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THE INTERNATIONAL SPACE STATION: ADDRESSING OPERATIONAL CHALLENGES

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

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COMMITTEE ON
SCIENCE, SPACE, AND
TECHNOLOGY
CHAIRMAN LAMAR SMITH

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Statement of Subcommittee Chairman Brian Babin (R-Texas)
The International Space Station: Addressing Operational Challenges

Chairman Babin: Since 2013, the ISS program has experienced a number of challenges. As a can-do nation, America has always been committed to identifying challenges, addressing them and advancing to reach our destiny. We have that same commitment with the ISS. During this time, astronauts have experienced water leaks in their suits three times, with one incident occurring during a spacewalk. On April 26, 2013, an unmanned Russian Progress cargo vehicle damaged a laser radar reflector when docking with the ISS. On January 14, 2015, a false alarm of an ammonia leak caused the crew to retreat into the Russian segment. On October 28, 2014, an Orbital Science's unmanned cargo launch failed just after launch. On April 28, 2015, a separate Russian Progress cargo vehicle failed to reach the ISS. On June 7, 2015, a planned re-boost of the ISS using a docked Progress vehicle failed but eventually was successful after troubleshooting. On June 10, 2015, a visiting Soyuz vehicle unexpectedly fired its engines without being commanded. Most recently, on June 28, 2015, a SpaceX unmanned cargo launch failed as well.

All of these incidents highlight the challenges of operating in space, and remind us that NASA's contractors, engineers, and astronauts must be ever vigilant. These events have challenged ISS operations, but the fact that the program was able to effectively respond to these set-backs is a testament to NASA, the ISS partners, and the contractors. We do not know the root causes of some of the accidents yet, but once we have more information, we will be better suited to review those individual events. In the meantime, this hearing allows us to evaluate the operational status of the ISS, review efforts to utilize the unique asset, and assess the prospects for future operations.

The ISS is one of the most complex and expensive man-made objects ever built. The American taxpayer currently invests approximately three billion dollars per year in this laboratory. We must ensure that every dollar is spent effectively and efficiently. The ISS offers a unique microgravity environment for scientists and engineers to utilize. NASA recently released its "Benefits to Humanity" publication this week detailing the many benefits that ISS provides back to our lives here on Earth. From advances in our understanding of human health and performance to our use of new materials to the utilization of robotics and satellites, the benefits we receive from the ISS are many and diverse.

In addition to the benefits back on Earth the ISS offers the conditions necessary to prepare and develop critical technologies for deep space and long-duration human spaceflight missions. Successive NASA Authorizations direct the Administration to utilize the ISS for this purpose. The Human Research Program and Advanced Exploration Systems program at NASA are on the cutting edge of developing the systems we need to send humans deeper into the Solar System than ever before. Right now, Captain Mark Kelly is on day 104 of his year-long mission to study the effects of long duration human spaceflight.

In addition to the utilization efforts of NASA's research programs, the NASA Authorization Act of 2005 designated part of the ISS as a National Lab and the NASA Authorization Act of 2010 directed the Administration to sign a cooperative agreement with a non-profit to manage it. NASA selected the Center for the Advancement of Science in Space, or CASIS, to lead this effort. The Government Accountability Office noted in a recent report that CASIS has made great strides in fulfilling the mandate under the law but that more work needed to be done to ensure that measurable progress was being made in a quantifiable manner. I hope to hear from NASA today that the agency is making progress towards answering this recommendation from GAO.

As we keep an eye on the present operation and utilization of the ISS, we must also look to the future. Last year the Administration announced support for the extension of the ISS program from 2020 to 2024. At present, federal law limits the life of the ISS to 2020. Absent action from Congress to extend it, the Administration would be required to begin closeout of the program.

There are many questions about the request for this extension. The bipartisan, House-passed NASA Authorization of 2015 requires the Administration to provide a report to Congress on efforts by the Administration to utilize the ISS and how to quantify benefits back to the Nation for the required investment for extension. It also requires the Administration to develop a government-wide utilization plan for the ISS to ensure that every minute the facility is in orbit we are doing what we can to get the most out of it. These reports are critical for Congress to understand the issues that inform whether to extend the ISS.

This Committee has a responsibility to ensure that the American taxpayers are getting all that they can from every dollar they send to the Federal Government. I believe this investment is worthwhile and that the benefits far outweigh the cost. Support for the ISS and its operations and utilization is not a partisan issue, it is an American issue and I look forward to working with my friends on the other side of the aisle and our partners in the space industry to understand how we can all meet the operational challenges facing the ISS program.

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Testimony of John Elbon

Vice President and General Manager

Boeing Space Exploration

July 10, 2015

Chairman Babin, Ranking Member Edwards, and members of the Committee, on behalf of The Boeing Company, thank you for the opportunity to testify today to provide an update on Boeing's role in the International Space Station (ISS).

Boeing is extremely proud to have supported NASA in the design, integration and assembly of the ISS. As NASA's prime contractor, Boeing delivered the U.S. elements of the ISS and provided system integration and stage-by-stage assembly on orbit of all U.S. and international elements. We continue in the ISS sustainment role today.

On November 2^{nd} the world will celebrate 15 years of continuous human presence in space, with international crews living and working aboard ISS. At a time when many decry a gap in America's space program as we transition from the Space Shuttle to commercial transportation solutions, we who know ISS know that America and our partner nations are making advances in space every day.

Consistent with the Committee's request, I am pleased to share some of these advances as I address current ISS operational capabilities and improvements to maximize ISS utilization, as well as Boeing's role in technical issue resolution in cooperation with NASA and the International Partners.

Current Operational Capabilities.

The International Space Station has been recognized as the largest, most complex international scientific and engineering project in history and the world's largest endeavor in space to date. Ongoing improvements have made ISS even better.

The Station brought together hardware and software from 16 countries, 37 states and more than 10,000 suppliers, often with first-time integration occurring on orbit. About the size of an American football field, the ISS is larger than a six bedroom house and has the internal pressurized volume of a Boeing 747.

An electrical power system with eight miles of wiring receives its power from more than an acre of solar arrays – a surface area that could cover the U.S. House chamber three times. Those same solar arrays make ISS the brightest object in the night sky after the moon. Featuring three dedicated research laboratories – the U.S. Destiny Laboratory, the European Space Agency's Columbus Laboratory, and the Japanese Kibo Laboratory – ISS is the world's preeminent microgravity research facility.

ISS is an engineering marvel, a beacon for international cooperation, and a shining example of what can be achieved through strong leadership and unity of purpose for the benefit of humankind.

As NASA's contractor for sustaining engineering for the ISS, Boeing is responsible for maintaining the station and ensuring the full availability of the unique research laboratory for NASA, International Partners, other U.S. government agencies and private companies.

<u>Operational Efficiencies and Improvements.</u>

Boeing continues to work with NASA to reduce the costs of sustaining the International Space Station. Over the past 10 years, we have reduced the cost of our sustainment role by more than 30 percent.

This savings has enabled NASA to fund ISS improvements such as the NASA Docking System, which includes the International Docking Adapter (IDA) – a critical component supporting the increase in the number of commercial vehicles visiting the Station and enabling NASA and the International Partners to increase the crew size on Station. The crew spends approximately 35 hours a week dedicated to space station science and research. When we increase crew size by one, the research time nearly doubles.

ISS Space to Ground communications channels have been improved, allowing for more real time interaction between crew members performing experiment tasks on-orbit and science experts on the ground. This real-time dialogue enables quick adjustments to research parameters while the experiment is being conducted, providing more meaningful results.

ISS now provides higher quality video downlinks to support more detailed observations and a higher rate data downlink to send more science data to analysts on the ground more quickly. Higher speed data downlinks are particularly important due to the large data sets coming down from ISS.

The ISS power system has been upgraded to 110 VAC. This is important because it allows the use of commercial-off-the-shelf hardware on ISS instead of more expensive custom or highly modified equipment, which can deter prospective researchers. Because 110 VAC is what most ground-based laboratories use, this also allows easy transition of equipment and significantly lowers the cost of laboratory outfitting.

These improvements help to keep ISS operating at peak efficiency today and provide a basis for continuing strong performance well into the future. Boeing recently completed a technical assessment of the useable life of major ISS hardware components. Our study indicates that the Station will be operable to at least 2028. Long-term viability of the Station is an important factor in continuing to attract researchers, who invest considerable time in preparing their experiments for conduct in space.

<u>Maximizing ISS Science and Utilization.</u>

The continuing on-orbit reliability of ISS and the improvements made to further enhance research capabilities are a boon to maximizing facility utilization. Our experiences and investigations on ISS are providing many benefits and improvements both to enable continuing human space exploration, and also to improve the quality of life here on Earth.

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

To put the distance from the Earth to Mars in perspective, if the Earth were a classroom sized globe, the ISS would be less than a half of an inch from that globe, the Earth's moon would be about 30 feet from the globe, and Mars would be another 10 miles farther away. Testing and learning on the space station – here, close to the resources of home – is proving to be an intelligent early step on the threshold of deeper space exploration.

The ISS is a test bed for learning how the body reacts to prolonged weightlessness, and allows us to develop countermeasures now. We are learning today the effects and extent of bone loss in zero-g. We are also learning the long-term effects on the neuro vestibular system, as well as the impacts to our ocular system.

We are learning self-sustainment skills, such as growing food in space and recycling water. All of these things are important to learn and understand before we explore farther into our solar system.

Research on ISS has led to numerous improvements on Earth – from the medical field, to Earth observations, to providing clean water in underdeveloped countries, to how we diagnose and treat patients in remote areas.

Space station research has led to medication that can help offset the effects of osteoporosis. Space research could also lead to cures for Duchenne Muscular Dystrophy and vaccines for things like staph infection and Salmonella poisoning.

In addition, the technology that went into developing neuroArm, the world's first robot capable of performing surgery inside an MRI, was developed from the Canadarm (developed by MDA for the U.S. Space Shuttle Program) as well as Canadarm2 and Dextre, the Canadian Space Agency's family of space robots performing the heavy-lifting and maintenance on board the International Space Station.

I'd like to expand on some of the ISS science that I find particularly exciting.

WATER RESOURCE MANAGEMENT

Water resource management challenges and hydrological technology development needs are global priorities and provide the opportunity to assert regional leadership.

The challenges of human spaceflight continue to drive innovation in water resource management. Life support systems used in space require water recycling and filtration processes to operate over long periods without potential resupply capabilities. This technology can be applied to address regional water challenges today and in the future.

Similarly to how we reuse waste water on board the ISS, schools in third world countries are utilizing this technology in areas where fresh water is scarce. Last year, a school in Morocco's capitol became the first public facility to use this type of recycling system.

The system relies on a set of organic and ceramic membranes with holes just one ten-thousandth of a millimeter in diameter, which is 700 times thinner than a strand of human hair. These tiny pores filter out unwanted compounds in water, including nitrate – a problematic pollutant that comes from agricultural fertilizers.

Additionally, an orbital complex like ISS can be used for remote sensing purposes, collecting data from space characterizing agricultural productivity, vegetative trends, seasonal ecosystem dynamics, water depth, clarity and sea floor data.

BIOTECHNOLOGY

The biotechnology industry faces significant challenges, given the growing demand for products in the medical, agricultural and environmental fields.

Worldwide research efforts in the areas of molecular and cellular biology to treat and cure human diseases and disorders have exceeded $700 Billion dollars annually. Advances in molecular and cellular biology are essential and necessary to protect and maintain the health of all citizens. New biotech research investigations being conducted in the unique microgravity environment of space are revealing previously unknown biological clues valuable in cancer, genetics and aging research. Unmasking the effects of gravity allows researchers to view proteins as intricate, three-dimensional structures and identify potential medical treatment candidates.

As one specific example, protein molecules crystallized in microgravity have revealed vital structural clues to help identify a viable treatment for Duchenne Muscular Dystrophy (DMD). DMD is the most prevalent form of muscular dystrophy affecting 1 in 3,000 boys (over 50,000 young males in the U.S. today). The average life expectancy of a person with DMD is 25 years and there is currently no cure.

Japanese scientists were able to identify a previously unknown water molecule associated with an inhibitor protein which may be the key to unlocking a potential cure. In addition to medical applications, advances in Biotechnology research in space may also contribute to development of agricultural land and the reclamation of new lands to satisfy the need for increased agricultural production due to high population growth.

BONE LOSS

In 2010 the FDA approved AMGEN's drug Denosumab, which was used initially for treatment of postmenopausal osteoporosis and subsequently for treatment of bone metastases. Both applications were developed in partnership with the ISS sciences team.

PORTABLE ULTRASOUND TRAINING AND TREATMENT

ISS astronauts were trained to use portable ultrasound to diagnose issues like broken bones and collapsed lungs that might occur on orbit where medical facilities are limited. This same method is now being used to train third-world doctors and care providers to treat patients where modern technology is not available. This training has translated to treatment of more than 40-thousand patients in underserved countries, like Brazil, due to diagnosis through portable ultrasound.

TARGETED METHOD OF CHEMOTHERAPY DRUG DELIVERY; CLINICAL BREAST CANCER TRIALS NOW IN DEVELOPMENT

This treatment has the potential to change how we address cancer—a devastating illness that has touched many of our lives.

Patients receiving invasive cancer treatment must endure ravaging side effects, including nausea, immune suppression, hair loss and even organ failure, in hopes of eradicating cancerous tissues in the body.

Aboard the ISS, a process known as microencapsulation is being investigated, which may be able to more effectively produce tiny, liquid-filled, biodegradable micro-balloons containing specific combinations of concentrated anti-tumor drugs. Using specialized needles, doctors can deliver these micro-balloons, or microcapsules, to specific treatment sites within the patient. Treatments that target cancerous tissues reduce the general toxicity of chemotherapy or radiation to the surrounding healthy tissues. This kind of targeted therapy may soon revolutionize cancer treatment delivery.

<u>Working with NASA and the International Partners to Resolve Technical Issues.</u>

To ensure ISS continues to achieve its science mission, Boeing supports NASA and the International Partners with technical and operations skills for responsive issue resolution.

We work closely with NASA in the ISS Mission Evaluation Room at the Johnson Space Center, providing ongoing mission support for resolution of on-orbit technical and operational issues. Technical issues are vetted through the NASA flight operations processes, and interdisciplinary problem resolution teams are assigned to investigate root causes and implement solutions.

In addition to the technical support provided by our dedicated ISS personnel, Boeing is able to draw upon technical experts in a full range of engineering and operations disciplines from across the Boeing Enterprise, including our space, defense, and commercial airplanes businesses.

NASA manages the relationship with the ISS International Partners and leads decisions related to technical anomaly resolution. Supporting the NASA role with the International Partners, Boeing maintains international industry relationships that facilitate technical issue resolution.

Because of the ISS, international cooperation remains constant for space and serves as a bridge for other diplomatic discussions. As a leader and the major supporter of the ISS, the United States is in position to continue to champion a global vision for space exploration.

Closing Remarks.

Over the past several years, I've had the opportunity to interact with leaders in countries that are not engaged in the ISS or do not yet have a space program. Without exception, in every one of these conversations about space exploration, people express a strong desire to be involved in space, and more specifically in the International Space Station.

They see the value of ISS – to inspire their youth to pursue STEM education, to create economy-expanding high technology industries, and to provide a significant source of national pride.

For the United States and our International Partners, the ISS provides all these benefits and much more. Fundamentally, the ISS is a one-of-a-kind laboratory facility where researchers are now leveraging the unique microgravity environment of space to revolutionize how we treat medical conditions and manage natural resources. In addition, ISS serves as a valuable prerequisite to advanced space exploration – a place near Earth to test our deep space exploration wings before flying farther beyond low Earth orbit.

Grand as it is, *building* the ISS is not a crowning achievement. We must continue *utilization* of ISS as a practical resource for advancing science, and improving the human condition. And to derive the *full benefit* of ISS, we must use it as a place to ensure our readiness for traveling much farther in space.

We at The Boeing Company are committed to supporting NASA and keeping ISS healthy and continuously capable to support every aspect of its bold mission – improving life on Earth and enabling exploration beyond.

Thank you.

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BY WITNESS
July 10, 2015

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

before the

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

Mr. Chairman and Members of the Subcommittee, thank you for the opportunity to appear before you today to discuss the status of the International Space Station (ISS) Program, as well as our efforts to conduct microgravity research and promote U.S. economic activity in low-Earth orbit (LEO), and expand human spaceflight beyond LEO. The ISS represents an unparalleled capability in human spaceflight that is increasing our knowledge of basic physics and biology. This knowledge is benefiting our lives here on Earth and enhancing the competitiveness of private industry here in the United States. The research and technology demonstrations onboard the ISS are providing the basis for extending human presence beyond the bounds of LEO and taking our next steps into the proving ground of cis-lunar space. With the Administration's proposed extension of the ISS until at least 2024, NASA has the opportunity to more fully utilize research, and commercial and international partnerships to ensure that the U.S. continues to be the world leader in human spaceflight and to enable U.S. industry to realize the commercial benefits of research and development in the microgravity environment of space.

The ISS is vital to NASA's mission to extend human presence into the solar system. In order to prepare for human expeditions into deep space, we must first use the unique environment of ISS to conduct the research and technology demonstrations necessary to keep our crews safe and productive on long-duration spaceflights. The ISS – which has been home to a continuous human presence on orbit for almost 15 years – is NASA's only long-duration flight analog for future human deep-space missions, and it provides an invaluable laboratory for research with direct application to the exploration requirements that address human risks associated with deep-space missions. It is the only space-based multinational research and technology test bed available to identify and quantify risks to human health and performance, identify and validate potential risk mitigation techniques, and develop countermeasures for future human exploration. As NASA learns more about the changes to the human body from spaceflight and develops countermeasures to support long-duration missions, this same research is providing unique insight into problems facing our aging terrestrial population. Through the National Laboratory and the Center for the Advancement of Science in Space (CASIS), U.S. companies are taking advantage of new research opportunities that may provide a competitive edge. Across a range of disciplines and applications, ISS research ultimately benefits people on Earth.

Cargo and Crew Transportation

In order to realize the full potential of the ISS' capabilities, the platform is serviced by a fleet of operational vehicles, including two U.S. cargo resupply vehicles: Space Exploration Technologies'

(SpaceX) Dragon and Orbital ATK's Cygnus. These two providers have flown a combined total of eight cargo missions to the ISS under the Commercial Resupply Services (CRS) contracts, which were awarded on December 23, 2008. The cargo flights have demonstrated the viability of the Government use of commercially provided services – rather than owning and operating the spacecraft and launch vehicles – for the delivery of experiments, supplies, and spares to the Station, enabling NASA to focus its development efforts on deep-space vehicles to take our astronauts beyond LEO. Further, both companies have demonstrated their resourcefulness in dealing with challenges. NASA anticipates awarding one or more CRS-2 contracts later this year.

The overall cargo strategy of having multiple providers has served NASA well, and the importance of having multiple providers is critical for assured cargo access to the ISS, as has been demonstrated by recent losses of Orbital ATK Cygnus, Russian Progress, and SpaceX Dragon cargo flights to ISS. NASA was able to continue ISS operations and research by relying on SpaceX after the Cygnus cargo vehicle anomaly last fall. Orbital is expected to recover and return to flight before the end of 2015. Orbital ATK acquired a launch on an Atlas V vehicle while its Antares launcher is outfitted with a new engine. This strategy allows Orbital ATK to use its Cygnus vehicle and resume cargo delivery capability later this year. The ability of Orbital ATK to quickly integrate Cygnus with an Atlas V is a direct result of their experience in integrating their satellites onto different launch vehicles. The basic CRS-1 contract premise of obtaining cargo services enabled Orbital ATK to creatively acquire a new launch vehicle. This demonstrates the effectiveness of our current contract strategy. Late last month, the SpaceX-7 cargo mission experienced an anomaly during launch. SpaceX has demonstrated extraordinary capabilities in its first six cargo resupply missions to the Station, and we know they can replicate that success. We will work with and support SpaceX to assess what happened, understand the specifics of the failure and correct it to move forward. These events are reminders that spaceflight is difficult, but we learn from each success and each setback, and our commercial cargo program was designed to accommodate the loss of cargo vehicles. With the delivery last week of supplies aboard a Russian Progress vehicle, and with the prospect of a Japanese H-II Transfer Vehicle (HTV) flight in August, we do not anticipate any need to delay the upcoming Soyuz 43S launch later this month, which will return us to six-crew operations and research.

In the area of crew transportation, while NASA continues to develop Commercial Crew capability to provide crew transportation and rescue services to the ISS, the Russian Soyuz spacecraft currently provides these services. The ISS routinely hosts six crewmembers on long-duration missions with the support of two Soyuz spacecraft. The limit in crew size is driven by the Soyuz three-crew-carrying capability. There are currently four Soyuz missions per year to accomplish ISS crew rotations.

NASA's plans for research through 2017 are based having six crew on ISS, including the Human Research Program objectives we need to accomplish during this period to keep on track to reduce or retire risks for deep-space exploration. It should be noted, however, that Station has – from time to time – hosted only three crew during brief transition periods. Before the loss of the SpaceX-7 cargo flight, the current period of three-crew operations had resulted in the deferral of a docking adapter installation, as well as the deferral of some Node 1 preparation tasks. In addition, a rodent experiment was dropped from the SpaceX-7 cargo flight, and some fluid shift experiments were moved to the next Expedition. At this point, NASA anticipates that the current period of having three crew aboard will not last longer than a few weeks, after which, we will staff back up to six crew and resume the normal rate of research activities. Beyond 2017 when U.S. crew providers come on line, our plans count on having an ISS crew complement of seven. Even after losing the docking adapter on SpaceX-7, NASA will have time to add docking capability to ISS to support the first U.S. commercial crew flights.

In 2014, NASA contracted with two U.S. providers for crew transportation and rescue services for ISS. The Commercial Crew Transportation Capability (CCtCap) contracts will complete the development of domestic systems to provide safe, reliable, cost-effective access to and from ISS. SpaceX's Crew Dragon and Boeing's CST-100 spacecraft will begin ferrying our crews to Station from U.S. soil by the end of 2017, contingent upon receiving the full amount requested in the FY 2016 Budget Request, enhancing the robustness of our transportation system and ending our sole reliance on Russia for the provision of these services. U.S. commercial crew capabilities will enable the Station crew to be expanded from six to seven astronauts and cosmonauts, resulting in a doubling of on-orbit research time to almost 80 hours per week. This is because the seventh crew member will be able to focus his or her time almost exclusively on conducting experiments, rather than on Station operations and maintenance.

I want to thank this Committee for authorizing full funding in FY 2016 for our Commercial Crew Program. It is vitally important that NASA receive this funding level to keep the development of these systems on track for flights in 2017. If the Agency is funded with a Continuing Resolution for the first quarter of FY 2016, NASA will need to address how it will fund our partners' development activities at the current contractual schedule. The CCtCap contractors are only required to work on milestones to the extent that NASA has obligated funding for those milestones. If funding is not available in FY 2016 for the initial FY 2017 milestones, the contractors will have to stop work or work at risk until additional funding can be obligated, existing CCtCap contracts will need to be renegotiated, most likely resulting in schedule delays and increased contract cost, and NASA will need to continue to rely solely on Russian Soyuz capability to meet America's requirements for crew transportation services. NASA has no plans to downselect the number of partners in response to lower-than-requested funding levels. As experience has shown with cargo, NASA's plan to establish a redundant crew transportation capability is critically important for robust, safe ISS operations. This redundancy is even more critical during the development phase. We appreciate the Committee's support for our plan to end sole reliance on Russia for crew transportation through contracts with two U.S. providers.

With over 350 American companies across 36 states working toward this goal, there are significant economic benefits to returning these launches to American soil. At the same time, every dollar we send overseas rather than investing at home represents an investment we could be making in ourselves rather than in the Russian economy.

There are also longer term fiscal considerations to consider. NASA projects that the average seat price will be $58 million per seat for Commercial Crew. The currently contracted seat price for Soyuz for 2017 is approximately $76 million per seat.

Sustainability of ISS and Extension to 2024

The ISS continues to be a very healthy system operating well within prudent technical margins, and consistently demonstrating outstanding steady-state performance that meets or exceeds prior engineering estimates. While systems were originally specified to be both reliable and maintainable, the operational experience NASA and its Partners are gaining is providing invaluable information on reliability and maintainability standards for future application to spacecraft design and mission planning. This enables systems needed for long-duration spaceflight to be tested in preparation for missions far from Earth for which reliability and maintainability are absolutely required. Just as short-duration Space Shuttle flights prepared us for long duration Station flights, ISS is preparing us for missions that will not have the option of immediate crew return in the event of an anomaly.

In January 2014, the Administration announced its intent to extend ISS operations until at least 2024. The research we will conduct on ISS through 2024 will be essential to the safe and effective conduct of human exploration beyond LEO. This extension is also critical to commercial sector planning for the use of the ISS. Industry requires the planning stability provided by the extension in order to consider further investment in microgravity research and transportation services. Commercial LEO development, spurred in part by the continuation of ISS, will also help enable exploration and make NASA resources available for deeper space exploration.

In addition to the United States, the Government of Canada has announced that Canada will continue its participation in the ISS to 2024. There have been multiple public indications that Russia will continue participating in the ISS program through 2024; Roscosmos (the Russian Federal Space Agency) has publicly commented that it expects to receive government authority by the end of the year to continue ISS beyond 2020. The Government of Japan has also indicated that its decision to support ISS operations beyond 2020 will likely be made in the near future after internal government deliberations are completed. The European Space Agency is expected to address ISS operations and utilization beyond 2020 at their ministerial meeting in late 2016. The ISS Partners have expressed support for continuing research on ISS, and see tremendous benefit for extended research opportunities.

As NASA has moved into Station's intensive utilization phase, we have become more cost-efficient in ISS operations. In the FY 2016 President's Budget Request, ISS Operations and Maintenance (O&M) is only 35 percent of the ISS request. The majority of the request, 55 percent, is for ISS Crew and Cargo Transportation. The remaining 10 percent is for ISS Research. Since the ISS was extended to 2020 in 2011, NASA has reduced the ISS O&M budget through a combination of efficiencies in sustaining activities, some content reductions, and cutbacks in operations overhead. While NASA continues to look for further efficiencies, we have already achieved a level of efficiency that allows us to productively operate and sustain the ISS, keep our crews healthy and safe, and support utilization with substantially reduced resources. Ongoing activities to responsibly lower the O&M cost of the ISS include changes to our contracts to incentivize efficiency, lower overhead cost, and apply targeted enhancements in technology investments to reduce manpower-intensive processes. These activities are assumed in the FY 2016 President's Budget Request.

ISS Research

The ISS supports research across a diverse array of disciplines, including high-energy particle physics, Earth remote sensing and geophysics experiments, molecular and cellular biotechnology experiments, human physiology research (including bone and muscle research), radiation research, plant and cultivation experiments, combustion research, fluid research, materials science experiments, and biological investigations. In addition, the ISS is an invaluable platform for technology development efforts. Research and development conducted aboard the ISS holds the promise of next-generation technologies, not only in areas directly related to NASA's exploration efforts, but in fields that have numerous terrestrial applications. The ISS will provide these opportunities to scientists, engineers, and technologists through at least 2024. Beyond being a feat of unparalleled engineering and construction, as well as international collaboration, the ISS is a place to learn how to live and work in space over a long period of time and foster new markets for commercial products and services. Remarkably, 83 countries/areas worldwide have participated in ISS utilization.

NASA's 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 could have broad impacts on Earth as it advances our ability to support long-duration human exploration.

On March 27, 2015, NASA astronaut Scott Kelly and cosmonaut Mikhail Kornienko of Roscosmos launched to the ISS to begin a one-year mission aboard the orbiting outpost. NASA and Roscosmos selected several collaborative investigations for this mission to evaluate the effects of long-duration spaceflight on humans. Each of the U.S. investigations will be grouped into one of seven categories: functional, behavioral health, visual impairment, metabolic, physical performance, microbial, and human factors. Researchers expect the mission's investigations to provide data on biomedical, performance, and behavioral changes and challenges astronauts may face when they embark on longer-duration missions, like those to an asteroid, Mars, or beyond. Data from the expedition will be used to determine whether there are ways to further reduce the risks on future long-duration missions to an asteroid and eventually Mars.

The investigations involving astronauts Scott and Mark Kelly, who are identical twins, will provide NASA and outside researchers with a genetic blueprint and broader insight into the subtle genetic effects and changes that may occur during long-term (i.e., one year) spaceflight as compared to Earth-based environments. The studies will focus on four areas: human physiology, behavioral health, microbiology/microbiome, and molecular or -omics studies (-omics refers to a system-level approach to studying molecular biology; examples include genomics, proteomics, and metabolomics). Although the investigations conducted on the Kelly brothers are not expected to provide definitive data about the effects of spaceflight on individuals — because there are only two subjects for data collection — they do serve as a demonstration project for future research initiatives. These investigations may identify changes to pursue in research of larger astronaut populations.

NASA is also exploring open-source science where databases are made available to a large number of researchers for investigation. This approach is in contrast to the past practice of one researcher "owning" all of the data from their investigation. This open-science approach shares a large data set of information with researchers for a variety of investigations

A National Laboratory in Orbit

In the NASA Authorization Act of 2005 (P.L. 109-155), Congress designated the U.S. segment of the ISS as a National Laboratory, and directed the Agency to seek to increase the utilization of the ISS by other Federal entities and the private sector. Subsequently, in the NASA Authorization Act of 2010 (P.L. 111-267), Congress directed that the Agency enter into a cooperative agreement with a not-for-profit organization to manage the activities of the ISS National Laboratory. On August 31, 2011, the Agency finalized a cooperative agreement with CASIS to manage the portion of the ISS that operates as a U.S. National Laboratory. CASIS works to ensure that the Station's unique capabilities are available to the broadest possible cross-section of U.S. scientific, technological, and industrial communities. The goal is to support, promote and accelerate innovations and new discoveries in science, engineering, and technology that will improve life on Earth. NASA's National Laboratory partners can use the unique microgravity environment of space and the advanced research facilities aboard Station to enable investigations that may give them the edge in the global competition to develop valuable, high technology products and services. The National Laboratory will help establish and demonstrate the market for research in LEO beyond the requirements of NASA.

Use of the ISS as a National Laboratory has increased significantly since FY 2012, which was the first full year of operations by CASIS. CASIS is reaching its full allocation of National Lab resources and it expected to continue to do so for the foreseeable future. The growth is coming from non-traditional areas, specifically from the commercial sector. Commercial projects for research and technology development on the ISS National Lab have increased from three in FY 2012 to 107 in FY 2014. This includes such industry leaders as Merck, Novartis, and Eli Lilly. Expanded capabilities, such as the ability to conduct model organism research on the ISS, using rodents as well as other organisms, has helped draw this interest. Commercial efforts have also included perhaps the largest purely commercial provision of services using the ISS, the deployment by NanoRacks of dozens of Dove cube satellites for Planet Labs.

Similarly, use by other Government agencies, including the National Institutes of Health and Department of Defense, has also begun to broaden, totaling 11 investigations in FY 2014. Finally, investigations from academic institutions rose from 31 in FY 2012 to 90 in FY 2014. Grant funding for research through the National Lab continues to grow, from $2.1 million in FY 2012, to $5.9 million in FY 2014. Additionally, NASA is collaborating with CASIS to enable sustained investment and research activities onboard the ISS across industry and other Government agencies that will transcend the life of the Station. The ISS International Partners are also seeking to expand the base of researchers using their assets on the ISS and are very interested in the National Lab model. This will expand research, and commercial participation, in low-Earth orbit.

ISS – Benefits to Humanity

Almost as soon as the ISS was habitable, researchers began using it to study the impact of microgravity and other space effects. In the physical and biological sciences arena, the ISS allows researchers to use microgravity conditions to understand the effect of the microgravity environment on microbial systems, fluid physics, combustion science, and materials processing, as well as environmental control and fire safety technologies. The ISS also provides a test bed for studying, developing, and testing new technologies for use in future exploration missions. Although each Station partner has distinct agency/national goals for ISS research, each partner collectively shares a unified goal to extend the resulting knowledge for the betterment of humanity. In the areas of human health, telemedicine, education, and Earth observations from space, there are already demonstrated benefits. Pharmaceutical development research, Station-generated images that assist with disaster relief and farming, and education programs that inspire future scientists, engineers, and space explorers highlight just some of the many examples of research that can benefit humanity.

ISS crews are conducting human medical research to develop knowledge in the areas of: clinical medicine, human physiology, cardiovascular research, bone and muscle health, neurovestibular medicine, diagnostic instruments and sensors, advanced ultrasound, exercise and pharmacological countermeasures, food and nutrition, immunology and infection, exercise systems, and human behavior and performance. Many investigations conducted aboard ISS will have direct application to terrestrial medicine. For example, the growing senior population may benefit from experiments in the areas of bone and muscle health, immunology, vestibular response and balance, and from the development of advanced diagnostic systems. The ISS requires telemedicine be used to monitor and treat crews. Optical Computerized Tomography (OCT), fundoscopy, and tonometry are now routinely used onboard the ISS to diagnose and monitor any progression of Visual Impairment Intracranial Pressure (VIIP) syndrome. The ISS Ultrasound aides in the remote diagnosis of a variety of conditions ranging from musculo-skeletal issues and abdominal pains to infection of soft tissues. Similar equipment and techniques can be used on Earth to provide medical care to patients without requiring their travel to a hospital or doctor.

The ISS also plays an important role in promoting education in the science, technology, engineering, and mathematics (STEM) fields, inspiring students to pursue scientific and technical careers. Astronauts aboard ISS participate in educational downlinks with schools, and engage in communicating with people around the world using “ham” radio. The ISS Program also conducts experiments that involve student participation. One example is the Synchronized Position Hold, Engage, Reorient, Experimental Satellites (SPHERES) facility. SPHERES are three bowling-ball sized spherical satellites that are used inside the Station to test telerobotics operations in addition to spacecraft formation flight and autonomous rendezvous and docking maneuvers. NASA, along with the Defense Advanced Research Projects Agency, with implementation by the Massachusetts Institute of Technology, has co-sponsored “Zero Robotics SPHERES Challenge” competitions for high school and middle students from the U.S. and abroad. The competitions challenge students to write software code, which is uploaded to the robots on

ISS, and the SPHERES satellites then execute the instructions, in areas such as formation flight and close proximity operations. Student finalists were able to watch their flight program live on NASA-TV.

Conclusion

The ISS has now entered its intensive research and technology demonstration phase. Station will continue to meet NASA's mission objective to prepare for the next steps in human space exploration. Closer to home, NASA's National Laboratory partners can use the unique microgravity environment of space and the advanced research facilities aboard Station to enable investigations that may give them the edge in the global competition to develop valuable, high technology products and services. Furthermore, the demand for access to the ISS enables the establishment of robust U.S. commercial crew and cargo capabilities. Both of these aspects of the U.S. segment of the ISS as a National Laboratory will help establish and demonstrate the market for research in LEO beyond the requirements of NASA.

With NASA as the lead integrator on ISS for the international partnership, the ISS allows the U.S. to demonstrate global leadership in human spaceflight and technology development. ISS and the teams that operate it are an amazing global resource.

NASA appreciates this Committee's ongoing support of the ISS as we work together to support this amazing facility which yields remarkable results and benefits for the world.

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

United States Government Accountability Office

Testimony

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INTERNATIONAL SPACE STATION

Challenges to Increased Utilization May Affect Return on Investment

Statement of Shelby S. Oakley
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Sourcing Management

GAO-15-722T

GAO Highlights

Highlights of GAO-15-722T, a testimony before the Subcommittee on Space, Committee on Science, Space, and Technology, House of Representatives

July 2015

INTERNATIONAL SPACE STATION

Challenges to Increased Utilization May Affect Return on Investment

Why GAO Did This Study

The United States has spent tens of billions of dollars to develop, assemble, and operate the ISS over the past two decades. NASA plans to spend about $22 billion more from fiscal year 2016 through 2020—with over half of that planned for transportation—on the ISS. In January 2014, the Administration proposed extending the life of the ISS to at least 2024 to take further advantage of the investment in the ISS. Since 2005, Congress enacted several laws to increase utilization of the ISS by commercial and academic researchers. The NASA Authorization Act of 2010 required NASA to enter into a cooperative agreement with a not-for-profit entity to manage the ISS National Laboratory and in 2011 it did so with CASIS. CASIS is charged with maximizing use of the ISS for scientific research by executing several required activities.

This statement will provide an overview of (1) NASA's budget for ISS and the factors affecting budget levels through 2020, (2) several challenges that could impact effective utilization of ISS by both NASA and CASIS, and (3) steps that NASA and CASIS could take to better document and assess CASIS's progress in this regard.

This statement is based primarily on GAO's April 2015 report (GAO-15-397) as well as other prior reports and testimonies. GAO also conducted a limited amount of additional audit work in June 2015 to update certain information.

View GAO-15-722T. For more information, contact Shelby S. Oakley at (202) 512-4841 or oakleys@gao.gov.

What GAO Found

Based on GAO analysis of the National Aeronautics and Space Administration's (NASA) fiscal year 2016 budget estimate, the agency anticipates that the costs to operate, sustain, perform research, and provide crew and cargo transportation to the International Space Station (ISS) are projected to increase by almost $1 billion—or almost 53 percent—from fiscal year 2015 to fiscal year 2020 when the projected costs are expected to exceed $4 billion. The majority of the total projected cost increase for ISS is attributable to commercial crew and cargo transportation. The budget for ISS cargo and crew transportation is currently planned to increase by over $700 million from fiscal year 2016 to fiscal year 2020—or over 55 percent of the total ISS budget—which includes the purchase of six Russian Soyuz seats in 2018 and commercial crew missions beginning in fiscal year 2019. The costs to operate the ISS and perform research are expected to be stable with only slight increases through fiscal year 2020.

NASA and the Center for the Advancement of Science in Space (CASIS)—a non-profit entity selected to manage non-NASA research on the ISS National Laboratory—must overcome several challenges to increase utilization and achieve a better return on investment. NASA and CASIS officials told GAO that the ISS will be challenged to meet an expected increase in demand for crew time and certain research facilities. Securing cargo transportation has also presented challenges. CASIS-sponsored researchers have experienced cost increases of almost $500,000 because of a cargo resupply launch failure in October 2014 and delays to other cargo resupply missions. GAO found that absorbing the increased cost has been a challenge for CASIS given its limited research budget and it could be faced with additional cost increases given the June 2015 launch failure of another cargo resupply mission.

In April 2015, GAO found that CASIS had taken steps to manage and promote research activities on the ISS National Laboratory, but that CASIS and NASA could do more to objectively define, assess, and report progress toward increased utilization. While CASIS had established annual metrics, it did not establish measurable targets for these metrics. GAO has previously reported that performance metrics should have quantifiable targets to help assess whether overall goals are achieved. Consequently, GAO recommended that the ISS program and CASIS develop measurable targets for CASIS's metrics for fiscal year 2016 and beyond. NASA concurred with this recommendation and indicated that these targets should be established by the end of 2015. GAO's April 2015 report also found that while NASA performs an annual assessment of CASIS's performance, the assessment is not documented. This type of documented information can support future assessments of return on investment. GAO recommended that NASA document the annual program assessment of CASIS performance. NASA concurred with this recommendation and plans to take action in response to CASIS's 2015 annual report. Because CASIS is allocated at least 50 percent of ISS research capacity, ensuring that CASIS continues to make progress promoting research activities and achieving its goal to increase utilization of ISS is essential to demonstrate a return on investment for the tens of billions of dollars already invested and that will continued to be invested in ISS.

Chairman Babin, Ranking Member Edwards, and Members of the Subcommittee:

Thank you for the opportunity to discuss our work on the National Aeronautics and Space Administration's (NASA) management of the International Space Station (ISS). The United States has spent tens of billions of dollars over the past two decades to develop, assemble, and operate the ISS, which has been used as a manned research outpost continuously for over 14 years. NASA plans to spend about $22 billion more from fiscal year 2016 through 2020—with over half of that planned for transportation—to enable further scientific research the agency views as critical to future human space activities. In January 2014, the Administration proposed extending the life of the ISS by a minimum of 4 years to at least 2024 to take further advantage of the investment in the ISS. Congress enacted several laws to increase utilization of the ISS by commercial and academic researchers.[1] In response to direction in the NASA Authorization Act of 2010, in 2011 NASA selected the Center for the Advancement of Science in Space (CASIS), a non-profit entity, to manage non-NASA commercial and academic research aboard the ISS National Laboratory. Because CASIS is allocated at least 50 percent of ISS research capacity and was created to maximize the value of the ISS investment, future success of the ISS as a research platform is partially dependent on CASIS's success.

My statement today will provide an overview of NASA's budget for ISS and the factors affecting budget levels through 2020. In addition, my statement will also focus on several challenges that could impact effective utilization of the ISS by both NASA and CASIS as they continue their efforts to demonstrate that the research and technology development performed aboard the ISS National Laboratory benefits life on Earth and develop commercial markets that can be sustained in low-Earth orbit. Finally, I will discuss steps that NASA and CASIS could take to better document and assess CASIS's progress in this regard.

[1] Commercial Space Act of 1998, Pub. L. No.105-303, § 101; National Aeronautics and Space Administration Authorization Act of 2005, Pub. L. No.109-155, § 507; and National Aeronautics and Space Administration Authorization Act of 2010, Pub. L. No. 111-267, § 504.

In preparing this statement, we primarily relied on work conducted to support our April 2015 report.[2] Additionally, we relied on our prior reports and testimonies, including those related to CASIS's management of the ISS National Laboratory, the agency's acquisition approach for commercial crew transportation, and ISS sustainment and utilization.[3] Information on our scope and methodology is available in the reports cited in this statement. We also conducted a limited amount of additional audit work in June 2015 to update information on CASIS's efforts to increase utilization of the ISS and planned commercial crew and cargo partner missions. The work upon which this statement is based was performed in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient and appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Background

The ISS supports research projects with state of the art facilities for Earth and space science, biology, human physiology, physical science, and materials research, and provides a platform to demonstrate new space-related technologies. The ISS currently has three crew members in the U.S. operating segment who, according to NASA officials, devote a total of approximately 35 hours per week to conduct research. The remaining crew time is used for operations and maintenance of the ISS, training, exercise, and sleep.

[2]GAO, *International Space Station: Measurable Performance Targets and Documentation Needed to Better Assess Management of National Laboratory*, GAO-15-397 (Washington, D.C.: April 27, 2015).

[3]GAO, *NASA: Significant Challenges Remain for Access, Use, and Sustainment of the International Space Station*, GAO-12-587T (Washington, D.C.; March 28, 2012); *International Space Station: Approach for Ensuring Utilization through 2020 Are Reasonable but Should be Revisited as NASA Gains More Knowledge of On-Orbit Performance*, GAO-12-162 (Washington, D.C.; December 15, 2011); and *National Aeronautics and Space Administration: Acquisition Approach for Commercial Crew Transportation includes Good Practices, but Faces Significant Challenges*, GAO-12-282 (Washington, D.C.: December 15, 2011).

Congress Directs Changes in Management of the ISS

Since 2005, Congress has directed several changes regarding the management and utilization of the ISS. For example, the NASA Authorization Act of 2005 designated the U.S Operating Segment of the ISS as a national laboratory and the NASA Authorization Act of 2010 directed the NASA Administrator to provide initial financial assistance and enter into a cooperative agreement with a not-for-profit organization to manage the activities of the ISS National Laboratory for non-NASA utilization of the ISS research capabilities and available facilities.[4] The 2010 act also requires the ISS National Laboratory-managed experiments to be guaranteed access to and use of at least 50 percent of the U.S. research capacity allocation including power, facilities to keep experiments cold, and requisite crew time onboard the ISS through September 30, 2020. Our April 2015 report provides a synopsis of these legislative actions.[5]

In August 2011, after a competitive process, NASA signed a cooperative agreement with CASIS, a not-for-profit entity, to manage the activities of the ISS National Laboratory through September 30, 2020.[6] CASIS is bound by the responsibilities outlined in the cooperative agreement, which tasks it with maximizing the value of the ISS National Laboratory by stimulating interest and use of the ISS for scientific research by directly soliciting potential users and fostering a market to attract others. CASIS is also charged with maximizing the use of the ISS for advancing science, technology, engineering, and mathematics education. Pursuant to the cooperative agreement, NASA will provide CASIS $15 million annually through 2020, of which it will seek to award at least $3 million in research grants. CASIS officials have stated that the remainder of NASA funding is used for infrastructure and direct costs such as labor and travel-related expenses. Further, CASIS is also responsible for soliciting non-NASA funding for research by targeting various sources.

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[4]Pub. L. No.109-155, § 507 and Pub. L. No. 111-267, § 504.

[5]GAO-15-397.

[6]The Administration recently proposed extending the operational life of the ISS from 2020 to at least 2024. Our prior work has shown that it is technically feasible to extend the ISS operational life to at least 2028.

NASA Is Taking Steps to Establish Commercial Transportation Capability

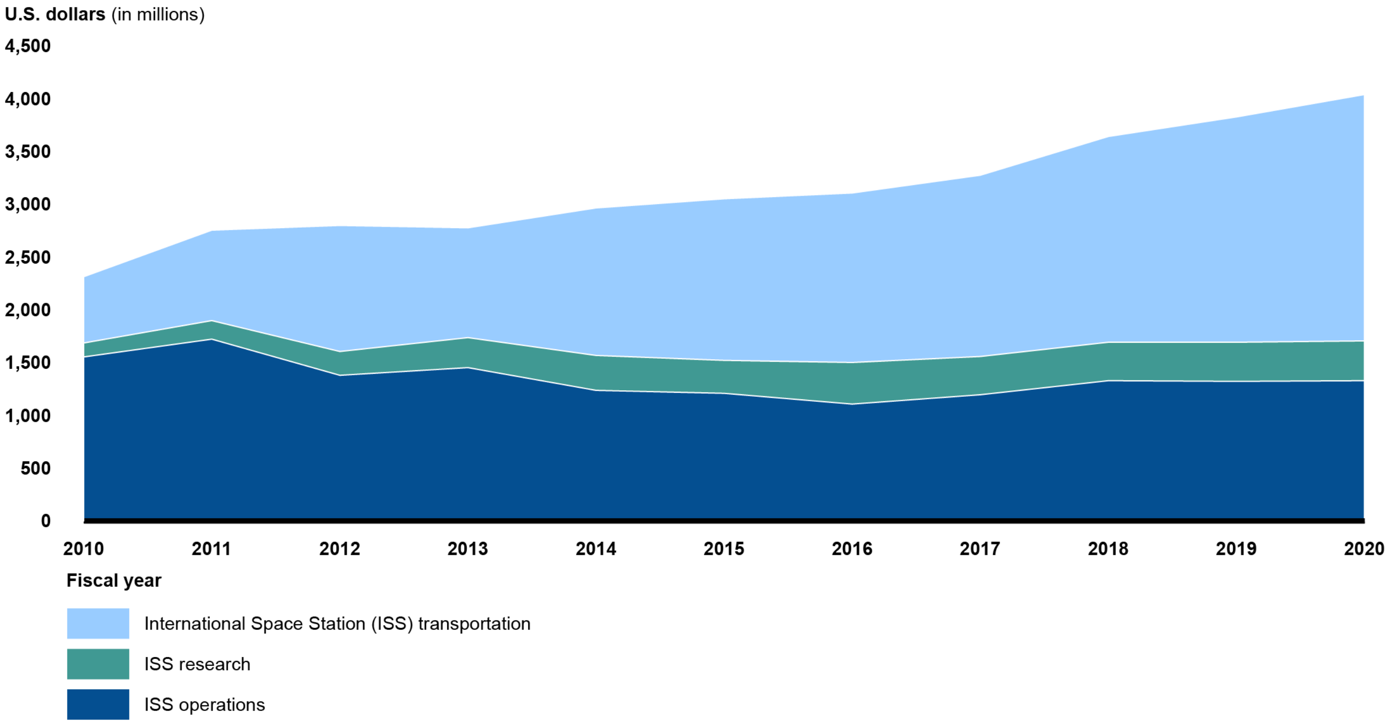
In 2005, NASA established the Commercial Crew and Cargo Program to facilitate the private demonstration of safe, reliable, and cost-effective transportation services to low-Earth orbit and encourage innovation in the private sector. The goal of this program is to enable the government to buy both cargo and crew commercial transportation services at a reasonable price. NASA is procuring cargo transportation to the ISS through a commercial resupply services contract that was signed with Orbital Sciences Corporation (Orbital) and Space Exploration Technologies Corporation (SpaceX) in 2008. As of April 2015, SpaceX has launched six successful resupply missions and Orbital has launched two successful resupply missions. Orbital and SpaceX are scheduled to provide 8 and 15 resupply flights, respectively, through December 2017, although the number of Orbital flights may be modified. Orbital resupply flights to the ISS were deferred pending a review of a launch failure that occurred during a resupply launch in October 2014, which resulted in the loss of that mission. According to NASA officials, both Orbital and NASA are still reviewing the mishap and have not provided final reports as of June 2015. The ISS program anticipates that Orbital will resume missions by the end of 2015; however, the flight will use an Atlas rocket to launch a Cygnus spacecraft instead of Orbital's Antares launch vehicle. In late June 2015, SpaceX experienced a launch failure during a cargo resupply launch that resulted in the loss of that mission. NASA is currently evaluating the impact this recent launch failure will have on the ISS program. In September 2014, NASA released a request for proposals for its Commercial Resupply Services 2 (CRS2) requirements, which would result in a follow on contract to the Commercial Resupply Services contracts that were awarded to SpaceX and Orbital in December 2008. NASA expects to award CRS2 contracts in September 2015 for cargo transportation services beginning in 2018, about 4 months later than anticipated.

NASA has relied upon Russia to provide crew transportation to and from the ISS since the retirement of the Space Shuttle in 2011. NASA has purchased crew launches from Russia through 2017 and crew rescue and return through mid-2018. NASA purchases seats—at a cost of over $65 million each in 2015—aboard Russian Soyuz space capsules. To support its goal of obtaining low cost domestic crew transport, in September 2014, NASA awarded contracts to The Boeing Company (Boeing) and SpaceX to develop a capability to transport astronauts to and from the ISS. Those awards include a minimum of two to a maximum of six crewed service missions per provider. The Commercial Crew Program, which is outside of the ISS program, is currently responsible for the cost to develop this capability and will also fund one crewed service flight per provider. ISS program officials have stated that they expect the first service flights to take place in fiscal year 2018. The ISS program will fund the remaining service flights. NASA expects this capability to be available in fiscal year 2018; however, it is unclear whether those vehicles currently in development under the commercial crew program will be ready in time. Once this capability has been established, NASA plans to increase the number of astronauts in the U.S. operating segment of the ISS from three to four.

ISS Budget Projected to Rise to Account for Increasing Transportation Costs while Operations and Research Costs Remain Stable

NASA makes a significant investment in the ISS program each year. Based on our analysis of NASA's fiscal year 2016 budget estimate, the agency anticipates that the costs to operate, sustain, perform research, and provide crew and cargo transportation to the ISS are projected to increase by almost $1 billion—or almost 53 percent—from fiscal year 2015 to fiscal year 2020 when the projected costs are expected to exceed $4 billion. See figure 1 for ISS funding from fiscal year 2010 through fiscal year 2020.

Figure 1: International Space Station Funding by Budget Element for Fiscal Years 2010 through 2020



Source: GAO presentation of NASA data. | GAO-15-722T

The majority of the total projected cost increase for ISS is due to the ISS program's need to pay for commercial crew and cargo transportation. The budget for ISS cargo and crew transportation is currently planned to increase by over $700 million from fiscal year 2016 to fiscal year 2020, at which point it will comprise over 55 percent of the total ISS budget. ISS program officials told us that in fiscal year 2017, the program will begin to fund commercial crew missions that are expected to take place in fiscal year 2019.[7] NASA has also initiated steps to purchase six Soyuz seats from Russia for flights to the ISS in 2018, the cost of which ISS program officials said was accounted for in the projected transportation costs. If NASA determines that domestic commercial entities are able to fulfill crew transportation requirements in 2018, those vehicles will become NASA's

[7]According to ISS officials, the Commercial Spaceflight Program will fund the first flight for Boeing and SpaceX and the ISS program will then fund the second and any subsequent crewed flights.

primary transportation source to the ISS and the Soyuz seats purchased may then be utilized as backup transportation or to augment future ISS needs.

Based on our analysis of NASA's fiscal year 2016 budget estimate, the cost to operate the ISS is expected to be relatively stable with only slight increases through fiscal year 2020. The ISS operations costs decreased $500 million—or 30 percent—from a peak in fiscal year 2011 through fiscal year 2015. Operations costs are expected, however, to increase by approximately $130 million from fiscal year 2017 through fiscal year 2020, which NASA officials attribute in part to inflation and the addition of the fourth crew member. Our past work on Department of Defense (DOD) aircraft systems similarly found that operations costs can increase over time.[8] There may be other factors that could increase operations costs for the ISS over time such as the need for additional spare parts and mitigations needed for structural issues. The ISS program has implemented a number of initiatives that have yielded cost savings or containment. For example, NASA reduced operations costs by scaling back ISS program and contractor workforce levels and by combining several contracts. The NASA Inspector General currently has ongoing work assessing NASA's efforts to combine and consolidate ISS contracts for operations and maintenance.

NASA also projects that the cost for the ISS Research account will remain stable through fiscal year 2020, when research costs are expected to be about 9 percent of total ISS projected costs. Within this account, NASA provides limited funding to CASIS—$15 million per year—of which a minimum of $3 million is to be used to sponsor non-NASA research aboard the ISS by commercial, academic, and other government agency users. Although NASA research costs are projected to remain stable, CASIS sponsored research is not limited to this $3 million minimum. For example, our analysis of CASIS information shows that CASIS has averaged more than $4.3 million in grants paid out to researchers each fiscal year since 2012 and has paid over $15 million to its grantees through March 2015.

[8]GAO, *Defense Management: DOD Needs Better Information and Guidance to More Effectively Manage and Reduce Operating and Support Costs of Major Weapons Systems*, GAO-10-717 (Washington, D.C.: July 20, 2010).

NASA and CASIS Face Challenges to Increase Utilization and Sustain the ISS Which Could Affect Return on Investment

As we reported in April 2015, NASA and CASIS must overcome several challenges to increase utilization and sustain the ISS until 2024 and achieve a better return on the investment. According to NASA and CASIS officials, as CASIS increases the number of experiments for the ISS National Laboratory, the demand for crew time and certain research facilities aboard the ISS is expected to increase and officials project the ISS National Laboratory will be challenged to meet that demand. NASA officials told us that while the demand for crew time is currently manageable, it remains allocated at or near 100 percent, as the three crew members on the U.S. segment of the ISS utilize most of the 35 hours scheduled per week to conduct research. Crew time for research is expected to double on the ISS National Laboratory once the crew increases from three to four astronauts in fiscal year 2018 because, according to NASA officials, the additional crew member will devote most of his or her time to research. NASA's ability to support increased utilization through an additional crew member, however, is reliant on commercial crew providers providing the promised capability and NASA's ability to fund the effort. Both Boeing and SpaceX plan to hold demonstration flights to the ISS in 2017, but risks remain for both contractors.

According to CASIS officials, they have been challenged to raise additional funding from external sources to supplement the amount of funding provided by NASA. CASIS officials attributed this challenge to the fact that CASIS is a new non-profit entity and the value of performing research aboard the ISS has not been fully demonstrated. Although CASIS's business development team is actively identifying partnerships and funding opportunities with commercial and non-profit granting organizations, CASIS officials said that it takes time to identify, develop, and mature these partnerships to result in funding support. Through December 2014, CASIS reported that it had received funding commitments from external sources of approximately $12 million to support its research mission. However, according to CASIS's fiscal year 2014 annual report, published in December 2014, CASIS received contributions totaling only $9,193 in 2014. NASA officials stated that doing research aboard the ISS National Laboratory can take upwards of 2 to 3 years to plan and execute, timelines that are generally not acceptable to commercial companies that desire a more rapid return on their investments. CASIS and NASA officials also told us that the value of doing research aboard the ISS National Laboratory has to be further demonstrated so commercial industries can be convinced it is worth the high investment.

We also reported in April 2015 that the ability to secure cargo transportation for selected research investigations to the ISS is outside of CASIS's control and has presented challenges. NASA provides launch services to the ISS National Laboratory through its commercial resupply services contracts and CASIS receives cargo allocations for its sponsored research. Budget shortfalls due in part to the effects of sequestration and the Orbital launch failure have resulted NASA cancelling 4 of 46 planned cargo flights through 2020. In January 2015, NASA's Aerospace Safety Advisory Panel noted that both commercial cargo launch providers had struggled to meet desired launch dates and that the schedule performance must significantly improve to enable consistent scientific research on the ISS.[9] The panel added that there will be additional pressure on cargo logistics while Orbital works through its plan to resume cargo missions. This pressure will likely be increased because of the June 2015 launch failure of a SpaceX cargo resupply mission. We found that such launch failures and delays have resulted in cost increases for CASIS-sponsored researchers. For example, the rocket launch failure to the ISS in October 2014 resulted in the loss of several CASIS-sponsored research investigations at a total cost of almost $175,000 which includes hardware and materials, labor consulting, and grants. In addition, launch delays for another cargo resupply mission resulted in over $300,000 in cost increases for several researchers. This included costs for additional materials and samples such as biological payloads that have a limited viability or very specific requirements associated with the timing of the payload flight and often require consumables such as gas and water that must be replenished when a launch is delayed. Absorbing the increased cost has been a challenge for CASIS given its limited research budget, but it is addressing the cost increases due to delays by asking researchers that have biological payloads to identify the impact and associated costs for launch delays in their budgets so it can plan for budget reserves, as necessary.

[9]National Aeronautics and Space Administration, *NASA Aerospace Safety Advisory Panel Annual Report for 2014* (Washington, D.C., Jan. 28, 2015). The Aerospace Safety Advisory Panel was established by Congress in 1968 to provide advice and make recommendations to the NASA Administrator on safety matters. The panel reviews safety studies and operations plans and advises the NASA Administrator and Congress on hazards related to proposed or existing facilities and operations, safety standards and reporting, safety and mission assurance aspects regarding ongoing or proposed programs, and NASA management and culture issues related to safety.

To extend the ISS service life to 2024 or beyond, NASA must ensure that spare parts are sufficient and available when needed and that the structures are sound. In December 2011, we found that NASA had a reasonable approach to determine, obtain, and deliver necessary spare parts to the ISS through 2020.[10] At that time, we found that NASA had given equal weight to manufacturers' predictions and actual performance. However, because NASA has generally found failure rates for replacement units to be lower than manufacturers' predictions, over time the resulting estimates could prove to be overly conservative. More recently, the ISS program reported that one part was failing at rates greater than projected and that spares were not available as a result. In December 2011, we recommended that NASA should reassess the relative weight given to original reliability estimates of spares' life expectancies as performance data accumulates. NASA concurred with this recommendation and the ISS program has taken action to revisit to the methods it uses to calculate the need for spare parts for the ISS. NASA performs an annual assessment of the spare parts, which has resulted in the procurement of spare parts based in part on actual hardware performance. In our December 2011 report, we also found that NASA is using reasonable analytical tools to assess structural health and determine whether ISS hardware can operate safely through 2020. On the basis of prior analysis of structural life usage through 2015 and the robust design of the ISS structures, NASA anticipated that—with some mitigation—the ISS will remain structurally sound for continued operations through 2020. At the time of our 2011 review, NASA had assessed only 40 percent, by weight, of the assembled ISS because most of the ISS structures have not been on orbit long enough to accumulate the data needed for analysis. NASA expected to complete ISS structural assessments in early 2016. These are positive steps; however, continued efforts such as this will be important to ensure that processes NASA uses to evaluate the need for spare parts are adequate to operate and sustain the ISS for at least an additional 4 years.

[10] GAO-12-162.

Objective Assessment of Progress Needed to Demonstrate Return on Investment

Despite these challenges, in April 2015, we reported that CASIS had taken steps to carry out its responsibilities to manage and promote research activities on the ISS National Laboratory as outlined in its cooperative agreement.[11] For example, CASIS had identified key research areas and released seven requests for proposals to solicit interest for research projects. While we noted this progress, we found that CASIS and NASA could do more to objectively define, assess, and report progress toward increased utilization. Specifically, we found that while CASIS had established annual metrics that met most of the key attributes of successful performance measures, it did not establish measurable targets or goals for either fiscal year 2014 or 2015 metrics. We have previously reported that performance metrics should have quantifiable, numerical targets or other measurable values, which help assess whether overall goals and objectives were achieved.[12] We concluded that without these targets, NASA and CASIS cannot conduct assessments of CASIS's efforts to increase ISS utilization that are objective, measurable, or conclusive. To enable such assessments, in April 2015 we recommended that the ISS program manager work with CASIS to collectively develop and approve measurable targets for CASIS's metrics for fiscal year 2016 and beyond. NASA concurred with this recommendation and indicated that these targets should be established by December 31, 2015.

Also in our April 2015 report, we found that while NASA performs an annual assessment of CASIS's performance, the assessment is not documented. Federal standards for internal control call for information to be recorded and communicated to management and others who need it to carry out their responsibilities. This type of documented information is important to support decision making and to support future assessments of return on investment. However, without definitive and documented assessment factors, NASA will also be challenged to take action in response to CASIS performance. According to the cooperative agreement between NASA and CASIS, continued funding of CASIS is contingent on the scientific progress of the project and that NASA will assess such progress in fiscal year 2020 to make a determination about whether to extend or terminate the cooperative agreement.[13] We concluded that

[11] GAO-15-397.

[12] GAO, *Tax Administration: IRS Needs to Further Refine Its Tax Filing Season Performance Measures*, GAO-03-143 (Washington, D.C.: Nov. 22, 2002).

[13] The current cooperative agreement includes a provision for extension beyond 2020.

without documentation based on objective measures of performance, NASA lacks support to make such a decision. We therefore recommended that the ISS program manager document the annual program assessment of CASIS performance in order to provide CASIS management actionable information to better fulfill its responsibilities. NASA concurred with the recommendation and stated that officials would begin documenting the agency's annual program assessment in response to CASIS's 2015 annual report. It will be important that NASA and CASIS follow through on their commitments to have objective measures that will enable NASA to measure CASIS's progress to increase utilization and demonstrate the return on the investment of the ISS.

In conclusion, the ISS offers the potential for scientific breakthroughs, a unique test bed for new technologies and applications, and a platform for increased commercial and academic research and NASA has made an important commitment to the future of research aboard ISS by proposing to extend operations to 2024. Key to supporting this commitment is effectively managing the challenges that could affect efforts to maximize the return on investment for the tens of billions of dollars that have been spent on the ISS. Achieving greater utilization of the ISS and its unique capabilities, showing the benefit of commercial and academic research, and demonstrating success to generate increased interest from potential users could help NASA demonstrate such a return. Because CASIS is allocated at least 50 percent of ISS research capacity, ensuring that CASIS continues to make progress promoting research activities and achieving its goal to increase utilization of the ISS is essential. Even with an extension of operations to 2024, CASIS has limited time to demonstrate that the research and technology development performed aboard the ISS National Laboratory benefits Earth and commercial markets can be sustained in low-Earth orbit. By NASA and CASIS working together in the coming years to address challenges that could negatively affect increased utilization of this unique research facility and to identify and document objective measures of success to demonstrate a return on investment, such a return might be realized.

Chairman Babin, Ranking Member Edwards, and Members of the Subcommittee, this completes my prepared statement. I would be pleased to respond to any questions that you may have at this time.

GAO Contacts and Staff Acknowledgments

GAO Contacts

For questions about this statement, please contact me at (202) 512-4841 or oakleys@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this testimony.

Staff Acknowledgments

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Statement by

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Before the

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

The International Space Station: Addressing Operational Challenges

July 10, 2015

Abstract

During this decade of International Space Station (ISS) operations, NASA has made enormous strides to develop and implement a research program that will take humans to Mars. The evolving exploration architecture incorporates a space life sciences strategy aligned with the National Research Council's recent Life and Physical Sciences Decadal study. Research remains constrained by competing priorities, limited funding, available crew time, and powered up- and down-mass. To capitalize on the remaining life of the ISS, and to keep the United States at the forefront of exploration, a robust ground-based research program that fully engages the help of the external science community must be aligned with a flight research program designed to keep humans healthy in fractional gravity environments for periods of time exceeding a year. By doing so we can achieve the penultimate goal of the ISS program; to endow future space explorers with the knowledge, skills and abilities to operate independently from Earth.

Mr. Chairman and Members of the Sub-Committee:

Good morning. I thank you for the opportunity to discuss the status of research using the International Space Station. I have been a space life sciences researcher for more than 25 years, regularly funded by grants from NASA. From 1996-1998 I took leave from my academic position at The Pennsylvania State University to serve as a payload specialist astronaut, or guest researcher, on the STS-90 Neurolab Spacelab mission, which flew on the space shuttle Columbia in 1998. I have more than 15 years of experience advising

NASA on its life sciences strategy and portfolio, either as a direct consultant or through committees of the National Academies of Science, Engineering and Medicine. I help evaluate NASA's Bioastronautics Research Program for the Institute of Medicine. I am also inaugural member of the National Research Council's (NRC) newly constituted Committee on Biological and Physical Sciences in Space (CBPSS). Part of our charge is to monitor NASA's progress in implementing the recommendations contained in, "Recapturing a Future for Space Exploration: Life and Physical Sciences Research for a New Era," published by the NRC in 2011[1].

The ISS provides a unique platform for research. Past NRC studies have noted the critical importance of the ISS's capabilities to support the goal of long-term human exploration in space. These capabilities include the ability to perform experiments of extended duration, the ability to continually revise experiment parameters on the basis of previous results, the flexibility in experimental design provided by human operators, and the availability of sophisticated experimental facilities with significant power and data resources. The ISS is the only platform of its kind, and it is essential that its presence and dedication to research for the life and physical sciences be fully employed for as long as it is practicable to do so.

To prepare for this hearing, you asked four specific questions:

1. What are the opportunities and challenges in conducting space life and physical science research on the ISS and what should be done to address them?
2. What are some of the most critical areas of ISS research in space life and physical sciences to enabling the long-term goal of sending humans to the surface of Mars, and what is the status of progress on that research?
3. How are priorities for research on the ISS established and is there a clear and well understood process for aligning ISS resources with those priorities?
4. What are the implications of the proposed extension of ISS operations to 2024 on research and what criteria should Congress use to consider the proposed extension?

In the time allotted, I'd like to share my generally positive view of NASA's progress, and provide some specific suggestions to maximize the use of this extraordinary national resource that has been orbiting our planet every 90 minutes for the past 17 years. My comments will not stray far from my areas of expertise in the life sciences, but many of them should be applicable to the physical sciences as well.

1. *What are the opportunities and challenges in conducting space life and physical science research on the ISS and what should be done to address them?*

The 2009 report from the Review of U.S. Human Spaceflight Plans Committee (the "Augustine Commission") emphasized that future astronauts will face three unique stressors[2]:

- prolonged exposure to solar and galactic radiation;
- prolonged periods of exposure to microgravity; and,

[1] http://www.nap.edu/catalog/13048/recapturing-a-future-for-space-exploration-life-and-physical-sciences
[2] http://www.nasa.gov/pdf/396093main_HSF_Cmte_FinalReport.pdf

- confinement in close, relatively austere quarters along with a small number of other crew members who must live and work as a cohesive team for many months while having limited contact with their family, friends and culture.

All of these stressors are present in the ISS environment. Martian operations add more stressors: a dusty, dim, energetic environment and a gravitational field that is a little more than a third of our own. Research to address the biological response to fractional gravity is perhaps the area most impacted by changes to the ISS program over the decades. Unless we improve our research centrifuge capabilities on the ISS, we accept a risk of sending humans to Mars with little or no knowledge of how mammalian biology responds in a gravitational field other than Earth's.

My colleagues in the science community report that two of the major challenges to the biology research portfolio are limited access to the ISS and limited crew time. Some types of research, particularly that employing small mammals, is very time consuming to execute. Animal husbandry for a single rodent experiment can easily outstrip available ISS crew time for research during an increment. We can reasonably anticipate that competition for crew time will become worse as the facility ages, and demands on crew time to perform necessary maintenance become more acute.

Access to the ISS for research is not just a matter of access to space, it is a matter of competing programs. ISS research time is allocated in roughly equal proportions between NASA sponsored, peer-reviewed science and projects sponsored by the Center for the Advancement of Science in Space (CASIS), regardless of what that research might be. The outcome is that National Laboratory research and peer-reviewed, NASA-sponsored research vie for scarce resources such as crew time and positions on the flight manifest; in some cases forcing NASA research to lower-fidelity Earth-based analogs such as bed rest research for muscle atrophy and bone demineralization.

The extension criteria report requested by Congress in the NASA Authorization Act of 2015 creates opportunities to better coordinate NASA and CASIS sponsored research. For example, the ISS Program Office could require an experimental definition phase to maximize science return by combining compatible experiments and expanding biospecimen-sharing experiments to answer the most pressing research questions.

2. *What are some of the most critical areas of ISS research in space life and physical sciences to enabling the long-term goal of sending humans to the surface of Mars, and what is the status of progress on that research?*

The biological risks associated with exploration-class spaceflight are far from being mitigated. This conclusion is based on analysis of 40 years of NASA-sponsored research.

Since the days of Skylab, NASA-funded investigators conducted an aggressive and successful biological research program that was robust, comprehensive, and internationally recognized. Beginning with those early efforts, and continuing with our international partners on the *Mir* and the ISS, we have built a knowledge base that defines the rate at which humans adapt during spaceflight up to six-months duration, with four data points exceeding one-year duration. Right now, we are expanding the one-year database! To prepare for Mars, we need to extend the duration further – up to three years - using a combination of astronaut volunteers and small mammals such as rats and mice.

In *Life of Reason*[3], George Santayana warned that, "those who cannot remember the past are condemned to repeat it." We should not forget the precipitous drop in NASA-sponsored research in the first decade of the millennium. The 2001 peak of 1014 separate research tasks was slashed to just 364 in 2010. Space biology and the physical sciences were particularly hard hit, losing about 80% of their research portfolio.

Congress heard the research community's concerns, and we are most thankful for your response. The NRC's Life and Physical Sciences (LPS) Decadal Survey - completed in 2011 as a response to a request from Congress introduced in 2008 authorization language - prompted a sea change in NASA's approach to biological and physical sciences research.

The LPS Decadal summarized and sequenced 65 high priority research tasks. Furthermore, the Decadal study created two notional research plans aligned with specific priorities; one being a goal of rebuilding a research enterprise and the other a goal of a human mission to Mars. More about these goals later.

3. *How are priorities for research on the ISS established and is there a clear and well understood process for aligning ISS resources with those priorities?*

My response to this question considers general aspects of peer-reviewed research projects that are solicited through open competition. All NASA-sponsored space life and physical sciences research is conducted in this way.

Developing strategic priorities for ISS research is not a new concept. Notable examples from this millennium include:

- The NASA-sponsored Research Maximization and Prioritization Task Force, commonly known as ReMAP, which reported its findings in 2002, representing the breadth of translational research in the biological and physical sciences.
- The ISS utilization studies organized by the National Research Council in 2005.
- Most recently, the Life and Physical Sciences (LPS) Decadal Research Plan; the first decadal survey of NASA's life and physical sciences programs. The guiding principle of the study was, "to set an agenda for research in the next decade that would use the unique characteristics of the space environment to address complex problems in the life and physical sciences, so as to deliver both new knowledge and practical benefits for humankind as it embarks on a new era of space exploration." Furthermore, the LPS Decadal organizers were tasked with

[3] http://www.gutenberg.org/ebooks/15000

establishing priorities for an integrated portfolio of biological and physical sciences research in the decade of 2010-2020.

Why have we asked the prioritization question so many times, and why must we do so again? Because space research informs two broad, often competing, goals: One centers on intrinsic scientific importance or impact; research that illuminates our place in the universe, but cannot be accomplished in a terrestrial environment. The other goal values research that enables long-term human exploration of space beyond low-earth orbit, and develops effective countermeasures to mitigate the potentially damaging effects of long-term exposure to the space environment. Over the past 25 years, other review panels, both internal and external to NASA, have defined similar goals. In the case of the LPS, research was categorized as either (1) required to enable exploration missions or (2) enabled or facilitated because of exploration missions. I prefer the more contemporary synonyms of "discovery" and "translational" research.

Throughout the history of the United States space program both goals have been important, but their relative importance has changed over time. In the early part of the Apollo era, the limited amount of biological and physical research that occurred was focused on the health and safety of astronaut crews in a microgravity environment. Until late in the Apollo program, significant research questions that did not contribute directly to a successful Moon landing received lower priority. In contrast, more regular access to space provided by the space shuttle afforded an opportunity for discovery research to take higher priority; an emphasis that fared poorly in the austere NASA budgetary environment of the mid-2000's.

Thus, the relative priority of these two goals of research - enabling long-term human exploration of space (translation) and answering questions of intrinsic scientific merit (discovery enabled by space research) – shifts according to NASA's programmatic goals.

I make note of the fact that section 201 NASA Authorization Act of 2015 articulates a translational goal of sending humans to Mars, while section 718 emphasizes discovery research. The key question is this: *Shall discovery or translational research takes precedence in the mature years of the ISS research program?* If it is translational research to prepare for a human trip to Mars, then the ISS research portfolio should be tailored accordingly.

The LPS Decadal Survey provides a very detailed scheme to evaluate the importance of proposed research on the International Space Station. It includes eight unique criteria to prioritize research[4], as follows:

- *Positive Impact on Exploration Efforts, Improved Access to Data or to Samples, Risk Reduction.* The extent to which the results of the research will reduce uncertainty about both the benefits and the risks of space exploration
- *Potential to Enhance Mission Options or to Reduce Mission Costs.* The extent to which the results of the research will reduce the costs of space exploration

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

- *Positive Impact on Exploration Efforts, Improved Access to Data or to Samples.* The extent to which the results of the research may lead to entirely new options for exploration missions.
- *Relative Impact Within a Research Field.* The extent to which the results of the research will provide full or partial answers to grand science challenges that the space environment provides a unique means to address.
- *Needs that are Unique to NASA Exploration Programs.* The extent to which the results of the research are uniquely needed by NASA, as opposed to any other agencies.
- *Research Programs That Could Be Dual-Use.* The extent to which the results of the research can be synergistic with other agencies' needs.
- *Research Value of Using Reduced-Gravity Environment.* The extent to which the research must use the space environment to achieve useful knowledge.
- *Ability to Translate Results to Terrestrial Needs.* The extent to which the results of the research could lead to either faster or better solutions to terrestrial problems or to terrestrial economic benefit.

Some of these criteria emphasize discovery; others translation. The LPS Decadal Survey prioritizes specific research tasks for each criterion. Again, the Survey appropriately stopped short of weighting or prioritizing criteria against each other because of the programmatic implications. That responsibility – to prioritize either discovery research or Mars - falls largely to the executive and legislative branches. When this question is decided, then the LPS decadal should be a useful tool to program research for the remaining life of the ISS.

Operationally, the ISS Program Office prioritizes all the research to be conducted on each ISS increment. It is a well understood process: CASIS receives a 50% allocation, followed by human research, then technology demonstrations. What resources remain are allocated to the Biological and Physical Sciences Program and the Science Mission Directorate payloads. Both the Human Research and Biological and Physical Science utilize the LPS Decadal criteria for prioritization within their respective programs, but it is not apparent the extent, if any, that LPS Decadal criteria are used to prioritize research across the four programs.

Lastly, it is worth noting that ISS research expenditures, which in FY 2012 constituted about 8%, or $225M, of ISS program costs, are not anticipated to keep pace with overall cost growth of the ISS program.

4. What are the implications of the proposed extension of ISS operations to 2024 on research and what criteria should Congress use to consider the proposed extension?

To evaluate the proposed extension, one of the first tests that Congress should apply can be answered with a yes or no. "Is NASA prepared to operate a robust research program through 2024?" In my opinion, the answer is an unqualified, "yes!" The scope of change in NASA life and physical sciences in the past four years has been remarkable. Allow me to highlight some notable examples:

- In 2011 NASA reorganized the remnants of a once robust life and physical sciences program to form the Space Life and Physical Sciences Research and Applications Division (SLPSRA). The program is formulated to execute high quality, high value research and application activities in the areas of space life sciences, physical sciences and human research. This reorganization acknowledges – in point of fact, celebrates – both the discovery and translational outcomes of research in the biological and physical sciences.

- Consistent with recommendations in the LPS Decadal, the Biological and Physical Sciences Program has restarted regular research announcements for ground-based and flight experiments. As a rule, these proposals are externally peer reviewed. In FY2014, 30 proposals were funded; 9 of them flight experiments.

- NASA is making greater use of advisors in the National Academies of Science, Engineering and Medicine. In October of 2014 the NRC instituted a new Committee on Biology and Physical Sciences in Space (CBPSS) chaired by Betsy Cantwell (University of Arizona) and Rob Ferl (University of Florida). Part of the Committee's charge is to monitor the progress in implementation of the recommendations contained in, the LPS Decadal.

- The Human Research Program has been aligned with a global exploration strategy. Annual solicitations for research have resumed. The past four quarters for which summaries are available included 212 research publications and more than 277 research proposals.

- We now have an American astronaut on a one-year mission to the ISS, with a unique opportunity to examine his genomic response to this environment.

- The technical content of the Human Bioastronautics Roadmap is in the middle of a five-year review of its 33 risks and 299 research gaps relevant to health and operations in space. The project is being conducted by the Institute of Medicine.

- NASA's Human System Risk Board tracks a subset of 23 risks that require additional research. While all but one have some level of risk mitigation for a one-year stay on the Moon, about half (N=11) do not have any substantive level of risk mitigation for three-year planetary operations.

I think it's reasonable to conclude that NASA has planned its life and physical sciences enterprise to take advantage of ISS research capabilities. The greatest remaining knowledge gaps are for Design Reference Missions on Mars for more than one year.

A recent NASA Office of the Inspector General (OIG) report[5] identified several concerns for continued ISS operations through 2024. There are four aspects of the report that I'd like to address:

First, the OIG found that ISS extension to 2024 could permit NASA enough time to mitigate an additional seven risks of long duration spaceflight. Nevertheless, extended utilization was not expected to fully mitigate another 11 human health risks prior to 2024, and two additional risks could not be mitigated using the ISS. The OIG concluded that NASA**,** "needs to prioritize its research aboard Station to address the most important risks in the time available." I think this conclusion misses an important point. The likelihood and consequences of at least 11 of the 13 unmitigated risks are dependent on the tasks required of a crew during a Mars Design Reference Mission. Today, there are simply too many degrees of freedom in the task set to establish useful risk criteria. Therefore, before the capabilities of the ISS to mitigate these risks can be evaluated, the risk must be better understood by performing a thorough task analysis of Martian operations.

Second, the report did not address powered down mass to any great extent. This is a critical need when biological samples, including live organisms, are to be returned to the ground for additional study.

Third, the OIG emphasized average crew time as a metric to quantify research utility. Although there are other metrics, including number of investigations, use of allocated space, up-mass, down-mass, and power, thermal, and data usage; in general, NASA does not consider these measures primary indicators of research utilization[6]. What is missing is a method to evaluate the *efficiency* of on-orbit research. Specifically, what percentage of crew time allocated to research is used to conduct it, compared to ancillary functions for such as setting up and stowing equipment? A similar focus has improved extravehicular operations on the ISS. I suspect that we will find that some of the highest priority research, such as studies using small mammals, is also the least efficient; requiring substantial amounts of crew time to set up experiments. If this is true, then increasing efficiency, for example, by improving coordination between NASA and CASIS, could be another way to capture more crew time for research in high priority areas.

Fourth, the OIG notes that research time is constrained with a six person crew. To maximize research utilization, we need to think about a seventh scientist crew member when commercial crew systems can support him or her.

Summary

We desperately need to increase research capabilities in space by translating findings from cell culture to reference organisms and mammalian models such as mice and rats to future flight crews. Translational research is the "gold standard" of the NIH, and it is what the research community, and the American people, should expect from the

[5] http://oig.nasa.gov/audits/reports/FY14/IG-14-031.pdf
[6] https://oig.nasa.gov/audits/reports/FY13/IG-13-019.pdf

International Space Station. We need the capability to house and test model organisms on the ISS for extended periods of time, and whenever possible, to expose them to loading forces that approximate Mars. But equally important, we need adequate time for crew to prepare and conduct these experiments. The potential return is immense; the application of this research to our aging public could become one of the most important justifications for an extended human presence in space.

My LPS Decadal Survey colleagues and I contend that NASA can and should continue to restore a high level of programmatic vision and dedication to life and physical sciences research, to ensure that the considerable obstacles to human exploration missions to Mars can be resolved. This will depend on NASA embracing life and physical sciences research as part of its core exploration mission and re-energizing a community of life and physical scientists and engineers focused on both discovery and translational research.

To maximize ISS research, it is of paramount importance …

- That the life and physical sciences research portfolio supported by NASA, both extramurally and intramurally, receive high attention.
- That NASA's research management structure be optimized to meet its discovery research, translational research, and commercialization goals. The utility of a coherent research plan that is appropriately resourced and consistently applied to enable exploration cannot be overemphasized. This will require improved coordination with CASIS.
- That the research portfolio be based on both discovery and translational programmatic priorities, and with specific destination(s) and mission tasks in mind.
- That there is sufficient external oversight to help NASA reach its research goals.

My top recommendations are the following:

- Articulate a timeframe for delivering and completing an operational risk mitigation plan for a multi-year human mission to Mars, and vet both the plan and the timeframe with the external scientific community.
- Review the essential resources for extended mammalian research on the ISS, including a seventh crew member; a scientist-astronaut whose nominal responsibilities are science programming.
- Extend biological science experiments to cover a substantial portion of a mammalian life cycle, and incorporate fractional (Martian) gravity exposure where possible.

Mr. Chairman, given sufficient resources, I am optimistic that NASA can deliver another decade of rigorous translational research. It's what the scientific community expects, and the American people deserve. I sincerely thank you for your vigilant support of the nation's space program, and the opportunity to appear before you today.