will simply break even, and one-third will successfully pay for all the others and then some. Often, only a few breakout successes within an investment portfolio constitute a vast majority of the ROI for a venture capital firm. Thus, private investors seek to quickly determine if a bet placed on a company will succeed or fail, primarily focusing their attention on the ones that show the most promise. This dynamic means startups often have only 12–24 months of funding remaining to prove they are worth continued support from the venture community, or left behind in the annals of entrepreneurial endeavor.

It is worth noting that investors have the entire economy's array of industries on which to place their bets—space is but one sector, and effectively must compete for limited investment capital against scalable businesses in the software, consumer product, industrial, biomedical, and a multitude of other sectors as well.

I mention this because in addition to the critical, daily challenge of proving our technological concept, we must also reckon, on a daily basis, with the equally critical challenge of meeting growth metrics sufficient to remain an attractive private investment in repeated 12–24 month do-or-die timeframes.

The Startup Perspective

The above business-building parameters have real and immediate implications for the way in which we think about and approach many aspects of our R&D. For example, as capital is infused in discreet funding rounds spaced approximately 12–24 months apart, we face not only short-term execution timelines, but also must simultaneously focus on achieving long-term goals that may be years into the future, well past our current funding amounts. Interruptions to this timeframe, even on the order of weeks or months, are highly impactful and can cause an increase in business risk.

As a startup in the launch services industry, test infrastructure is paramount to validating our technologies. However, this infrastructure is extremely slow and expensive to procure, develop, and operate. In the context of already enormous initial risks, neither founders nor VC's have much desire to spend the bulk of our precious time and capital toward de-risking what we view to be commodity infrastructure: test sites, launch facilities and ranges, and other commonly required development facilities.

Growing a small business in the environment sketched above has serious ramifications for the way we think about potential partnerships with the government and it will continue to do so at every stage of our company's life cycle, exemplified by the many "Series" of investment rounds a startup goes through and the partnerships that would be of maximum use at each stage:

- *Early Stage—"Series Seed":* Lower barriers to entry through contracts: NASA's Tipping Point, Announcement of Collaborative Opportunity (ACO), Small Business Innovation Research (SBIR) program, DARPA and DoD opportunities
- *Product Development—"Series A":* Test stands, bigger infrastructure, Venture Class Launch Services, DARPA and DoD opportunities
- *Growth—"Series B/C":* Launch pads and infrastructure, launch licenses and regulation, larger government contracts and recurring payload launch procurement
- *Scale—"Series D+":* Certification for flying government payloads, large procurement contracts like Commercial Resupply Services (CRS), Commercial Orbital Transportation Services (COTS), and Commercial Crew Development (CCDev) incentivize early private investments and close the loop on investor ROI as well as bootstrap commercial success

Our key partnership to date has involved working closely with NASA's Stennis Space Center. After a brief description of our engagement with Stennis, the remainder of this testimony examines the ways in which Relativity has approached vital government partnerships. It includes a discussion of specific policy and regulatory fixes we believe could go a long way towards unencumbering the next generation of commercial space companies.

Working With NASA Stennis Space Center

In February 2016, Relativity was contacted by the DoD accelerator MD5 to be one of their pilot companies. MD5 is a public-private partnership between the DoD, NYU, and other top research universities that accelerates startups by helping provide and facilitate access to government infrastructure. As a result, Relativity signed a Reimbursable Space Act Agreement with NASA Stennis Space Center in

mid-2016 for an extensive engine test campaign on an existing test stand. This agreement has allowed Relativity to reimburse NASA for direct costs incurred during the facility buildup, upgrade, and testing of our in-house designed rocket engines.

We are pleased to report we have completed over six dozen hot fire tests to date with routine testing ongoing. We thank NASA Stennis Director Dr. Richard J. Gilbrech, along with David Coote, Gary Taylor, Ray Nichols, and the rest of the Stennis team for their work in helping us achieve these results to date, and look forward to our continued progress in the future.

Relativity chose to partner with NASA and was initially drawn to partnership opportunity with Stennis due to the fact that the testing infrastructure was already built and that its team previously ran several successful testing campaigns. Working with NASA has saved Relativity almost a year toward commencing hot fire testing, enabling us to meet our targets far sooner than if we had to build our own engine stand from scratch and it allows us to develop faster against our current funding timelines. It is also important to note that our public-private partnership with Stennis allowed Relativity to invest in other unique elements of our technology development because we had capital available to deploy for those key initiatives rather than being forced to spend money on building our own engine test stand. Investing in the truly unprecedented side of our technology development, which is a critical element of our planned business model, has the additional benefit of putting us in a better position to receive further private funding.

By partnering with the U.S. Government and using NASA's existing infrastructure, Relativity was able to more quickly test our proprietary new technologies, grow our operations, and ultimately accelerate our time-to-market so that we will eventually be competing with domestic and foreign competitors on an international scale. Working with Stennis on a "lean team" approach has provided solid learning experiences for both sides, and we wish to take these lessons learned and carry them forward in an expanded, future public-private partnership if Relativity's business needs can be optimally met.

Policy Recommendations: Startups and The Future of Partnerships

Public-private partnerships have provided critical resources for our company's initial success. However, we have learned a lot about working with the government along the way and would like to offer a few suggestions for improvement. Our desire here is not merely self-interested: We firmly believe that opening and strategically building up specialized government infrastructure could act as an "accelerator" of space startups, in much the same way that President Eisenhower created the highway system and catalyzed the automobile industry.

We recognize that the commercial space legislation under consideration today and in the weeks ahead may not be the proper vehicle for space infrastructure investments. But we also recognize that infrastructure writ large is very much a topic of discussion in Washington and an issue that generates bi-partisan support. Ultimately, we believe that if public-private partnerships can incentivize and maximize investment into the space industry from private sources they will, in turn, maximize the impact the U.S. Government can have in fostering the industry, further consolidating our Nation's dominant position when it comes to exploring the cosmos.

(1) Maximizing and Updating Launch Infrastructure

As mentioned above procuring and qualifying launch infrastructure—launch pad, ground support equipment, range and communication systems, and flight termination safety systems—is a daunting task for any company, and particularly for a startup that is simultaneously developing new manufacturing technologies and an orbital rocket on a timeline of just a few years.

Relativity strongly support initiatives like NASA's development of a mobile Universal Propellant Servicing System (UPSS) and the Autonomous Flight Termination Systems (AFTS) developed by DARPA and NASA, as these are perfect examples of the types of commodity infrastructure development by the government, which adequately meet the needs of private companies looking to reach operational status more quickly and cost effectively.

Of particular note is that for small class launch vehicles, the lack of accessible West Coast launch sites able to meet polar, sun synchronous, and retrograde orbital inclinations leaves many small satellite customers stuck with launching on foreign rockets from India, Russia, and Europe. Internationally located FAA-licensed launch sites, such as in New Zealand, are privately developed and not open to other U.S. companies, and have technical advantages that are nearly impossible to replicate in the United States other than potentially in Hawaii or other remote Pacific islands. One potential near-term option is to help create a small launch vehicle pad similar

in design to KSC's 39C at Vandenberg Airforce Base in California, or another suitable West coast location. Regardless, with emerging small satellite customers split between desiring launches from the East coast and West coast due to the orbits they provide, startups like Relativity must think about multiple launch facilities and operations spread across the country.

The lack of a singular launch complex able to serve the bulk of small satellite customers is a thorny problem to solve, but we have postulated that the use of an offshore drone ship launch platform could potentially alleviate this problem by launching in international waters under an FAA license. The concept we envision is less complex than the repurposed oil platform known as "Sea Launch," and is more akin to the reverse of the drone ships and barges SpaceX and Blue Origin have pioneered for landing recovered boost stages. We believe it is worth mentioning as a potential area for further regulatory and technical investigation. The expected influx of massively higher frequency of launches in the coming years will present new regulatory challenges. It could cause an eventual bottleneck where multiple small launchers and satellite constellations alike would be constrained in servicing a new wave of commercial customer needs. Even proposing an uncharted solution like international drone ship or barge launch goes to show just how dire the launch bottleneck could be with current regulatory processes and launch site limits to the total number of flights possible per year in the United States. This is also a key issue that is pushing companies to investigate air launch as an alternative solution, again with daunting technical unknowns and operational challenges.

Finally, we are grateful for the government's foresight in helping to create ready-access launch pads and propellant loading systems such as 39C in Kennedy Space Center. However, Relativity is concerned that 39C is located too close to the Space Launch System (SLS) pad 39B, potentially risking multi-month schedule delays as a national asset like SLS will rightfully take schedule priority. Due to this proximity to SLS, we are nervous about potential insurance premium increases that launching at 39C could entail. We also believe it will be difficult to serve multiple companies effectively from the same location, and while there appear to be several available moth-balled facilities at Cape Canaveral, for example, the growing scarcity of mature launch pads will hinder new entrants' ability to meet customer demand.

(2) A New Model for Service Agreements

The current incarnations of the Space Act Agreement (SAA) and Commercial Space Launch Act (CSLA) agreement contain problematic provisions for handling conflicting test stand priorities.

We fully understand that in the event of a national emergency the government may require the use of test infrastructure. Our primary concern is that as the SAA and CSLA are currently drafted, if another commercial company wants to use the same test stand as us (or any other launch startup) NASA would be required to accommodate them in a presumed "one-month on, one-month off" type testing arrangement. This is troubling to a startup company where a delay of this sort could seriously jeopardize our ability to hit milestones with enough momentum required for further private funding. This is precisely the sort of scheduling conflict that could wreak havoc with development deadlines, and thus force us to seek highly inefficient alternatives, *i.e.,* building our own infrastructure. We are willing to reimburse direct costs and pay site maintenance fees in exchange for additional guarantees. If launch startups had a window of time during which we could lease engine and stage test stands this would go far to make us more comfortable relying on government infrastructure during critical development phases before operation.

Agreements with local centers like Stennis are extremely valuable but risky mechanisms in the way they are formed. They save new small launch startups precious time and money but they are negotiated in an ad-hoc, case-by-case manner which creates a significant risk variable. A more certain framework and policy stance for making agreements between privately funded startups and the U.S. Government for infrastructure use could greatly help startups in particular navigate public-private partnerships.

Relativity thus proposes the creation of a "Commercial Space Lease Agreement"—a new framework similar to a reimbursable SAA or CSLA but with provisions for leasing development testing infrastructure at direct cost in much the same way launch infrastructure like LC–39A and LC–13 at Kennedy Space Center is leased. To ensure competition for an agreement of this type, public notices much like LC–39A and LC–13 could be held for a period of time, with similar optionality on proposing either exclusive-use or multi-user operations. Investment dollars from venture capital often follow—not precede—winning these types of agreements, worth noting for comparison of proposals versus more entrenched and initially-funded competitors. Potentially leasable facilities which are not considered moth-balled could

be selectively duplicated or expanded to ensure a higher number of participants have equal access as the space industry grows. Continued support for flexibility in the Company's choice of using either Company or Government personnel, and supporting Company-funded facility upgrades and modifications are critical to ensuring the best-of-both-worlds in a testing infrastructure public-private partnership. As we envision it, a Commercial Space Lease Agreement framework would lower competitive barriers to entry and promote significantly more efficient use of private capital and time, while reducing risk across the breadth of company development phases by providing more certainty in negotiation outcomes.

(3) Reimagining Procurement

While Relativity is currently entirely privately funded, the opportunity for any company to apply for competitive partnership contracts provides essential support and valuable signaling to potential commercial customers.

As a startup operating under aggressive financial goals, Annual Recurring Revenue (ARR) is a key long-term metric and far superior to helping build our bottom line than one-off revenue generating events such as Venture Class Launch Services (VCLS). VCLS is an excellent opportunity for a company like ours because it enables us to gain initial traction, generate revenue, and validate that we can attract new commercial customers. While I strongly support any further rounds of flight opportunities where we may apply for funding, a one-off launch contract is unable to move the needle on a private investor's ROI expectations—although we understand that with the current incarnation of VCLS, that outcome perhaps was not the intent. We would also point out that delays in contract awards, yearly submission cycles, and any lags in funding a company once a contract has been awarded may cause undue harm to a startup where weeks and months are counted.

We would encourage NASA to investigate a modulated version of the program that provides for recurring and larger launch contracts over multiple launches. This could include a hybrid model of sorts, one that predicated the award of a full contract on the successful execution of an initial run of two-three launches over an agreed-upon period time. Failure to meet clear benchmarks along the way would result in the immediate termination of such an agreement. Alternatively, some version of new public-private contracts like the Commercial Resupply Services (CRS), Commercial Orbital Transportation Services (COTS), and Commercial Crew Development (CCDev) that is geared towards smaller and newer launchers would also incentivize early private investment.

(4) Avoiding the Licensing Logjam

The question of adequate resources for the Office of Commercial Space Transportation has been raised in previous hearings, but as a company that plans to soon join the ranks of those applying for launch licenses with greater and greater frequency, it is of the utmost importance in our minds that AST receive sufficient funding and personnel to avoid a significant back up in licensing applications. We understand that there is a broader and healthy debate taking place about AST's role vis-à-vis that of the Department of Commerce's Office of Space Commerce but this should in no way supplant a critical focus on ensuring AST is equipped to carry out its current mission.

(5) Continuing to Support a Robust Satellite Market

Low cost, frequent, predictable orbital launch is simply the first step in accessing space and creating a large impact above Earth and beyond. Support of satellite companies—both established and emerging—is needed to ensure the large total addressable market investors need to see grows and matures. Issues such as orbital debris reduction need to be tackled in a way that do not limit the potential revenues of satellite companies or the launchers that fly them. Limits to the total number of satellites in orbit would be more damaging than service lifetime limits, tracking requirements, or end-of-life deorbit requirements. This is especially true as many proposed orbital constellations specifically benefit from a high number of payloads circling the globe with rapid iteration of their technologies. We also support innovative solutions to spectrum rights that increase the number of satellite companies able to cost-effectively serve their customers without interference. Our potential customers need to access space today to prove their business models and survive until tomorrow, and we do not wish to hinder them in doing so. Thus, we do not support an explicit ban on unsubsidized foreign launchers as we wish to instead work on public-private partnerships to create other incentives toward fielding a low-cost U.S. designed, manufactured, and flown—non-ICBM derived—orbital vehicle for small satellite constellations.

Conclusion: A Startup Vision for Commercial Space in the 21st Century

For the most part, Relativity has had an overwhelmingly positive experience in its partnerships with NASA and MD5. However, we believe it is important to point out that from conversations with our peers not every commercial space startup feels the confidence to rely on public-private partnerships in key development infrastructure roles yet.

Take, for example, this vital question of engine and vehicle stage testing infrastructure. A dearth of available stands, an occasionally cumbersome engagement process, an uncertain prioritization process—those challenges and more will push many startups to spend valuable private funds building their own test stands and support hardware. Building our own development testing infrastructure continues to be an expensive and inefficient process that results in a loss of time, money and creative energy that could be better spent on cutting edge innovation rather than on items which are proven commodities—and which the U.S. Government is perfectly placed to provide access to be it via existing infrastructure or through the targeted, gradual buildup of new infrastructure to meet the demands of a new generation of private space exploration companies.

Lastly, it is worth noting that no matter which strategy a company pursues, startups like Relativity initially compete directly with much larger and more well-funded competitors through new ideas, development speed, equity ownership, and novel big-payoff technologies. It is that willingness to innovate in the face of uncertain risk that uniquely bonds startups, even as competitors. There is one other thing that any startup worth its salt has in common: ambition. We grind and labor and persevere not merely to get rich—there are probably easier ways to do that—we do it to change the world. Commercial space startups do it because we want to change the world by reaching the cosmos.

Relativity is here today as a representative example of a successful partnership with the United States Government. We also recognize that we are here today as one humble example of the hundreds of dynamic space startups currently hard at work in suburban garages and repurposed airplane hangars all across America. The United States Government has not always been known for the nimbleness of action that characterizes your average startup. But I would be so bold as to venture that we are united by one thing that is greater than all of us: A vision. A vision of the Stars and Stripes on the first spaceship to safely land men and women on Mars. A vision of how we will guide this world, our home, into a more fantastic future by learning to understand new worlds and applying that knowledge to our own. A vision of all the other missions that will expand the limits of our known universe and the bounds of the human spirit. What could be more human and American than aspiring to do something in the face of the impossible—and succeeding?

Chairman Cruz, Ranking Member Markey, Members of the Committee—thank you for this opportunity.

I look forward to working with you in the months and years ahead.

Senator CRUZ. Thank you, Mr. Ellis.

Mr. Hughes.

STATEMENT OF TIM HUGHES, SENIOR VICE PRESIDENT, GLOBAL BUSINESS AND GOVERNMENT AFFAIRS, SPACE EXPLORATION TECHNOLOGIES CORP. (SPACEX)

Mr. HUGHES. Mr. Chairman, Ranking Member Markey, Senator Nelson, Senator Gardner, and members of the Committee, thank you for the opportunity to participate in this important hearing.

I'm pleased to be here today representing the nearly 6,000 men and women of SpaceX who are working hard every day to provide NASA, the Department of Defense, and our commercial customers with critical launches to space.

SpaceX is a firm believer that public-private partnerships between commercial space entities and the government, if carried out with the right structure and the right incentives, are among the best ways to rapidly, safely, and cost effectively advance America's space program.

Before outlining some views on how to best leverage commercial partnerships, I wanted to give the Committee a quick update on what has been happening at SpaceX of late.

To begin, since the start of the year, we've completed 10 missions, including 3 in just a 12-day period, and these have included landings of our first-stage booster, both at land and at sea.

In addition to flying our commercial customers, SpaceX is routinely supporting cargo resupply missions to and from the International Space Station. And we have, in a set of historic firsts, successfully launched two previously flown boosters for commercial customers.

Separately, we're making great progress on a fully reusable next generation launch system, which will enable large-scale human and cargo transportation to and from the surface of Mars.

And most importantly, we are laser-focused on safely and reliably launching astronauts onboard our Falcon 9 and Dragon 2 capsule with this launch to occur next year. This will restore America's human space flight capability for the first time since the Shuttle retired in 2011. And as noted by the Chairman, it will end our Nation's reliance on Russia to carry our own astronauts into space.

Mr. Chairman, this is an exciting and dynamic time for space exploration. With new commercial space companies emerging, private capital investment and commercial space ventures surging, and new technologies and competition offering rapid innovation, affordability, and flexibility, now is the time for the U.S. space enterprise to make maximum use of commercial capabilities.

There are a few points to that end that I'd like to make. First, we encourage the Committee to look back on the NASA COTS program. It offers important lessons about the utility of public-private partnerships and the right way to carry them out. NASA structured the COTS program very wisely. It shared the risks, the costs, and the rewards of developing new space transportation capabilities. Under the program, NASA provided seed money for the demonstration of private space flight capabilities, and it issued payments only after a company met technical or financial performance metrics.

By using this approach, NASA was able to leverage its $800 million investment in the program alongside significant commercial investment, and it yielded two new U.S. medium-class launch vehicles and two new cargo spacecraft. This partnership moved at rapid speed with the first flight of the Falcon 9 and Dragon to orbit occurring in less than 4 years, and with the first flight of an operational mission to the Space Station in less than 6 years.

The features associated with the COTS program can be more broadly applied now to the development of deep space exploration systems for transportation, habitats, communications, reconnaissance, and resource utilization. In general, they include the use of pay-for-performance milestone-based structures under firm-fixed-price contracts. Contractors should be paid when they deliver and they should take risks and they should share risks. Additionally, the government should set high-level requirements, objectives, and goals, but should not dictate how private partners achieve those goals. This encourages fresh thinking and creative problem solving.

Further, competition is critical to the overall success of any such program.

Overall, NASA should once again pursue a parallel track with nontraditional partners meant to augment and increase the probability of the long-term success of the Nation's space exploration goals. We recommend a new competitive public-private partnership modeled on COTS for deep space exploration.

Objectives here could include a sustained lunar presence, a large cargo carriage to Mars, commercial space habitats and weigh stations to other planets, or a deep space communications program meant to supplement our current capabilities. Regardless, we believe a competitive performance-based partnership program with relatively small investment by the government would yield great results for the Nation, along with high-paying jobs and critical national space capabilities.

Mr. Chairman, thank you once again for the opportunity to share some thoughts on this topic. I look forward to any questions that you might have.

[The prepared statement of Mr. Hughes follows:]

PREPARED STATEMENT OF TIM HUGHES, SENIOR VICE PRESIDENT FOR GLOBAL BUSINESS AND GOVERNMENT AFFAIRS, SPACE EXPLORATION TECHNOLOGIES CORP. (SPACEX)

Mr. Chairman, Ranking Member Markey, and Members of the Committee,

Thank you for the opportunity to participate in this important hearing on "Reopening the American Frontier." SpaceX is a firm believer that public-private partnerships between U.S. commercial space entities and the Government are the optimal vehicles to rapidly, safely, and cost-effectively advance space exploration and settlement of the solar system.

Under your leadership, the Committee recently has reviewed an array of matters, including regulatory reform to enable commercial space to thrive and revisions to the Outer Space Treaty, which are critical to ensuring the Nation's continued leadership in space exploration. Today's hearing provides a timely opportunity to discuss the nature of NASA's recent successful partnerships with private industry and to review how the United States can leverage such innovative approaches in its deep space endeavors going forward. SpaceX's direct and significant experience working under unique, innovative public-private partnerships with NASA should help to shape the contours of this dialogue. In addition to existing programs at NASA focused on deep space exploration transportation and architectures, NASA again should pursue a parallel track that leverages non-traditional, public-private partnership approaches to increase the likelihood of success for the Nation's space exploration objectives.

From its beginning, SpaceX has leveraged American innovation, technical savvy, and an iterative culture to yield the most advanced space launch vehicle and spacecraft systems in history. We are grateful for NASA's ongoing support, which has been critical SpaceX's success. We are proud to provide a dependable and affordable ride to space for NASA, the Department of Defense, and the world's most sophisticated commercial satellite manufacturers and operators. Today, we regularly conduct critical un-crewed cargo resupply missions to and from the International Space Station (ISS) with our Dragon spacecraft—which was developed in partnership with NASA—and next year, we will begin launching American astronauts on American rockets for the first time since the Space Shuttle was retired in 2011. Commercially, SpaceX has restored the U.S. as a leader in global commercial satellite launch, taking back a market that had been wholly ceded to Russia and France for over a decade. As we look to the future, SpaceX is committed to continuing to support America's space program and to contribute to our national exploration objectives through reliable, innovative, and affordable access to space.

To begin, it bears noting that the National Aeronautics and Space Act of 1958 identifies one of NASA's core mission areas as follows: "[t]o seek and encourage, to

the maximum extent possible, the fullest commercial use of space."[1] Additionally, the National Space Transportation Policy expressly directs Federal agencies to "[p]romote and maintain a dynamic, healthy, and efficient domestic space transportation industrial base," and to do so, in part, by cultivating "increased technological innovation and entrepreneurship in the U.S. commercial space transportation sector through the use of incentives such as non-traditional acquisition arrangements, competition, and prizes."[2] American policy-makers dating back to the formation of NASA have recognized that the commercial use of space represents one of the country's greatest assets—private sector ingenuity and capital, rather than cost-plus contracts and open-ended requirements. This, coupled with unique Government capability, technical insight, experience, and resources, will sustain and grow American leadership in space, and more broadly, benefit all of humankind.

My testimony today will focus on the following areas:

(1) The NASA Commercial Orbital Transportation Services (COTS) program should serve as an object lesson in successful, high-value public-private partnership approaches. The COTS program resulted in significant new capability for the U.S. Government, saved hundreds of millions in taxpayer money, and helped restore U.S. competitiveness in commercial space launch. The lessons learned through COTS—a program to support cargo transportation to low-Earth orbit (LEO)—could easily be transposed on innovative partnership arrangements for deep space exploration going forward.

(2) Public-private partnerships and commercial-type contract approaches under the Federal Acquisition Regulations (FAR) can provide cost-effective, accelerated development and deployment of new space capabilities, if properly constructed and tailored. Here, my testimony will focus on how the unique features of such approaches can and should be applied to deep space exploration initiatives to keep America at the cutting of edge of space technology within reasonable budgets and timetables.

(3) Specific commercial partnership concepts for deep space exploration can complement and enhance the space exploration efforts NASA is currently undertaking through more traditional contract and development approaches. Here, my testimony sets forth some possibilities that are additive, and emphasizes that no single approach is perfect. That is, it is evident that the country will benefit by applying multiple different approaches and enabling multiple different, redundant pathways to space exploration.

I. SpaceX Today

Founded in 2002, SpaceX employs approximately 6,000 people dedicated to designing, manufacturing, and launching rockets and spacecraft in and from the United States. To this end, SpaceX was created with the express goal of dramatically improving the reliability, safety, and affordability of space transportation. We have made that goal a reality. And, of course, our ultimate goal is to help to establish a permanent human presence in the stars, with an initial focus on Mars as a destination.

To date, the SpaceX Falcon 9 launch vehicle has successfully launched 37 times, all while achieving important evolutionary reductions in the cost of space launch. Among other things, SpaceX has focused on making our rockets reusable. After several years of self-funded research and development on reusability, beginning with critical work at our McGregor, Texas Rocket Development Facility, SpaceX has now recovered a total of 13 Falcon 9 first stage boosters since December 2015—5 at Landing Zone 1 at Cape Canaveral Air Force Station and 8 aboard our autonomous spaceport droneships at sea. After a four-month qualification program, SpaceX successfully launched and landed a previously-flown Falcon 9 booster in March of this year, placing a high-value telecommunications satellite into orbit for SES, a global satellite operator. This was an historic first for an orbital-class booster. In June 2017, SpaceX repeated this success with the launch of the BulgariaSat-1 satellite using a flight-proven booster, which itself had previously launched in January of 2017.

Currently, SpaceX has approximately 70 missions on manifest, representing more than $10 billion in signed contracts for a diverse and growing set of customers, including NASA, the Department of Defense, commercial satellite operators, and allied international governments. As our business continues to grow, SpaceX, as tech-

---

[1] Pub. L. 115–10, title III, § 305(b), title IV, § 443(b), Mar. 21, 2017, 131 Stat. 32, 47, added items 20148 and 20149.

[2] National Space Transportation Policy. November 1, 2013. Available at: *https://www.nasa.gov/sites/default/files/files/national_space_transportation_policy_11212013.pdf*

nology companies should, invests heavily in the company's manufacturing and launch infrastructure and advanced research and development projects, including spacecraft development.

We remain laser-focused on reliability and safety as we prepare to launch U.S. astronauts next year. This is a sacred responsibility that we approach with the utmost dedication and diligence. Additionally, we continue efforts to reach a cadence of a launch every two weeks or less for 2017, with an even higher rate planned for 2018; to move toward rapid and complete reusability of our boosters; to launch our Falcon Heavy launch vehicle later this year, which will be the most powerful rocket to launch since the Saturn V Moon rocket; to develop and produce the initial prototypes for our broadband satellite system; and to continue design and development work of a Mars launch vehicle architecture. Critically, all of this innovation is occurring in the United States, creating high-paying jobs, advancing technology, and generating substantial economic activity.

To update the Committee on SpaceX's major milestones for 2017:

- We have completed 10 missions in the past 7 months, for a total 37 successful Falcon 9 launches overall. Recently, SpaceX launched 4 successful missions in 32 days (3 of those in just 12 days);
- We have already successfully completed two cargo resupply missions to the ISS for NASA, CRS–10 and CRS–11, which was the first re-flight of a Dragon spacecraft;
- We successfully launched two flight-proven Falcon 9 rockets for commercial satellite customers;
- We successfully delivered the NROL–76 national security payload to orbit for the National Reconnaissance Office (NRO) on May 1, 2017, the first dedicated national security mission flown by SpaceX, under an innovative, commercial services contract;
- We were awarded a second GPS III missions under a competitive procurement in the Evolved Expendable Launch Vehicle (EELV) Program, yielding a significant cost savings to the Air Force;
- We have launched missions from both active East and West Coast launch sites; and,
- We are completing final upgrades to the Falcon 9 (Block 5), after which we'll focus much of our launch vehicle engineering talent on SpaceX's Mars vehicle.

SpaceX maintains its manufacturing and engineering headquarters in Hawthorne, CA; a satellite system design and development office in Redmond, WA; a Rocket Development and Test Facility in McGregor, TX; and launch pads at Cape Canaveral Air Force Station, NASA Kennedy Space Center, Vandenberg Air Force Base, and, soon, a commercial launch site near Brownsville, TX. SpaceX also relies upon a network of more than 4,400 American suppliers and partners—an investment in the American industrial base when others are spending heavily abroad.

II. COTS: A Successful Model for Public Private Partnerships

The Commercial Orbital Transportation System (COTS) program has been widely and correctly hailed as a major success for NASA and its commercial partners, delivering significant new capability to the Government at incredible value to the taxpayer.[3] After the Space Shuttle Columbia disaster in 2003, all Space Shuttle flight operations were suspended for more than two years, and the United States became reliant upon foreign governments to carry both American cargo and crew to the International Space Station (ISS). In 2006, NASA established the COTS program to develop new U.S. cargo capability to serve as a follow-on to the Space Shuttle Program for missions to ISS. COTS was an innovative, commercially competitive program that successfully leveraged private sector dollars and ingenuity through public-private partnerships.

The COTS program was the first of its kind for NASA: a pay-for-performance partnership between the U.S. Government and private businesses to rapidly design and prototype critical technologies. NASA structured the COTS program as a collaborative partnership with the commercial space industry, sharing the risks, costs, and rewards of developing new space transportation capabilities. Under the program, NASA provided seed money for the development of private spaceflight capabilities, but issued payment only after a company met technical and financial per-

[3] "The development of commercial cargo vehicles is considered by many as one of the major success stories at NASA in the last decade." Jeff Foust, "For commercial cargo, ideas old and new," The Space Review, March 23, 2015. Available at: *http://www.thespacereview.com/article/2717/1.*

formance milestones. The participating COTS contractors, likewise, invested in the program and put their own financial skin in the game. The contractual mechanism utilized was a "Space Act Agreement" (SAA), which allows the agency to rapidly design and prototype technologies, and allows contractual flexibility such that private parties can contribute financially to what would otherwise be a Government effort. The SAA has its genesis in "other transactions authority," which exists in Federal statute for NASA, as well as the Department of Defense and many other Federal agencies.

NASA competitively awarded a COTS Space Act Agreement to SpaceX and another entity in 2006. For SpaceX, the SAA ultimately represented a total of $396 million of NASA investment, primarily focused on development of the Dragon cargo capsule and two demonstration flights of the Falcon 9 launch vehicle and Dragon spacecraft. SpaceX in turn invested more than $500M (at that time) in the development of the Falcon 9, including launch sites, production, and test facilities.[4] In only four years, SpaceX went from a clean sheet design to launch of the Falcon 9 and the first orbit and reentry of Dragon—an unprecedented reduction in development time for a complex space system that was realized under the SAA approach.

In May 2012, Falcon 9 successfully launched Dragon to orbit and the spacecraft then successfully berthed with the Space Station, a mere six years after contract award. Shortly thereafter in October 2012, the first operational mission under the follow-on Commercial Resupply Services (CRS) contract lifted off, resulting in mission success and kicking off a new area of U.S. resupply to the space station.

This level of output and speed relative to expenditures is unprecedented in the aerospace community and marked a major success for NASA and its innovative approach to restore a critical capability. In short, this was a major win for the U.S. taxpayer, for U.S. manufacturing, for NASA specifically, and for the U.S. commercial space industry. It was perhaps the greatest "bang for the buck" that NASA has ever achieved.

Notably, in August 2011 NASA, using the NASA-Air Force Cost Model (NAFCOM), determined that had Falcon 9 been developed under a traditional NASA approach, the cost would have been approximately $4 billion. The analysis also showed development of the Falcon 9 would have been approximately $1.7 billion based on the traditional commercial models and assumed factors. However, NASA independently verified SpaceX's development costs of both the Falcon 1 (our early "pathfinder" vehicle) and Falcon 9 at approximately $390 million in the aggregate ($300 million for Falcon 9; $90 million for Falcon 1).[5]

Beyond COTS, NASA has had other successes utilizing the innovative and flexible framework enabled by Space Act Agreements.[6] For example, NASA successfully worked with Bigelow Aerospace, which makes expandable modules and habitats for use in space. Here, once again NASA used an SAA applying a firm-fixed-price structure and leveraging significant private investment by Bigelow, to launch the Bigelow Expandable Activity Module (BEAM) to the ISS. SpaceX launched BEAM to the Space Station on April 8, 2016 during a cargo resupply mission. Once Dragon berthed with the Space Station, NASA astronauts extracted the BEAM module from Dragon's unpressurized trunk and attached it as a new module to the ISS. When activated, BEAM expanded to ten times its size at launch to provide more than 565 cubic feet of new volume to the Station and became the first human-rated expandable module in space. With this success, Bigelow and others will now develop technologies for habitats in low-Earth orbit and beyond, which will likely later be utilized by space agencies and commercial customers for in-orbit research labs, habitats in LEO, lunar orbits, on Mars or elsewhere.[7]

III. Value of Partnerships and Commercial-Type Partnerships

By any accounting, the COTS program has been an historic success. According to NASA, "[b]ecause these were partnerships, not traditional contracts, NASA leveraged its $800M COTS program budget [less than a single Space Shuttle mission] with partner funds. This resulted in two new U.S. medium-class launch vehicles and two automated cargo spacecraft and demonstrated the efficiency of such partner-

---

[4] SpaceX has continued to invest in reliability, performance, and reusability enhancements for Falcon 9.

[5] NASA Deputy Associate Administrator for Policy, "Falcon 9 Launch Vehicle: NAFCOM Cost Estimates," August 2011. Available at: *https://www.nasa.gov/pdf/586023main_8-3-11_NAFCOM.pdf*

[6] See: NASA, "Public-Private Partnerships for Space Capability Development: Driving Economic Growth and NASA's Mission," April 2014. Available at: *https://www.nasa.gov/sites/default/files/files/NASA_Partnership_Report_LR_20140429.pdf*

[7] NASA, "Bigelow Expandable Activity Module (BEAM)," May 31, 2017. Available at: *https://www.nasa.gov/mission_pages/station/research/experiments/1804.html*

ships."[8] We encourage the Committee to consider ways to take the lessons learned from the COTS program and more broadly utilize of the basic features of this approach in future public-private partnerships that extend to deep space exploration initiatives.

The basic features of the COTS program include:

(1) Establishing high-level requirements and encouraging contractors to execute against them with creative, innovate, and cost-effective solutions, reducing "requirements creep" and encouraging new thinking. The COTS program required contractors to meet a clear set of established safety and interface ISS requirements and high-level milestone requirements, rather than implementing overly-specified and ever-changing detailed Government requirements. This requires the Government customer to tell contractors what they need to be done, rather than prescribing how to do it. Coupled with firm, fixed-price arrangements, the Government Accountability Office (GAO) has found that "the use of firm-fixed-price contracts—along with well-defined requirements and a sufficient level of knowledge about critical technologies—presents the least risk to the government."[9]

(2) Using firm, fixed price, pay-for-performance, milestone based agreements or contracts, creating proper incentives on the contractor to execute toward successful conclusion, and discouraging continuous Government requirement changes that add costs and delay schedules. Pay-for-performance creates proper incentives on both sides of the Government/contractor relationship. Here, the GAO has reported: "[f]irm-fixed-price contracts place the onus on the contractor to provide the deliverable at the time, place, and price negotiated by the contractor and the government. In addition, firm-fixed-price contracts place the maximum risk on the contractor as well as full responsibility for all costs and any resulting profit or loss."[10]

(3) Maximizing competition, which is critical to drive value and performance, and improve quality of service to the customer. Again, GAO has reported that "promoting competition can help save the taxpayer money, improve contractor performance, and promote accountability for results."[11]

(4) Requiring a significant private capital contribution to the overall program. The COTS agreements required commercial partners to share costs and provide a significant percentage of the overall total investment, resulting in lower costs to the Government and high incentives for commercial firms to drive toward operational success to generate revenue and recoup their investment.

(5) Tolerating programmatic risk, and easy termination for failure. One of the major early lessons learned under the COTS model was borne of the failure of Rocketplane-Kistler, one of the original winners of the first competitive down-select, alongside SpaceX. Ultimately, Rocketplane-Kistler was unable to execute against one of the financial milestones in its agreement with NASA. As a result, NASA was able to early terminate the agreement without significant lost investment or time, and pivot to OrbitalATK (then Orbital Sciences) to serve as the second provider under the program. This flexibility to terminate contracts and rapidly "stop the bleeding" on non-functional programs is one that is largely lost when applied to traditional FAR-based contracts.

(6) Encouraging new, non-traditional companies to work with NASA. Due to the complexity and cost associated with conforming to traditional FAR-based contract requirements, start-up companies with small teams and no expertise interfacing with the complex regulatory and contractual environment associated with U.S. Government are often deterred from participating at all. As a result, the Government is often not at the cutting edge of new commercial technology offerings. The use of Space Act Agreements—as with COTS—can help enable such firms to do business with the Government.

(7) Facilitating the development of new markets, and leveraging market-driven pricing to support U.S. Government requirements and missions. Today, SpaceX is the world's leading commercial launch services provider measured by manifested launches. A substantial majority of our more than 70 missions

---

[8] NASA, "Commercial Orbital Transportation Services: A New Era in Spaceflight," February 2014. Available at: *https://www.nasa.gov/sites/default/files/files/SP-2014-617.pdf*

[9] Government Accountability Office, "NASA: Acquisition Approach for Commercial Crew Transportation Includes Good Practices, but Faces Significant Challenges," December 2011, (GAO–12–282). Available at: *http://www.gao.gov/assets/590/587021.pdf.* (Emphasis added).

[10] Ibid.

[11] Ibid.

under contract are commercial. This year, we are on track to launch more than half of the world's accessible [12] commercial missions to geostationary transfer orbit (GTO). Next year, we expect to launch a majority of the world's missions to GTO with our Falcon 9 and Falcon Heavy launch vehicles.

Prior to SpaceX entering the commercial space launch market with the Falcon 9 launch vehicle, the U.S. had effectively ceded this market to France and to Russia, and no U.S. company had launched a single commercial mission to GTO since 2009. SpaceX has brought this multi-billion dollar market back to the United States. The benefit to NASA, and to the entire U.S. Government when buying launch services, is that commercial competitiveness drives launch prices lower for the Government customer (since costs are widely distributed instead of borne entirely by the Government), increases the robustness of the launch company's business, and increases reliability and launch heritage through higher flight rates. As a result of COTS—at least with respect to SpaceX—NASA and the Department of Defense are paying lower prices for launch with higher performance than in the past.

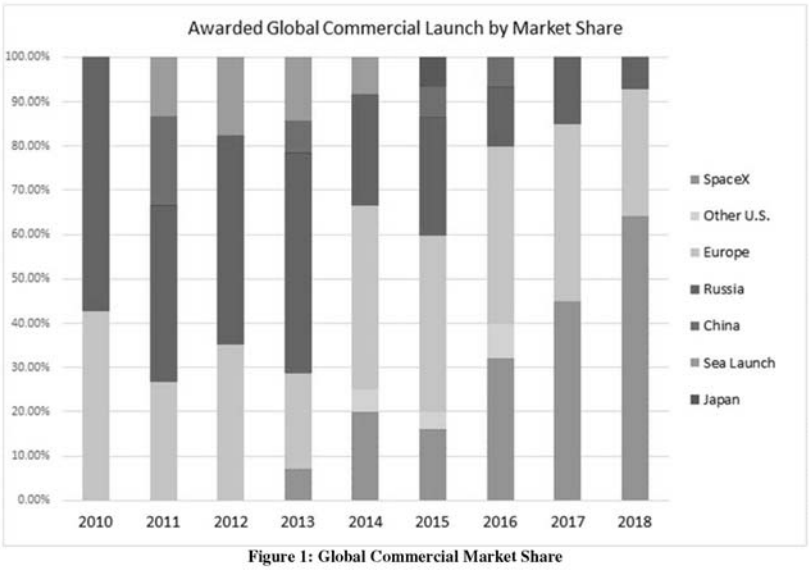

Figure 1: Global Commercial Market Share

IV. Recommendations for Increasing Use of Public-Private Partnerships for Deep Space Exploration

SpaceX applauds this Committee for examining ways in which public-private partnerships and commercial arrangements can contribute to the Nation's space exploration objectives, just as they have done to enhance America's capabilities in low-Earth orbit. To this day, America's achievement of landing men on the Moon and returning them safely to Earth likely represents humankind's greatest and most inspirational technological achievement. This was accomplished in eight years using slide rules and pencils, with engineers literally inventing rocket science as they progressed. Now, other nations like China seek to replicate an achievement America first accomplished 48 years ago.

With the technology advancements and increased knowledge through decades of work by NASA in deep space, including Mars, the United States is now well-positioned to build upon past achievements in space and surpass them. Coupled with the NASA resources and unique expertise, American ingenuity, the principles of free enterprise, and the benefits of competition, the United States can do more in space than has ever been accomplished previously.

SpaceX recommends that, in parallel with existing programs at NASA focused on deep space exploration transportation and architectures, NASA again leverages non-traditional, public-private partnerships to improve the likelihood of success for its

[12] Not all of the world's commercial satellite launches are open to competition.

space exploration objectives. By leveraging flexible, innovative contracting approaches as well as private capital, NASA and the space program could generate efficiency gains and accelerate progress, while expanding the potential pool of technology companies contributing to the overall effort to expand humanity's presence in the solar system and ultimately establish settlements on other planets.

What are the goals and near-term outcomes of such an approach?

- *American Aspiration and Inspiration.* The last astronaut left the surface of the Moon in 1972, and no one has returned since. Despite being an historic achievement for America and humankind, the Apollo program did not create a lasting, sustained presence in deep space for humanity. A permanent human presence on the Moon presents humanity's next obvious foothold outside of Earth. However, rather than look back to the Moon alone, the United States should also lead the world to the next great destination: Mars. Moving beyond the Earth-Moon system will open the broader solar system to human exploration, a potentially generations-long enterprise. Both missions would enable settlement and tap into America's spirit of exploration.
- *U.S. Leadership.* A realistic and sustainable human exploration program will demonstrate American leadership in space exploration, technology innovation, and scientific discovery for many years to come. This leadership will enhance the American economy, extend America's technological edge, and project American power. The technologies and applications developed invariably will have beneficial impacts to America's national security goals and space superiority.
- *American Jobs and Industrial Growth.* Every dollar spent on effective public-private partnerships and commercial-type contracts to establish an American presence on the Moon or Mars represents an investment in our economy, our technological infrastructure, and our ability to achieve accelerated advancements in space exploration and settlement. A viable Moon or Mars program will create tens of thousands of high-tech, high-paying American jobs and revitalize the U.S. manufacturing sector in order to develop and produce large scale systems for deep space transportation and capability (*e.g.,* propulsion systems, launch vehicles, spaceships, orbiting reconnaissance systems, and communications satellites), as well as systems to enable a permanent human presence on celestial bodies other than Earth (*e.g.,* life support systems, habitats, surface power, surface exploration, and resource extraction). A Moon-Mars initiative that leverages the strengths of the U.S. Government and the strengths of the private sector and invests in America's workforce will create new, high-paying American jobs in dozens of states—but most importantly, it will move the Nation's space exploration goals meaningfully forward.

To run in parallel with existing programs and increase the probability of success of establishing initial human presence on the Moon or Mars within the next in eight years to ten years, NASA could build upon the already demonstrated successful COTS model and create a similar COTS-like program for deep space exploration initiatives based on the following proven elements:

- *Competition.* NASA should hold an outcome-oriented, open competition, and award initial contracts to at least four companies. Later, NASA should down-select to at least two contractors to maintain competition and, critically, to have back up capability. Companies (or teams of companies) can compete with existing or novel designs and technologies.
- *Focus on Performance Goals Not Requirements.* Like the COTS program, NASA should set overall goals and establish clear milestones for the program and enforce only the necessary level of requirements and conduct continuous insight to ensure contractors are meeting milestones. NASA should let private companies determine how to achieve high-level requirements, rather dictate detailed specifications that suffocate innovation and ingenuity.
- *Fixed-Price, Milestone-Based Payments.* NASA should pay for performance achieved along the way, on a firm, fixed-price basis that encourages rapid prototyping and development, rather than only use traditional cost-plus Government contracts that historically have resulted in cost overruns and led to schedule delays.
- *Contractor Investment/Public-Private Partnership.* The benefits and burdens of funding such a program should be shared by the Government and awardees, with commercial space partners making commitments of at least one-third of the funding for any bid made. This will buy-down risk for the Government, incentivize performance, and demonstrate commitment. Corporations should view this as an investment in technology and potential follow-on business.

Mr. Chairman, I appreciate your invitation to testify before the Committee today. Commercial-type contracts and public-private partnerships have resulted in significant successful outcomes for NASA and the Nation with respect to space capability. The principles applied in past programs for low-Earth orbit capability can and should be applied to deep space exploration. The United States can achieve incredible advancements in technology by coupling NASA's established capabilities, technical skills, and resources with those of the private sector and American entrepreneurship.

Again, we appreciate and support the work this Committee has undertaken to address policy matters before the commercial space industry, and we look forward to continuing the dialogue.

Senator CRUZ. Thank you, Mr. Hughes.

Dr. Jah.

STATEMENT OF DR. MORIBA K. JAH, ASSOCIATE PROFESSOR, AEROSPACE ENGINEERING AND ENGINEERING MECHANICS, COCKELL SCHOOL OF ENGINEERING, THE UNIVERSITY OF TEXAS AT AUSTIN

Dr. JAH. Chairman Cruz, Subcommittee Ranking Member, Mr. Markey, and other members, Senator Nelson, thank you very much for having me here today coming to you from UT Austin.

I would like to speak to you a little bit today about some of the problems that we have in space and why it's critical that we do some problem-solving with not just government, but academia and private industry.

Right now, the United States Strategic Command maintains a database or a catalog of about 23,000 objects the size of a softball and large all the way to school bus size. The good news is that they are maintaining this day in and day out and really working hard at it. The bad news is that it's not all the objects in space that can threaten critical space services and capabilities.

Before, when space first started with Sputnik, you only had a few objects on orbit, so it wasn't very difficult to know where things were or where things could be, but with 23,000 objects that are being tracked and others that are detected but not tracked for a variety of reasons, it poses a huge problem.

The other thing, too, is that we have countries like India, they just broke this record of launching 104 satellites in one fell swoop just a few months ago. They're going to continue to do this and just saturate the orbits with a lot of satellites, which in and of itself isn't a bad thing. We shouldn't be concerned with congestion; we should be concerned with not understanding where these things are going, how they're behaving, so that we can help businesses and commerce thrive.

I really like the analogy of the Western Frontier of old because that's what space is pretty much today. Basically you have some folks that are going up there trying to make money. The big bonanza seems to be putting as much on orbit to look down to track human-based activity or to monitor the Earth. Also, you have OneWeb and SpaceX that are looking to do global Internet. These are all great things.

But the guidelines that have been put in place to protect that sanctuary, which no longer is quite the sanctuary it was in terms of orbital safety and long-term preservation of space activities, those guidelines are ill-suited because they were based on a para-

digm of decades ago, not what we're facing now with all these new launches. And, again, the new launches aren't a problem; the problem is that we don't have a space traffic management system to really understand how best to do these things.

For instance, all the objects that the USSTRATCOM tracks, they're all modeled as spheres. How do we regulate spheres? How do we understand which sphere is doing what when? It's very difficult to do. On the roadways, we have guidelines on how to manage the traffic. Things are based on size, how many axles, that sort of thing. Trucks that are carrying hazardous material are treated very differently than Vespa scooters. Maritime oil tankers are treated very differently than kayaks and canoes. What do we have for space? Nothing. We don't have anything today, and that is a problem. There's a vacuum that needs to be filled, and the United States is in the best position to do that collaboratively between government, academia, and industry.

Russia is basically saying that they want to have the UN lead a space traffic management system. That's not a widely adopted viewpoint for a variety of reasons. And so, again, the United States is in a great position to show some leadership and do something about this.

Regarding that space traffic management system, what should this space traffic management system do? For sure, it should ensure the safety of operations in space, maximize and incentivize commercial opportunities. I hear some people on orbit saying, "Oh, FCC, please don't grant any more licenses because any single object up here is going to pose this risk of cataclysmic failures and all these things." That's not necessarily the case. We have an unquantified risk because there is so much that we still don't know. There is science that still needs to be done.

We also need to provide transparency. USSTRATCOM is doing the best it can to provide orbital safety products, but they can't disclose where everything is in space for very good reasons, so they shouldn't be asked to do that, and this is a good reason why I agree with General Hyten here why that should be moved outside of the DoD's purview.

A CSTM, a Civil Space Traffic Management System, should observe and monitor, track and catalog these objects, and inform the public of where things are at for orbital safety purposes and reasons.

And with that, I say thank you again very much for having me here. And I look forward to answering any questions that you may have.

[The prepared statement of Dr. Jah follows:]

PREPARED STATEMENT OF MORIBA K. JAH, PH.D. ASSOCIATE PROFESSOR, AEROSPACE ENGINEERING AND ENGINEERING MECHANICS, COCKRELL SCHOOL OF ENGINEERING, THE UNIVERSITY OF TEXAS AT AUSTIN

Mr. Committee Chairman Thune, Mr. Subcommittee Chairman Cruz, Subcommittee Ranking Member Mr. Markey, and other members of this subcommittee, thank you for the invitation to appear before you today to share my view of some salient issues that affect orbital safety, space traffic, and the future of our Nation's space exploration and exploitation program. It is an honor to be seated at this table with some of our world's Space sector giants. My name is Moriba Jah. I'm an engineer, scientist, and a technologist. The views I express today have been shaped through an 18-year aerospace engineering career in government, industry and aca-

demia. I started my career as a member of the technical staff of the NASA Jet Propulsion Laboratory. I navigated a variety of spacecraft to Mars and Asteroid Itokawa, and also developed advanced spacecraft navigation algorithms toward autonomy and improved orbital knowledge, beginning with Mars Global Surveyor and ending with the Mars Reconnaissance Orbiter mission. After JPL, I worked as a Civil Servant in the Air Force Research Laboratory, where I led the design, development, and implementation of algorithms that have successfully and autonomously detected, tracked, identified, and characterized man-made objects in space, so called "Resident Space Objects," to include orbital debris. My last position within AFRL was as the Mission Lead for Space Situational Awareness. Amongst my achievements, I was given the highest award that can be earned as an AFRL employee, that of AFRL Fellow. Currently, I am fortunate to serve on the faculty of the Aerospace Engineering and Engineering Mechanics Department, in the Cockrell School of Engineering at the University of Texas at Austin. At UT Austin, I lead a research program called ASTRIA focused on the design, development, and technical transition of astronautical sciences and technologies relevant to Spacecraft Navigation, Space Situational Awareness, and Space Traffic Management. I am a Fellow of several organizations and professional societies and serve as a chair and member of several major space-related national and international technical committees. However, I am here today as an individual and the views I express are mine alone. I'd like to also thank my wife Cassaundra, and children Denali, Inara, and Satyana for lending me to you, today.

Executive Summary

We have laws, regulations, and norms of behavior on our roadways, waterways, and airways. We classify and regulate traffic based upon things like size, maneuverability, weight, hazard potential, and others. An oil tanker is treated very differently than a kayak. A truck carrying hazardous fuel is treated quite differently than a Vespa scooter.

Do we have an equivalent Civil Space Traffic Management (CSTM) System? No. Do we need one? Absolutely. Why? Uncontrolled and unpredictable growth of the use of near Earth space. What form could a CSTM System take? What role should America have in it? This is what I am here to discuss.

To be clear, the question is not, "do we need a Civil Space Traffic Management system" but rather, "What form does such a system involve and how do we design, test, implement, enforce, and maintain the system."

Today, I'm going to address this problem by briefly establishing:

- Why we need such a CSTM system
- What could be the components of a CSTM system
- What are the next steps required to put this into effect

Regarding the "why" of us needing a CSTM System, I'll begin by saying that our Space Domain and Environment is no longer the sparsely-populated state-actor-dominant sphere of activity it was decades ago. Our need to explore and grow has motivated the commercial sector, epitomized by our own people the likes of Mr Jeff Bezos and Elon Musk, to discover the state-of-the-possible and turn that into our state-of-practice. This is exactly what we want to see happen and indeed foster and encourage. However, the U.S. is not the only country with growing activities in space. India, just recently broke the record for the largest number of deployed satellites in a single launch, 104 to be exact. Licenses are currently being sought for the launch and deployment of thousands of satellites, within the next few years. So, who is rigorously and comprehensively analyzing the growth of the Resident Space Object population and how does this affect Orbital Safety of Operations and the Long-Term Sustainability of Space Activities? The view of most space actors and investors is that it is someone else's problem! I vehemently disagree.

The Space Domain and Environment is still much like our Western Frontier of old. It suffers from a lack of monitoring, vast geographical sparsity, potential for "lawlessness", lack of environmental protection, etc. Space Piracy has likely already happened, is happening, and will happen so long as we lack the ability to comprehensively monitor all space activities. This unfortunate human behavior has happened in all other domains and to expect the Space Domain to be an exception is naïve at best. The problem is exacerbated by the fact that our space technology has made access to space cheaper, which has brought greater numbers of space actors to participate in the space commerce sector, much like what the Transcontinental Railroad did for businesses connecting the East Coast with the Western Frontier.

The United States of America has developed, maintains, and distributes, to the rest of the world, the largest free record of cataloged man-made objects in space, so called "Resident Space Objects". This catalog is owned and operated by the U.S.

Department of Defense, specifically our dedicated men and women of the U.S. Strategic Command (USSTRATCOM). Many organizations and entities around the world use these Orbital Safety products on a daily basis. However, for the growing needs and demands of the space community these products have been shown many times to be inadequate. They incur an increasing burden upon the USSTRATCOM primary mission, which is National Defense.

We need a CSTM system because:

- Orbital Debris experts worldwide agree that
  - Compared to what is being tracked in our USSTRATCOM catalog, the number of mission-damaging and debris-generating RSOs (1 centimeter in diameter and larger) is at least 100 times greater.
  - Two-Line-Elements (TLEs), which provide basic orbital information on RSOs, are insufficient to meet growing Orbital Safety needs because the theory is based on averaged motion and they lack any measure of uncertainty.
- We do not fully understand the reasons we cannot track more objects. All untrackable objects pose an unquantified level of threat or hazard to space operations and safety.
- For reasons of National Security, USSTRATCOM cannot be fully transparent in providing knowledge of where all trackable RSOs are located in space. This is at odds with efforts at the United Nations Committee On Peaceful Uses of Outer Space (UN–COPUOS) where we talk about transparency and confidence building measures (TCBMs) for collaboration.
- Russia has suggested the creation of a UN-developed and led effort to perform Space Traffic Management/Control. This is not a view accepted by everyone, but if we do not step up as leaders and provide a meaningful solution for others to join and follow, someone else absolutely will. It's only a matter of time.
- Europe is developing their own Space Situational Awareness (SSA) program and their own catalog of RSOs, as well as many other nations, in part because the USSTRATCOM products do not meet their SSA and STM needs and requirements.
- The number of RSOs is growing at a rate that is outpacing global governance measures for the space domain and environment.

What are the proposed components of a Civil STM System?

The CSTM Mission should:

- Assure the safety of operations in space.
- Maximize, foster, and incentivize the use of commercial capabilities and data sources.
- Provide transparency, advocacy of informed guidelines, and safety services as a public good to preserve the space environment for continued, unhindered, and uncontested access and use of space.

The CSTM Primary Functions would be to:

- *Observe and Monitor:* Space Domain and Traffic Observations, Space Situational Awareness (SSA)
- *Track and Catalog:* Identify, Characterize, and Catalog Objects; Relational Statistics, Catalog Updates, Traffic Attribution, Achieve Track "Custody"
- *Analyze and Inform:* Information Dissemination, Safety Products, Conjunction Data Messages

What are the next steps required to put this into effect?

- Provide the FAA with an adequately funded and resourced mandate to: (1) use their STM Pilot Program to work with the community and provide the first instance of a Civil STM system and (2) begin collecting and exploiting space object (*e.g.,* non-SSN tracking) data for orbital safety purposes, with an eye to do this via a Public-Private-Partnership.
- Create or expand the existing role of NASA to: (1) lead the technical requirements for a robust, effective, and meaningful CSTM System, and (2) to work closely with other government agencies, industry, and academia.
  - Conjunction Analysis concerns itself with predicting close approaches between any two RSOs; it is a growing and changing field, and research into new methods is critical to keep up with the rapidly changing and marginally predictable space environment. NASA already has a research investment in this

area (the CARA Program at Goddard Space Flight Center) that can be leveraged along with 30+ years of developing and executing this capability for use by civil space operators. It is government's role to retire risk, invest in Science and Technology (S&T) Research and Development (R&D), and share the results with the community to encourage growth.

- Invest in and expand the role of University Affiliated Research Centers (UARCs) as foundational, dedicated, and focused government-academic partnerships to solidify science and technology (S&T) research and development for critical space-related core technical competencies and technology risk-retirement needed by the U.S. Space Exploration program and Commercial Space Industry.
- Engage and craft mechanisms for Industry to get their investment and participation in a CSTM System:
  - Satellite manufacturers
  - Satellite launch providers
  - Space Insurance Brokers and Providers
  - Commercial Space Situational Awareness Providers
  - Space Angel Investors and Venture Capitalists
  - Space Service Users

Mr. Chairman, in the years since the end of World War II, American Exceptionalism has set standards to which the world has aspired. Right now, today, the world needs leadership in this issue. Implemented effectively, Space Traffic Management will provide secure access to space for our critical national infrastructure. It will guarantee America can lead the world in the commercial exploitation of space, and that America can maintain its lead over the world in space exploration and space science. This committee could provide that leadership, and the opportunity to act is before you.

Narrative

In my vast travels around the globe, speaking to and collaborating with space scientists, engineers, and policymakers, it is evident that "American Exceptionalism" is still invoked and desperately yearned for, by the many. America's leadership in the space domain, underscored by taking on and delivering upon what seemed to be an impossible feat, to send humans to another celestial body and return them safely, has inspired not only our great nation, but an entire planet, and seeded some of the world's most creative and innovative ideas.

Exploration is critical to who we are as a species; it drives our growth and evolution. When our minds and bodies are idle, we tend to self-defeating behaviors. What brings out the best in Americans? Rising to great challenges, and working as a nation to overcome them. What got Americans to the Moon and back, safely and repeatedly? Government, Industry and Academia working seamlessly, together. No one sector could do it by themselves.

The U.S. Strategic Command (USSTRATCOM) currently has over 24,000 records active in its space situational awareness database, commonly referred to as the Department of Defense "catalog." Of these, well over 18,400 records correspond to well-tracked, well-understood RSOs in Earth-centric orbit, roughly 1,300 of which are operational satellites; the rest are so-called "space junk." The remaining records in USSTRATCOM's active space situational awareness database are not as well-tracked or understood, which creates uncertainty when operational satellites are screened against them to identify possible spaceflight safety hazards, or conjunctions. The number of RSOs is increasing given an increase in launches, and on-orbit breakup events (*i.e.,* when one RSO collides with another, a satellite explodes, or breaks on its own due to space aging and material fatigue and stresses). If we could track every detected object, we could wrap a sensible Space Traffic Management system around that and even develop empirically-based policies and regulations. Unfortunately, it is hypothesized that we can only track a few percent of the total number of RSOs that can cause loss, disruption, or degradation to critical space services, capabilities, and activities. In other words, we have an orbital iceberg equivalent of sorts. The ability to track an object in space depends on two main factors: our ability to detect the object AND our ability to uniquely identify the object. This is to underscore that an object that is detectable does not imply it is trackable, and this is a critical distinction to make moving forward.

Tracking an object means that we know where it was, is, and have some idea of what it is and where it will be. Think of how we track air traffic, where the aircraft is in the custody of someone who monitors its motion and relationship to other aircraft. The following Figure (1) puts into perspective the problem we face in our in-

ability to track more of the objects we can detect. It was generated from real data collected by the U.S. Space Surveillance Telescope, about to be shipped to Exmouth, Australia. It is worth mentioning that while we will soon have a long-awaited Space Fence on Kwajalein, the results are likely to be much like with the Space Surveillance Telescope, as seen in Figure 1. When one has an exquisite sensor and it's unique, you'll get very accurate observations during a very small part of the total orbit and you'll be observing things that other sensors will not or cannot. Think of a hula-hoop. An exquisite sensor is having one hand on this hoop. Think about the variety of ways in which the hula-hoop can rotate if you only grab it with one hand. This is like the ambiguity you will have with a unique and exquisite sensor. It will help but you'll have a large number of objects that you can detect but will be unable to track.

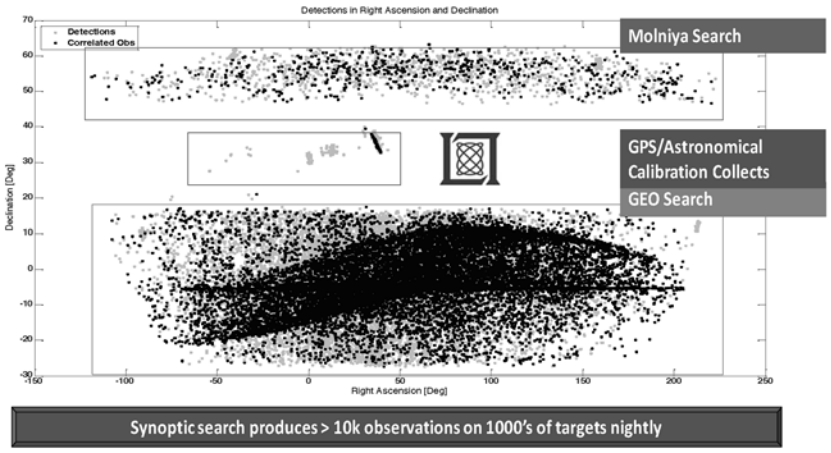

Figure 1. A Single Night's Worth of Resident Space Object (RSO Detections (for various orbital regions) from the U.S. Space Surveillance Telescope (SST) in New Mexico. Detections (dots) that are Black are those believed to be from known (cataloged) RSOs. All else (Cyan) are Detectable but Untrackable RSOs.

So, what prevents us from doing better at tracking objects in space? First, we don't have ubiquitous observations, meaning we don't persistently detect all objects all of the time. In fact, we generally have very sparse observations on any given object in space. Globally, we do not share observational data as a community. This lack of data sharing is perhaps the single most problem in us having a more robust space traffic monitoring and management capability. Secondly, every single object in the world's largest space object catalog (that of our DoD) is represented and modeled as a sphere, a cannonball in space! Needless to say, there aren't many man-made cannonball-shaped objects in space. Only those space objects whose motion is not significantly different from that of a sphere in between observations, are ones we can "track." Gravity is what I call an equal opportunity accelerator: just tell me where you are and I will tell you your acceleration due to gravity, regardless of your size, shape, material constitution, orientation, etc. However, there are non-gravitational forces experienced by objects and all of these depend on the object's physical characteristics. Thus, the lack of a rigorous object characterization and classification scheme is a strong contributor to our inability to track more objects in space. When we wish to understand any population of things, we first "tag" individuals in that population and then "track" these individuals through time, space, frequencies, and evaluate their interaction with other individuals and their environment. We formulate hypotheses, test them, and draw conclusions based upon evidence. We do not do this, rigorously and scientifically, for space objects. If we wish to someday have a Code of Conduct for Outer Space, we will need to know how many classes or species of space objects there are, and how each class moves, behaves, is influenced by the local environment, etc. Trucks carrying hazardous fuel are regulated differently than Vespa scooters, Oil Tankers on our seas are regulated differently than kayaks and canoes. So, why would we treat all things in space as the same thing . . . cannonballs? The following figure (2) is a cartoon to show the difference between the limitations imposed by assuming space objects to be cannonball-like versus what they actually are like.

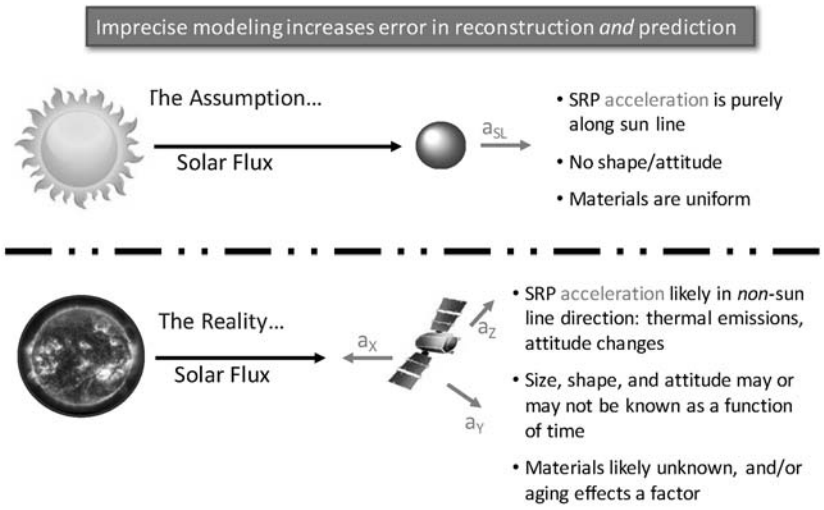

Figure 2. Difference between the motion experienced by a spherical (cannonball-like) space object and a satellite with realistic size, shape, orientation, and material properties. For the sphere, the acceleration due to the sun's effects are unidirectional. In reality, our tracking data informs us that objects experience accelerations due to the Sun's effects in 3-dimensional space (multi-directional).

Lastly, regarding our inability to track more objects in space, are the mathematics and physics we use to process the observed data and infer physical quantities regarding these objects. It really matters . . . call these our algorithms. Our representation of uncertainties is demonstrably and inarguably oftentimes flawed, unrealistic, and inconsistent amongst our software and tools. The following figure (3) shows a picture our current problem with having multiple detections at multiple times and having to find clever methods of uniquely identifying objects in order to make them go from detectable to trackable. Most RSOs are defunct and therefore do not self-report their identities.

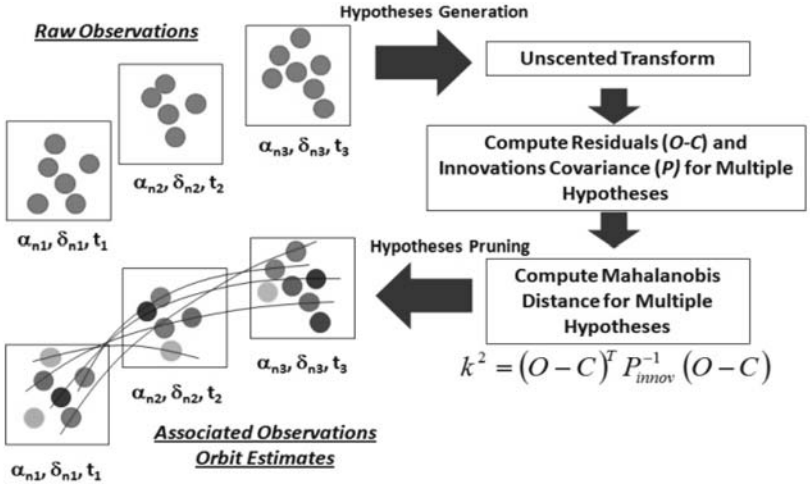

Figure 3. How to Uniquely Identify Space Objects from a Set of Unidentified Detected Objects in Order to Make Detectable Objects, Trackable. The method shown here is one of Multiple Hypothesis Testing as a mechanism to decide which detections should be paired to which objects.

If the RSO population was held constant, I'd say we'd have more time on our hands to figure this all out. However, our global space environment is on a path of suffering a *Tragedy of the Commons* given that our Geospace belongs to all humans and that many space actors behave according to their own self-interests without full consideration of the impact of their space operations and activities on the whole environment . . . our Space Commons!

As the cost of access to space is decreasing, the number of space actors is increasing. It's like what the Transcontinental Railroad did for helping businesses explode, connecting the East Coast and Western Frontier. Just a few months ago, we saw a record-breaking 104 satellites being deployed by India's PSLV space capabilities. Unfortunately, while they did assess potential collisions amongst these 104 satellites, no one performed analyses of potential collisions between those 104 newly deployed satellites and the remainder of the current RSO population. OneWeb just recently received the "green light" from the FCC to equip LEO with over a thousand satellites that will aim to provide global internet. SpaceX will surely be soon to follow with a planned ~4000 satellites.

As experienced in the Western Frontier of old, the environmental impact of runaway mining and prospecting was harsh and detrimental in many instances. Examples are mercury poisoning, silt in our water sources, etc. Our space environment is becoming much more commercially driven and populated. Many "New Space" companies or start-ups are getting significant investment from Angel Investors and Venture Capitalists who are focused on getting a Return On Investment (ROI) within a few years, believing Space Traffic and Orbital Safety to be someone else's problem. I have personally found an absence of space operations expertise amongst the workforce driving some of these "New Space" ventures, causing me further concern regarding orbital safety and long-term sustainability of space activities. There is a mentality of "take risks and fail often." While this worked well for software companies in Silicon Valley, we can't afford to have this exact mentality in space.

Existing orbital safety methods, information, and processes are not designed to handle the current space traffic conditions let alone the planned activities with larger satellite constellations. There are no standard "rules of the road" for space operations and activities, and we should avoid creating these in a vacuum, absent informed science and technology. While USSTRATCOM provides orbital safety products to the world for free on behalf of the U.S. Government, for very good reasons it cannot simultaneously be fully open and transparent and this is a self-evident obstacle to meaningful international collaboration and partnership due to its defensive responsibilities. I'm in full agreement with Gen Hyten, Gen Raymond, Rep Bridenstine, Rep Babin, and others in that a Civil Space Traffic Management (CSTM) system makes good sense to enabling more innovative U.S. space operations into the future.

A government-only solution makes no sense given that transparency, open sharing, ease of working with international partners, etc. is a strenuous situation for the U.S. Government at best. The government also lack the full spectrum of expertise required to do this job exceptionally well. A commercial-only solution makes no sense because no single entity has the solution to such a multi-disciplinary problem, nor does it have all the expertise required. Moreover, funding a company or consortium of companies to do this is likely to result in an inability for external input to be well received and incorporated. I've witnessed and experienced this, many times, as a Civil Servant.

Therefore, I propose that the best solution moving forward would be to create a Non-profit Civil Space Traffic Management (CSTM) Public-Private-Partnership (PPP) that will:

- Accelerate the pace and reduce the costs of CSTM development by modernizing approaches to SSA and STM, with focus on long-term sustainability of space activities, through the creation of new federated data standards, measurement standards, models and ontologies, open source software, and data management and analysis techniques that aid in the scientific evaluation of the efficacy and safety of space operations, and attendant policies.
- Act as a neutral public-private entity that could create consortia of industry, academia, and government for collaboration and sharing of databases, computational techniques, and standards.
- Operate a CSTM system that provides the accuracies and products necessary to safely enable innovative and non-traditional commercial uses of space.

The CSTM Mission should be to:

- Assure the safety of operations in space.

- Maximize, encourage, and incentivize the use of commercial capabilities and data sources.
- Provide transparency, advocacy of informed guidelines, and safety services as a public good to preserve the space environment.

The CSTM Primary Functions would be to:

- *Observe and Monitor:* Space Domain and Traffic Observations, Space Situational Awareness (SSA)
- *Track and Catalog:* Identify, Characterize, and Catalog Objects; Relational Statistics, Catalog Updates, Traffic Attribution, Achieve Track "Custody"
- *Analyze and Inform:* Information Dissemination, Safety Products, Conjunction Data Messages

The Tenants of a Non-Profit CSTM Public Private Partnership (PPP) would be to provide and incentivize:

- *Open observational data*—All collected or acquired data will be made open and available for 3rd party analysis to improve learning and enable high Quality of Service domain analysis.
- *Open catalog of space objects and events*—All derived conclusions from CSTM data will be made open and available for 3rd party verification and peer-review of results and conclusions.
- *Open Safety Advisory Services*—As these services are intended to be a global public good, they will be made available to the world.
- *Open and objective verification of data and analyses*—As the CSTM capabilities and processes improve, impartial feedback will be made available to all service providers in the spirit of achieving increasingly effective Quality of Service.
- *Open Market*—It is not the role of the FAA to define the economics of the data and/or analysis marketplace. The intent of the CSTM PPP is to empower industry to stay involved in the provision of service to all space domain actors.
- *Open Workforce Development*—It is to the benefit of all for the specialized skills required of effective space traffic managers to proliferate globally. To this end this CSTM PPP will support mechanisms which result in the education of additional skilled space traffic managers and analysts.

The Benefits of a CSTM PPP are that it would:

- Provide standard and benchmark data sets that enable quantifiably consistent comparative analyses between competing tools, techniques, and algorithms.
- Provide the government with a transparent mechanism to guide and exploit CSTM activities and capabilities AND a sustained/focused investment in STEM education.
- Provide industry with a free foundational CSTM service and a marketplace of focused, cost-shared and openly available sciences and technologies that it can "pick up" and operationalize/commercialize for its own profit.
- Provide academia with a sustained scientific and technological CSTM research and educational investment, to ensure that the U.S. is stocked with capable and skilled workforce to handle the scientific and technological problems of tomorrow.

How does industry profit from such an activity, financially? It can easily wrap profit-making services around the foundational "for public good" layer of orbital safety services and products. It lowers the bar for entry for new space initiatives as they don't need to shoulder the burden of self-providing of these orbital safety services. It's like the benefit of the U.S. developed, owned, and operated Global Positioning System (GPS)! Think of not only the paradigm-changing science but explosion of commerce that has resulted from this U.S. Government investment and service. Many companies have developed profit-making applications which exploit the layer of foundational service provided by GPS.

I also propose that the FAA's Center of Excellence in Commercial Space Transportation be leveraged as an existing mechanism under which a larger academic consortium could be assembled, invested in, and properly leveraged for Space Traffic Management. The current FAA CoE CST membership would need to be expanded upon and increased but focused funding would need to be appropriated and delivered to the CoE with a strategic roadmap on how the S&T is developed and transitioned to both government and industry. Several University Affiliated Research Centers (UARCs) should also be invoked, invested in, and leveraged, to be foundational partners in this STM research and development effort. The UARCs

could provide foundational capabilities and sciences to the FAA CoE CST and those CoE academic members could then focus them uniquely on STM needs and requirements, working closely with the government and commercial communities.

Two remaining points for me to make are (1) our society has become too risk averse. We say that we want to push the boundary of exploration except that we are intolerant to failure. This is a gross inconsistency. You can't have leading edge exploration with zero failure. Failure should be calculated but embraced as a necessity of pushing the limits of our science and technology. We maintain a leading edge by assuming and embracing risk. We would have never gotten man to the moon and back, safely, without taking risks! Had we not achieved this lunar exploration first and convincingly, our world would be quite different today, and I'm not sure it would be for the better. (2) I have been asked if the U.S. Government should take great strides in providing security clearances to as many academics as possible. My answer is, "no." Instead, put the effort in declassifying material that should have never been classified to begin with and material that no longer requires it. In other words, make as much information available to the largest pool of smart and passionate people as possible, without sacrificing national security needs, and our country will emerge victorious!

The motto of my research program at UT Austin, ASTRIA, is:

Ex Coelestis, Scientia . . . Nihil Arcanum Est! This loosely translates to, "from the heavens, knowledge . . . nothing hides!"

As Ever,

MORIBA K. JAH, PH.D.
Associate Professor,
Aerospace Engineering and Engineering Mechanics,
Cockrell School of Engineering,
The University of Texas at Austin.

Senator CRUZ. Thank you, Dr. Jah.

Mr. Cabana.

STATEMENT OF ROBERT D. CABANA, DIRECTOR, JOHN F. KENNEDY SPACE CENTER, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Mr. CABANA. Chairman Cruz, Ranking Member Markey, Senator Nelson, thank you for this opportunity to appear today to discuss NASA's public-private partnerships enabling commercial space. I submitted a statement for the record, but I've got a few remarks.

Since the end of the Shuttle program in July 2011, the Kennedy Space Center has gone through a major transformation, establishing itself as the Nation's premier multiuser spaceport, enabling both government and commercial operations to and from low-Earth orbit and beyond. This would not have been possible without the authorities granted by law that allowed us to establish the public-private partnerships that have totally reshaped KSC and Florida Space Coast. And I would like to thank Senator Nelson for his help in support of this effort.

Following the last flight of the Space Shuttle, KSC performed a thorough evaluation of all its facilities, identifying those necessary to support the Space Launch System and Orion, those that were excess and could support commercial operations, and those that were no longer needed and could be razed, thus, reducing our operating costs and becoming more cost efficient and effective.

Using a notice of availability in 2011, KSC went out to the commercial space industry to see who might be interested in operating and maintaining the excess facilities not scheduled for demolition. Working directly with the commercial space industry, and in partnership with Space Florida, KSC now has SpaceX, Boeing, and the Air Force all operating from former Shuttle facilities. And in Explo-

ration Park, a research and development park, on Kennedy property, but outside the secure perimeter, Blue Origin is now building a manufacturing facility approximately half the volume of the Vehicle Assembly Building for their New Glenn rocket, and OneWeb is building a satellite manufacturing facility.

These partnerships are not successful just because of the unique facilities made available, but also because of the effort made to allow our commercial partners as much autonomy as possible in their day-to-day operations.

Public-private partnerships work. Instead of having these facilities rust away in the salt air, we have enabled a vibrant and diverse commercial-government operation on the Space Coast that has already seen eight successful launches by SpaceX this year.

The International Space Station is a unique National Laboratory in low-Earth orbit that provides a destination for our commercial partners: Orbital ATK and SpaceX for resupply under the Commercial Resupply Services Contract, and Sierra Nevada Corporation, under CRS–2, as well as the destination for the Commercial Crew Program for Boeing and SpaceX, who will be flying crews to the International Space Station on test flights next year.

The NASA investment in ground systems to launch deep space exploration systems creates enormous synergies with private investment, leading to our shared future in space. As we move deeper into space with SLS and Orion, NASA is looking to expand our public-private partnerships through Next Space Technologies for Exploration Partnerships–2, or NextSTEP–2, where in August of last year, six companies were selected to develop prototypes or concepts for deep space habitats.

Public-private partnerships have worked well at KSC and across the agency. In order for us to be a successful nation, we need both government and commercial space integrated together. KSC is committed to successfully meeting NASA's mission needs and continuing to grow as a multiuser spaceport.

In all of human history, only three nations have sent humans to space: the United States, Russia, and China. Today, at the Kennedy Space Center, there are four United States companies building hardware and infrastructure to launch humans to orbit: Blue Origin, Boeing, Lockheed Martin, and SpaceX. I think that's pretty darn amazing and something that we can be proud of as a nation, and public-private partnerships have played a key role in making that happen.

Thank you for your time. And I look forward to your questions, sir.

[The prepared statement of Mr. Cabana follows:]

PREPARED STATEMENT OF ROBERT D. CABANA, DIRECTOR, JOHN F. KENNEDY SPACE CENTER, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Chairman Cruz, thank you for the opportunity to appear today to discuss NASA's public-private partnerships and enabling commercial space.

Since 1962, when it was formally established as NASA's Launch Operations Center, the Agency's John F. Kennedy Space Center (KSC) has helped set the stage for America's adventure in space. From the early days of Project Mercury, Gemini, and Apollo to the Space Shuttle and International Space Station (ISS) programs, from the Hubble Space Telescope to the Mars rovers, KSC enjoys a rich heritage in its vital role as NASA's processing and launch center.

Today, KSC is upgrading its ground systems in preparation for America's next great spaceflight endeavor—the exploration of deep space beyond low-Earth orbit with the Space Launch System and Orion. KSC's Ground Systems Development and Operations Program has transformed Launch Complex 39B to support the Space Launch System (SLS) heavy-lift vehicle and the Orion crew vehicle and the overall Exploration Systems Development work for human exploration of deep space. By the end of this calendar year, the construction of all the hardware and facilities necessary to support the processing and launch of the SLS and Orion will be complete and validation testing will ensue. The Orion spacecraft for Exploration Mission-1 is currently being built in the recently refurbished Operations and Checkout Building High Bay, and Launch Complex 39 will be ready to support the first test flight of the SLS and Orion in 2019.

In keeping with the history of terrestrial exploration, Government-led space exploration has enabled the rise of private sector space ventures that build off of Government-emplaced infrastructure. Since the end of the Space Shuttle Program in 2011, KSC has utilized public-private partnerships to establish itself as the Nation's premiere multi-user spaceport, supporting both Government and commercial flights to and from low-Earth orbit and beyond. With the extension of the International Space Station to at least 2024, the Commercial Crew Program is working diligently with our commercial providers, Boeing and SpaceX, to carry astronauts on flight tests to the Space Station from United States soil in 2018. Meanwhile, our Launch Services Program continues to procure and manage the commercial launch services needed to launch NASA's scientific, weather, and communications satellites, as well as robotic missions into the solar system and beyond. We have been successful in numerous commercial partnerships that have been instrumental in revitalizing underutilized facilities at no cost to NASA and taxpayers, while enabling commercial space operations.

NASA and KSC are moving forward into a new era of human spaceflight with activities in both low-Earth orbit and deep space, and we are committed to partnering with industry to enable commercial spaceflight companies to manufacture, process, and launch their systems from the Space Coast.

KSC's Philosophy on Public-Private Partnerships

Following the 2004 decision to end the Space Shuttle Program, it became clear that many of the facilities utilized to support the Shuttle would not be required to support SLS or Orion. Therefore, NASA conducted an assessment of the $2.7 billion worth of Shuttle assets to identify those we needed and those we did not. As a result of that assessment, KSC was able to determine which of those facilities should be demolished and which should be candidates for partnerships with outside entities. In 2010, KSC created what is now known as the Center Planning and Development (CPD) directorate to manage the strategic planning for this transition. CPD is tasked with developing partnering opportunities with Federal and non-Federal entities, including broadly announcing opportunities seeking partners to use KSC assets, as well as evaluating unsolicited partnership offers and ensuring that proposed partners offer value compatible with NASA's vision and strategic goals. Using this process, KSC was able to (1) leverage underutilized facilities to help U.S. companies develop new capabilities, reduce the cost of space activities, and create jobs on the Space Coast, while (2) preserving and revitalizing critical NASA assets by transitioning financial responsibility for those facilities to our partners.

KSC's Partnerships

Through a January 2011 Notice of Availability, NASA sought to identify potential outside interest in KSC assets that the Agency determined to be partially or fully available for other users at the conclusion of the Space Shuttle Program. The Notice sought to ensure broad awareness and visibility of the anticipated opportunities for partnerships between NASA and industry and other non-Federal public entities. NASA's purpose in pursuing such partnerships was to maximize utilization of KSC's unique infrastructure, while minimizing the Center's operations and maintenance (O&M) burden, and to enable commercial space operations.

KSC's partnership efforts have resulted in agreements of varying sizes with commercial entities, universities, as well as Federal, state, and local government for physical assets and services. The types of services range from providing launch sites to access to technical capabilities. KSC has been able to use our extensive launch vehicle and processing expertise to enhance the success of our commercial partners.

Looking across the KSC landscape, you can visually see the construction and modifications that Blue Origin, Boeing, Florida Power and Light (FPL), OneWeb, Space Florida, SpaceX, the U.S. Air Force and others have made to grow the industry on the Space Coast. Blue Origin is building a 750,000 square foot manufacturing

facility, just outside of KSC's secure area in Exploration Park, which is about half the volume of our historic Vehicle Assembly Building.

All three former Orbiter Processing Facilities house new spacecraft, the former Shuttle main engine shop is being used by Boeing to manufacture the service modules for its CST–100 Starliner spacecraft, and the former Processing Control Center will be used to monitor on-site spacecraft manufacturing and processing and throughout mission phases.

FPL currently is using 60 acres of former orange grove as a solar field to produce 10 megawatts of power to supply the grid. As part of our agreement, FPL built a one-megawatt solar field for NASA to offset our energy costs. FPL is responsible for the O&M of the solar field for 30 years.

OneWeb Satellites is building a 150,000-square-foot factory in the Exploration Park. OneWeb, in partnership with Airbus' American branch, intends to build 2,000 satellites that will form a constellation capable of wirelessly connecting every portion of the world to the Internet.

SpaceX commenced launches from Launch Complex 39A in February of this year. Amidst launches, they are modifying the launch pad to support future commercial crew missions aboard the company's Crew Dragon, as well as future Falcon Heavy launches.

In 2013, NASA selected Space Florida to take over operations at the Shuttle Landing Facility (SLF). Through this partnership, KSC's 15,000-foot runway can be converted to accommodate a wide range of users, supporting Government and commercial needs, while removing NASA's responsibility to maintain the associated facilities.

NASA has also selected Orbital ATK to negotiate an agreement under which it will occupy and operate from Vehicle Assembly Building High Bay 2, and negotiations are underway to use other processing facilities. These facilities are some of the largest on KSC and contribute significantly to the Center's O&M costs. NASA seeks to build on that success by continuing to search for opportunities to partner with outside organizations to reduce Government costs and enable the aerospace industry.

International Space Station

As NASA's processing and launch center, KSC is the gateway to the Station along with the Wallops Flight Facility. NASA is continuing to develop initiatives to use the Station to enable increased commercial investment and to transition to more public-private partnership models. The Center for the Advancement of Science In Space manages the activities of the ISS National Laboratory to increase the utilization of the Space Station by other Federal entities and the private sector. National Laboratory partners can use the unique microgravity environment of space and the advanced research facilities aboard Station to enable investigations that may give them the edge in the global competition to develop valuable, high-technology products and services.

Under the original Commercial Resupply Services (CRS) contracts, our two commercial cargo partners, SpaceX and Orbital ATK, provide cargo deliveries to Station. Through CRS contract modifications, KSC has been able to provide processing support of Orbital ATK's fourth, sixth, and seventh Cygnus cargo resupply missions to the Space Station. This opportunity enabled Orbital ATK to capitalize on the Center's expertise and infrastructure while also enabling the use of an alternate launch vehicle for cargo resupply missions to enhance operational flexibility. KSC also is currently looking at future partnership opportunities with Sierra Nevada Corporation as part of the follow-on CRS–2 contract.

NASA's commercial crew providers, Boeing and SpaceX, are developing the Starliner and Crew Dragon spacecraft, respectively. These companies have made significant progress toward returning crew launches to the United States, and NASA anticipates having these capabilities in place by 2019 to regularly fly astronauts on operational missions safely to and from Station. The crew and cargo vehicles, as well as the launch vehicles developed by these providers, have the potential to support future commercial enterprises as well.

It is NASA's intention to transition low-Earth orbit operations to private platforms and capabilities enabled by commercial markets, academia, and Government agencies, including NASA, that have an interest in and need for research and activities there. NASA continues to seek ways to further commercialize operations on the International Space Station. The next payload processing contract, Research, Engineering, Mission and Integration Services or REMIS, will enable the design and conduct of science operations in low-Earth orbit by the commercial market. The contract is targeted to be awarded July 2017.

Deep Space

NASA looks forward to expanded partnerships as we leave low-Earth orbit and head for deep space. In August 2016, NASA selected six United States companies to help advance our mission to put humans deeper into our solar system by developing ground prototypes and concepts for deep space habitats.

Through the public-private partnerships enabled by Next Space Technologies for Exploration Partnerships-2, NASA and industry partners will expand commercial development of space in low-Earth orbit while also improving deep space exploration capabilities to support more extensive human spaceflight missions.

Expandable habitats are one such concept—they require less payload volume on the rocket than traditional rigid structures, and expand after being deployed in space to provide additional room for astronauts to live and work inside. The Bigelow Expandable Activity Module (BEAM) is the first human-rated expandable habitat to be tested in space. During its two-year demonstration attached to the Station's Tranquility port, crew members will routinely enter the habitat to take measurements and monitor its performance to help inform future designs of habitat systems. BEAM will be tested to see how it performs in the thermal environment of space and how it reacts to radiation, micrometeoroids and orbital debris.

Government and Industry

Public-private partnerships have worked well at KSC and across the Agency. In order for us as a Nation to be successful, we need both Government and commercial space exploration. For instance, industry's vital role in low-Earth orbit transportation has lowered development and launch costs, and enabled NASA to invest in uncharted territories, like new technologies and deep space exploration. The work we do together and the lessons learned that we share are essential for the United States space economy.

Conclusion

KSC is committed to successfully meeting NASA's mission requirements and continuing to grow in its role as a multi-user spaceport that launches NASA's deep space exploration missions and catalyzes the continued growth and development of the commercial space industry. The long-term strategy to expand United States access to space and stimulate the development of the domestic launch industry continues to gain traction and minimize operating costs. NASA remains committed to meeting our Nation's goals in deep space human exploration with careful stewardship of our critical resources and wise investment of taxpayer dollars. NASA is making strides toward these goals with KSC's transformation into a multi-user spaceport of the future, where both Government and commercial space operations can be conducted and support one another.

In all of human history only three nations (United States of America, Russia, and China) have launched humans into space. Today at the Kennedy Space Center, there are four United States commercial companies building systems to launch people from the Space Coast (Blue Origin with the Space Vehicle, Boeing with the CST–100 Starliner, Lockheed Martin with NASA's Orion, and SpaceX with the Crew Dragon). This is an amazing time for our Nation, and one that I am proud to say that we have enabled at KSC.

Senator CRUZ. Thank you, Mr. Cabana.

And thank you to each of you for your testimony.

In the last Congress, this committee worked with our counterparts in the House to enact the U.S. Commercial Space Launch Competitiveness Act. One of the major components of that legislation was the continuation of the regulatory moratorium, preventing the FAA from implementing regulations governing commercial space flight that would affect the operations of the crews' transportation capabilities currently under development. While there is a regulatory moratorium right now pertaining to the FAA—and this is a question to any of the witnesses—can any of you identify for this committee any regulations that in your judgment are having a negative impact on the industry that Congress should examine?

Dr. JAH. Yes. Thank you. Right now, there's a policy issue that needs to be fixed with regards to commercial companies being able to go up in orbit and provide space situational awareness data to

folks. Other countries can do that; we can't yet. And NOAA has to provide a waiver for these companies to be able to do that. Unfortunately, there are reasons that some people feel, well, we should really take a look at this to figure out the best way forward, but I think that that will be something, a positive thing that could be done, is to remove that barrier because I think that's a severe hindrance in us being able to monitor and understand what's going on in space.

Senator CRUZ. OK. That's helpful.

Anyone else?

Mr. HUGHES. With respect to launch and reentry, this is governed by the FAA. And SpaceX, for instance, has 70 launches on manifest. Nearly all of them will be commercially licensed. The cadence and pace with which we are now launching, combined with startup companies and other companies that will be offering launch from the United States very soon, gives rise to concerns that the existing regulatory regime isn't rightsized for this volume of launch. So we want to make sure that the FAA has the right resources to carry out the launches and not be an inhibitor to growth in this business.

We also think the time is ripe for the FAA to go back and scrub the Part 400 regulations that are used for launch and reentry. They were written at a time where the United States might be launching six to eight times a year. They aren't really rightsized at this point for the volume that we're talking about. And here we're talking about things like transitioning from one-off boutique licenses to mission authorizations for missions that look similar in nature, and moving rapidly toward a recognition that the cadence of pace and launch dictates a new approach by the FAA. And here's—this is an area where we think a re-review would be quite helpful.

Senator CRUZ. Now, when you talk about rightsizing, are you focused on dollars and manpower, or do you think there need to be structural changes as well?

Mr. HUGHES. Primarily focusing on dollars and manpower, but, you know, I think any sort of study on this should look to the way to optimize any structure.

Senator CRUZ. Another significant component of the Commercial Space Launch Competitiveness Act was extending the life of the International Space Station to 2024. It is not clear from a technical perspective when we will reach the end of life of the ISS. However, to ensure that our national space program doesn't face a gap in capability post-ISS similar to what we are experiencing post-Space Shuttle, the NASA Transition Authorization Act of 2017 instructed NASA to come up with a plan so that at some point we can have a smooth transition from the ISS to our next capability.

To each of the witnesses, in your judgment, what will our national space program look like post-ISS? And do you have any recommendations for what the next major capability should be?

Mr. MANBER. Obviously, I spend little time thinking about that. Thank you, Senator.

As we look out in the next decade, we don't think there will ever be a facility in low-Earth orbit like the International Space Station. You can tell it was built by governments. I mean, it's just large,

it's connected. So if you want to do microgravity research, well, you don't really maybe want visiting astronauts. It's just everything is together in one place.

So logically, as you look out, you see a multiplicity of commercial platforms, some unmanned for in-space manufacturing. We are focused on in-space manufacturing deployment. Some will be for professional astronauts, warehouses, fuel depots, stepping stones as we go to deep space. We're looking at supporting ventures like Blue Origin and Orion as they go further out into deep space. We're looking at it with factories and warehouses.

So the answer to your question is I think we're going to see a multiplicity of commercial platforms, less expensive, dedicated to one use, just as you have on the Earth.

Senator CRUZ. Anyone else?

Mr. HUGHES. I share the view that low-Earth orbit will become a place where there are multiple platforms. There are a number of companies working on really exciting technologies for space habitats, whether in conjunction with the International Space Station, if it goes in the direction of privatization, or independent of the International Space Station. And to Jeffrey's point, this can be viewed as a stair step into deeper space exploration needs.

So when we talk about the U.S. enterprise after the International Space Station, I think it's important to think about a sustained human presence out further whether it's the Moon or Mars, SpaceX's focus, we've made no mistake about it, is focused on Mars. It's really one of the reasons for our being, to put human boots on Mars.

And NASA's program right now is focused on Mars as well. And we think there are complementary things that could occur to make sure that there is a sustainable presence on Mars long term, for instance, large cargo carriage to Mars to put the resources in place that would allow permanent human presence. That's not something that's currently in the trade space, and it might be something that would be really ripe for a prize or for a public-private partnership that sets a high-level requirement against which companies could bid to demonstrate their capability to do that.

Senator CRUZ. OK. Very good.

Senator Markey.

Senator MARKEY. Thank you, Mr. Chairman, very much.

Mr. Cabana, do you believe that there is a risk that we will lose key scientific and research capabilities in space if we largely turn over functions closer to Earth to private companies? What is the balance there to make sure that as a nation we are guaranteed to have access to that knowledge?

Mr. CABANA. Yes, sir. Well, I think the International Space Station has proven to be an outstanding test bed in preparing the Nation to actually have a permanent presence in low-Earth orbit to enable the commercial operations. I agree with the other panel members that have said that, you know, eventually it's NASA's goal to move out of low-Earth orbit. We know how to do that, and utilizing the Space Station as a stepping stone to enable operations to low-Earth orbit, I think we will establish the commercial presence to allow NASA to focus on the more challenging mission of exploring beyond our home planet.

So I think that as commercial space grows—and it's critical that we have a transition from the International Space Station and low-Earth orbit, that we continue to maintain that presence. I think that we will be able to do science in low-Earth orbit, and NASA will also participate in that science. It won't be a NASA space station, hopefully it will be a commercial space station that's up there as we transition, but that doesn't mean that we won't continue to do science in low-Earth orbit participating with our commercial partners. And I think that's where these commercial-government—these private-public partnerships are going to be critical to making that happen.

Senator MARKEY. OK, great. Thank you. Now, how do you believe the public would be best served by the National Lab when the International Space Station is retired? Should it be hosted by a new International Space Station or should it be hosted by a private station, or should it be a public-private partnership?

Mr. CABANA. Sir, I'm going to defer on that one to other folks at NASA, and we'll give you a more detailed written statement for the record rather than my opinion.

Senator MARKEY. Anyone out there have a view? Does SpaceX have a view, Mr. Hughes?

Mr. HUGHES. I think there's a natural progress for the International Space Station to transition to a private venture. When you look at the overall NASA budget, there is obviously a significant outlay year after year for the International Space Station. And if you want to do bigger things in space, eventually you may transition off the International Space Station into these broader goals. That said, the International Space Station is, as Mr. Cabana indicated, a critical stepping off point for deeper space exploration, and we shouldn't move off it prematurely.

Senator MARKEY. Mr. Cabana.

Mr. CABANA. I would just like to enforce that point. I think it's critical that we don't end the International Space Station until we have established commercial operations in low-Earth orbit. So right now the Space Station serves as a critical destination for our commercial partners for both crew and cargo as we develop this capability for commercial entities to operate in low-Earth orbit.

Senator MARKEY. And what do you think a reasonable timeframe would be, Mr. Cabana, for NASA reaching a conclusion as to what makes the most sense for the next era?

Mr. CABANA. Well, again, I agree, you know—I support—it's really good that we have until 2024, the Space Station would be capable of going beyond that. Again, I think it's something that we need to look at, and working with Bill Gerstenmaier in NASA headquarters, we can give you a more detailed answer on that.

Senator MARKEY. Thank you, Mr. Cabana.

Yes, Mr. Manber.

Mr. MANBER. Yes. If I may say that as I said in my remarks, that certainty is very important to us in the private sector. And so it's almost less important to us whether it's 2024 or 2026, as at some point in the next several years, I call for 2019, we say if these conditions are met in the private sector, we can see transitioning from current Station services so that we're able to raise the capital and other requirements that are necessary.

Senator MARKEY. So you're saying you don't want the decision in 2024 or 2026, that in 2019, everyone can adjust to the new——

Mr. MANBER. If the decision is announced and let's say you and Congress task NASA to say, "What would be the conditions?" We would like to see that by 2019 where we in the private sector can then begin to prepare and be ready by—I think we'll be ready before 2024, but if the Station is there to 2026 or 2028, fine, as long as we have certainty.

Senator MARKEY. Do you agree with that, Mr. Cabana, that the sooner that kind of a policy can be established, the better it will be for everyone, government and private sector?

Mr. CABANA. I think that it's important to work together with the government, with Congress, and the private sector to come up with a date that we want to transition from the Space Station, but we have to ensure that there is something to transition to.

Senator MARKEY. Exactly.

Mr. MANBER. Exactly.

Senator MARKEY. Mr. Manber?

Mr. MANBER. Yes, I would of course agree. I lived through the Shuttle gap, and we're all living through it now, and given the foreign interests as well, it's very important that the United States does not give up its role in low-Earth orbit.

Senator MARKEY. So are you saying, Mr. Manber, but it's better that we telescope the time-frame that it will take for us to reach some certainty——

Mr. MANBER. Yes.

Senator MARKEY.—because that plan would then most likely unleash a lot of the capacity——

Mr. MANBER. Yes, exactly.

Senator MARKEY.—which we have. So NASA has a stake.

Mr. MANBER. Right.

Senator MARKEY. The American—yes.

Mr. MANBER. And I'll say that I've been frankly pleasantly surprised how serious NASA—we interface with the folks at Johnson Space Center—how seriously they are taking this issue. And we're speaking to them monthly about, "How do you have, let's say, an International Space Station and also have a commercial platform at the same time? When does NASA give up offering on Station certain services if we have a platform and it also offers those services?"

These are complex issues. We recognize that. And I'm very pleased at how much our NASA colleagues are looking into this, but for us, it's certainty. We need private sector capital, and the first thing they ask us is, "When is the—," you know, "What's the policy?"

Senator MARKEY. Can you explain that to me just a little bit more? You're kind of saying that NASA is like a carnivorous vegetarian. It's——

[Laughter.]

Mr. MANBER. I wasn't aware I was doing that.

[Laughter.]

Senator MARKEY. Well, in a way you were.

Mr. MANBER. Yes. Well——

Senator MARKEY. You were saying, well—you know, there's an old song, "Did you ever have to make up your mind to choose as to one and leave the other behind? Did you ever have to make up your mind?" And that's what you're saying, that that creates more certainty in the private sector——

Mr. MANBER. Yes.

Senator MARKEY.—because they know then what their opportunities are, they can go to the capital markets and then they can move. So can you just expand upon that a little bit?

Mr. MANBER. Yes, yes. I mean, NASA and all the partners on the International Space Station have done a tremendous job of looking at, "How do you utilize a station? What do we use it for? How do we work together?" And now they're looking at, "How do you involve the private sector?" So I give them full credit for this mindset change.

But we've also identified at NanoRacks four to six markets that are not silly markets like branding or advertising, but certain in-space manufacturing and other markets we can't do on the International Space Station. It's holding back the development of in-space resources. It can't be done in the Station because it's manned. It can't be done on the Station because there are certain international requirements.

So as we look at further utilization, clearly there is a sunset where the Station has proven itself. I mean, my company's revenue is dependent on Station, so don't get me wrong, I'm not being critical, but the Station is serving its purpose, and we, in the private sector, believe in public-private partnerships, we can offer commercial platforms, we just need to know what you folks in Congress want from us.

Senator MARKEY. I understand. Thank you.

Thank you, Mr. Chairman.

Senator CRUZ. Thank you, Senator Markey.

Dr. Jah, on January 11, 2007, China launched a ballistic missile from Xichang Space Launch Center that aimed at a nonoperative Chinese weather satellite, the Fengyun 1C, completely destroying the satellite. The destruction of the satellite created more than 3,000 pieces of space debris, the largest ever tracked, and much of it is expected to remain in orbit for decades. According to NASA, more than 21,000 orbital debris larger than 10 centimeters are known to exist today.

For members of this committee who may not be as familiar with space debris, could you please explain the current state of space debris, how it is impacting space exploration, and what steps Congress should consider taking to address this issue?

Dr. JAH. Absolutely. Thank you very much. So, correct, there are about 21,000 pieces of debris that the U.S. Strategic Command tracks and maintains every day.

What are these things? Well, for one thing, most of the things that we launch in space don't come back, and at the end of their lives, it's almost like the car runs out of fuel, it just stops wherever it stops, and then you go get another car and you jump into that, and then you keep on driving. That's the state of what's going on up there.

Now, are there highways in space? Absolutely. There are certain orbital regimes that are being more and more impacted. In fact, thank you, Mr. Cruz, for the example with the Chinese ASAT test. At the sun synchronous altitude—so there are these kind of Goldilocks places, places where the gravity field is just right so that certain missions can be enabled for Earth observation, for communication satellites, the geostationary ring. So there are certainly Goldilocks kind of regimes. And sun synchronous orbital altitudes are becoming more and more congested.

Where the Chinese decided to do this was really a bad place because it falls into that sun synchronous orbital regime, a place where other people are trying to put satellites, like OneWeb and SpaceX, and these sorts of things.

And so what it does is two things. One, because we don't really understand the risk and we're not able to track everything because the smaller pieces are very difficult to track. I mean, 1-centimeter diameter pieces can be mission catastrophic, and those are extremely difficult to track.

So we detect many things. We can't track everything for a variety of reasons. Certain orbital altitudes are becoming more congested. And, again, it's not so much the number of things that we should be concerned about, but it's not being able to predict where these things are going to be from one moment to the next, and you have USSTRATCOM that are providing these free services to the globe saying, "We predict that at this time at this place there is a likelihood of collision of two objects," so that operators can try to move out of the way.

But how many of those are real? How many of those would actually happen? That's very difficult to calculate. And so that's part of the problem when it comes to the debris. It's increasing, it's not going down. There is no way to clean the stuff up. The European Space Agency has something called Clean Space, they're trying to identify different pieces of debris that they can go and remove, but it's not economically feasible to do that because it costs more to bring something down than to put something up that works.

And politically, it's not very feasible because any given nation that has a piece of debris assigned to them, they're the sovereign owners of that piece of garbage, and so it becomes problematic to just go up and clean other people's stuff.

Senator CRUZ. So are there any steps we can take that would be positive in terms of addressing this challenge?

Dr. JAH. Yes, sorry about that. So I think positive steps are, one, monitor things more collaboratively. And what do I mean by that? So USSTRATCOM has a Space Surveillance Network. It collects these data and it tries to produce orbits for things, but the actual sensor observations aren't shared. They're not shared with other people for very good reasons. Different countries have different sensors. And so everybody has their own eyes, but we don't have all eyes together.

And so because we don't share these observations kind of ubiquitously internationally and with other partners, I think the first step is create a data lake where all these observations can come together, expose it to as many people as possible to analyze, and just infer things, and through the exercise of the analysis and the

inference, I think you're going to end up with a better idea of what's up there and understand that better.

Senator CRUZ. So the FAA's Office of Commercial Space Transportation has licensed ten spaceports in seven states since 1996: two each in California, Florida, and Texas, and one each in Oklahoma, Alaska, New Mexico, and Virginia. I wanted to ask the witnesses, how is NASA working with these spaceports to support or enable its missions? And what can NASA be doing better?

Mr. CABANA. From a NASA point of view, we work very closely with the Air Force and the FAA at the Kennedy Space Center to make commercial operations a lot easier than they have been in the past. I think we've got a great partnership with the FAA, and especially the 45th Space Wing and General Monteith right now as we work to make it easier to launch from KSC, what's required for a commercial launch license, how the commercial customers meet that requirement.

As far as operating away from NASA's Kennedy Space Center, I'm not familiar with what NASA is doing in direct regards with any other spaceport. Now, we're working with other commercial customers to supply services for NASA, such as Virgin Galactic in the future, and so on, and they'll be operating, of course, out in New Mexico. So from that point of view, we work with the commercial customers, not necessarily the spaceports themselves.

Senator CRUZ. Anyone else on this?

Mr. HUGHES. I just wanted to echo some things in Mr. Cabana's statement there. First of all, I read his statement with great interest because it's remarkable the transition that Kennedy Space Center has undertaken since Shuttle retirement in 2011. Bob and his team have done an amazing job bringing commercial firms to Kennedy and getting us to a place where we can operate effectively. And the cadence of launch that I mentioned earlier that SpaceX is undergoing is a direct tribute to the work that he and his team are doing. And that is true relative to the Air Force, the 30 Space Wing and the 45th, General Monteith, Colonel Hough.

I think one of our chief concerns relative to the ranges and the spaceports is that there is infrastructure that could probably use modernization: the roads, some of the bridges. The electrical infrastructure at Vandenberg in particular is aging. We've had situations in the past where actually the electricity had gone out prior to a launch. And Senator Nelson has been very active in helping to modernize the infrastructure at the spaceports.

In order to keep the commercial companies running in conjunction with NASA, I think additional modernization of infrastructure would be quite helpful.

Senator CRUZ. Thank you.

Senator Markey.

Senator MARKEY. Thank you, Mr. Chairman.

Let me come back to you, Mr. Manber, if I can. Your initial partnership with NASA involved no funding from the agency to your company, which when dealing with the government is quite an innovative approach, and importantly, this meant that NanoRacks assumed most of the risk of the arrangement and could benefit from success, but protect taxpayers' dollars because very few of them were exposed.

Can you talk about how you see that expanding in the years ahead and what that could mean for as long as there is an established understandable policy for, again, a more rapid innovative era to unfold?

Mr. MANBER. It's a great question, Senator, because there are some things that governments do well and there are some things that government does not do well. And one of the things that government does well is provide some of the basic infrastructure that the private sector cannot. And just as Mr. Hughes was just alluding to, the infrastructure, the roads, in space, we have the Space Station, and it's a foundation, it's a platform. And what the private sector is doing through companies like mine is we're leveraging that investment that you've made on behalf of the taxpayer.

So really moving forward, I see the public-private partnerships of the future being where there are occasions where the government continues to provide an infrastructure. It could be, for example, the lower cost or space transportation that SpaceX and Dream Chaser and Orbital and others will be doing, and leave it to the private sector to provide some of the add-on services.

It could be, as we've talked about now with Orion, where there are certain basic things that the government is supporting, but the private sector, as I mentioned earlier, provides the fuel depots, the warehouses, at our cost, and we look to customers, whether it's in the government or whether it's in the private sector, asteroid mining or whatever it might be.

So some of my colleagues talk about this utopian view with less government. I don't see that and I don't welcome that. We need government, of course, as regulator, we need government as provider of infrastructure. So I think we need to find the right—I mean, look at aviation. I'll leave my expertise for a moment and say in this country, the government provides the safety officials, the FAA, and the air traffic controllers, and the government helps maintain the airports, but the private sector has the planes, sells the tickets, and worries that we get home on Thanksgiving along with the government. So for me, that's a model that may work in space as we move further out, with the government providing the infrastructure and the private sector selling the tickets.

Senator MARKEY. Mm-hmm. Interesting. Although there are many who want the FAA to be privatized as well.

Mr. MANBER. I said I was leaving my expertise.

[Laughter.]

Senator MARKEY. No, I appreciate that, provides this Committee.

Mr. MANBER. Yes.

Senator MARKEY. So, Mr. Hughes, could you speak to that question of where you see the balance in the future?

Mr. HUGHES. Yes, yes. So as we move into outside of low-Earth orbit into deep space exploration, I think that there's obviously a program of record right now that is NASA's central focus for deep space exploration, but I think it can be readily supplemented with public-private partnerships to allow us to sustain a permanent presence in space. So I mentioned earlier the idea of putting forward either prizes or high-level requirements that companies can meet relative to maintaining that human presence. One idea might be for the government to put forward high-level requirements rel-

ative to large cargo to Mars, or vertical takeoff and landing demonstrations on the Moon, or perhaps even something like establishing a more robust communications network that would enable more rapid and efficient communication to and from Mars.

Senator MARKEY. Do you need a prize to do it——

Mr. HUGHES. You don't——

Senator MARKEY.—or is the reward financially sufficient in order to make sure once the rule is set, that it's more like the Oklahoma Sooners, and they're just ready to go once they know what the rules are? So do we really need a prize?

Mr. HUGHES. No, I actually don't think a prize is necessarily the right approach. A prize could be one way to pursue it, but actually I think the preferable approach would be a COTS-like program that I referenced in my testimony where there would be some element of public-private partnership where high-level requirements are set, companies put their own skin in the game in conjunction with the government, and there's a long-term market against which you work.

Senator MARKEY. Mm-hmm. Interesting. OK.

Thank you, Mr. Chairman.

Senator CRUZ. Thank you, Senator Markey.

Senator Sullivan.

STATEMENT OF HON. DAN SULLIVAN,
U.S. SENATOR FROM ALASKA

Senator SULLIVAN. Thank you, Mr. Chairman, and I appreciate you and the Ranking Member holding this hearing. I think it's a—you know, we've always got to look out to the future and be inspired, and I think that's what we're trying to do here in a lot of ways. And I appreciate the witnesses and all your expertise on this important issue.

I wanted to ask about the importance of U.S. FAA-licensed spaceports to commercial space launches. In Alaska, we have the Pacific Spaceport Complex in Kodiak. Actually, just yesterday, you may have seen in the news, it conducted a THAAD missile test that was very successful.

And can you give me from your perspective what the benefits are from a commercial perspective of having these kind of—they go into really one of the topics of the hearing, which is really a public-private partnership approach, a little bit different from, say, the Kennedy Space Center. But just your thoughts on the importance of those kind of space complexes that we have like, for example, in Kodiak?

Mr. ELLIS. I can speak to that one. Thank you, Senator Sullivan. So as Dr. Jah pointed out before, there are different types of orbits, and there's kind of a Goldilocks zone that different markets fit into. So for us, especially being a small satellite launch company, and as OneWeb and SpaceX and these companies are making constellations, that having a launch site that is geography dependent to the technical requirements of the customer is very important. So in Alaska, at the Kodiak site you reference, you could reach what's called polar or sun synchronous orbits——

Senator SULLIVAN. And it's the only non-government-owned space complex that allows you to do that in the world, correct?

Mr. ELLIS. I'm not sure about the world, but in the United States that is true.

Senator SULLIVAN. Yes.

Mr. ELLIS. There is also a military missile range in Hawaii, Barking Sands, but they are doing more missile testing.

Senator SULLIVAN. But—go ahead.

Mr. ELLIS. Yes. So it's just very important that we look at markets and how they're changing and what needs customers have because right now having a West Coast launch site that is accessible other than Kodiak, it is a challenge.

Senator SULLIVAN. Great. Thank you. Any other thoughts on just kind of those kind of commercial space complexes, space launch complexes, what they can do for our capability?

Mr. HUGHES. So a little bit different than the spaceport concept, I can speak to SpaceX's experience with launch sites. So we have two launch sites at Cape Canaveral and one launch site at Vandenberg Air Force Base, and then a private launch site under development in Texas. Our work at Vandenberg and at Cape Canaveral has been critical, and we worked hand-in-glove at the Cape with Mr. Cabana's team to establish processes by which we can provide commercial launch, national security launch, and NASA launch as well.

And in the absence of public-private partnerships like the kind that enabled SpaceX to take on LC–39A, which is our newest launch site, the former Shuttle site, we would be inhibited from taking on the big manifest that we've acquired. Right now we have 70 launches on manifest. We took more than 50 percent of the global market last year for commercial satellite launch away from the French and the Russians. And in the absence of our commercial partnerships with NASA at both Kennedy and Vandenberg, we would not be able to service that manifest. So it's quite critical.

Senator SULLIVAN. Great. Let me broaden kind of a topic here. Did any of you—did any of the witnesses see the movie *The Martian*?

[Laughter.]

Senator SULLIVAN. So I took one of my daughters to see the movie *The Martian,* and I'm not a Hollywood movie critic or anything, but when you come out of a movie and your eighth grade daughter says, "Boy, I need to study math and science more because that looks like that could be a real interesting future," to me that was pretty inspiring and a pretty good movie.

And what do you see we should be doing to try to inspire the next generation of Americans beyond movies like that that can get them interested in what this whole hearing is about, which is kind of the future of space where, you know, in the NASA days and the Apollo space mission days, every young American was inspired? I think we've lost some of that, but we can regain it.

You guys are the experts. What do you think beyond just a good Hollywood movie we can be doing to inspire the next generation of Americans to do more math and science and maybe be on Mars in a couple decades? Yes. Anyone.

Dr. JAH. Yes. So thank you, Senator Sullivan. I think first and foremost, one of the things that—you mentioned Apollo and that

sort of inspiration. Those were days of what I would call real exploration where we strapped on the idea of taking risk.

Senator SULLIVAN. Yes.

Dr. JAH. I think we've become very risk averse——

Senator SULLIVAN. And why? Why did—after the Shuttle accidents and things like——

Dr. JAH. Yes. So the thing is, you know, taxpayers say, "I want to know where my dollars are going. I want guaranteed success as much as possible." And when you start levying those requirements of it has to be successful or else—I mean, JPL had a couple failures as well with Mars when I worked at JPL. And so when you levy that requirement, that really turns into doing the last thing that you did that worked, and that is not really pushing the boundary of exploration. And I think allowing NASA to go back to those days of you're in a risk retirement kind of mentality, and, you know, some bad things are going to happen and some lives are likely to be lost, I think strapping on that idea of risk to get out there and explore, I think that's the thing that will inspire our next generation, is to see bold moves and not just argument upon argument and incremental kind of things, but just bold, "We're going to do this and we're committed to it, and it's just going to happen."

Senator SULLIVAN. By the way, the Chairman and I are very interested in missile defense, and we hear that a lot from our experts in the missile defense area, that the risk of failure really inhibits us from making significant advances.

Anyone else on that question? I know—sorry, Mr. Chairman, is that all right?

Senator CRUZ. Take your time.

Senator SULLIVAN. OK. Thank you.

Mr. CABANA. I would like to add to that, sir. I think taking risk is important, I just want to take informed risk. I want to understand the risk that I'm taking and mitigate it as best as possible. Our Visitors Center at the Kennedy Space Center, it's totally run by—there are no appropriated dollars that run it.

Last year, we set a record for the number of visitors that we had, 1.6 million, and we're on track to beat that this year. There is great interest in space. And I go over there on a regular basis, and I'll just walk up to kids and ask them, "Hey, how did you enjoy your day?" and it's the exact right mix of entertainment, but also learning. And they are truly inspired when they see what's going on, when they see our history, but they also get a chance to see what our future is. And I think to continue to generate that interest in students today to pursue math and science, we need to continue on the path we're on.

We have to continue having launches at the Cape. I don't care what rocket it is or what's on it. Anytime a rocket ship leaves planet Earth, that is an inspiring experience, and people walk away from it motivated and enthused and wanting to be part of what we're doing.

I think we're on the right track. We just need to follow through, continue to build on what we've done, continue to have commercial launches, to have an exploration program for NASA to go beyond planet Earth to work in partnership with our commercial compa-

nies to make that happen. I think we're doing all the right things and we've just got to press ahead.

And I want to make—I read the book, the book is a lot better than the movie, but I saw the movie, too. I want to make *The Martian* happen for real.

Senator SULLIVAN. Yes.

Mr. CABANA. Everything except that part for the story at the beginning——

Senator SULLIVAN. Yes, we don't want to leave Matt Damon on Mars.

Mr. CABANA. I don't want to leave anybody behind. But——

Senator CRUZ. Do you have someone in mind that you want to leave there?

[Laughter.]

Mr. CABANA. No, but I volunteer to go. I'm ready. I think we need to continue to pursue this bold path that we're on and continue to have the success that we're having, and that's going to continue to generate this interest in math and science.

Senator SULLIVAN. Anyone else?

Mr. MANBER. Yes. Sorry. If I may make two quick comments. The first is on the risk aspect, one of the toughest things at NanoRacks was getting NASA and the Space Station program early on to recognize that failure was OK as long as it didn't hurt the safety of the crew. And they were just so focused that we had to build the customers' payloads so it would work 100 percent of the time, but the customer didn't want to pay that cost. And maybe they get 70 percent of their results, as long as it didn't—and today we're at a point with the Space Station program where they understand failures on the private sector side. If I don't get the hardware to work, my customer doesn't pay me. And so we're reaching a very interesting balance with NASA now.

On the education, let me say that one of the biggest surprises for NanoRacks when we started was our early customers were educational schools, and it's gotten to be such a huge program for us that we've created a new company, a public benefits company, called DreamUp. And it's separate from us. And we've flown four or five schools in Texas, in Houston. We've flown I think it's something like 40 high schools, we've flown high schools in Israel, 160 congressional districts of schools, with no NASA funding. And some of the parents have bake sales, they get together, they get local—the Subaru dealers, gives them sponsorship.

And so I can tell you that in the trenches out there, you know, in the small towns, the enthusiasm for space and education and research is huge, and that DreamUp is growing significantly, and it's wonderful, and there is no government funding.

Senator SULLIVAN. Great. That's great to hear. Anyone else on that important topic?

Mr. ELLIS. Yes, yes, I can speak to it. So as CEO of Relativity, I am humbled to speak on behalf of all of venture-backed startups. I can definitely tell you if you're getting venture capital, you do not dream small, you dream big, and you take huge risks, and you're looking for outsized returns.

So I think that setting an example, you know, myself, being a 27-year-old co-founder of a space company that's now tested rocket en-

gines at NASA Stennis Space Center, that I hope to be an inspiration for other people, and that members that join our team at Relativity and all of the other venture-backed startups are able to see that success, and having more winners will actually inspire people to go make that reality happen themselves.

Senator SULLIVAN. Great.

Mr. HUGHES. And I'll jump in as well. So SpaceX's goal, stated goal, for years now is to make humanity a multi-planetary species, a rather lofty goal, and it's one that we deeply believe in, and it drives almost every decision that we make within the company. And so I think setting big goals like that is critical.

And the way that the government can help to encourage this through public-private partnerships are to set high-level requirements and not tell companies how to complete them, but, rather, establish the requirements, partner with the companies to get them done and to get them in a way that is rapid and efficient, safe and reliable. There are a number of opportunities I think that we've got out to the right here to complement our existing program to get to Mars that can rely upon commercial capabilities, set these big goals, let private capital work in conjunction with government money to achieve these goals, and get it done in 4 to 8 years.

Senator SULLIVAN. Great. Thank you.

And thank you, Mr. Chairman. Thank you for holding this hearing. And I didn't get a—are you a fan of *The Martian* as well?

Senator CRUZ. I am, although an even more important technological innovation, if any of you could develop a lightsaber——

[Laughter.]

Senator CRUZ.—I think that would truly energize interest in space exploration.

I want to thank all the witnesses for being here. I think this was a productive hearing, a helpful hearing, with a lot of good, positive suggestions that came out of it.

The hearing record is going to remain open for 2 weeks. During this time, any Senators that have follow-up questions for the record, they're asked to submit them for the record, and upon receipt, the witnesses are requested to submit their written answers to the Committee as soon as possible.

And with that being said, thank you again. This is hearing is adjourned.

[Whereupon, at 10:29 a.m., the hearing was adjourned.]

A P P E N D I X

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. DAN SULLIVAN TO JEFFREY MANBER

Challenges Hindering DOD-Commercial Partnerships

Question 1. Earlier this year, in response to a provision that I included in the FY2017 National Defense Authorization Act (NDAA), the Department of Defense (DOD) released an Arctic strategy that among other points, highlights severe challenges caused by the limited satellite and terrestrial communications above 65 degrees north. When the DOD needs to quickly address gaps in capabilities, commercial partnerships can—where appropriate—play a key role in filling these needs.

What are the primary challenges that have hindered or prevented you from working with the U.S. Government to fill critical gaps in U.S. space capabilities, like the domain awareness and communications gaps in the Arctic?

Answer. There are challenges to working with the U.S. Government, but in more cases than before there is a mutual understanding that the commercial community can provide services, rather than hardware. And these services are economically efficient, and place the burden of risk not on the taxpayer but on the commercial organization. We are moving the scale of the needed public private partnerships more to the private sector. We at NanoRacks welcome that. But challenges remain. They are contractual and they are challenges of mindset. To many in the USG, small is still not desirable. Whether small hardware or smaller budget. It is changing, but it remains an obstacle. Also contractual. For a company like NanoRacks some of the key programs require an onramp that is thousands of pages long and require dedicated proposal writers who understand the jargon. During the Mercury and Gemini and Apollo days, some of the contracts were several pages long. We need a return to that. Here is what the USG needs. Please provide. If you don't provide, you don't get paid. If you do provide, here is the rate.

Internet Access in Rural Areas

Question 2. In Alaska, many places do not have any connectivity and many times are not even connected by road. It is costly to deploy telecommunications infrastructure, and while these communities are extremely innovative, a lack of connectivity hinders business growth and increased economic activity.

Commercial space provides the possibility of increased communications, including satellite-based broadband internet, at a reduced cost. Especially if the cost of launches continues to decline, this could provide real benefits to consumers in extremely rural places like Alaska.

How can recent advances in commercial space help provide broadband-level Internet to the most rural areas?

Answer. First off, commercial space offers a diversification of in-space opportunities. To be specific, this means that states like Alaska can have their own spaceport. How wonderful. We support the development of regional spaceports that meet the needs of the region. In this case, for Alaska, it is polar orbit launches that can accommodate small satellite constellations that meet much of the needs of the business and residential sectors. Commercial space offers off the shelf opportunities in satellite communications, satellite navigations, earth observation to monitor environmental issues and so on. There is now growing private sector capital available where there is a regional customer.

Question 3. Is latency still an issue?

Answer. As we understand, latency is still an issue.

Thank you for allowing us to respond. We welcome further dialogue on advancing commercial in-space services via the Alaska spaceport to meet the needs of the people of Alaska.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. DAN SULLIVAN TO TIM ELLIS

Challenges Hindering DOD-Commercial Partnerships

Question 1. Earlier this year, in response to a provision that I included in the FY2017 National Defense Authorization Act (NDAA), the Department of Defense (DOD) released an Arctic strategy that among other points, highlights severe challenges caused by the limited satellite and terrestrial communications above 65 degrees north. When the DOD needs to quickly address gaps in capabilities, commercial partnerships can—where appropriate—play a key role in filling these needs. What are the primary challenges that have hindered or prevented you from working with the U.S. Government to fill critical gaps in U.S. space capabilities, like the domain awareness and communications gaps in the Arctic?

Answer. Relativity is a new launch services provider for payloads following the "small satellite" form factor of less than 1,000 kg. Satellites in this weight class can potentially be a primary solution to communication gaps in remote locations, such as the Arctic areas described.

Primary challenges include open access to a launch site capable of satisfying the commonly used polar or sun synchronous orbits used by these satellite communication systems. Geography dictates that in the United States, a West Coast launch location is ideal to reach high inclination orbits without prohibitively flying over land or using a costly "dog leg" flight maneuver, such as from Wallops Island. The Pacific Spaceport Complex on Kodiak Island, Alaska is one such potential commercially-usable site, as well as Vandenberg Airforce Base in California. Both sites would need modification to be ideally capable of launching cryogenic liquid fueled orbital rockets optimized for small satellite launches. Some of these modifications include shipping, receiving, and ground transport infrastructure for rocket vehicles, cryogenic propellant loading and ground handling equipment, and expanded support for Autonomous Flight Termination Systems. We are beginning conversations with both sites to assess applicability to Relativity's needs, and would be happy to follow up with any other roadblocks or challenges we find.

A potential Hawaiian island located site, or drone and barge ship launch platform, could also help solve the challenge of U.S.-based launch sites open to smaller orbital rockets performing on a commercial basis. Streamlining procurement by the government through expanded use of Other Transaction Agreements (OTA) would incentivize emerging companies and startups with the most cutting-edge technologies to work with the government earlier in their lifecycles. This is due to the lower overhead requirements and streamlined procurement process agreements such as OTA's provide, which reduce the burden on personnel-strapped startups and allow transactions to happen more quickly for both parties.

Internet Access in Rural Areas

Question 2. In Alaska, many places do not have any connectivity and many times are not even connected by road. It is costly to deploy telecommunications infrastructure, and while these communities are extremely innovative, a lack of connectivity hinders business growth and increased economic activity.

Commercial space provides the possibility of increased communications, including satellite based broadband internet, at a reduced cost. Especially if the cost of launches continues to decline, this could provide real benefits to consumers in extremely rural places like Alaska.

How can recent advances in commercial space help provide broadband-level Internet to the most rural areas?

Answer. Relativity believes we are at the beginning of a huge growth phase in satellite Internet and connectivity capabilities. Several major, well-funded constellations of distributed "small satellites" are being developed that would greatly aid in solving the issue of rapidly deployable, low cost, high bandwidth access to remote areas such as in Alaska.

As mentioned above, this future is possible "especially if the cost of launches continues to decline". Relativity and several other private, commercial space launch companies are emerging to fill the needs of the emerging small satellite sector. Currently, none of the proposed and in-development Low Earth Orbit (LEO) satellite constellations are in full operating service. There is great promise, with significant funding going to both satellite companies and the launchers that will serve them. However, for the space ecosystem to capitalize on this opportunity requires an ROI incentive for continued private funding, advanced technology development, infrastructure buildup, and successful relationships with regulators and the U.S. Government.

Question 3. Is latency still an issue?

Answer. Yes. For streaming internet, video and voice communications, and applications with high inout bandwidth needs, latency at traditional Geosynchronous Earth Orbits (GEO) high above the Earth will always inhibit these systems from serving these low latency applications. This is a fundamental physical limit to the speed of signals traveling through a long, fixed distance through space. Medium Earth Orbits (MEO) and Low Earth Orbits (LEO) increasingly improve latency by locating satellites at lower and lower altitudes, and thus shorter transmission distances and times to the surface of the Earth. However, using MEO and especially LEO satellite constellations necessitates much larger numbers of satellites to provide continuous, effective coverage due to the orbital periods and ground tracks they require. The future of distributed LEO satellite constellations promises latency and bandwidth that is comparable to terrestrial coaxial cable and fiber internet, however none of these constellations are currently fully operational and are in various development phases.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. DAN SULLIVAN TO TIM HUGHES

Challenges Hindering DOD-Commercial Partnerships

Question 1. Earlier this year, in response to a provision that I included in the FY2017 National Defense Authorization Act (NDAA), the Department of Defense (DOD) released an Arctic strategy that among other points, highlights severe challenges caused by the limited satellite and terrestrial communications above 65 degrees north. When the DOD needs to quickly address gaps in capabilities, commercial partnerships can—where appropriate—play a key role in filling these needs.

What are the primary challenges that have hindered or prevented you from working with the U.S. Government to fill critical gaps in U.S. space capabilities, like the domain awareness and communications gaps in the Arctic?

Answer. SpaceX agrees that commercial partnerships can serve to rapidly support the development and deployment of capability for the Department of Defense, as well as other U.S. Government entities. We recommend the Government make fuller use of innovative Federal contracting strategies, like Other Transaction Authority (OTA) and commercial contracting methods in leveraging commercial capability. Specifically, some challenges include:

- Government requirements that add cost and schedule delay;
- Vague or poorly defined requirements;
- Use of non-commercial contracts and the imposition of unnecessary or inappropriate contract clauses and requirements onto commercial contracts;
- Costs and time associated with certification of commercial products and commodities for Government use;
- Number and scope of compliance documents associated with DOD contracts;
- Onerous and time-consuming proposal process for DOD contracts; and
- Unnecessarily slow acquisition processes.

Internet Access in Rural Areas

Question 2. In Alaska, many places do not have any connectivity and many times are not even connected by road. It is costly to deploy telecommunications infrastructure, and while these communities are extremely innovative, a lack of connectivity hinders business growth and increased economic activity. Commercial space provides the possibility of increased communications, including satellite-based broadband internet, at a reduced cost. Especially if the cost of launches continues to decline, this could provide real benefits to consumers in extremely rural places like Alaska.

How can recent advances in commercial space help provide broadband-level Internet to the most rural areas?

Answer. SpaceX agrees that even the latest terrestrial telecommunications infrastructure is often costly (or cost-prohibitive) with respect to extending broadband services to remote areas, particularly to certain terrains like those in Alaska. We also recognize the undeniable social and economic value that comes when communities can access quality, high-speed broadband. The disparity in available service to rural and "hard-to-reach" areas is the result of the heavy, up-front capital expenditures that terrestrial build-outs require to connect small and dispersed communities in such remote locations. Regulatory approvals, such as environmental approvals and local rights of way issues associated with siting cable and fiber broadband infrastructure, compound this problem. Additionally, given higher lati-

tudes, traditional satellites located high above the equator often cannot "see" all of Alaska's territory with comparable speeds and costs offered elsewhere in the Continental U.S.

SpaceX seeks to address the challenges of access by developing a next-generation satellite system that will apply innovative technologies to provide rapid broadband data rates and minimal latency. Initially, the SpaceX system will consist of 4,425 satellites operating in 83 orbital planes in orbits close to the Earth. This will include polar orbiting satellites designed specifically to serve high-latitude areas like Alaska. The SpaceX constellation is designed to provide a wide range of broadband and communications services for residential, commercial, institutional, governmental, and professional users worldwide. The goal of the system is to provide high-speed, low-latency broadband directly to end-users.

Our planned satellite constellation would remove the per-mile construction costs inherent in rural and remote broadband access solutions and bypass the complexity of expanding terrestrial broadband networks (for instance, digging trenches, environmental approvals, and property rights issues). By operating close to the earth, the system will replace typical speed and latency complaints from current-generation satellite broadband offerings with service speeds, latencies, and pricing equivalent to terrestrial and 5G wireless technologies available in urban centers.

By investing upfront in a large-scale global satellite constellation, the cost of reaching additional customers—even in the most remote areas of the world—becomes incremental. Because the system will bring global coverage, including high-latitude customers, the cost of reaching these areas becomes essentially the price of a consumer terminal.

Commercial space is further contributing to the deployment of such systems by driving down the high cost of launch. SpaceX, for example, has developed its Falcon 9 rocket to be highly reliable and affordable. We have further innovated to enable our rockets to be reusable by landing the first stage of rockets on land or at sea on ocean-going droneships, and then re-launching previously flown boosters. Reduced launch costs will enable the deployment of large satellite constellations that can then help Alaskans get connected to affordable, high-speed broadband internet.

Question 3. Is latency still an issue?

Answer. Current-generation satellite broadband services utilize geostationary (GEO) satellites that fly at altitudes of 35,000 km, resulting in higher latencies (typically around 250 milliseconds) as the broadband signals traverse to and from the satellite in space. By contrast, the SpaceX broadband system will operate in low-Earth orbit (LEO), at altitudes ranging from 1,110 km to 1,325 km. This dramatically shorter distance allows for latencies between 25–35 milliseconds.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. DAN SULLIVAN TO DR. MORIBA K. JAH

Challenges Hindering DOD-Commercial Partnerships

Question 1. Earlier this year, in response to a provision that I included in the FY2017 National Defense Authorization Act (NDAA), the Department of Defense (DOD) released an Arctic strategy that among other points, highlights severe challenges caused by the limited satellite and terrestrial communications above 65 degrees north. When the DOD needs to quickly address gaps in capabilities, commercial partnerships can—where appropriate—play a key role in filling these needs.

What are the primary challenges that have hindered or prevented you from working with the U.S. Government to fill critical gaps in U.S. space capabilities, like the domain awareness and communications gaps in the Arctic?

Answer. Thank you for the question sir. The primary challenges I have had have been:

(1) There is no real strategic and coordinated investment in government-related science and technology (S&T) research. There is an army of researchers and academics waiting to tackle our most dire S&T challenges and problems, but we cannot engage this community without a dedicated investment. Moreover, the small investment in S&T research that currently exists is scattered and each government entity funds work without being aware of what other government entities are funding. The U.S. Government is likely paying may times for the same work without knowing it. Each government entity needs to be free to invest in S&T research as it needs to satisfy its own gaps but much benefit could be had by having an office that coordinates this investment such that S&T can be leveraged across the government and to prevent funding the same work more than once. There should also be a strategic roadmap that

clearly identifies how the S&T research will be transitioned as it matures. The U.S. Government should also favor companies that propose solutions that leverage or build upon previous U.S. Government (taxpayer) investment. Germany has so called "Fraunhofer Institutes [1]" which are an effective marriage between government, industry, and academia. The U.K. has the so called "Satellite Applications Catapult."[2] The U.S. has so called "University Affiliated Research Centers."[3] These too should be reenergized and enlisted to serve a cohesive government, industry, and academic partnership in S&T research and development and risk retirement. These could be made to augment or compliment Public-Private-Partnerships for space domain awareness, space traffic management, orbital safety, and space commerce.

(2) The National Science Foundation (NSF) has not been historically keen to fund research in space-related technologies, areas where the Air Force Office of Scientific Research (AFOSR) has but AFOSR has a much much smaller budget. If the NSF could be motivated to complement AFOSR's investment areas in these topics, that would be greatly beneficial.

(3) Many U.S. Government meetings have required security clearances which I have, but most researchers do not. More unfortunately is that almost all of these meetings are absent any classified information being exchanged or shown. I've questioned why the U.S. Government continues to over-classify material and the answer is complicated. However, a great effort must be undertaken in making as much information as possible, available to the scientific and technological communities if we wish to empower our country in maintaining a leading edge regarding our space services and capabilities.

(4) The U.S. Government has focused upon developing systems making sure that the space systems (including the ground segments) themselves are robust and work, but paying much less attention to the accuracy of information being generated and distributed by these space systems. No one has been assessing the physical and statistical consistency amongst various space situational/domain awareness funded efforts. The assumption is that as long as different products and applications meet interface control requirements, all is good. This is a flawed assumption that works to our collective detriment. The world's best plumbing can distribute potable water or sewage.

(5) The U.S. Government is losing its internal competency to quantify and assess the goodness and accuracy of funded projects and delivered products. So, it relies strongly on what is called SETA support or FFRDCs. Unfortunately, these oftentimes work in their own self-interest and under the guise of information security, avoid independent scrutiny and peer-review. Many innovative, disruptive, and paradigm-shifting solutions never make it to the U.S. Government's table so to speak. The U.S. Government lacks an independent and unbiased group of people who can help it quantify and assess products to meet its needs for space situational and domain awareness. Scientific and Technological solution developers, providers, and integrators must never be the same people!

(6) Very rigid acquisition processes also hinder rapid and agile deployment of space services and capabilities, like communications in the Arctic. I suspect that initiatives like the Defense Innovation Unit Experimental (DIUx)[4] is a method to remedy this discrepancy.

Internet Access in Rural Areas

Question 2. In Alaska, many places do not have any connectivity and many times are not even connected by road. It is costly to deploy telecommunications infrastructure, and while these communities are extremely innovative, a lack of connectivity hinders business growth and increased economic activity.

Commercial space provides the possibility of increased communications, including satellite-based broadband internet, at a reduced cost. Especially if the cost of launches continues to decline, this could provide real benefits to consumers in extremely rural places like Alaska. How can recent advances in commercial space help provide broadband-level Internet to the most rural areas?

---

[1] *https://www.fraunhofer.de/en/institutes.html*
[2] *https://sa.catapult.org.uk/services/centres-of-excellence/*
[3] *http://www.acq.osd.mil/chieftechnologist/publications/docs/20130426_UARC_Engagement Guide.pdf*
[4] *https://www.diux.mil*

Answer. This is a very relevant question. Companies such as Planet Labs[5] have demonstrated an innate capability to rapidly and effectively deploy space based assets to fill gaps. Planet has paved the way for companies such as OneWeb and SpaceX to deploy massive numbers of space-based assets to deliver the very capabilities that you desire for Alaska and the world writ large. The activities of these companies should be encouraged and assisted as appropriate, without sacrificing the ability to motivate competing technologies. General Hyten created a commercial cell in the National Space Defense Center[6] for Battlespace Management, Command, and Control (BMC2) at Schriever AFB in Colorado Springs. The U.S. Government could take a page from this book and create a commercial cell that addresses communications and global Internet to meet our national needs. Perhaps this could be championed under the newly formed National Space Council.

Question 3. Is latency still an issue?

Answer. Yes, latency is very much still an issue but this can be mitigated and remedied via (a) leveraging other on-orbit assets as effective relays (b) heavily investing in quantum computing and communications as recently demonstrated by China.[7] (c) investing in autonomous satellite systems and networks (*e.g.,* via the Air Force Research Laboratory's Space Vehicles Directorate[8] including academic partnerships, and the Operationally Responsive Space[9] office) that can capitalize on Machine Learning and Artificial Intelligence to self-heal/repair and reconfigure in near real time in the presence of sensed latencies and/or outages.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. DAN SULLIVAN TO ROBERT D. CABANA

Challenges Hindering DOD-Commercial Partnerships

Question 1. Earlier this year, in response to a provision that I included in the FY2017 National Defense Authorization Act (NDAA), the Department of Defense (DOD) released an Arctic strategy that among other points, highlights severe challenges caused by the limited satellite and terrestrial communications above 65 degrees north. When the DOD needs to quickly address gaps in capabilities, commercial partnerships can—where appropriate—play a key role in filling these needs.

What are the primary challenges that have hindered or prevented you from working with the U.S. Government to fill critical gaps in U.S. space capabilities, like the domain awareness and communications gaps in the Arctic?

Answer. NASA employs several kinds of commercial partnership mechanisms to address U.S. space capabilities, including—but not limited to—Federal Acquisition Regulation (FAR)-based contracts to fulfill Agency requirements, as well as funded and unfunded Space Act Agreements (SAAs), which support and encourage commercial innovation. The Commercial Resupply Service (CRS) contracts, under which Space Exploration Technologies (SpaceX) and Orbital ATK have been providing cargo resupply to the International Space Station (ISS), are examples of the former. NASA's Lunar Cargo Transportation and Landing by Soft Touchdown (Lunar CATALYST) initiative, which has established multiple no-funds-exchanged SAA partnerships with U.S. private sector entities, is an example of the latter. The purpose of these SAAs is to encourage the development of robotic lunar landers that can be integrated with U.S. commercial launch capabilities to deliver payloads to the lunar surface. NASA looks forward to continuing commercial partnerships to address Agency requirements and to support commercial innovation in the future.

As to addressing U.S. space capabilities such as domain awareness and military communications in the Arctic, the Committee may wish to contact the Department of Defense for details on their efforts in these areas.

Internet Access in Rural Areas

Question 2. In Alaska, many places do not have any connectivity and many times are not even connected by road. It is costly to deploy telecommunications infrastructure, and while these communities are extremely innovative, a lack of connectivity hinders business growth and increased economic activity.

---

[5] *https://www.planet.com*

[6] *http://breakingdefense.com/2017/04/jicspoc-morphs-to-national-space-defense-centerwhat-it-means/*

[7] *http://www.sciencemag.org/news/2017/06/china-s-quantum-satellite-achieves-spookyaction-record-distance*

[8] *http://www.kirtland.af.mil/Units/AFRL-Space-Vehicles-Directorate/*

[9] *http://www.kirtland.af.mil/Units/ORS/*

Commercial space provides the possibility of increased communications, including satellite-based broadband internet, at a reduced cost. Especially if the cost of launches continues to decline, this could provide real benefits to consumers in extremely rural places like Alaska.

How can recent advances in commercial space help provide broadband-level Internet to the most rural areas?

Answer. While NASA defers to private industry to articulate the business case supporting the provision of services to specific customers, a number of companies currently offer launch services and satellite-based communications services that could potentially increase broadband Internet access in rural areas.

Question 3. Is latency still an issue?

Answer. Please see response to Question #2, above. NASA defers to private industry on the specifics for their ability to provide broadband Internet service to rural areas.

○