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CHALLENGES AND OPPORTUNITIES FOR HUMAN SPACE EXPLORATION

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BEFORE THE

SUBCOMMITTEE ON SCIENCE AND SPACE

OF THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION UNITED STATES SENATE

ONE HUNDRED THIRTEENTH CONGRESS

FIRST SESSION

APRIL 23, 2013

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CHALLENGES AND OPPORTUNITIES FOR HUMAN SPACE EXPLORATION

TUESDAY, APRIL 23, 2013

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

The Subcommittee met, pursuant to notice, at 2:38 p.m. in room SR–253, Russell Senate Office Building, Hon. Bill Nelson, presiding.

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

Senator NELSON. Good afternoon. Welcome to the second hearing of this subcommittee in the 113th Congress. Today, we are going to focus on the challenges and the opportunities for human space exploration beyond low-Earth orbit.

Human space exploration, we want to get back in that business. It is vital to our space program. It is vital to the science community. It pushes America's best and brightest to the limits of their creativity, and all of us on Earth benefit from it. The allure of exploration keeps our students in science, technology, engineering, and mathematics. Just look what the Apollo program did, creating a whole generation of young scientists and engineers and mathematicians. And, of course, it helps our country in our leadership in aerospace basic research and other high-technology areas.

In the authorization bill from two and a half years ago, we required NASA, "to expand permanent human presence beyond low-Earth orbit," calling on the agency to explore beyond LEO for the first time since the 1972 Apollo 17 mission, beyond low-Earth orbit.

Under the guidance of that authorization bill, NASA has been working with the Nation's space industry to sustain a human presence on board the International Space Station. It is designated as a national laboratory, one component of it. And with NASA's guidance, one U.S. commercial company has already delivered cargo to the station. And just this past Sunday, another commercial company successfully tested its new rocket, and that rocket will deliver cargo to the station later on. Efforts to enable commercial crew delivery capabilities are also well under way, and we look forward to those successes.

And so NASA sits at the nexus of the public and private space sectors, and these partnerships enhance what we can accomplish in space.

For exploration beyond low-Earth orbit, LEO, NASA is currently building and testing hardware for the new Space Launch System and the Orion crew capsule. These technologies will carry our astronauts further into space than ever before.

In 2014, a test of Orion will fly the capsule 15 times higher than the ISS before returning it to Earth at speeds near those that General Stafford, who is one of our participants today, reached in his reentry in the Apollo 10 mission. And that Orion capsule is now undergoing final construction in the O&C building at the Kennedy Space Center. Its heat shield, the largest ever built, is on its way from Massachusetts.

And following this test, the heavy-lift rocket and the capsule will fly together for the first time in 2017 and then carry its first crew in 2021.

NASA is also preparing its people and infrastructure to support this space exploration. To ensure that future missions have adequate ground support, of course, what they are going through is the upgrades of all of the ground support equipment and launch infrastructure. And those will enable us in NASA, the military, and also the operations in the commercial space sector.

So where do we go with these capabilities? Mars is the goal. With the right technology, SLS and Orion will be able to enable a wide range of human missions and destinations, which describe, going back to the authorization bill, include, "the surface of the Moon and near-Earth asteroids."

Two weeks ago, NASA announced its plan to capture a small asteroid and redirect it to a stable orbit around the Moon. And the concept is still being studied, but if NASA can find a suitable asteroid and redirect it with a robotic mission in time, our astronauts could visit and study the asteroid during a 2021 SLS-Orion flight. And so we are going to hear about that today.

Research is also under way to better prepare astronauts for the dangers of exploration beyond low-Earth orbit. The Johnson Space Center in Texas, the hometown of this subcommittee's Ranking Member, Senator Cruz, houses NASA's Human Research Program. Many who have traveled into space participate in an annual physical at the Johnson Space Center.

NASA is going to continue to learn about the effects of microgravity on the body when an American and a Russian start their 1-year stay on board the International Space Station. We are learning a lot about the effects of zero-G and bone loss as a result of zero-G. We are going to learn at the Johnson Space Center all of the effects that we possibly can on radiation on the human body and how to protect us when we are going all the way to Mars, and what are the kinds of shields that we have to have in case there is a solar explosion on the way to those planets, or, in fact, if we are on a Moon base, what do we have to protect human life.

So NASA's exploration efforts are strong, and they are well under way. And there are a lot of challenges, particularly in this fiscal climate that we find ourselves. But with the leadership that we have seen, with the creativity, with the dedicated contractor force and the civil service workforce, then we would have reason to believe that NASA can achieve the goals.

And so I want to welcome our witnesses here. I want to thank them. This is going to be an exciting topic to discuss.

Our first witness is NASA's Associate Administrator for Human Exploration and Operations, Bill Gerstenmaier. And he is going to give us an update on SLS and Orion and on the technology needed for this human exploration and on this "gee whiz" asteroid mission.

Then, of course, we are very fortunate to have someone who is not a stranger to this subcommittee, and he is our Air Force, retired, Lieutenant General Tom Stafford. He went down and orbited the Moon on Apollo 10. And, of course, one of the great thaws in the Cold War occurred high above the Earth in 1975 when a Soviet crew joined up with an American crew and they lived together in space for 9 days in the midst of the Cold War. General Stafford was the commander of that mission. And who better to discuss the value of international partnerships, especially in human space exploration, than the man who has been there and seen it since its inception? And, of course, in his position when he left the astronaut office, went back into the Air Force, he was the Deputy Chief of Staff for Research, Development, and Acquisition and was involved in the initiation of a stealth fighter. He wrote the initial specifications for the B–2 stealth bomber. He knows technology.

And then we have Mr. Steve Cook, the Director of Space Technologies for Dynetics. He is going to address NASA's partnerships with industry, the roles of government and private sector together in human exploration, as well as the policy needs.

And so, thank you all for being here.

Senator Cruz?

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

Senator CRUZ. Thank you, Mr. Chairman, for calling this hearing today on the path of human space exploration.

Thank you to each of our distinguished panel members for joining us this morning. I appreciate the opportunity to stand side-by-side on this vital national priority and the opportunity today to hear from this distinguished panel on your wisdom and insight and your years of experience on space policy, in particular addressing NASA's long-term mission and any challenges that are presented to that mission by the path we are on today.

I also look forward to hearing further about how the commercial sector is making an important contribution to achieving these goals and how we can further expand that partnership, including perhaps learning lessons about how government can be more efficient and how our space program can continue to generate opportunities for commercialization that generates economic growth and jobs throughout the private sector.

It is critical that the United States ensure its continued leadership in space. And that will require broad support from a range of stakeholders, from the general public to the U.S. Government to the scientific community. And I look forward to this opportunity to learn from each of our distinguished panel members here today.

Thank you.

Senator NELSON. And we want to welcome in the audience a number of people that are attending the suppliers' conference of the SLS-Orion suppliers.

And so, let's start with you, Mr. Gerstenmaier. We will go right down the table. And then we will get into some questions after all of you have testified.

Your formal remarks are inserted in the record, and if you would share with us verbally a shortened version.

Thank you.

STATEMENT OF WILLIAM H. GERSTENMAIER, ASSOCIATE ADMINISTRATOR, HUMAN EXPLORATION AND OPERATIONS, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Mr. GERSTENMAIER. Thank you very much for asking me to represent the NASA team for this hearing on challenges and opportunities for human spaceflight.

This is a very good time for human spaceflight. The International Space Station is making tremendous progress in space-based research. The ISS is beginning to show its potential as a world-class research facility. Many of the early findings have direct application for people on the Earth.

Expedition 34's patch had the statement, "Off the Earth, for the Earth." This statement captures well one of the reasons for ISS. There are several Earth science payloads scheduled to fly in the next year as a direct application of that expedition's statement.

The recent results from the Alpha Magnetic Spectrometer are also providing unique data on the potential for dark matter in the universe. The Alpha Magnetic Spectrometer is also providing unique data on the cosmic background radiation environment of space. This data will be critical as we send humans beyond the protection of Earth's magnetic fields.

Lastly, the Center for Advancement of Science in Space, CASIS, is beginning to find real interest in space-based research from a variety of new users. ISS is doing great things.

Commercial cargo is proceeding well, with SpaceX having completed two cargo missions to the ISS. The next Space Station mission will carry an externally mounted optical communications package and an Earth-viewing high-definition camera also mounted on the outside of ISS.

Orbital just completed a test flight of the Antares rocket from Wallops on Sunday. This was a tremendous accomplishment, both for the vehicle and the launch pad. Orbital will next fly a demonstration mission to the ISS in June or early July.

U.S. companies are stepping up to the task of keeping the International Space Station resupplied. Commercial Crew is making tremendous progress in implementing the acquisition strategy and vehicle designs. The draft RFP for the certification and demonstration flight should be out in the next 2 months.

All of these efforts complement the use of ISS in demonstrating the commercial value of space.

The heavy-lift launch vehicle, SLS, and Orion are also making tremendous progress. The SLS design is maturing. Welding equipment is being assembled in New Orleans. And by the end of this

year, all major weld schedules will be completed for the core stage. The goal is to begin manufacturing next year in New Orleans.

The Orion capsule is in Florida being outfitted and tested for its test flight next year. The heat shield, as you said, was in Boston having thermal protection material installed. This test flight will provide critical entry performance data for the heat shield. It is really exciting to see a flight vehicle being assembled and outfitted in Florida again.

Finally, work is beginning on the B–2 test stand at Stennis. This stand will test the core stage propulsion systems in late 2016 prior to shipping the core stage to KSC for flight in 2017.

The work on the service module with the European Space Agency for Orion is continuing, with significant progress being made. It is clear that international cooperation will be part of any future exploration endeavor.

NASA has announced a strategy that unites scientific observation, technology development, and human spaceflight activities into a unified approach. The first step in this strategy is an asteroid-retrieval mission with crew-aided sample return on Orion. The mission will use the work done in the Science Mission Directorate for asteroid detection, work done on solar electric propulsion by the Space Technology Mission Directorate, and work done on the Orion and SLS by the Human Exploration and Operations Mission Directorate. The experiences learned from this mission will provide a critical framework for human exploration beyond low-Earth orbit.

This is an exciting time in human spaceflight. We have made tremendous progress in the last year, and we have solid plans for the future. I look forward to your questions. Thank you.

[The prepared statement of Mr. Gerstenmaier follows:]

PREPARED STATEMENT OF WILLIAM H. GERSTENMAIER, ASSOCIATE ADMINISTRATOR, HUMAN EXPLORATION AND OPERATIONS, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Mr. Chairman and Members of the Subcommittee, thank you for the opportunity to appear before you today to discuss NASA's human spaceflight efforts. The Human Exploration and Operations (HEO) Mission Directorate encompasses NASA's human spaceflight activities in Low-Earth Orbit (LEO), the development of exploration vehicles to take astronauts beyond LEO, research and technology development efforts to enable deep space exploration, and critical infrastructure and operational capabilities that ensure NASA's ability to conduct testing, launch science missions, and communicate with its spacecraft across the solar system. The Agency is developing spaceflight capabilities to send humans to an asteroid by 2025 and on to Mars in the 2030s. We are building the world's most powerful rocket, the Space Launch System (SLS), and a deep space exploration crew vehicle, the Orion Multi-Purpose Crew Vehicle (MPCV). American astronauts are living and working in space on board the International Space Station (ISS), conducting an expanding research program with an array of partners. By partnering with American companies, we are resupplying the ISS and launching these missions from U.S. soil, and we are on track to send our astronauts to space from American shores in just the next few years.

The International Space Station: Frontier of Research and Technology Development in LEO

The ISS, with its international crew of six orbiting Earth every 90 minutes, is an unparalleled asset for the conduct of research and technology development in a unique, microgravity environment. The ISS has transitioned from an era of assembly to one where our full focus is on operations and research to: (1) improve our ability to live and work in space, including enabling human exploration beyond LEO; (2) develop a demand-driven commercial transportation and research market in LEO; (3) enable science, engineering research, and technology development in the fields of Earth, space, life (biological and human research), and physical sciences;

and (4) derive tangible benefits for folks on Earth. As of September 2012, 1,549 experiments had been conducted aboard ISS, involving more than 1,500 scientists from 68 countries, resulting in more than 588 scientific publications. The first results from the Alpha Magnetic Spectrometer (AMS) experiment on ISS were announced at CERN (the European Organization for Nuclear Research) on April 3, 2013. This cosmic ray particle physics detector will increase our knowledge of physics and astrophysics, and help address the mysteries of dark matter.

The ISS is enabling advances in science and research that benefit humanity today and hold the promise for further advances and discoveries. For example, research onboard ISS has already assisted coastal disaster recovery efforts across the globe through Earth imaging sensors. Research is also contributing to understanding many ailments faced by the elderly, including bone loss (osteoporosis), immune system degradation, and loss of balance. The ISS is also conducting technology demonstrations and development efforts to advance human and robotic exploration beyond LEO and serving as the foundation for an international exploration partnership. We are grateful to Congress for extending NASA's exception under the Iran, North Korea, Syria Non-proliferation Act (INKSNA), which will allow the Agency and its international partners to continue to operate ISS through at least 2020.

Working closely with the ISS Program, HEO's Space Life and Physical Sciences Research and Applications (SLPSRA) Division advances our knowledge of biological and physical sciences, and the Human Research Program continues to develop biomedical science, technologies, countermeasures, diagnostics, and design tools to keep crews safe and productive on long-duration space missions. The progress in science and technology driven by this research is expected to have broad impacts on Earth as it advances our ability to support long-duration human exploration. SLPSRA also serves as NASA's liaison to the non-profit Center for the Advancement of Science in Space (CASIS), which is now managing the ISS National Laboratory for research being done on ISS by the academic and commercial organizations participating in the evolving utilization of LEO space for innovative new purposes.

NASA's plans for the coming year on ISS include preparing for an extended duration, year-long human-crewed mission to explore human adaptation to space, continuing to utilize the ISS for technology demonstrations enabling future exploration, and the addition of three Earth Science instruments that will exploit ISS capabilities to study winds over the oceans and the movement of dust, smoke, and pollution through the atmosphere.

The Space Technology team at the Johnson Space Center in Texas is working to increase capabilities for the Robonaut 2 demonstration on ISS and further the Agency's development of next-generation tele-robotics systems. In addition, Space Technology is using the SPHERES satellites on ISS to demonstrate autonomous rendezvous and docking techniques and liquid slosh dynamics which serves to validate mission design for both spacecraft and launch vehicles.

There are two U.S. companies supporting the ISS under Commercial Resupply Services (CRS) contracts. Space Exploration Technologies (SpaceX) was awarded 12 cargo flights to the ISS, and Orbital Sciences Corporation (Orbital) was awarded 8. SpaceX executed its first cargo mission to the ISS in October 2012 using the Falcon-9 rocket and the Dragon spacecraft, successfully delivering cargo and returning scientific samples to Earth. Recently, SpaceX successfully completed its second CRS mission. The Dragon spacecraft lifted off from Cape Canaveral Air Force Station in Florida on March 1, 2013, carrying about 1,268 pounds (575 kilograms) of supplies and investigations. On March 26, it returned about 2,668 pounds (1,210 kilograms) of science samples, equipment and education activities. Orbital's first contracted cargo resupply mission under CRS is slated for later this year. Orbital launched its Antares rocket this past Sunday from the new Mid-Atlantic Regional Spaceport Pad-0A at the Agency's Wallops Flight Facility in Virginia. The test flight was the first launch from the pad at Wallops and was the first flight of Antares, which delivered the equivalent mass of a spacecraft, a so-called mass simulated payload, into Earth's orbit.

Promoting the Development of American Commercial Crew and Cargo Systems

NASA's Commercial Spaceflight efforts support the development of safe, reliable, and affordable commercial systems to transport crew and cargo to and from the ISS and LEO. A top priority for NASA and the Nation is to affordably and safely launch American astronauts and their supplies from U.S. soil, ending our reliance on foreign providers and bringing that work back home.

In the area of cargo transportation system development, SpaceX has successfully completed its Commercial Orbital Transportation Services (COTS) efforts, and only two activities remain for Orbital under the COTS program: launch vehicle test flight

and ISS cargo mission demonstration. Orbital plans to conduct a demonstration flight of the Antares with the Cygnus spacecraft to the ISS this summer under the COTS effort, prior to commencing contracted cargo resupply flights to ISS, as noted above.

The Commercial Crew Program (CCP) aims to facilitate the development of a U.S. commercial crew space transportation capability by 2017, and full funding of the FY 2014 request is essential to restore a human spaceflight capability to the United States in this timeframe. Reduced funding will delay the operational availability of domestic commercial services, extending the period during which NASA will be solely reliant on international partners to provide crew transportation and rescue services to the ISS. Since initiating this program in 2009, NASA has conducted two Commercial Crew Development (CCDev) competitions for industry to advance commercial crew space transportation system concepts and mature the design and development of elements of the system. In August of 2012, NASA announced new agreements with three American companies—Boeing, Sierra Nevada and SpaceX—to develop and demonstrate the next generation of U.S. human spaceflight capabilities under the Commercial Crew Integrated Capability (CCiCap) program. Between now and May 2014, NASA's partners will continue to perform tests and mature their integrated designs. Certification of these systems has begun in parallel under a separate Federal Acquisition Regulation-based contract known as the Certification Products Contract (CPC). NASA anticipates releasing a draft Request for Proposals (RFP) for phase two of this effort in July of this year, with the final RFP to follow in October 2013. Once commercial crew transportation systems are certified by NASA, the Agency plans to procure transportation services from commercial entities for NASA-sponsored personnel to and from the ISS.

Preparing to Send Astronauts Beyond LEO into Deep Space

Because our commercial space partners continue to make rapid and cost-effective progress toward meeting the Agency's requirements for access to the ISS and to LEO, NASA is able to focus its human exploration resources to develop the deep space capabilities represented by the SLS and Orion MPCV. NASA's exploration efforts include the Orion MPCV spacecraft, SLS heavy-lift launch vehicle, and Exploration Ground Systems (EGS) infrastructure required to support crewed missions of exploration into deep space, including a mission to send astronauts to an asteroid that has been redirected into a stable orbit around the Moon.

Orion will carry four astronauts to, and support operations at, destinations in our solar system for periods of up to 21 days. Exploration Flight Test-1 (EFT–1), an uncrewed, atmospheric entry test mission of the Orion to test spacecraft systems, is on track for launch in FY 2014. EFT–1 will see Orion conduct two orbits of Earth and reenter the atmosphere at a high speed characteristic of a returning deep space exploration mission. The test will provide valuable data about the spacecraft's systems, most importantly, its heat shield. The flight test article for this mission is already in place at the Kennedy Space Center and being readied for this test. In 2012, NASA signed an agreement with the European Space Agency (ESA) for ESA to provide a service module for the Orion spacecraft's Exploration Mission-1 in 2017. The new agreement is in accordance with existing International Space Station (ISS) agreements and builds on NASA's existing strong cooperative relationship with ESA on ISS and other activities. It continues and expands international collaboration as humans explore new frontiers in the solar system.

The heavy-lift SLS will initially be capable of lifting 70–100 metric tons before evolving to a lift capacity of 130 metric tons. The SLS will use a liquid hydrogen/liquid oxygen propulsion system, with a Core Stage utilizing existing Space Shuttle Main Engines for the initial capability. While the first two SLS launches will feature five-segment solid rocket boosters (SRBs) based on the Space Shuttle SRBs, NASA is looking to the future and Advanced Boosters, which may be either solid or liquid rockets. For the upper stage, SLS will use an Interim Cryogenic Propulsion Stage (ICPS) for the first two exploration missions. NASA is evaluating the appropriate phasing of advanced boosters and upper stages to meet mission architecture needs and within the budget. Later missions will use an upper stage to realize the 130-metric-ton capability beyond 2021.

Exploration Ground Systems (EGS) will develop the necessary infrastructure and procedures at the Kennedy Space Center to prepare, assemble, test, launch, and recover the Exploration architecture elements. EGS will focus on the launch complex as an integrated, multi-use capability to enable more efficient and cost-effective ground processing, launch and recovery operations.

NASA plans to launch Orion on the uncrewed Exploration Mission-1 test flight in 2017, and the first crewed flight of SLS/Orion—Exploration Mission-2—in 2021. These two missions will test and demonstrate these systems, which will be used to

send a crew to visit an asteroid which has been redirected into a stable lunar orbit. It should be noted that these dates are dependent on the full funding of the President's FY 2014 budget request for the Human Exploration and Operations Mission Directorate. Together, SLS, Orion MPCV, and EGS represent a critical step on the path to human deep space exploration.

NASA's Advanced Exploration Systems (AES) Division is pioneering approaches for rapidly developing prototype systems, demonstrating key capabilities, and validating operational concepts for future human missions beyond LEO. Activities focus on crewed systems for deep space, and robotic precursor missions that gather critical knowledge about potential destinations in advance of crewed missions. Major products include systems development for reliable life support, asteroid capture mechanism risk reduction, deep space habitats, crew mobility systems, advanced space suits, and autonomous space operations. As prototype systems are developed, they are tested using NASA ground-based facilities or flight experiments on the ISS. The AES Division works with the Space Technology Mission Directorate to infuse technologies into exploration missions, and with the Science Mission Directorate on robotic precursor activities.

An Integrated Exploration Mission

The President's Fiscal Year 2014 budget request continues to implement the bipartisan strategy for space exploration approved by Congress in 2010, a plan that advances U.S. preeminence in science and technology, improves life on Earth, and protects our home planet, all while helping create jobs and strengthening the American economy. This budget reflects current fiscal realities by aligning and leveraging relevant portions of NASA's science, space technology, and human exploration capabilities to achieve the President's challenge of sending astronauts to an asteroid by 2025.

As part of the agency's overall asteroid strategy, NASA is planning a first-ever mission to identify, capture, and redirect an asteroid into orbit around the Moon. The overall mission is composed of three separate and independently compelling elements: the detection and characterization of candidate near-Earth asteroids; the robotic rendezvous, capture, and redirection of a target asteroid to the Earth-Moon system; and the crewed mission to explore and sample the captured asteroid using the Space Launch System (SLS) and the Orion crew capsule. This mission represents an unprecedented technological challenge—raising the bar for human exploration and discovery, while helping protect our home planet and bringing us closer to a human mission to Mars in the 2030s.

Each mission element will heavily leverage on-going activities across the Human Exploration and Operations, Space Technology, and Science Mission Directorates. We are currently working to align on-going activities across these directorates to affordably achieve the objectives while we plan this mission. Progress will continue conditional on feasibility and affordability. Funding provided within the President's FY 2014 budget request will augment our existing activities in Space Technology, Science, and Human Exploration and Operations to: enhance our near-Earth asteroid detection and characterization assets; accelerate advanced solar electric propulsion development; and design and test capabilities to capture a small asteroid in space.

Conclusion

NASA, with our commercial and international partners, has embarked on a new phase of human space exploration and development. In LEO, we are beginning to see the real benefits of the efforts of many nations to construct the ISS. The Station has now entered its research phase, and the recently announced initial results from AMS reflect just one area in which this unique microgravity laboratory is producing results. This phase, which will continue through at least 2020, will benefit NASA's exploration goals, but also go beyond this by enabling other governmental and non-governmental entities to conduct wide-ranging experiments that we anticipate will result in a variety of terrestrial benefits. This is best reflected in the slogan incorporated into the ISS Expedition 34 crew patch: "Off the Earth . . . For the Earth."

All of this research will be supported by a new way of doing business: the use of commercially provided services rather than Government-owned vehicles to transport crew and cargo from Earth to LEO and back again. We are also working aggressively to bring the new domestic commercial cargo providers on board. Private enterprise and affordable commercial operations in LEO will enable a truly sustainable step in our expansion into space—a robust, vibrant, commercial enterprise with many providers and a wide range of private and public users will enable U.S. industry to support NASA and other Government and commercial users safely, reliably,

and at a lower cost. NASA is proud to help in laying the groundwork for the emerging LEO space economy.

The cost-effective commercial systems will enable NASA to focus its own development efforts on the Orion MPCV and SLS, which will send NASA astronauts on missions of exploration beyond LEO. These systems will be flexible enough to support many different mission scenarios, in the decades to come. One of NASA's greatest challenges will be to reduce the development and operating costs (both fixed and recurring) for human spaceflight missions to sustain a long-term U.S. human spaceflight program. Our commercial crew program will reduce the cost of U.S. access to low-Earth orbit while ending our sole reliance on other nations for delivering crew to the International Space Station. We must also plan and implement an exploration enterprise with costs that are credible and affordable for the long-term. We are committed to developing an affordable, sustainable, and realistic next-generation human spaceflight system that will enable human exploration, scientific discovery, broad commercial benefits, and inspirational missions that are in the best interests of the Nation. Technology development is a critical enabler for cost-effective exploration and we are committed to the development of the necessary technologies required to explore our solar system. We need your continued support for this effort.

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

Senator NELSON. General Stafford?

STATEMENT OF THOMAS P. STAFFORD, LIEUTENANT GENERAL, UNITED STATES AIR FORCE (RET.); ASTRONAUT (RET.)

General STAFFORD. Chairman Nelson, Ranking Member Cruz, and staff members, I am once again honored to appear before you today to discuss our Nation's space program.

But before we begin, I would like to take a moment to note that probably we would not be here today on this specific subject but for the crucial work done back in 2010 by you, Mr. Chairman, as well as former Ranking Member Senator Kay Bailey Hutchison of Texas, and by the key Committee Staff Members, Ann Zulkosky and Jeff Bingham, and then the House Science Committee that was headed by Congressman Ralph Hall of Texas and his staff. It was your work in crafting the NASA Authorization Act of that year which mandated the development of the heavy-lift Space Launch System and the Orion multipurpose crew vehicle that has allowed us to envision a robust future for NASA and the American space program.

At a time when bipartisan cooperation in Congress can be hard to find, your work stands out as a shining example of what can be done when men and women of goodwill are working side-by-side, put aside their differences, and work together for the larger service of our country's interest. As a retired Air Force General Officer, former astronaut, and a citizen of this country, I thank you, sir.

Now, three years later, that 2010 Act still bears directly on the issues to be discussed at this hearing, which are of critical importance to our space program today: the choice of resources, destinations, sensible mission planning, and funding to reach them, the role of the new heavy-lift SLS and the Orion vehicle in carrying out these missions. The new technologies and systems, some of which Mr. Gerstenmaier has described, will be needed beyond SLS and Orion in a manner which NASA can most effectively collaborate with international and with its commercial partners.

In setting and reaching national goals, there is certainly a broad and challenging range of issues. And I will try to address them the

best I can in the time I have with the opening statement, and then be pleased to respond to your questions.

To put my remarks in context, I would like to take us for a moment back to 1991 and the publication of "America at the Threshold: America's Space Exploration Initiative." This report was prepared by the Synthesis Group in a year-long study that was chartered by President George H.W. Bush and I had the honor to lead. Our charter was to examine in some detail exactly the questions we are here to address: destinations, missions, systems, technologies, and collaboration.

This was not the first such Presidential-chartered assessment, and it certainly wasn't the last. The vast majority have reached the fundamental same conclusions: The core of national and international critical thought on space policy has been consistent over several decades and among nearly all the groups that have studied it. Possibly the best service I can perform for the Committee today is to remind us all of that fact and to summarize these core conclusions. They can serve as a useful guide for us today and in the future if we would only heed them.

Leadership in space, for any society that can aspire to attain it, is a key to leadership here on the Earth and in human society for all generations to come. While national leadership comes with obligations to partners, to allies, it is nevertheless the only proper goal to which America should aspire. Strategies and policies based on this understanding of leadership have placed our Nation in the role of the world's most influential country.

Failure to take this influence into space, failure to lead in the development of the next human frontier, will consign our Nation to a backwater in which others but not ourselves will shape the destiny of human society for the generations to come.

America's leadership, its power, and its influence in the world today was not, as some once thought, a matter of manifest destiny. It was earned for us today by our ancestors. We must earn it anew for our descendants. And we have earned it, and we must earn it in many ways and places. And one of those certainly, sir, is in space.

Thank you, and I will be honored to answer any questions.

[The prepared statement of General Stafford follows:]

PREPARED STATEMENT OF THOMAS P. STAFFORD, LIEUTENANT GENERAL, UNITED STATES AIR FORCE, (RET.); ASTRONAUT (RET.)

Chairman Nelson, Ranking Member Cruz, and Members of the Committee—I am once again honored to appear before you today to discuss our Nation's space program. But before we begin, I would like to take a moment to note that we would not even be here today, you would not be holding this Hearing, but for the crucial work done back in 2010 by you, Senator Nelson, as well as by former Ranking Member Senator Kay Bailey Hutchison, by key Committee Staff Members Jeff Bingham and Ann Zulkosky, and by the House Science Committee under the leadership of then-Chairman Ralph Hall. It was your work in crafting the NASA Authorization Act of that year, which mandated the development of the Space Launch System and the Orion Multi-Purpose Crew Vehicle, which has allowed us to envision a robust future for NASA and the American space program. At a time when such bipartisan cooperation in Congress can be hard to find, your work stands as a shining example of what can be done when men and women of good will are willing to put aside their differences and work together in the larger service of our Nation's interests. As a retired Air Force General Officer, former astronaut, and citizen of this country, I thank you.

Three and more years later, that 2010 Act still bears directly on the topics to be addressed in this Hearing, topics which are of critical importance to our space program today: the choice of resources, destinations, sensible mission planning and funding to reach them, the role of the heavy-lift SLS and the Orion crew vehicle in carrying out these missions. With the new technologies and systems which will be needed beyond SLS and Orion, and the manner in which NASA can most effectively collaborate with international and commercial partners in setting and reaching national goals is certainly a broad and challenging range of issues. I will try to address them as best I can in the time I have for this opening statement, and then I will be pleased to respond to your questions.

To put my remarks in context, I would like for a moment to take us back to 1991 and the publication of "America at the Threshold: America's Space Exploration Initiative". This report was prepared by the Synthesis Group, a group I was asked by President George H.W. Bush with the honor to lead. Our charter was to examine in some detail exactly the questions that we are here to address today: destinations, missions, systems, technologies, collaboration. This was not the first such presidentially chartered assessment, and it wasn't the last. The vast majority have reached essentially the same fundamental conclusions. The essential core of national, and indeed international, critical thought on space policy has been remarkably consistent across several decades and among nearly all of the groups which have studied it. Possibly the best service I can perform for this Committee today is to remind us all of that fact, and to summarize these core conclusions. They can serve as a useful guide for us today, and in the future, if we would only heed them.

Leadership in space is, for any society that can aspire to attain it, a key to leadership on Earth and in human society, for all the generations to come. While leadership comes with obligations to partners and allies, it is nonetheless the only proper goal to which America should aspire. Strategies and policies based on this understanding have placed our Nation in the role of the world's most influential nation. Failure to take this influence into space, failure to lead in the development of the next human frontier, will consign our Nation to a backwater in which others, but not ourselves, will shape the destiny of human society in the generations to come. American leadership, power, and influence in the world of today were not, as some once thought, a matter of "manifest destiny". It was earned for us today by our ancestors. We must earn it anew for our descendants. It must be earned in many ways and in many places. One of those is space.

The choice of destinations has, in all humility, already been made for us. The surface of the Moon is by far the most interesting near-term challenge confronting mankind in space. It is our proper next frontier. We know so much more today than we did when the Synthesis Group published its report, and everything we know has served only to reveal the Moon to be ever more interesting. Regions of permanent sunlight, enormously valuable for supplying power to an early lunar base, and nearby regions of permanent shadow, valuable for the trapped water they contain, exist at each of the lunar poles. The lunar crust is rich in oxygen and other materials which can be mined and used to develop a human future in space that will not always depend upon bringing supplies up from Earth. We know now that the Moon is far more than a dusty ball of rock. It is our nearest neighbor in space, and the key to the human future in space.

After the Moon, when we have learned something of how to live on a world other than our own, we will be prepared to venture farther out, to go more than three days away from home. That next exploration will be to Mars, a place we can be by the early- or mid-2030s, if only we can summon the required consistency of policy and purpose for more than the length of a single presidential administration.

There has been debate in the last few years about a human mission to an asteroid, or about robotic missions to bring an asteroid back to cislunar space, where it can be studied by astronauts and scientists without venturing too far from home, too soon. These ideas do have some inherent scientific interest. They should not be the central theme of any sensible long-term human spaceflight program. Such missions are an interesting adjunct to the far more interesting theme of human presence of the Moon and, later, and expedition to Mars. These enterprises can, and should, occupy our energies for the foreseeable future in space.

Regarding technologies and systems, every credible study concerning how to go about expanding our reach in space focuses, inevitably, on the need for heavy-lift launch capability, along the lines of the 130 metric ton capability planned for SLS, or more. This is the floor of useful capability for interplanetary exploration, not the ceiling.

For the development of cislunar space and the Moon, this heavy-lift launch capability must be topped with a large, liquid-hydrogen fueled upper stage. This is sim-

ply the most efficient approach to space exploration of which we know, today and for the foreseeable future.

To go to Mars, we need more. We need an upper stage powered by a nuclear thermal rocket. Yes, it is possible to get to Mars without a nuclear rocket, but why would we try to do so? Far from being an artifact of a science fiction movie, a nuclear upper stage is something we once had—a working, space qualified nuclear rocket lacking only a flight test. It was meant to fly on the Saturn 5, the launch vehicle that took me and twenty-three of my colleagues to the Moon. That combination could have taken us to Mars; instead, it was scrapped in 1973, four decades ago now, because President Nixon decided that we weren't going to venture beyond the Moon, and indeed that we were not even going to stay there, would not consolidate the gains for which three of my friends had given their lives.

I have said that we should make it the Nation's business to lead in space. We should. But I have also noted that leaders need partners and allies. I personally commanded our Nation's first international space mission, Apollo-Soyuz, a mission designed and carried out at the height of the Cold War. From that mission came, after the fall of the Soviet Union, the Shuttle-Mir program and, later, full Russian partnership in the International Space Station with ourselves and a dozen other spacefaring nations. In the very long run, the greatest legacy of the space program will be the international partnerships we have forged to build the International Space Station, and will forge again when we are ready to return to the Moon and go on to Mars.

Last year at a joint meeting with the ISS advisory task force and our Russian counterparts, the Roscosmos Advisory Expert Council, the independent groups that together review and identify major issues for the ISS, our Russian counterparts asked to give us a separate briefing. This briefing outlined their initial proposed next 20–30 years of human spaceflight exploration. It was interesting to note, that they proposed the exploration be based on an international partnership which would be managed by the same process that the present International Space Station is managed. They outlined the use of the SLS and Orion spacecraft and their space hardware which would include their new Angara booster along with the ESA Arrianne booster and the Japanese H–2 booster. The Russians said they consider the Moon another continent which to explore and eventually an expedition to Mars which would be powered out of LEO by a nuclear thermal rocket. This planning is now working its way up for approval in the Russian government.

Concerning the value of such partnerships, I will say this: we are simply less likely to fight with those nations and societies with whom we seek partnerships in the pursuit of challenging enterprises. Space exploration is an ideal venue for such partnerships and such enterprises. I was a military man for my entire career, one way or another, and I will tell you what every veteran knows: no military man wants to see his friends fight and die if there is any possible way to avoid it. Partnership in space exploration offers us one of those ways.

The Apollo-Soyuz mission was the shining light during the Cold War era in our relationship with the Soviet Union. Today, the ISS is the shining light of our partnership with our 15 partners, and the people of their countries, even though other issues between our countries may wax and wane. Our future of human space exploration beyond LEO to the Moon and eventually to Mars can also be a shining light to all of the countries who are our partners in this great endeavor.

Chairman Nelson, Ranking Member Cruz, Members of the Committee: this concludes my opening remarks. I stand ready to answer your questions.

Senator NELSON. Thank you, General.

Mr. Cook?

STATEMENT OF STEPHEN A. COOK, DIRECTOR, SPACE TECHNOLOGIES, DYNETICS, INC.

Mr. COOK. Chairman Nelson and Senator Cruz, I want to thank you for your continued support of the NASA Space Launch System and many exploration programs and for conducting this hearing into the challenges and opportunities for human space exploration, particularly your focus on the synergy between government and the commercial sector, focusing on how a stable, long-term national exploration strategy can provide an environment for commercial ventures to thrive.

The timing could not be more critical. The ramifications of the decisions you make could impact space exploration for the rest of this century.

Since 2009, I have had the pleasure and honor of serving as the Director of Space Technologies at Dynetics, Incorporated, a 38-year-old employee-owned business in Huntsville, Alabama, with 1,400 employees.

Prior to my private sector career, I spent almost 20 years at NASA. From 2005 until 2009, I served as manager of the Ares projects, the predecessor to the SLS, at NASA's Marshall Space Flight Center. Previously, I spent several years in the 1990s with the DC–XA and X–33 flight demonstrators, which were early attempts to move toward commercial-backed space transportation.

Unfortunately, the fissures that have developed within the space community over the past 4 years have too often pitted the commercial and government space sectors against each other in an us-versus-them debate. This is very unfortunate and counter-productive. Historically, successful government-backed exploration efforts have been linked inextricably with commerce. Government-private-sector partnerships have literally expanded the human footprint.

At its core, commercial means that the private sector bears the burden of the investment, the resultant risk, as well as the subsequent reward. This principle has been a standard of U.S. economic growth since our founding. Private companies can be profitable by providing products and services and by creating new wealth. However, commercial successes need not be limited to the commercial sector. Partnerships between government and industry can produce valuable products that can benefit the space sector as a whole.

The current landscape is rife with recent success stories. Some that I have some personal examples with are: Dynetics' first commercial satellite, FASTSAT, is a culmination of a public-private partnership between Dynetics and NASA-Marshall. Dynetics invested its own money, supplying the vast majority of the capital for the program, while NASA supported the project on a cost-reimbursable basis in terms of the conceptual idea, engineering capabilities, and facilities. The result: a spacecraft ready in 16 months that met rigorous government flight standards. FASTSAT successfully operated for 24 months, 100 percent past its design life.

Additionally, private industry can take systems developed under contract to NASA and leverage these for other purposes. This has been done successfully in aerospace projects for decades. Recently, in a full and open competitive process, NASA selected several SLS advanced booster risk-reduction projects. Dynetics has partnered with Pratt & Whitney Rocketdyne in developing a liquid booster concept based on the Apollo Saturn V's F–1 main engine. Our team is taking a flight-proven design originally developed by NASA and is merging it with the best of modern commercial manufacturing techniques.

In addition, we have an agreement with NASA-Marshall which allows us to engage experts in propulsion, test, and manufacturing and utilize tooling on a cost-reimbursable basis. It is a win-win. Dynetics is pleased to support NASA and looks forward to the next phase of the competitive process, slated for 2015.

The bottom line is this: When we keep things simple using models proven in other markets over time, the commercial sector and the U.S. Government can work together in harmony, not against one another.

For this public-private partnership to succeed, a stable space policy is necessary, a space policy that transcends election cycles. A major policy and program shift now away from the core principles of the 2010 NASA Authorization Act would be very damaging to U.S. leadership in space. A consistent, long-term policy will allow both commercial and government efforts to thrive. Laying out clear goals, destinations, and dates will provide an environment in which the market can and will respond.

In closing, we must recognize the need to work together as a community and realize that, as in many other exploration efforts, commerce and exploration go hand-in-hand. Let's focus on the power of the "and" versus the tyranny of the "or." In doing so, we must recognize that the U.S. Government plays a vital role in undertaking projects that have no business case—high-risk, high-capital, and long-payoff endeavors. And we must recognize that commercial means that the private sector bears the burden of the investment and the risk.

Thank you for the opportunity to testify today. I am excited and optimistic about the future, and I look forward to enabling it for generations to come. I will be happy to answer any questions you have.

[The prepared statement of Mr. Cook follows:]

PREPARED STATEMENT OF STEPHEN COOK, DIRECTOR, SPACE TECHNOLOGIES, DYNETICS, INC.

Mr. Chairman and Members of the Subcommittee, I want to thank you for conducting this hearing into "Challenges and Opportunities for Human Space Exploration," and particularly the synergy between government and the commercial sector, focusing on how a stable, long-term national exploration strategy can provide an environment for commercial ventures to thrive. The timing could not be more critical, as the Deputy Administrator of NASA stated in her response to the recent Government Accountability Office (GAO) assessment of NASA's large-scale projects, "programs are experiencing an uncertain and unstable funding environment, which can drive less than optimal phasing of current and future program work and can result in program cost increases." [1]

This is an exceedingly important discussion. The ramifications of the decisions you make could impact space exploration for the rest of this century.

Since 2009, I have served as the Director of Space Technologies at Dynetics, Inc., an employee-owned business headquartered in Huntsville, Alabama, with over 1,400 employees specializing in Space Systems—propulsion, launch systems, small satellites, and test; Intelligence—foreign materiel exploitation; Aviation—unmanned aircraft systems (UASs) and sensor integration; and Missiles—aerodynamics, avionics, and precision-guided munitions. Founded in 1974, Dynetics has earned a reputation for excellence in analysis and engineering. I have gained first-hand an appreciation for the challenges facing the private sector in the aerospace market, especially in the current political and economic climate.

Prior to my private sector career, however, I spent almost 20 years at NASA. From September 2005 until September 2009, I served as manager of the Ares Projects—the predecessor to NASA's Space Launch System (SLS)—at NASA's Marshall Space Flight Center (MSFC) in Huntsville, Alabama. It was a large, complex, government-funded and -led space launch project. Previously, however, I spent several years in the 1990s with the DC–XA and X–33 flight demonstrators—early at-

[1] U.S. GOV'T ACCOUNTABILITY OFFICE, GAO–13–276SP, NASA: ASSESSMENTS OF SELECTED LARGE-SCALE PROJECTS, 92 (Apr. 17, 2013) [hereinafter *2013 GAO Report*] (comments of Lori B. Garver, Deputy Administrator for NASA).

tempts to move towards commercial-backed space transportation.[2] I have always been a supporter of both government and commercial space transportation efforts.

Unfortunately, the fissures that have developed within the space community over the past four years have too often pitted the commercial and Government space sectors against each other in an "us vs. them" debate. This is very unfortunate and counterproductive. In what other field do we have such arguments about the roles of government and the commercial sectors? For example, we do not argue about the need for a Navy run by the U.S. Government nor do we want the U.S. Navy transporting cruise passengers. Historically, successful governmental-backed exploration efforts have been linked inextricably with commerce: from the exploration of the new world by Columbus to finding a Western trade route to the Orient; from the exploration of the West by Lewis and Clark to mapping routes for commerce. Government-private sector partnerships have literally expanded the human footprint.

Average Americans are largely unaware of the critical role our space presence plays in the comforts they enjoy in their daily lives, not to mention its critical importance within the defense sector.[3] If the space community continues to circle the wagons and shoot inward, we risk their support and we run the risk of making space more irrelevant to the public.

Role of Government

A fundamental role of the government is to provide for our Nation's defense—this is a long-established governmental function, enshrined in our Constitution, and there can be no argument against it. Another crucial role of government, however, is to take on endeavors that have benefit to society, are high-risk in nature, require significant amounts of capital, and have long payback times—in other words, ventures that the private sector cannot take on by itself. These are typically fundamental infrastructure projects—expensive, but which offer long-term societal benefits. For example, the U.S. Government underwrote the development of the maritime system, the transcontinental railroad, and the interstate highway system: these took years to fully mature, but undisputedly opened up our country in palpable, life-altering ways.

The U.S. Government does not operate in a vacuum, however. While the Government *invests* in infrastructure, it has always relied on private companies for the labor required to complete the projects, as well as to set up the support systems along the way—from telegraph offices to gas stations to restaurants and hotels, the private sector has provided goods and services necessary to get the job done.

Commercial programs may, by necessity, move more quickly because businesses must make a profit to keep their doors open. While government programs may move at a more deliberate pace, for those truly difficult tasks—those the private sector will not or cannot take on—a meticulous and measured approach is prudent. It is the price we are willing to pay, and must pay, for innovation and achieving our government's mission and objectives.

It is undisputed that space is a perfect market for a strong, supportive U.S. Government presence—after all, establishing a robust space presence is difficult, both technically and economically. Both sectors can learn from each other, as is clear from NASA's focus today on affordability.[4]

Commercial-Government Partnerships

At its core, "commercial" means that the private sector bears the burden of the investment, the resultant risk, as well as the subsequent reward. This principle has been a standard of U.S. economic growth since our founding. A corollary is that companies doing business with the Government should be subject to a higher standard to ensure that such business is transparent and auditable, particularly given that public funds are at stake. Private companies can be profitable by providing products

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[2] *See, e.g.,* Stephen Cook *et al.,* "The Reusable Launch Vehicle Technology Program," AIAA SIXTH INTERNATIONAL AEROSPACE PLANES AND HYPERSONICS TECH. CONF., AIAA–95–6153 (Apr. 1995) *and* Stephen Cook *et al.,* "X–33 Reusable Launch Vehicle Structural Technologies," AIAA 7TH INTERNATIONAL SPACE PLANES AND HYPERSONIC SYSTEMS AND TECHNOLOGIES CONFERENCE, AIAA–96–4563, (Nov. 1996).

[3] This subject was also discussed in a recent hearing before this Subcommittee on "Assessing the Risks, Impacts, and Solutions for Space Threats," held on March 20, 2013. *See, e.g.,* Assessing the Risks, Impacts, and Solutions for Space Threats: Hearing Before the S. Subcomm. On Science and Space, 113th Cong. (2013) (statement of Dr. Joan Johnson-Freese, Prof. of Nat. Sec. Aff. At Naval War Coll., Newport, R.I.). "[B]ecause of the resounding *success* of NASA and other organizations that have been responsible for putting space infrastructure into orbit, Americans [are] totally oblivious to the role that spaces assets play in [daily activities]. *Id.* at 2 (emphasis in original).

[4] *See, e.g.,* "2011 NASA Strategic Plan," NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (2011), available at *http://www.nasa.gov/news/budget/index.html.*

and services and by creating new wealth (*e.g.,* opening up new markets like Helium-3 mining in space). However, commercial successes need not be limited to the commercial sector: partnerships between Government and Industry can produce valuable products that can benefit the space sector as a whole. The current landscape is rife with examples of recent commercial-Government program success stories.

For example, Dynetics' first commercial satellite—the Fast, Affordable, Science and Technology SATellite (FASTSAT)—is the culmination of a public-private partnership between Dynetics, Inc., and NASA's Marshall Space Flight Center (MSFC). Dynetics invested its own money, supplying the vast majority of capital for the program, while NASA MSFC supported the project in terms of the conceptual idea, engineering capabilities, and facilities. The result? A spacecraft ready for flight in 16 months from inception at approximately one-third the cost of the competition—all while meeting rigorous NASA and Air Force flight readiness standards. Additionally, the satellite successfully operated for 24 months—100 percent past its design life. Dynetics now markets this satellite to other users. Dynetics assumed the financial risks and can now reap the rewards of the program's success. NASA was able to spin off its conceptual ideas to commercial industry and put engineers to work on a fast-paced flight project.

Another example of a commercial venture leveraging NASA's investments is Bigelow Aerospace's efforts to develop a commercially backed inflatable space station. Robert Bigelow, with his own funds, leveraged a NASA-developed concept called "TransHab" into a self-supporting space habitat approach, flying two Genesis test modules in space.[5] Bigelow recently announced that it has partnered with NASA to fly a test module on the International Space Station.[6] While leveraging NASA investments, Robert Bigelow has funded the development of the inflatable technology with his own money—taking the risk as well as the resultant reward. Dynetics was pleased to supply the forward propulsion system for his free-flyer module using an innovative hydrogen/oxygen system.[7]

The Government-Industry partnership can work multiple ways—for instance, commercial investments may be further developed in partnership with NASA for space-based applications. For instance, Dynetics' Advanced Materials and Nanosystems (AMN) group is working to partner with NASA to leverage commercial investments in nanomaterials and structures to space-based applications. Dynetics researchers have pioneered a new rapid prototyping method that will revolutionize manufacturing techniques for providing dramatically stronger and lighter structures. This technology will enable game-changing leaps forward in areas such as reduced vehicle mass and improved functionality and durability of spacecraft components, including electronics and radiation shielding. In partnership with NASA, this groundbreaking method of producing strong, lightweight structures—in effect reducing mass properties while increasing strength—will revolutionize the space industry.

Finally, private industry can take systems developed under contract to NASA and leverage these for other purposes. This has been done successfully in aerospace projects for decades, and could be especially useful for NASA projects—for example, NASA's Space Launch System (SLS). In a full and open competitive process, NASA recently selected several SLS advanced booster risk reduction projects. Dynetics is partnered with Pratt and Whitney Rocketdyne in developing a liquid booster concept based on the Apollo-Saturn V's F–1 main engine to give NASA the most affordable, reliable, and highest performance booster possible. Our team is taking a flight-proven design—originally developed by NASA—and is merging it with the best of modern, commercial manufacturing techniques, such as additive manufacturing. In addition, we have a Letter of Agreement with NASA MSFC, which allows us to engage experts in propulsion, test, and manufacturing and utilize state-of-the-art weld tooling on a cost-reimbursable basis. Under this agreement, we are able to tap into NASA expertise, facilities, and equipment, while NASA is able to offset its own costs and work hand-in-hand with Industry on a rapid schedule project—a win-win for both Government and Industry. While the prime focus is for NASA boosters, such

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[5] The Genesis I and II modules were launched in 2006 and 2007, respectively. Tariq Malik and Leonard David, "Bigelow's Second Orbital Module Launches Into Space," SPACE.COM (June 28, 2007, updated 8:08 PM), *http://www.space.com/4007-bigelow-orbital-module-launches-space.html.*

[6] *See* Brian Vastag, "International Space Station to Receive Inflatable Module," WASH. POST, Jan. 16, 2013, *http://www.washingtonpost.com/national/health-science/international-space-station-to-receive-inflatable-module/2013/01/16/8a102712–5ffc-11e2-9940-6fc488f3fecd_story.html* (last visited April 17, 2013).

[7] BIGELOW AEROSPACE SUNDANCER FORWARD PROPULSION SYSTEM, *http://www.dynetics.com/services/space/bigelow-aerospace-sundancer-forward-propulsion-system* (last visited April 17, 2013).

a system has direct commercial application in the expendable launch market. Dynetics is pleased to support NASA and looks forward to the next phase of the competitive process—slated for 2015—which will select one advanced booster provider for the SLS.

The bottom line is this: when we keep things simple using models proven in other markets over time, the commercial sector and the U.S. Government can work in harmony—not against each other.

Key to Commercial-Government Success: A Steady, Long-Term Space Policy

For this public-private partnership to succeed, a stable space policy is necessary—a space policy that transcends politics, administrations, and congressional terms. The cancellation of Constellation caused issues in the space sector that are still being felt today across many industries. Another major policy shift now would be even more damaging to U.S. leadership in space. Establishing a steady, long-term policy, grounded in the principles of the 2010 NASA Authorization Act,[8] will allow both commercial and Government endeavors to thrive. Laying out clear goals, destinations, and dates will provide an environment in which the market can and will respond.

First, there has been much discussion around the International Space Station (ISS) cargo and crew market, but I believe pursuing this market alone is too limiting for a space-faring nation, especially given our untapped potential. In fact, recent published studies[9] have shown that the ISS cargo and crew market is not large enough to support a robust commercial market. However, if we expand the space market to include destinations with untapped economic potential—for example, a lunar outpost that may support mining of minerals emplaced from asteroids over thousands of years—the wealth creation potential is virtually unlimited. In addition to new wealth creation, such an outpost would require the routine resupply of cargo and crew. The moon could be an ideal market for new space companies: penalty for failure is manageable, enterprise risk is reduced, and there is ample opportunity to refine designs through repeated utilization. Furthermore, the Government could guarantee a market for lunar outpost cargo prior to human return, serving as the anchor tenant.

In fact, the commercial sector has already shown interest in the Moon. For example, the Google Lunar X PRIZE was established in 2007 in part to incentivize the market to enable a commercially funded mission to the lunar surface, working to jump-start a lunar-based economic model. Dynetics is a member of one of 23 teams competing for the $30M prize—again, we have taken a risk, but we will also reap the reward. We have reduced some key risks, such as propulsion, by developing and testing a new thruster system leveraged from propulsion systems we developed for NASA and testing out key elements of a rover. This is not a technical problem, however, but rather a market issue.

A core market conundrum in this case lies in the fact that since a return to and exploration of the Moon was eliminated as the primary mission by the United States in 2010,[10] many international teams planning missions to the Moon have been eliminated, cut back, or made less of a priority.

Here is a case where a change in policy has had a direct effect on a commercial business case: if we change directions every few years, the market will not invest—and why should it? Like it or not, the Constellation Program was designed to implement civil space policy articulated by President Bush in the aftermath of the *Columbia* accident. It was modified, extended, and enhanced by both Republican and Democratic Congresses in the NASA Authorization Acts of 2005 and 2008. While the program transcended multiple Congresses, it did not do so with the last change in Administration.

Some lament the difficulty of explaining Space Policy, but I fundamentally disagree. While space is a complex endeavor, explaining it to our stakeholders—both the public and Congress—need not be complex. For example, I can explain the previous policy in a single sentence:

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[8] NASA Authorization Act of 2010, Pub. L. No. 111–267, (2010).

[9] *See, e.g.,* Michael D. Griffin, "Enabling Complementary Commercial and Government Enterprises in Space," IAC–11.E3.4.6, 62nd International Astronautical Congress, Cape Town, South Africa, (Oct. 2011). "The NASA Commercial Resupply Services (CRS) contracts for ISS cargo delivery offer a working example of a guaranteed market. However, [the] ISS market, whether for cargo or crew or both, is too small and likely too short-lived to bring about the robust commercial space industry that most space development advocates would like to see. The ISS is simply not a program having the strategic scope to provide the required market incentives. Something more is needed." *Id.*

[10] Including the NASA Authorization Act of 2010, *supra* note 8.

> "The United States will meet domestic and international commitments by using the Space Shuttle to finish the International Space Station (ISS), after which the Shuttle fleet will be retired and replaced by a new system to support space station crew transfer and logistics, enable human lunar return and sustained lunar presence, and pave the way for future voyages to Mars and the near-Earth asteroids."

Other important points are captured in both policy and law, including especially the intent to foster commercial development of space—but this one sentence captures the essence of the policy and legal direction for NASA's human spaceflight program for over five years. While I *am* a rocket scientist, it does not take one to write or understand a clear space policy.

Finally, it is clear that if we want to continue the successful model of international cooperation from ISS—a model that brought together nations from around the globe in a great peaceful enterprise—the United States must pick a course and stick with it. Constantly changing our policy makes us an unreliable partner, and as a result, will naturally push our friends and allies away to others. First, the United States does not want to become known as a country that breaks commitments. Second, it is *not* in the long-term strategic interest of the United States—from either an economic or national security standpoint—to encourage our friends to look elsewhere for partners in space.

Conclusion

In closing, public policy decisions *can* effectively spur collateral private development—the key lies in recognizing how the Government and Commercial sectors best work together.

We must recognize the need to work as a community and realize that—as in many other exploration efforts of mankind—commerce and exploration go hand-in-hand. We must recognize that the U.S. Government plays a critical role in undertaking projects that have no business case—high-risk, high-capital, and long-payoff endeavors—often in the form of infrastructure projects. We must recognize the value of international partnerships and show that we value and will keep our long-term commitments to our friends as a key part of our economic and national security. We must recognize that "commercial" means that the private sector bears the burden of the investment, the resultant risk, as well as the subsequent reward.

A stable, long-term space policy and supporting programs *can and will* allow the commercial space sector to flourish. A key element of this is picking destinations that can have long-term scientific and economic value. As one example, the establishment of a lunar outpost could align important strategic goals: it facilitates U.S. preeminence in cis-lunar space and provides the "anchor market" for expanding commercial space enterprises. While fundamental capabilities are necessary, dates and commitments have always been critical to enabling the commercial sector to plan and invest accordingly.

Never before has a robust Government-Commercial partnership been more critical. As the GAO report stated in its April 2013 assessment of NASA's large-scale projects, "Given the current fiscal environment, our findings underscore the importance of NASA remaining committed to its initiatives to reduce acquisition risk, especially with regard to management of its larger and more complex missions."[11] Continuing to develop a strong partnership between the Government and Commercial sectors will certainly "help NASA continue the improvements it has made to reduce cost and schedule growth in its portfolio and improve its ability to successfully manage the fiscal uncertainty that is likely to continue for many years."[12]

Thank you for the opportunity to testify today. I am excited and optimistic about the future in space and look forward to enabling it for generations to come.

Senator NELSON. Senator Cruz?

Senator CRUZ. Thank you, Mr. Chairman.

And thank you again to each of the witnesses today at this hearing.

Mr. Gerstenmaier, I would like to start with you. There has been much discussion recently about the asteroid rendezvous and retrieval mission. And I would like to ask you to share what NASA sees as the specific benefits of successfully accomplishing that mis-

[11] *2013 GAO Report, supra* note 1, at 70.
[12] *Id.*

sion and also what you see as the most significant obstacles to successfully accomplishing that mission.

Mr. GERSTENMAIER. I think in terms of the benefits of the mission, like I described in my oral remarks and said in my written testimony, this mission brings together some activities we were already doing.

The Science Mission Directorate was off busily looking for potentially hazardous objects that could impact the Earth. They were off surveying those. We will expand that to now look for smaller objects that could be part of this mission that we described.

We were also off looking at a demonstration flight to develop solar electric propulsion. That is needed if we are going to go the distances to Mars with cargo and crew eventually in that kind of timeframe. So, again, that brings in that solar electric propulsion activity that was going to occur.

It also gives us a very good destination for the Orion capsule and the SLS vehicle. It can reach this deep retrograde orbit where we would place this object to be examined.

It also gives us a tremendous amount of experience in operating in deep space. You know, we will be out in the vicinity of the Moon, roughly 9 days away from return back to the Earth, and that is very different than where we are today on Space Station, just several hours away.

So learning to operate with crews in those regions, in those distant regions, learning how to do the orbital mechanics, dynamics, all of those things really brings together all these aspects, the Science Mission Directorate's activities, the Space Technology Directorate's activities, and my directorate's activities, all together in a unified mission that really builds us a capability that will be critical for us to move forward. So that is really the advantage I see of this mission.

I think the challenges of the mission will be finding a suitable target to return. You know, it is sometimes talked about that—it is talked loosely that the target is dragged back to this orbit. It is not really dragged back; it is actually returning naturally to the Earth-Moon system. We will deflect it using the gravity of the Moon and the gravity of the Earth into this stable orbit for examination.

So it is not going to be easy to find this target. We believe there are many targets of this size. But we have not really looked at this smaller-diameter targets, or smaller targets.

So I think it will be a challenge to find the target. It will be a challenge to capture this target or attach the spacecraft to it. But, again, I think it will drive technology, it will drive capabilities that will be critical for us if we are really going to go beyond low-Earth orbit with humans and we are going to continue to explore space the way we have intended.

Senator CRUZ. Now, as I have been educated by our learned chairman, my understanding is that the mission contemplates bringing an asteroid back into orbit of the Earth in what would not be a more typical elliptical pattern, but rather a more irregular orbit.

Do I understand that correctly? And if so, could you explain that a little bit?

Mr. GERSTENMAIER. Yes, actually, the idea is to return the object to a deep retrograde orbit, which, in a reference frame of rotating with the Moon, it looks like it orbits the Moon at 75,000 kilometers off of the Moon. But if you look at it in more of an inertial frame, you will see the object kind of wander between the Moon and the Earth, and it looks like kind of a little loop that I think probably you saw.

What that is is the interaction of the gravity of the Moon with the gravity of the Earth that effectively keeps this object trapped in that orbit around the Moon. So I think the simplest way to think of it is in stable orbit around the Moon, but then if you change reference frames, it looks like a little curlicue kind of around the Earth and the Moon, in that direction.

But the orbit is unique in the fact that it is stable, and it is also exciting because we can get there with the early versions of the SLS and with the Orion. So we don't have to alter any of the plans we had for either Orion or SLS to go to this region.

Senator CRUZ. You know, one of the important roles, I think, that this subcommittee can play is helping NASA articulate the benefits of the space program to our Nation. And I would be curious how you would articulate to the man on the street why he or she should care about going and getting an asteroid.

Mr. GERSTENMAIER. I think one obvious thing to think about is, you know, we have recently had the 15-meter asteroid impact the Earth over Russia. For us to gain experience in understanding asteroids and surveying even the smaller ones I think can bring real benefit to folks here on the Earth.

Also, the techniques we will use of flying around and attaching a spacecraft to this object, those activities will have, again, direct application to helping to protect the planet. They are not 100 percent compatible for what you would do for an object in the tens of meters to several hundred kilometers size range compared to this little 7-meter object, but many of the techniques are similar. Much of the experience we gain could be very important as we try to protect our planet from these objects that are clearly in an orbit that could come back and impact the Earth.

So I think the benefit is you get a chance for us to actually understand better what objects are in the environment, not just the big ones but also the smaller ones. And then ultimately you develop some techniques that can help protect the planet from these objects if they were to approach the Earth.

Senator CRUZ. And if I could ask a final question to General Stafford, you have spoken about the benefits, in your opinion, of another manned flight to the Moon. I would welcome, if you could share with the Committee, what you would see of the benefits of another manned flight to the Moon and the relative benefits of that mission compared to the asteroid rendezvous and retrieval, to the extent one or the other is seen as mutually exclusive.

General STAFFORD. Thank you, Senator Cruz.

To me, it is not either/or. When you develop the SLS and the Orion and the support structure for this, from the control center at Houston, from the launch center at the Cape, you develop the capability. And the asteroid mission is a mission; it is not the total.

And in most of the studies that I have participated in and what we now have learned from the Russians of what they are looking at, their long-term plan, that the final goal is at least an expedition to Mars. But from that, you learn on the Moon. And I headed this group for nearly a year to study that. There is a whole book on it. And what we learned from that is the operational procedures and the hard work it takes to do this. There is a reason—you know, a lot of reasons.

As I started out the charge that I had from Vice President Quayle and President Bush, Sr., it was to give them the technology priorities and the architectures of how we do it. Approximately 4 months into the study, it became obvious to us that we should say not only how do you do this, sir, but why do you do this, why do you go back to the Moon. In fact, we had a senior steering group that asked us, "We have been to the Moon. Why don't we just go to Mars and do that?"

And so we dug into this. And it is very detailed, and the book is still regarded by some as a bible as far as space exploration beyond LEO. And it tells what you can do, and also it prepares you to go further out. But in providing this infrastructure, you have this.

And, again, when we talk about commercial, I can say this: that NASA itself has never built any hardware. Just like in the Air Force, where I was deputy chief of staff, when I had resource development and acquisition, the Air Force has never built a piece of hardware. We have done research in cooperation, but it has all been the commercial sectors that built it.

But, to me, there are many reasons that the Moon is the next goal to prepare in operations, and also it will do a lot of things inspiring generations.

And on that, on a recent visit to Russia last year with the advisory task force to the ISS that I chair—pro bono work there with about six or eight other people. We have our Russian counterparts in Roscosmos. They laid out to us, and I think we are the first Americans to see this, their proposed start of their next 20 to 30 years of human spaceflight. It is working its way up through the Russian government for approvals or modification.

And in that, I thought it was very important, Senator Cruz, that they said they would propose the same framework that the International Space Station is managed by, with the partners. We have it; it is working good. It is a shining light to the world of how people can work internationally. And this is what the Russians have proposed.

In that, they showed us that they would use the SLS-Orion, they would use their new Angara, their hardware, the Arrianne, and that. So it is a unifying portion. But there is a lot of reasons as to why, but the main reason, finally, and I think nearly every administration has said, yes, someday we should have an expedition to Mars.

Thank you, sir.

Senator CRUZ. Thank you, General.

Thank you, Mr. Chairman.

Senator NELSON. Well, thank you, Senator Cruz.

Mr. Cook, pick up on that. We have this plan with SLS and Orion. Prior to that, a robotic mission to capture and bring an asteroid to this retrograde lunar orbit. We learn from that. Perhaps we go back to the Moon's surface. We learn from that, as we are getting prepared for the 2030s to take humans all the way to Mars, to take cargo to Mars that could precede the humans.

And tell about how this is going to be a new opportunity for commercial involvement.

Mr. COOK. Well, Senator, that is an outstanding question.

If you look at the opportunities that are in space, I think we have too often thought of space as a very niche place, you know, where only a very few people can go at this point in the game. I think we have to change the game and look at it as a marketplace, much as the way Thomas Jefferson looked across the United States and what the potential economically would be for the Nation some 250 years ago.

So if we look at it in that context and you look at something such as an outpost, such as an outpost on the Moon, following up what General Stafford mentioned, you know, not only would an outpost like that be an opportunity for new wealth creation—you know, mining of minerals that have been placed on the Moon and then even on asteroids later on, for thousands of years. It could be mined for various uses. Helium–3, for example, for energy production, which I know you are familiar with, is one option.

But, as well, it is an opportunity for routine resupply of crew and cargo, much as what is going on with the International Space Station now, where it becomes a marketplace. You know, you will need tens and eventually hundreds of tons of cargo initially and then crew later that would have to supply outposts of these types. And that is a perfect marketplace for the commercial sector to get involved and to make investments.

But I think the key there is there has to be a long-term plan, there has to be dates associated with that long-term plan. And when there are and there are commitments, then the private sector will be willing to lay out business plans and business cases to be able to go and move forward. I think that is a key piece of this, in terms of how we move forward with the exploration.

I think there is, again, new wealth creation, logistics support. I mean, really, it is almost endless. The key is that long-term plan with those dates that allow us in the commercial sector to leverage that and look for ways to be profitable.

Senator NELSON. And, General Stafford, you were talking about international cooperation in the commercial development of these capabilities. Do you want to expand on that?

General STAFFORD. Well, the experience I had besides my first international effort was Apollo-Soyuz. But then as the Air Force Deputy Chief of Staff, I was the configuration manager of probably one of the largest international cooperations for defense, and that was production of the F–16. And that was well over a $100-billion program in which we had Norway, Denmark, Belgium, the Netherlands co-producing the airplane that was built in Texas by General Dynamics to start with and we continued on from that. But it was commercial entities in those countries.

So that was on the DOD side. And then from the Russian side, what they propose and what we are doing today, in that, again, it is commercial in that all the manufacturing is done by the commercial entities.

Now, then the market, as far as supplying, is what has been described here by both Mr. Gerstenmaier and Mr. Cook as supplying to the station. But the marketplace today is the U.S. Government and the partners that are on board there. But I have had experience both in the Department of Defense and also now in working there with the Russians on this.

Senator NELSON. Mr. Gerstenmaier, recently, NASA has said that the SLS is ahead of schedule. What has NASA done to make the SLS so different?

Mr. GERSTENMAIER. I am not sure the SLS is ahead of schedule. I would say we are on schedule.

But we are moving out pretty well with all our contract activities. You know, we picked the rocket design to be consistent with the budget environment we were in. For example, we used the shuttle main engines as the primary propulsion system on that rocket, so we didn't have to go do development initially for those liquid rocket engines.

Also, the solid rocket motors on the side, those came, again, from the previous programs and have basis back in the shuttle heritage, so we don't have to do any more qualification firings of those, or any more developmental firings for those. We need to do two more qualification tests.

So we are able to leverage off of a lot of our experience we have had before with the hardware design and rocket design to keep us moving forward.

So I believe the SLS is on track. It is still not easy. The equipment, the welding equipment is starting to show up down in New Orleans now and get assembled. We are starting to begin kind of the first series of welds, to make sure all that happens. The design work is getting done, the wind tunnel work is getting done. All of that has been completed. There are not any big problems or showstoppers with all that. But there is still a lot of work in front of the teams. But they are very motivated. They are moving forward, and we are making solid progress toward the 2017 timeframe.

Senator NELSON. As with the authorization bill, it was to utilize a lot of the technology that we had already developed. What are some of the gaps, technology gaps, that NASA and its partners have to overcome to operate in cislunar space?

Mr. GERSTENMAIER. Yes, there is a variety of kinds of things we need to look at in cislunar space.

As I described, when we operate in this vicinity around the Moon, you know, we are now days away from return, from safe return. So our vehicle needs to be, you know, fully redundant, fully capable of taking failures and still keeping the crew safe. We need to make sure we have the right medical provisions for the crew, that they can be in that condition for 9 days without any ability to get back to the Earth or to get to any kind of medical care.

Those are different ways of operating. You know, we have typically always been able to have an abort mode or an easy way to

get back. This is going to be a different way for us to operate in that region.

We also need to deal with the radiation environment of space. Again, we can deal with it for the short durations around the Moon, on these 22-day missions or so. But then, as we start venturing out into space, we are going to need to get some more shielding, look at some water to potentially shield, maybe some spacecraft designs to shield. So there is some work that needs to be done there.

And also the humans, we are learning a lot on Space Station how the human body thrives or lives or survives in space in the extended microgravity conditions. This 1-year increment with our crews we plan in 2015 will be a really important demonstration to see how well the human body really performs.

The Russians have flown in space for over a year before, so it is not brand-new territory for us, but they have not flown with all the detailed instrumentation and all the detailed medical exams that we will get during that increment. And that will really show us, is the human body really ready to go for these extended durations.

So we have lots of things to learn, both spacecraft-wise, human-vehicle-wise, et cetera, as we move forward.

Senator NELSON. Senator Cruz?

Senator CRUZ. Thank you, Mr. Chairman.

Mr. Cook, you had talked some about the potential for additional commercial involvement in human exploration beyond low-Earth orbit. Could you elaborate on what you see as the potential opportunities both in the near term and in the longer term?

Mr. COOK. Senator, thank you very much for the question. That is a good question.

And, again, from a standpoint, I think you look at it in two categories. One is in new wealth creation. This is probably more of the longer term. You have efforts out there today that are looking at mining asteroids. Planetary Resources, for example, has plans to do that. Also, there is a venture out there called B612 that is looking at asteroid detection, things of that nature.

Recently, NASA signed a Space Act Agreement with Bigelow Aerospace to look at the broader set of implications for what does the commercial marketplace look at beyond low-Earth orbit. And I think that is in a two-phase-gated approach. The results of that, I think, are going to be very interesting in terms of what comes.

But I think for new wealth creation, in particular, whether it be new space stations in low-Earth orbit, which is probably nearer-term, and there are plans that are in place for that now, as well as longer term, again, an outpost on the lunar surface, for example, could be used for mining purposes, that you are going to have to have logistics servicing of that outpost. And so those go hand-in-hand.

The key to that, again, is having that consistent, long-term plan in terms of how you want to put all that together.

Senator CRUZ. One thing you have referred to several times is potential opportunities for mining. I think it would be helpful if you could share our best knowledge and predictions as to what the mining opportunities might be either on asteroids or on the Moon itself.

Mr. COOK. Yes, there is a—and I would certainly be willing to take some more, Senator, some more time and respond to that more fully for the record. There are quite a few studies out there.

But, in particular, two minerals that have been talked about the most: Helium–3 that is in abundance on the Moon. That has potential application to fusion power here back on Earth, very clean power.

The key there is there has to be a low-cost infrastructure. You have to have the Interstate Highway System, if you will, between here and the Moon to be able to get it back and forth. That is where things like SLS comes into play, where that is the government-private-sector involvement, to be able to get the resources there to mine it and then bring them home, for example. And there has been a lot of work done on that by the University of Wisconsin, as a matter of fact.

And then platinum has come up as a—which is obviously a very valuable mineral that could be used back here on Earth.

Those are just two examples.

Senator CRUZ. Thank you.

Mr. Gerstenmaier, if Congress were to enact legislation that specified a specific major long-range goal for human exploration, say, a lunar base on the Moon or a human landing on Mars, how long would it take for NASA to develop the specific description of the component elements that would be needed to meet such an objective?

Mr. GERSTENMAIER. You know, when we look at both of those objectives you just described, I would say the SLS that we are putting together, the heavy-lift launch vehicle, it is designed to meet both of those objectives. Initially, it is 70 metric ton to low-Earth orbit capability; eventually grows to 130 metric ton capability to low-Earth orbit. That is the kind of heavy-lift capability we believe we need to get to Mars kind of destinations.

The Orion capsule is also, again, sized for that mission. It is more than a capsule. It is also provides a life support capability or kind of an emergency backup. It will have to be teamed with a habitation module if you are going to go extended durations in space. But if there is a problem with the habitation module, Orion has enough redundancy, enough space inside that it could be a safe haven for the crew for a period of time. So that is why it is bigger than a typical capsule.

So I think those two pieces are part of the infrastructure. We could lay out the other pieces of infrastructure we need. We need some of these operational techniques I described to you that would come from the asteroid mission. You can lay those in, put those in place.

You know, Mars is a huge step for us in terms of distance, radiation exposure, exposure of the crews to microgravity. Just the sheer magnitude of that activity is going to take some time for us to prepare. We have conceptually said 2030s sometime is the appropriate time for Mars, but we can only do that with sufficient funding and moving forward.

But we have those first pieces of that activity already in place with SLS and Orion. So I believe we are starting to put together that capability. We will continue to add to it as we go forward. This

asteroid mission fits in that same scenario. It also adds to that capability and eventually achieves those kinds of goals that you just described.

Senator CRUZ. Thank you, Mr. Gerstenmaier.

My final question I would like to address to General Stafford.

You are someone who has spent a lifetime in public service serving your nation, and you have been involved with space since really the dawn of the space age.

I would like to give you an opportunity to respond to the same question that I asked Mr. Gerstenmaier in the first round, which is, if you were talking to a man on the street, a young man, a young woman, today, and that individual asked, why should I care, what difference does any of this make to my life, how would you answer that question to the man or woman on the street?

General STAFFORD. Right, Senator, let me start from the macro and work down to the micro.

You know, recently, in the last few days, unfortunately we lost one of the great journalists of America, Mr. Allen Neuharth, who the chairman knew very well. And he started Florida Today, and then, against all odds, he started a national newspaper which you can now read internationally.

And Neuharth traveled throughout the United States consistently, and he would still write—his age was nearly 90—write a weekly column. And he had a pulse of the American people. And he stated—it was in a special edition that they made for him—that to be number one on the Earth, you also have to be number one in space. So from that, you need leadership. And leadership will take then with partnerships and that.

To get down more in specific terms, it talks about the inspiration that it gives to the younger people. That is, I think one of the great things that came out of Apollo besides the infrastructure we left there that you see at the Cape with the VAB and the pads and the knowledge of how we do this, the main thing is, what inspires you to go forward? And, to me, it is an inspiration and education. You say, sure, you can do inspiration and education with other means. But, to me, the inspiration and the education and the leadership and working with the other people is the main thing.

I wish I had time, sir, to go into what we worked on for that year to explain why we should go back there, besides how we should do that.

But one thing I would like to point out, with the infrastructure that is there now for most of the facilities and the heavy lift that the 2010 act puts forward, that type of vehicle, the SLS, will put in—and, again, they said 130 metric tons, Senator. They said that was a minimum, a floor, not the ceiling. And when the booster I commanded to the Moon shut off in low-Earth orbit before we kicked out to the Moon, we had 300,000 pounds. And today the heaviest lift launch vehicle available is a Delta IV that has 50,000 pounds.

Now, at times, some people will say, well, let's take it with a bunch of small ones and put them together. I am sure you or your staff have had people come by and say that. But it is just not possible because you would have to build, completely assemble, launch, check out.

And then way before that, let's go back nearly 50 years, and the senior people at NASA after President Kennedy said we will go to the Moon and return—I like the word return," sir.

[Laughter.]

General STAFFORD. It was decided that all the upper stages will have as fuel liquid hydrogen because of the great impulse it gives us. And that was what was the key to the Saturn V. And today the Air Force expendable launch vehicles, the upper stages are all liquid hydrogen. And it gives a specific impulse in a measure of about 450 seconds versus hydrocarbons, which are good for the first stage, maybe 300. And now solid-rocket motors are getting up near that 300 seconds. But you need that hydrogen to go out there.

There is also a problem, and that is, because of the temperature, minus 423 degrees, or in oxygen, the 290-some minus, it boils. And it tends to boil off like—I think the best thermal protection we have, we might get 1 percent or a half a percent a day boil-off. So you see where that leaves you.

So there are a lot of challenges for Mr. Gerstenmaier and a team to work on. But that was a heritage of Apollo that we left, as to how do we get the propellants, the facilities, and everything to go there, and how we should do it.

There is also another thing, and Senator Nelson and Minority Leader Hutchison put forth this bill. When you have this large SLS, you have a large diameter volume in there that you can carry a payload. When you have these small diameter rockets that people say they could put together, you do not have the volume for the payload. You just can't go and bolt them together. And you are also working against the boil-off all the time.

So I am sure you probably have had people come by and talk to you or your staff has on that. I just wanted to put that out there.

But back about the main thing, is the inspiration to the younger people. And I will be glad to provide your staff with one of those books.

Thank you, Senator.

Senator CRUZ. Very good. Thank you, General.

Thank you, gentlemen.

Thank you, Mr. Chairman.

Senator NELSON. Thank you, Senator Cruz.

General Stafford, on that point, share with us, since you were a part of the Apollo program, the generation of scientists and technicians and mathematicians that the early space program spawned.

General STAFFORD. Well, Mr. Chairman, it is amazing today that when talking to people or I get recognized or people I get introduced to, so many people have said, the reason that I studied to be an engineer or I studied to be a doctor or something was because I saw what you did in Gemini, what you did in Apollo, and that inspired me. Yes, I wanted to be an astronaut, I realized that the chances were very small, but that still inspired me. That is why I wanted to be there.

So I think there has been such a tremendous fallout from that that helped move our country forward. And you see where we stand. We still have the best research and development in the world in this country, and this technology is what makes this coun-

try great. When we lose that inspiration to go forward and have this technology, then we have lost a lot.

Senator NELSON. Now, let's go from the heights of inspiration to the depths of reality.

Mr. Gerstenmaier, what happens if sequestration across the board continues and affects the NASA budget in 2014 and beyond?

Mr. GERSTENMAIER. Well, simply, we can't deliver the programs that we have committed to you we would deliver.

You know, we can tolerate the 2013 sequester activity that occurred to us because we are prepared. But if it continues into 2014, the programs I described, the timetables I described to you, I don't believe we can continue to support it at the levels we did. So this is really going to be tough for us moving forward.

Senator NELSON. And are you in a position, from your platform of the 2013 budget and what you project into the future, are you in a position to really encourage the private sector to get involved and develop these space exploration technologies that are advanced?

Mr. GERSTENMAIER. Yes, I think, again, the President's budget that was just submitted or just released that you have seen for 2014 and now, that keeps these programs moving forward and includes some technology development. It also involves us working with the private sector to continue to move forward.

You know, we have done a lot in the cargo and crew world, but I think there is even more we can do in other areas. So we will continue to look to the private sector to partner with them to move forward. I think, as Mr. Cook said, the partnership between the government and the private sector needs to be there. We need to use each other, use the best of both activities to figure out a way to work jointly together and move forward. And I think that is key to us moving forward.

So, as we talked in this hearing, I think international is important to us, and then private-public partnership is also tremendously important to us.

Senator NELSON. General Stafford, when we were in the great space race to beat the Soviets to the Moon, they tried, they had this big rocket, and that big rocket blew up.

Tell about that and tell what happened there. And tell about the derivatives of that rocket, how they are actually using it in the commercial sector today.

General STAFFORD. Mr. Chairman, I will be glad to, to the best of my knowledge.

When we made the commitment to go to the Moon, the Soviet Union at the same time made the commitment to go too. But, again, one of the keys we made, as I mentioned, was a decision to go to liquid hydrogen in those upper stages and with large thrust engines, which we had never done before, and also the first stage.

And building a large rocket engine is a very difficult task. The bigger you get, the more then tend to go unstable and explode. In fact, when I was flying in the Gemini missions, the F–1 engines we had on the giant Saturn was still exploding on the test stands, which is not too much of a comforting feeling. But over a period of time, they worked out the right form of the injectors and worked that out.

That is one thing the Soviets never could work out, was to build a large single-chamber engine. And you even see it back into the Soyuz rockets they are flying. You see all those nozzles. They are really one engine but four barrels. And then on their RD–170, which had as much power as our F–1, they could not get a stable combustion, so they went to four different barrels.

Now, on the large N1, which was bigger than our Saturn V, it had nearly 10 million pounds of thrust, but instead they had 30 engines on the first stage. I would term it a plumbing nightmare. And I talked to my dear friends early on often; he watched as the first one started up and then exploded and blew pieces about 10 kilometers away.

And they did not have the technology, as far as the gimbals on it. And so they were going to change altitude by throttling the engines, which was not a bright thing to do. And they were going to use kerosene and liquid oxygen in all of their stages, which had the far lower impulse. So even though the booster had nearly 10 million pounds of thrust and weighed more than the Saturn V, it did not have near the payload to get out there, and they had too much complexity in that.

Now, the engines, those 30 engines they had on the first stage was called the NK–33; they have now been taken by Aerojet and modernized and called the Aerojet 26. And they have put gimbals on them, rechecked them, and they just recently flew perfectly on this flight by Orbital Sciences, which developed to—on their booster, which will go to supply cargo to the Space Station. So those are 45-year-old engines, but they have been modernized and evidently work perfectly, sir.

Senator NELSON. Mr. Gerstenmaier, Space Station, it is doing well, with a crew up there working on science. How about telling us, do you all have any feeling about, since we extended in law its life to 2020, what about extending it beyond 2020?

Mr. GERSTENMAIER. You know, our discussions with some of the commercial groups—and you could probably talk to the Center for the Advancement of Science in Space, the CASIS organization. You know, their feeling is that if they knew Station was going to be around beyond 2020, there might be a different market on the commercial side that would be interested in using Station.

So I think we are starting to hear kind of the groundswell from outside users and other folks that Station is proving to be a very vital asset. They would like to do research there. We are kind of starting to see a lot of Earth observation payloads go to Space Station in the next couple years. And I think if the horizon for Space Station was extended, the market might actually get a little bit larger.

But I think it would be worth a good discussion with the private sector about what they think about that and if they saw a bigger market if Station got extended and moved forward. But I am starting to hear general indications from the user community that extending the life of Space Station would be a very good thing.

Senator NELSON. Can you speak as to some of the vaccines that are being developed now and being tested?

Mr. GERSTENMAIER. Yes, there is not actual vaccine work being done, but it is more kind of generic research being done on Station.

The two big areas of interest are immune system degradation, which occurs in our crews-on-board station. Their immune systems are not as functional in space for some reason.

That proves an interesting way to test potentially new drugs that affect the immune system. We are going to have the ability to take rodents to space here next year on Space Station, and they can be used as a test medium for potentially new drugs that are being developed on the ground. And before a pharmaceutical company wants to take those into final FDA trials, they could actually do a very simple experiment to see if this candidate drug is effective in preventing the immune system from becoming less effective. So there is some work going on in that area.

We also see gene expression in space that is very different. That allows some innovative ways to go look at things such as, we have talked before about the salmonella vaccine that can be then developed based on indications of the variations in genes from samples that were flown to Station.

So there is quite a bit of interest in the pharmaceutical area along these lines in both potentially dealing with bacteria and the change in the genes that occur in space and then also in the immune side. So both of those are very promising areas that have real application to folks here on the Earth. This is another way of getting insight into potential new drugs and their effectivity, and we can do it in a fairly quick manner by using space to do that.

Senator NELSON. Did you say that the human immune system works better in space or less better?

Mr. GERSTENMAIER. Less better. It doesn't work as well.

Senator NELSON. And how about the vaccine for MRSA?

Mr. GERSTENMAIER. Again, it can also benefit potentially from this same gene expression thing. We can get a chance to go look at different ways the genes are expressed, and then that can potentially lead to potentially some type of drug that can help with MRSA.

So, again, it is giving us—what happens in microgravity is it gives us a unique insight into the way the bacteria and genes express differently in space than they do here on the ground. And that unique change can then let the researcher develop new techniques or new, I guess, ways to protect against the particular diseases that are there.

And there is a whole variety of them. MRSA is one. Any bacteria in space, a new, novel way of trying to protect against it can be developed from research in space.

Senator NELSON. I want to ask you, what are the other missions and destinations that are necessary as we get ready for a long-distance mission to Mars?

Mr. GERSTENMAIER. Again, I think Space Station can be kind of that first step. We can gain a lot about how the human performs for long-duration exposure to microgravity, so that is an important thing.

Station is also a good test bed to go look at life-support systems, the systems that generate oxygen, remove carbon dioxide, reprocess water. Those systems on Station can be run for extended durations, and we can develop a low-maintenance system that doesn't require a lot of maintenance, that doesn't require a lot of hardware to keep

it operating on Station, and we can improve that system essentially on Station.

So that long-duration life-support system that will be necessary to keep our crews alive on journeys to Mars, that can be tested on board Space Station. In fact, our next generation of life-support systems on Station we intended to be the exploration systems that we will fly in the future.

So Station is giving us a unique chance to experiment with technologies that we are going to need to go into the long-duration flights to distances such as Mars.

Senator NELSON. And describe how the Station will serve as a platform to develop the propulsion technologies to go to Mars.

Mr. GERSTENMAIER. Again, Station is a good platform to check things out. We have been looking at potentially installing some small thrusters on Station. We are not sure we are going to do this or not. They could look at drag make-up. But, again, it could be essentially a test facility for those small thrusters.

You know, we are also seeing, in the same vein, we are seeing a lot of instruments that people would like to add to their spacecraft. They can take those, again, to Space Station, they can check those instruments out on Space Station, and then they can add them later to their spacecraft.

So Station is proving to be a very interesting proving ground. You will see in the next coming years some things fly that are flying on dedicated satellites. For example, the carbon observatory that is going to fly is a dedicated spacecraft. There will be a companion set of instruments that are essentially the spare instruments from that spacecraft. Those will fly to Space Station. They will be attached to Space Station. And they will also give us insight into carbon generation on the Earth.

What is interesting is a satellite flies in a sun-synchronous orbit, so it looks at carbon generation at essentially the same solar time every day. So you see carbon generation at one point of the day. That is a very good standard that is understood. You can look at carbon generation on the Earth from that.

But then Station, because it flies in a different orbit, it looks at those same locations but at different times of day. So that is going to give the researchers some insight into carbon generation throughout the day. So it gives them a different look at the same phenomenon that they are doing with their dedicated spacecraft.

So there is a nice synergy between the dedicated spacecraft that takes science in a more pristine, more organized manner. Then there is the Space Station, because of its orbit, that picks up data in a little more random fashion that adds to that data and actually builds a better combined data set than individually.

So you will see that fly. There is an aerosol experiment that will also fly. And then there is a RapidScat, which looks at winds in front of hurricanes, also. So there is a whole variety of uses of Station that are starting to come about.

Senator NELSON. Well, you have just made the case, if we are going to Mars in 2030s, of why the Space Station ought to have the life beyond 2020, its legal life now in law.

And, Mr. Cook, we will let you be the cleanup hitter. Tell us, if you have an extended life of the Station, what does the private sec-

tor think of in the development and use of the properties of the Station in order to benefit the private sector?

Mr. COOK. Thank you, Senator.

I think Mr. Gerstenmaier has laid out, for example, vaccines, new things that could be manufactured in space, new vaccines, new materials, things of that nature. But I want to flip it around the other way, and there are some technologies that expand the marketplace of terrestrial companies today.

For example, one of the experiments that is being ready to be flown on International Space Station is an additive manufacturing experiment, where you can literally grow parts in space, you can grow items in space. And there are printing technologies that allow you to do that today that are commercially available now. And this allows for a whole new market for them, to be able to then take it to the Space Station and test it out and demonstrate it out, build prototypes of parts, build even some parts, in terms of—— and how does that work in space? Does it work as well as it does on the ground? It is another market.

There are technologies that we are involved with in terms of taking commercial nanotechnology, being able to grow tools and other systems from pretty much any metal or any combination of metal and ceramics in space.

And so you use the Space Station as the ability. Compared to Mars, getting logistics up and back to the Space Station is fairly straightforward. But once we go to Mars or anywhere else beyond low-Earth orbit, we have to be able to live off the land. And so using the Space Station as a platform for companies that have technologies that work here on Earth to expand there into space, I think additive manufacturing is one very exciting area that a longer-term space station would allow that to be fleshed out over time.

Senator NELSON. And, Mr. Gerstenmaier—I keep saying I'm on the final question, but we have been joined by the esteemed senator from Connecticut.

Explain either the Space Station or the retrograde orbit, of if you can park things there or have things on the Station as you develop the technologies to go to Mars, that you don't have to go back down onto the surface of Earth to resupply. Give us some of your thoughts there.

Mr. GERSTENMAIER. Yes, this asteroid-retrieval mission that we described in this deep retrograde orbit, you know, that is an interesting region of space.

Some of the things we could do there potentially are Mars sample return we have talked about. We could use a similar technique to return a sample from Mars to this region. Once it is in this region, it is stable for an extended period of time, probably multiple decades. So, therefore, we could pick up Mars samples from this region.

Some of the Lagrangian points are interesting gravity locations around the Moon. Potentially maneuvering from those to deep space destinations is interesting and intriguing to us. We need to learn more about these regions and how we can use essentially the gravity of planets and also the Moon to assist us in going to these various destinations throughout the universe.

Senator NELSON. So you could bring a Mars sample back, park it in the retrograde orbit, and go sample it whenever you want to because it would be stable, we would have access to get to it, and you wouldn't have to work on it by taking it all the way back to Earth and then coming out of Earth back into orbit.

Mr. GERSTENMAIER. That is correct. Especially the asteroid, if it was there, you know, one visit probably doesn't give you as much information as you would want. You know, Steve talked about some of the potential minerals and things on the asteroid. You could actually spend several visits there to go look at it, characterize it, understand are asteroids really a viable source of material for missions into space.

So, again, it gives you the advantage of having this object in a location where it will remain for an extended period of time and you can visit it with essentially the capabilities we have today.

Senator NELSON. Since the amount of gold on the planet would fill two large swimming pools, Mr. Cook, if you find an asteroid that has gold in it, I would say our space program would be off and running.

Mr. COOK. Yes, I think that is a fact. And I think, again, that is where me viewing space is not just a novelty and not just a niche place but is a marketplace that can be utilized for the benefit of mankind here in growing our economic sphere.

That is the approach we need to take. That is the approach that was taken in almost every other exploration effort I can think of over history. And we ought to be considering that collaborative effort from day one.

Senator NELSON. It is just like the Spanish explorers that found Florida. They were looking for gold, but look what they found.

All right, the Senator from Connecticut, Senator Blumenthal.

STATEMENT OF HON. RICHARD BLUMENTHAL,
U.S. SENATOR FROM CONNECTICUT

Senator BLUMENTHAL. Thank you, Mr. Chairman.

On that note, you know, I was thinking the last gold rush was by horse-drawn wagon, so we have come a long way, although our ultimate aspirations may be very similar.

And I want to thank all of you for your excellent testimony, which I have been following even while I have been absent here, through the wonders of our modern communication system.

And, also, thank you to our Chairman, Senator Nelson, for his leadership here on this committee.

I have a somewhat more mundane area of inquiry, and I won't belabor it because I know we are near the end here. But I am interested in how NASA, as its mission changes, as new programs are developed, Constellation folded into Orion, for example, changes its contract so as to maintain competitive bidding.

In other words, I am very interested in the openness and competitiveness of the contract awards so that when, in effect, the mission changes, if there is a need for new services or goods, is there also a move to maintain or open new rounds of competitive bidding.

I don't know who would want to answer that.

Mr. GERSTENMAIER. I guess I can answer that. I would say that, you know, we have requirements for justification for other than full

and open procurement, right? So there is a pretty—in the Federal acquisition requirements, there is a pretty strict set of criteria we need to meet to not go compete.

So our clear preference is we would go out and compete unless there is demonstratable advantage that shows it is of overwhelming advantage to the government for us to not compete. And things would be, is there a substantial investment already made in the previous program that is directly applicable to the next program? Those kind of considerations. Is there not really another competitor in this field? That is another consideration.

So we logically have to go through all those various constraints, understand those. And then if we show that there really is no advantage to competition, then we could potentially award through the justification for other than full and open procurement to one of the existing companies.

And we did that when Constellation went away. We went through each one of the major components. We looked at what was justifiable, where was a significant advantage for us to continue the existing contract, or we went out and competed some of those contracts.

And, you know, our experience shows we have made tremendous progress in SLS, and some of that is because we realized exactly what we said in the procurement timeframe. For example, on the core booster, we argued that the upper stage for the Constellation program was almost identical to the core stage in manufacturing, so we did not compete that particular contract.

And we were able to make tremendous advantage in that activity, as evidenced where we are. You know, we are a little bit over 2 years away from when we did that initial transition, and we are already in the process of being ready to manufacture hardware next year. So that shows how fast we were able to turn around. And that was justifiable and evidenced by the actual performance.

But our preference is clearly to do competition and to open it up. I am continually surprised by what the market can provide. I think competition is extremely healthy for us, and we need to look for competition wherever we can.

Senator BLUMENTHAL. What would be some examples or an example of what you decided to compete as compared to the instance you just mentioned where you decided not to compete it?

Mr. GERSTENMAIER. I am trying to think through some of the—I would say, like, for the cargo systems that we are using on Space Station, when we decided to pick a cargo resupply services contract, we actually put that out for a full and open competition. We had an extremely good competition for that activity. We ended up selecting the two companies that are starting to deliver cargo to space now, SpaceX and the Orbital Sciences Corporation.

But, again, that was a pretty intense competition between all those providers. I believe we have lowered the cost of cargo to Space Station because of that competition. So that is probably an example of where competition was good and helped get us a better value for what we are trying to do.

It was also interesting, the way we did that procurement. You know, typically we would build the spacecraft or contract out for the spacecraft itself. In this case, we didn't. All we did was acquire

a service. So that is another thing that is good for us, is when we see there is a market and they could potentially use that rocket to lift scientific payloads and other things, if there is a market beyond what our need is, in that case just asking for the service is much better than us actually asking to have the rocket built and then us, the government, owning that rocket. So that is another thing that you will see a lot of us doing more on, is actually just looking for the service.

And even the Exploration Flight Test that is going to occur next year, where we are going to look at the heat shield of the Orion capsule, we did that in a unique way. Typically, we would have procured the launch vehicle, we would have integrated the Orion capsule on top. But what we did there, again, is we kind of chose that as a service contract. We want the entry heat shield data, and so we didn't specify what rocket would be used for that. We left it up to the contractor to determine what rocket. They will do the integration of the Orion on top of that rocket, with us just kind of watching, so NASA is not directly involved.

So, again, we are looking at, I would say, an innovative way of getting a standard service that doesn't involve government ownership but lets the market go do that. And that is another extremely effective way I think we have been able to lower some of our costs and get better value for the government.

Senator BLUMENTHAL. And just one last question. Are there areas where you haven't made that decision about whether to compete it or noncompete it?

Mr. GERSTENMAIER. For some of our future work sitting out in front of us, we go through an acquisition strategy meeting. And through that acquisition strategy meeting we describe these factors I just described to you, and we figure out what the best approach is to try to acquire a service or a capability we need and what that approach ought to be. We review that with the senior leadership of the agency, and we go through a formal process to do that.

So there is——

Senator BLUMENTHAL. Great.

Mr. GERSTENMAIER.—quite a bit of work out in front of us that still needs to be decided.

Senator BLUMENTHAL. And my understanding is that, if I can put it in lawyer terms, not scientific terms, forgive me, that the burden of proof, in effect, is on the argument that there should be no competition. You are willing to go that route if there are clear advantages in cost or time or whatever to the United States, but otherwise you would go the compete route.

Mr. GERSTENMAIER. Yes. And that is what the Federal acquisition rules and regulations require us to do.

Senator BLUMENTHAL. Thank you.

Thank you very much, Mr. Chairman.

Senator NELSON. Thank you, Senator.

It has been a very good discussion. Thank you all for participating.

The meeting is adjourned.

[Whereupon, at 4:03 p.m., the hearing was adjourned.]

A P P E N D I X

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. AMY KLOBUCHAR TO WILLIAM H. GERSTENMAIER

Question 1. NASA relies upon a network of private partners across America to provide much of the hardware necessary for manned space flight. Those firms need long term certainty to be able to maintain a skilled workforce. Are you concerned that potential cuts to the Orion program could jeopardize the Nation's leadership in manned spaceflight?

Answer. The development of the Orion crew vehicle, heavy-lift Space Launch System (SLS), and enabling Exploration Ground Systems (EGS), as well as the commercial crew program, are maintaining the Nation's leadership in human spaceflight. Together, Orion, SLS, and EGS constitute the next critical step on the path to human deep space exploration. The FY 2014 President's Budget Request supports the funding necessary for these activities to maintain the Exploration Flight Test-1 (EFT–1), Exploration Mission-1 (EM–1), and Exploration Mission (EM–2) launch dates of 2014, 2017, and 2021, respectively. The Orion Program, including EFT–1 flight test preparation, provides experience and benefits to America's industrial base and supply chains. The industrial contractors and facilities involved with EFT–1 and the teams they employ, are gaining important experience, ensuring that the industrial base is exercised in accomplishing a spaceflight mission ahead of the 2017 EM–1 launch, the first launch of the Orion on the SLS.

Question 2. Administrator, as you may know, Minnesota is a leader in the medical device industry. A surprising number of the technologies used in the construction of medical devices were developed by NASA in pursuit of manned space flight. Could you talk about the spillover effect you see across America that continued investment in NASA will yield?

Answer. The benefits of NASA research are all around us: Knowledge provided by weather and navigational spacecraft; millions of passengers and packages traveling safely by air every day; efficiency in ground and air transportation; super computers; solar- and wind-generated energy; the cameras in many cell phones; biomedical technologies such as advanced imaging and infant formula; and the protective gear that keeps our military, firefighters, and police safe have all benefitted from the Nation's investments in aerospace technology.

Over 90 percent of the infant formula sold around the world contains a specific nutrient discovered by NASA during plant growth experiments for long duration space flight.

Over 75 percent of the cell phone cameras today operate on a device called the CMOS, camera-on-a-chip that was designed by a NASA engineer Eric Fossum working on cameras for deep space imaging.

NASA is now creating a future in space exploration that was unimaginable just decades ago. Exciting advances, like solar electric propulsion for robotic missions, the Mars Science Laboratory, new Earth-observing satellites, and the James Webb Space Telescope underscore the importance of today's investment in space technology for tomorrow's discoveries and accomplishments.

To make these incredible technologies come to life, NASA researchers, engineers, and contractors often work alongside our many partners in industry and academia. These partnerships don't just further our missions; they also create a large number of spinoff technologies with tangible benefits that are making an impact on our lives today.

From life-saving shelters to innovations that protect the environment to components that are making commercial space transport possible, technology transfer represents a core part of NASA's mission and identity. It ensures that what we do each and every day for space and aerospace delivers the greatest benefit to the public.

You can learn more about commercialized NASA technologies at: *spinoff.nasa.gov*.

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