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AUDIT REPORT

OFFICE OF AUDITS

# NASA'S EFFORTS TO MAXIMIZE RESEARCH ON THE INTERNATIONAL SPACE STATION

OFFICE OF INSPECTOR GENERAL

National Aeronautics and
Space Administration

REPORT NO. IG-13-019 (ASSIGNMENT NO. A-12-008-00)

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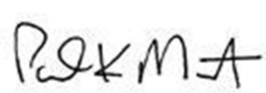


Paul K. Martin
Inspector General

## Acronyms

| | |
|---|---|
| CASIS | Center for the Advancement of Science in Space, Inc. |
| EVA | Extravehicular Activity |
| EXPRESS | Expedite the Processing of Experiments to the Space Station |
| FY | Fiscal Year |
| ISS | International Space Station |
| kg | kilogram |
| OIG | Office of Inspector General |

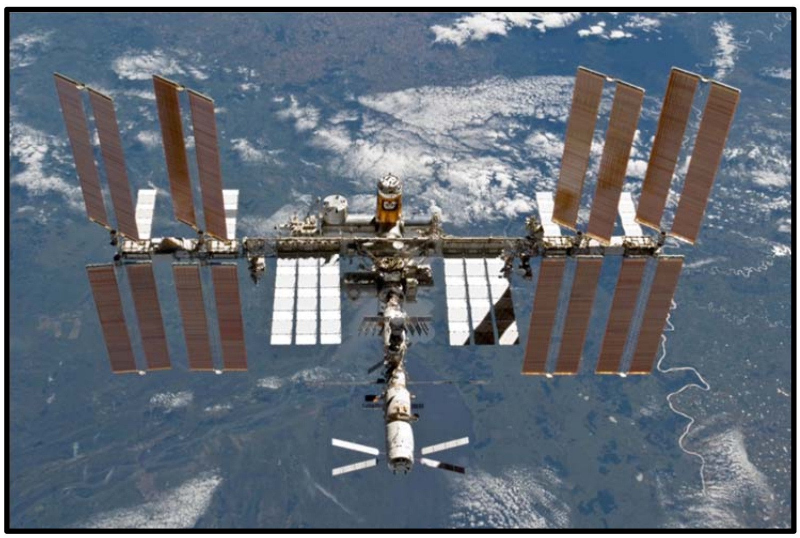
## OVERVIEW

# NASA'S EFFORTS TO MAXIMIZE RESEARCH ON THE INTERNATIONAL SPACE STATION

## The Issue

Given the high costs (approximately $60 billion spent by NASA alone) and extraordinary efforts expended to build the International Space Station (ISS or Station), national leaders have emphasized the importance of maximizing its scientific research capabilities.[1] The NASA Authorization Act of 2005 designated the U.S. segment of the ISS as a national laboratory (National Lab), and directed NASA to increase utilization of the National Lab by other federal entities and to foster commercial interest in conducting research on the ISS. Subsequently, the NASA Authorization Act of 2010 (Public Law 111-267) required NASA to enter into a cooperative agreement with a nonprofit organization to manage at least 50 percent of the Agency's available research resources on the ISS.

**Figure 1. The International Space Station**



Source: NASA.

In August 2011, NASA signed a cooperative agreement with the Center for the Advancement of Science in Space, Inc. (CASIS) to manage non-NASA research on the ISS. Pursuant to the agreement, NASA will provide CASIS $15 million annually. To

[1] Despite the fact that the Space Shuttle was used for ISS assembly missions, NASA considers the Space Shuttle Program an independent program from the ISS. For this reason, NASA does not include the cost of the Space Shuttle assembly flights in their calculation of ISS costs. If included, the overall cost would increase from $60 billion to $100 billion.

supplement these funds, CASIS is expected to raise additional funding through membership fees and donations and to work to encourage others to conduct self-funded research on the Station.[2]

In addition to CASIS's efforts, maximizing the ISS's research capabilities also depends upon the success of NASA's Commercial Cargo and Crew Programs. The Cargo Program is essential to ensuring the capacity to ferry experiments to and from the Station and the commercial crew vehicles currently under development will make it possible to staff the ISS with a full complement of seven crew members (rather than the current six), thereby increasing the amount of crew time available for research.

The NASA Office of Inspector General examined: (1) the current level of Station research, (2) CASIS's efforts to facilitate non-NASA research aboard the ISS, and (3) transportation challenges that could hinder full research utilization of the ISS. Details of the audit's scope and methodology are in Appendix A.

## Results

NASA has made progress towards maximizing the research capabilities of the ISS, but opportunities exist for greater utilization to more fully realize the Station's research potential and maximize the value of the United States' investment in building and maintaining the structure.

NASA uses three significant data points to assess utilization of ISS research capabilities:

- *Average weekly crew time* – Since 2011, NASA has exceeded its goal of spending an average of 35 hours per week on scientific investigations.

- *Number of investigations* – For the fiscal year (FY) ending October 2008, NASA performed 62 investigations. Since then, the annual number of investigations has been above 100.

- *Use of allocated space* – NASA expects that the utilization rate for space allocated for research purposes will increase in FY 2013 from about 70 percent to 75 percent for internal space and from 27 percent to 40 percent for external sites.

While no one measure provides a complete picture of the utilization rate, NASA has generally increased the level of activity for each metric since completion of ISS assembly in 2011. Further progress in maximizing the Station's research capabilities depends on

[2] In fiscal year 2012, CASIS met its requirement to enroll 50 paid members, and raised a total of $3,200 in membership fees.

(1) CASIS's ability to attract private funding to support research and to encourage companies and other organizations to conduct self-funded research and (2) the success of NASA's Commercial Cargo and Crew Programs.

**Private Funding.** Attracting private funding, matching investors with researchers, and fostering a market to conduct non-NASA research are significant challenges to NASA's efforts of maximizing the Station's research potential. First, NASA historically has received little interest from private entities for ISS research unless there was a substantial infusion of government funds.[3] Second, less costly ground-based research options may be available in some cases. Finally, potential users may be reluctant to allocate funds towards research when the likelihood of profitable results is risky.

Moreover, CASIS suffered a series of organizational issues early on that may have affected its initial fundraising efforts. In addition, although the organization met most of its early performance metrics, these metrics were focused primarily on achieving organizational milestones rather than measuring how successful CASIS has been in encouraging research on the ISS. Until NASA and CASIS establish precise metrics that reflect the degree to which CASIS is increasing non-NASA research on the ISS, it will be difficult to determine if CASIS is meeting the objectives of its agreement with NASA.

**Transportation.** The continued availability of dependable transportation for cargo and crew to the ISS is a key factor in maximizing the research capabilities of the Station. Four cargo vehicles currently support the ISS – Space Exploration Technologies Corporation's (SpaceX) Dragon, the Russian Progress, the European Automated Transfer Vehicle, and the Japanese H-II Transfer Vehicle. A fifth vehicle, Orbital Sciences Corporation's (Orbital) Cygnus, is expected to begin cargo flights in late 2013. All but the Progress carry NASA payloads to the Station, but only the Dragon can return experiments and other cargo to Earth. The other vehicles burn up during atmospheric reentry and therefore are suitable only for trash disposal. The Dragon's return capability is critical to maximizing the Station's research capabilities, as many experiments require samples to be brought back to Earth for analysis and examination.

After NASA retired the Space Shuttle in 2011, the Russian Soyuz became the only vehicle capable of transporting crew to the ISS. Between 2006 and 2008, NASA purchased one seat per year. Beginning in 2009, NASA started purchasing six seats per year. The price per seat has increased over the years from $22 million in 2006, to $25 million in 2010, to $28 million in the first half of 2011. During the second half of 2011, the price per seat jumped to $43 million.[4] The price has continued to increase. For

[3] "Commercial Market Assessment for Crew and Cargo Systems Pursuant to Section 403 of the NASA Authorization Act of 2010," (NASA, April 27, 2011).

[4] The largest increase occurred for launches planned for the latter portion of 2011, when retirement of the Space Shuttle and the lack of a U.S. domestic transportation capability increased NASA's previous demand for Soyuz seats. According to the Space Station External Integration Office, meeting this increased demand required upgrades to and modernization of Russia's manufacturing infrastructure, which resulted in a 57 percent increase in the cost per seat – from $28 million for launches in the first half of 2011 to $43 million for launches in the latter half of 2011.

example, the price of purchased seats for launches in 2014 and 2015 are $55.6 million and $60 million, respectively. In April 2013, NASA signed another deal with Russia valued at $424 million for six additional seats to carry NASA astronauts to the Station during 2016 through June 2017, and the price per seat has increased to $71 million.

NASA began the Commercial Crew Program in 2010 in part to end its reliance on the Soyuz for crew transportation to the ISS. The goal of the Commercial Crew Program is to facilitate the design and development of safe, reliable, and cost effective crew transportation to the ISS and low Earth orbit. In August 2012, NASA awarded the third round of development agreements for approximately $1.1 billion to three commercial partners.[5] NASA expects at least one commercial partner to provide crew transportation services to the ISS in 2017. However, NASA has not received the full amount of funds it requested for its Commercial Crew Program since 2011, and the Program continues to face an uncertain funding stream. For example, NASA requested $850 million for FY 2012 and $830 million for FY 2013 for the Program, but received only $406 million and $489 million, respectively. If this trend continues in the future, NASA likely will not meet its goal of having at least one vehicle transporting crew to the ISS in 2017. In that case, NASA would have to continue to purchase additional seats on Soyuz vehicles.

Reliance on the Soyuz limits the amount of research conducted on the ISS because the Soyuz does not have the capacity to support the maximum number of crew members that can inhabit the Station. NASA and its partners designed the ISS to support seven crew members. However, the Soyuz has a three-person capacity; therefore, only six crew members can safely be aboard the ISS at any time to allow for evacuation in case of an emergency (given that two Soyuz capsules are docked to the ISS at all times to serve as "escape vehicles.") According to the ISS Program Office, a seventh crew member could potentially add about 33 hours per week to the current amount of crew time devoted to research – a 94 percent increase.

Given its $60 billion construction price tag and almost $3 billion in annual operating costs, it is essential that NASA make a concerted effort to maximize the research capabilities of the ISS. The success of this effort largely hinges on two factors: the ability of CASIS to attract sufficient interest and funding from private users and investors and the availability of reliable transportation to and from the ISS for crew and cargo.

[5] SpaceX received $440 million for its Dragon capsule; the Boeing Corporation received $460 million for its CST-100 capsule; and Sierra Nevada Corporation received $212.5 million for its Dream Chaser capsule.

## Management Action

In order to better assess the performance of CASIS, we recommended that the NASA Associate Administrator for the Human Exploration and Operations Mission Directorate work with CASIS to develop precise annual performance metrics that measure CASIS's success at fostering private research on the ISS. In response to our draft report, the Associate Administrator agreed to develop such metrics. We consider the Associate Administrator's proposed action to be responsive and will close the recommendation once we verify the Agency has developed metrics.

In his response, the Associate Administrator also noted that CASIS is just one avenue to maximize ISS utilization, citing other ways in which NASA has expanded NASA-related research on the Station. Although we acknowledge these efforts, our report focused on increasing utilization of the National Lab by entities other than NASA, and CASIS is the primary mechanism through which NASA will pursue this goal. Accordingly, we continue to believe that CASIS's success is critical to maximizing the research capabilities of the ISS.

## CONTENTS

# INTRODUCTION

## Background

The Soviet Union launched the world's first space station, Salyut 1, in 1971.[6] NASA followed with Skylab in 1973. Both the Salyut and Skylab were designed to house crews for relatively short visits and were not capable of supporting continuous human occupation. In 1986, the Soviets launched the first component of their modular Mir space station. Mir was permanently occupied from 1989 through1999. In addition to Soviet cosmonauts, seven NASA astronauts visited Mir and NASA Space Shuttle Orbiters docked with the Soviet station nine times.

In the mid 1980s, the United States began negotiating with the Canadian, Japanese, and the European space agencies to build and operate a space station in low Earth orbit. Russia joined the partnership in 1993, and in 1998, assembly of the International Space Station (ISS or Station) began.

The U.S., European, Japanese, and Russian space agencies each constructed various ISS modules. The first module, Russia's Zarya, launched on a Russian Proton rocket in November 1998, and provided electrical power, storage, propulsion, and guidance for the Station. The following month, a Space Shuttle delivered the U.S. module, Unity, which connected fluids, environmental control and life support systems, and electrical and data systems to the Station and provided six docking locations for future modules. In July 2000, Russia placed the Zvezda Service Module into orbit, providing the main living quarters for the crew as well as environmental systems, electronic controls, and additional docking locations. In November 2000, two Russian cosmonauts and one American astronaut became the first crew members to live and work on the ISS. Almost nine years later in May 2009, with the addition of the fourth and final power-generating section, the ISS became capable of supporting six crew members at a time. In July 2011, assembly of the ISS was considered complete with the installation of the final express logistics carrier and the Alpha Magnetic Spectrometer.[7] Each agency's contribution to the ISS is shown in Figure 2.

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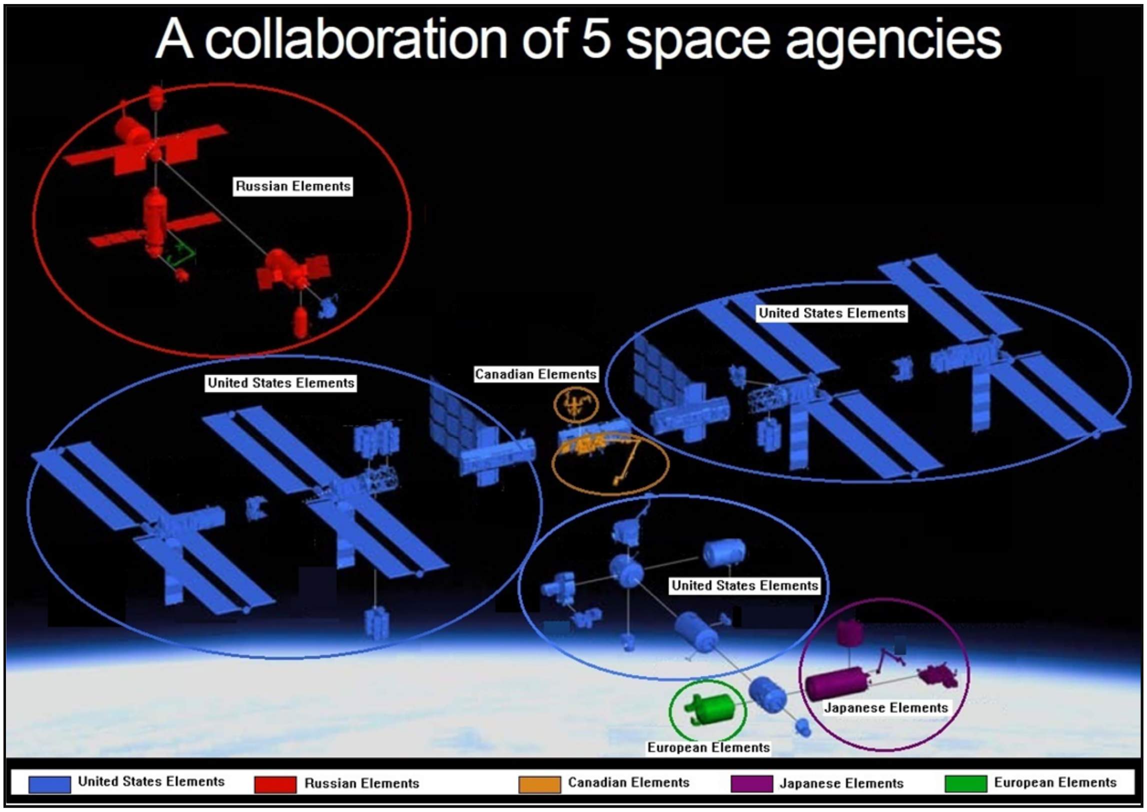
[6] The Soviets launched a series of Salyut stations, ending with Salyut 7 in April 1982.

[7] Alpha Magnetic Spectrometer provides data to advance human knowledge about the space radiation environment and fundamental issues about the origin and structure of the universe.

**Figure 2. ISS Partnership of Five Space Agencies**




Source: NASA.

**Historical Perspective of ISS Costs, Schedule, and Performance.** The final configuration of the ISS cost more, took longer to complete, and is less capable than planners envisioned. In 1984, NASA estimated the Station would be fully assembled by 1994 at a cost of $8 billion to the Agency. In the end, construction of the ISS was completed in 2011, at an estimated cost of $60 billion to NASA, plus another $40 billion for associated Space Shuttle flights. Similarly, initial plans for the ISS were for a Station that, in addition to serving as a laboratory for scientific research, would have had seven other distinct functions, including serving as a permanent observatory, a manufacturing facility, and a staging base for launching missions further into space.[8] In addition, the length of the ISS decreased from 493 to 357 feet (a 27.6 percent reduction compared to early plans) and the Station can support seven rather than eight crew members.[9] The cost growth, schedule delays, and functional changes resulted primarily from underestimating

[8] The other planned functions were a transportation node to process and propel vehicles and payloads to further destinations, a servicing facility, an assembly facility, and a storage depot.

[9] Although the Station can support seven crew members, at present only six can be on Station at one time in order to ensure evacuation in case of an emergency. The only vehicle currently carrying crew to and from the station is the Russian Soyuz, which has a three-person capacity and only two Soyuz capsules can be attached to the Station at one time.

the technical complexity of building the Station; changes in Federal government funding priorities; and the Challenger and Columbia Space Shuttle accidents which delayed and reduced the number of Shuttle flights devoted to ISS assembly.

**Efforts to Maximize Scientific Research on the ISS and Creation of the National Laboratory.** Given the high costs and extraordinary effort expended to build the ISS, national leaders have emphasized the importance of maximizing its scientific research capabilities. The NASA Authorization Act of 2005 (Public Law 109-155) designates the U.S. segment of the ISS as a national laboratory (National Lab) and directs NASA to work to increase utilization of the ISS research capabilities by other Federal entities and the private sector.[10] Similarly, the NASA Authorization Act of 2010 (Public Law 111-267) directs NASA to take all actions necessary to ensure the safe and effective operation, maintenance, and maximum utilization of the ISS through at least September 2020. In addition, the legislation requires NASA to enter into a cooperative agreement with a nonprofit organization to manage at least 50 percent of the Agency's available research resources on the ISS. Specifically, the Act requires the nonprofit to: (1) plan and coordinate ISS national laboratory research activities; (2) develop and implement guidelines, selection criteria, and flight support requirements for non-NASA research; (3) interact with and review recommendations of the ISS National Laboratory Advisory Committee; (4) coordinate transportation requirements in support of ISS national laboratory research and development objectives; (5) cooperate with NASA and other ISS users to ensure the enhancement and sustained operations of nonexploration-related research payload ground support facilities; (6) develop and implement scientific outreach and education activities; and (7) address matters relating to utilization of the ISS national laboratory research and development facilities that the Administrator considers appropriate.[11]

**Center for the Advancement of Science in Space, Inc.** In February 2011, NASA released a request for proposal seeking a nonprofit entity to fulfill the requirements of the 2010 Authorization Act. Four groups responded and NASA chose the Center for the Advancement of Science in Space, Inc. (CASIS). CASIS is a creation of Space Florida - a special district created by the State of Florida to foster the development of the space industry in the State.

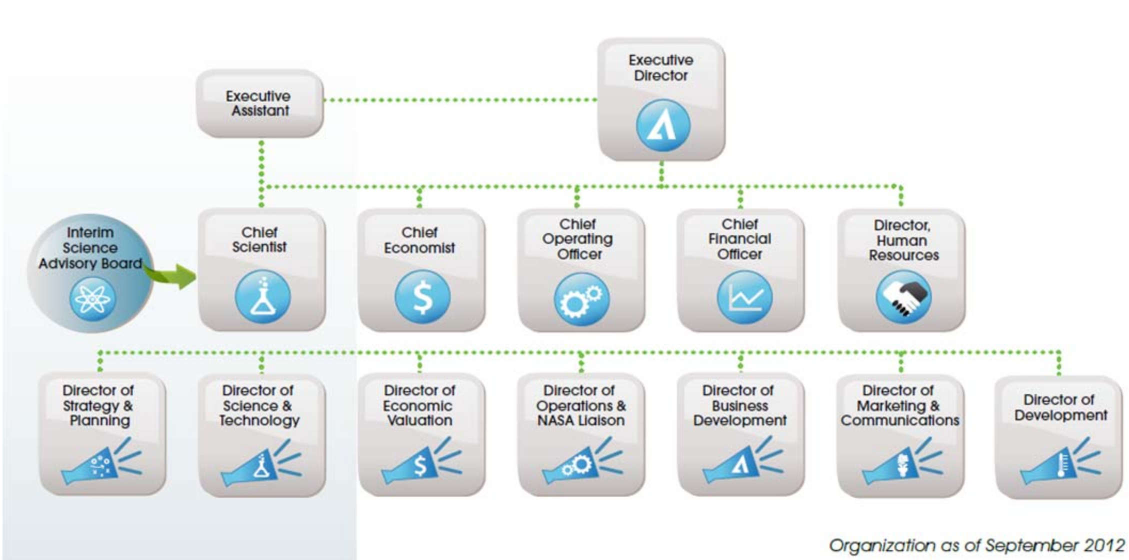
In August 2011, NASA finalized a cooperative agreement with CASIS to manage non-NASA research on the ISS. An Executive Director who reports to a 15-member

[10] The NASA Authorization Act of 2005 defines the "United States segment of the ISS" to mean those elements of the ISS manufactured by the United States or for the United States by other nations in exchange for funds or launch services.

[11] The NASA Authorization Act of 2008 (Public Law 110-422) required that the NASA Administrator establish the ISS National Laboratory Advisory Committee. This committee was tasked to monitor, assess, and make recommendations regarding effective utilization of the Station as a national laboratory and platform for research. NASA chartered this committee in 2009, but no members were ever seated. However, the functions of this committee are being performed by the Subcommittee for Operations under the NASA Advisory Committee.

Board of Directors manages CASIS's operations with a permanent staff that includes a Chief Scientist, Chief Economist, and Director of Development, among others (see Figure 3).

**Figure 3. CASIS Organization**




Source: CASIS 2012 Annual Report.

The cooperative agreement tasks CASIS with maximizing use of the ISS for scientific research by directly soliciting potential users and fostering a market to attract others. CASIS officials told us they attempt to achieve this goal by educating researchers on the ISS's research capabilities and utilizing their professional, academic, and personal contacts to match investors and researchers. CASIS stimulates research activity on the ISS in three ways: (1) funding proposals directly, (2) matching outside investors with researchers, and (3) encouraging self-funded research.

NASA provides CASIS with $15 million of funding each year, of which at least $3 million must be used to fund research grants.[12] CASIS may supplement the funding it receives from NASA through membership fees and private donations. As of October 2012, CASIS had raised only $3,200 through membership fees and will begin soliciting private donations in the third quarter of fiscal year (FY) 2013. In FY 2012, CASIS spent less than planned on its operations and carried over $3 million to FY 2013, creating a pool of $6 million from which it can directly fund research in FY 2013.

For research that it funds, CASIS solicits proposals through "research pathways" designed to support advancement of specific scientific fields such as life, material, and

[12] In contrast, NASA received $225.5 million in fiscal year 2012 to conduct all ISS research. The ISS research includes funding for biological and physical research, multi-user systems support, National Lab activities, and the ISS nonprofit management organization.

physical sciences.[13] As of March 2013, CASIS had released four solicitations: (1) to advance protein crystallization using microgravity, (2) for proposals to conduct material testing, (3) for utilization of existing hyper-spectral imaging for commercial product development, and (4) to develop strategies for support of stem cell research.[14]

For both solicited and unsolicited proposals, CASIS begins their evaluation process with a feasibility assessment, including considering whether a similar experiment has flown before, safety and risk management issues, and the amount of crew time needed to conduct the experiment. If a proposal is deemed feasible, CASIS evaluates its scientific and economic potential.

- *Scientific Evaluation*. To perform the scientific evaluation, CASIS establishes an external panel of subject matter experts who review the proposal and assign one of five ratings ranging from poor (not selectable) to excellent (top priority for selection). The scientific evaluation considers: (1) the significance of the proposed research to science, industry, and humanity; (2) the financial and demonstrated reliability of the researchers; (3) the innovative aspects of the experiment, such as new methods or coverage of multiple disciplines; (4) the ability of the experiment to satisfy CASIS's mission; and (5) if the project will benefit from being conducted in space and the researchers have the proper ground-based resources to conduct pre-flight operations.

- *Economic Evaluation*. To perform the economic evaluation, CASIS establishes an external panel of subject matter experts who review the proposal using the same rating scale, considering both commercial and intangible factors. The expert panel evaluates the commercial potential of proposals based on: (1) demonstrated management capabilities within and among the research team; (2) the likely impact on relevant markets; (3) the likely benefits to the economy and people of the United States; (4) the existence of a clearly presented business and operating plan; and (5) the likelihood that the relevant market is stable and has the potential to accept new products and competition. The intangibles the panel considers are the likelihood that: (1) the research will advance discovery and provide innovation solutions to broader aspects of U.S. society; (2) potential outcomes will exhibit the benefits of conducting research in space; and (3) results will improve quality of life and job and wealth creation and will bridge basic and applied sciences.

The CASIS Chief Scientist and Chief Economist work together throughout the evaluation process to provide feedback to potential researchers so that they understand what

[13] The solicitation identifies a maximum amount of potential funding that each proposal could receive if selected.

[14] Protein crystallization is a technique used to determine three-dimensional structures of protein molecules in order to examine potential methods of manipulating the behavior of the molecule. Hyper-spectral imaging collects and processes information from across the electromagnetic spectrum, which provides visual data and analysis across multiple fields, including agriculture, urban planning, and environmental studies.

improvements are needed for CASIS to accept the experiment. Once a proposal passes both the scientific and economic valuation process, CASIS's Chief Scientist and Chief Economist present the experiment to the Executive Director for approval. If approval is granted, CASIS facilitates communication between the researcher and a set of 25 partners who assist in designing the experiment, integrating the payload, and providing other support. For example, CASIS has partnered with NanoRacks, LLC – a company that provides interface capabilities for small, standardized payloads in order to connect to ISS power and data resources – to provide resources that will allow experiments to be exposed directly to the space environment. In addition, CASIS has a partnership with the Boeing Corporation to assist with the payload integration aspects of experiments once they are onboard the ISS. As of April 2013, CASIS had approved and selected 38 experiments to be conducted onboard the ISS, including Earth observation and life science experiments.

**Transporting Crew and Cargo to the ISS.** NASA's ability to transport crew and cargo to the ISS are key factors affecting the amounts and types of research that can be conducted there. As NASA and its international partners debated various possible designs for a space station in the 1980s and 1990s, they expected that the Space Shuttle would be available to support the Station throughout its lifetime.[15] In addition, NASA planned to build a vehicle capable of evacuating a seven-member crew so that the Station could be fully manned. However, funding for this vehicle was removed from the NASA budget in 2002, and following the accident that destroyed the Space Shuttle Columbia in 2003, the Shuttle Program was slated for retirement by 2010.[16]

In 2006, NASA began funding commercial companies to develop cargo vehicles to support the ISS. Although NASA had originally hoped these vehicles would be available in 2009 before the Space Shuttle vehicles retired, the first commercial resupply trip to the ISS by Space Exploration Technologies Corporation (SpaceX) did not occur until 2012. The other commercial company, Orbital Sciences Corporation (Orbital), is scheduled to begin ISS resupply missions in late 2013.

In planning for the Space Shuttle retirement, NASA expected to experience about a 2-year period (2010-2012) during which no U.S. vehicle would be available to transport NASA astronauts to the ISS and the United States would need to rely on the Russian Soyuz to ferry its astronauts to the Station. However, a series of developments has lengthened this gap significantly. The development schedule of NASA's successor to the Space Shuttle – the Crew Exploration Vehicle and its first stage vehicle Ares 1 – began to slip from its original 2012 availability date. In 2009, the Augustine Commission reported that at current funding levels, the Crew Exploration Vehicle would not be able to support the ISS until at least 2017. In 2010, NASA cancelled the Constellation Program and shifted focus to developing a commercial capability for ISS crew transportation (while at

[15] NASA's Space Station Program: Evolution of its Rationale and Expected Uses," (Congressional Research Service, April 20, 2005).

[16] NASA later added two additional Space Shuttle flights and the final Shuttle flight took place in July 2011.

the same time developing a Space Launch System that includes a “heavy lift” rocket and Multi-Purpose Crew Vehicle for exploration beyond low Earth orbit).[17] Currently, the Agency projects the earliest commercial crew vehicles will be operational is 2017. Consequently, the Soyuz will continue to be the only means of transporting NASA astronauts to the ISS until a commercial crew vehicle becomes available.

**Measures of Utilization.** NASA measures utilization of the U.S. laboratory portion of the ISS in several ways. The most significant of these measures are: (1) crew time spent on research, (2) number of investigations, and (3) occupancy of allocated research space.

Crew Time. Crew time refers to the number of hours crew members devote to research activities as opposed to other tasks required to operate and maintain the Station, sleep, exercise, eat, hygiene, and personal time. NASA divides each 24-hour period on the Station into 11 hours for work activities and 13 hours for other activities. Of the 11 work hours, 2.5 hours are set aside for exercise and 2 hours for planning and work preparation. NASA allocates the remaining 6.5 hours as follows:

- *Utilization and research (38 percent)* – This includes the actual manipulation by a crew member of an investigation and the set-up and removal activities associated with an experiment.

- *Visiting vehicle traffic operations (25 percent)* – When a vehicle visits the ISS, the crew must devote time to prepare for its arrival and departure. Each of the six types of vehicles that visit or are expected to visit the Station presents its own unique set of crew activities and configuration set-ups.[18] For cargo vehicles, the time to unpack, stow, and document the location of incoming supplies and to repack the vehicle with trash or other items for return to Earth is included in this category. For a crew vehicle, the time for crew exchange and information handover is included in this category.

- *Maintenance (13 percent)* – Includes corrective and preventive activities.

- *Medical operations (7 percent)* – The crew must maintain exercise and health monitoring equipment and perform activities for the Countermeasures, Environmental Health, and Health Maintenance systems.[19]

[17] The NASA Authorization Act of 2010 provided for a Space Launch System as a key component to travel beyond low Earth orbit. In addition, the Authorization Act required the Space Launch System to serve as a backup for ISS cargo or crew delivery requirements not met by commercial or partner-supplied vehicles.

[18] These vehicles are the Russian Soyuz and Progress, European Automated Transfer Vehicle, Japanese H-II Transfer Vehicle, SpaceX Dragon, and – depending on Orbital’s successful demonstration of cargo transportation capabilities in 2013 – Orbital Cygnus.

[19] Countermeasures are activities to mitigate undesirable physical, physiological, and behavioral health and performance effects of space flight upon crew members and crews.

- *Training (7 percent)* – This category includes emergency egress training, depressurization response, Soyuz evacuation, simulated fire drills, emergency response, procedures review, and robotics proficiency.

- *Extravehicular activity (EVA) operations (5 percent)* – Astronaut spacewalk activities conducted outside of the ISS, including pre- and post-EVA activities.

- *Routine operations (4 percent)* – Crew meetings, stowage management, audit of supplies and consumables (food and water), and public affairs events.

- *Resupply and outfitting (1 percent)* – Hardware and software upgrades and vehicle configuration changes.

In addition, unexpected events may reduce research time. For example, in September 2012, an unexpected EVA operation was required to address an issue with a bolt on an electrical power device. The crew spent several days troubleshooting and identifying a repair procedure and performing the actual repair, which reduced the time available for research activities during that period. More recently, two astronauts performed an unplanned space walk in May 2013 to replace a coolant pump assembly that was leaking ammonia from the thermal control system.

Investigations. NASA research aboard the ISS focuses on life and physical sciences, human research, exploration research and technology development, astrophysics, heliophysics, planetary, and Earth science. Examples of NASA investigations conducted aboard the ISS during the last 14 years include:

- *Cardiovascular Health Consequences of Long-Duration Space Flight***.** This research is expected to identify countermeasures to prevent astronauts from experiencing long-term cardiovascular health problems stemming from their time in space.

- *Preventing Bone Loss in Space Flight*. Bone loss and kidney stones are significant problems for astronauts during extended stays in space. Test results suggest that astronauts can reduce the risk of both through a combination of nutrients such as calcium and vitamin D, an effective exercise program, and minimal amounts of medication.

- *Alpha Magnetic Spectrometer.* A $1.5 billion particle physics experiment ferried to the ISS in May 2011 and attached to an exterior truss provides data to advance human knowledge about the space radiation environment and fundamental issues about the origin and structure of the universe.

- *Anomalous Long Term Effects in Astronauts' Central Nervous System*. According to the ISS Chief Scientist, this investigation assessed the radiation environment onboard the ISS, improved understanding of the impact radiation has on the human central nervous system functions, and studied the flashes from cosmic radiation that astronauts have reported since the Apollo flights.

In addition to NASA-directed research, other Federal agencies, academia, and commercial companies have conducted research on the ISS. Examples include:

- *Cancer Treatment Delivery.* Various members of the oncology community participated and used different microencapsulation techniques as an approach to cancer treatment.[20] Specifically, by using microcapsules containing anti-tumor treatment and visualization markers, the treatment can be directed right to the tumor, which has several benefits over systemic treatment such as chemotherapy.

- *Vaccine Development.* Researchers at Arizona State University and Durham Veterans Affairs Medical Center have flown experiments investigating microgravity effects on virulence and searching for therapeutic agents or vaccines against salmonella bacteria.

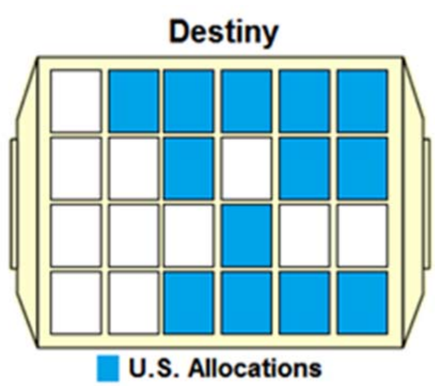
Occupancy of Allocated Space. NASA has 24 internal laboratory bays and 15 external sites on the ISS that house research investigations.

*Internal laboratory bays.* NASA's 24 bays in the U.S., European, and Japanese Labs contain racks, freezers, and other infrastructure that support biological, life science, and other types of experiments.

The U.S. Destiny Lab (Figure 4) contains 13 NASA bays with science racks consisting of:

- five Expedite the Processing of Experiments to the Space Station (EXPRESS) racks designed to accommodate smaller experiments;
- one fluids integrated rack;
- one combustion integrated rack;
- one window observational research facility;
- one minus 80 degree laboratory freezer;
- one materials science research rack;
- one microgravity science glove box; and
- two additional bays for utilization, stowage, and future use.

**Figure 4. NASA Racks in Destiny**



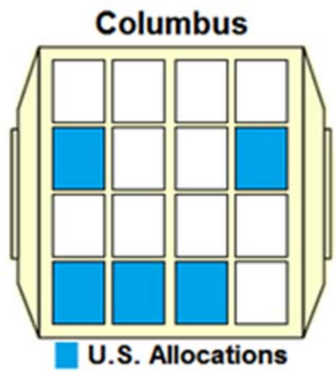

Source: NASA.

[20] Microencapulation is a single step process that forms tiny liquid-fields, biodegradable micro-balloons containing various drug solutions that can provide better drug delivery and new medical treatments for solid tumors and resistant infections.

The European Columbus Lab (Figure 5) contains five NASA bays with science racks consisting of:

- one EXPRESS rack;
- two human research facility racks;
- one muscle atrophy research exercise system; and
- one bay for utilization, stowage, and future use.

**Figure 5. NASA Racks in Columbus**

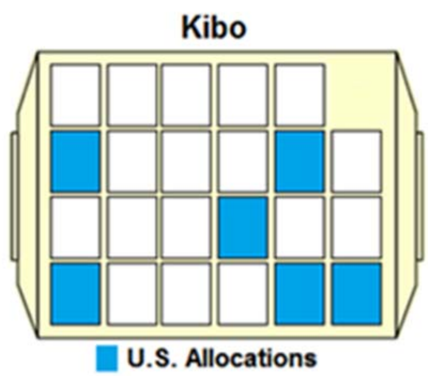



Source: NASA.

The Japanese Kibo Lab (Figure 6) contains six NASA bays with science racks consisting of:

- two EXPRESS racks;
- two minus 80 degree laboratory freezers; and
- two bays for utilization, stowage, and future use.

**Figure 6. NASA Racks in Kibo**




Source: NASA.

The fluids integrated rack is designed for experiments that investigate fluid physics. For example, the *Advanced Colloids Experiment-1* is the first in a series of microscopic imaging investigations of materials that contain small colloidal particles that remain evenly dispersed and distributed within a material.[21] The investigation takes advantage of the unique environment aboard the ISS in order to separate the effects induced by Earth's gravity and examine flow characteristics and the evolution and ordering effects within these colloidal materials. Understanding and improving the way particles react in

[21] A colloid is a substance microscopically dispersed evenly throughout another substance. A colloidal system consists of two separate phases: a dispersed phase (or internal phase) and a continuous phase (or dispersion medium) in which the colloid is dispersed. A colloidal system may be solid, liquid, or gas.

suspension is expected to help improve the shelf life and performance of materials such as paints, motor oils, food, and cosmetics. In Figure 7, an astronaut participates in an absence of gravity investigation. In this experiment, data is collected using probes connected to the astronaut's body and to a computer in an EXPRESS rack. This experiment evaluates differences in the way the brain controls conscious and unconscious motions such as breathing, sitting, and standing in environments with and without gravity.

**Figure 7. Investigation of the Connection between the Brain, Visualization, and Motion in the Absence of Gravity**


Source: NASA.

The combustion-integrated rack houses experiments that examine combustion. For example, the *Flame Extinguishment Experiment* assessed the effectiveness of fire suppressants in microgravity. The goal of this research was to explore fire suppressants for the next generation of space vehicles. In Figure 8, an astronaut works on a combustion experiment in the Destiny Lab.

**Figure 8. Astronaut working with the Combustion Integrated Rack Multi-user Drop Combustion Apparatus in the Destiny Lab of the ISS**

Source: NASA.

*External Sites*. NASA has access to 15 sites with power and data connections outside of the ISS. Experiments using these external facilities include studies of astronomy; Earth observation; and exposure to vacuum, radiation, extreme temperatures, and orbital debris.

For example, the *Space Communications and Navigation Testbed* consists of radios that provide ground-based mission planners the capability to reconfigure the radios on-orbit, which provides flexibility to adapt to new science opportunities and increased data return. Additionally, this flexibility allows teams to recover from anomalies in science payloads or communication systems and potentially reduce development cost and risk by using the same hardware platform for different missions.

In April 2012, CASIS announced a partnership with NanoRacks, LLC – the first commercial entity to create hardware capable of enabling research outside the ISS. According to CASIS officials, this agreement is an opportunity to enhance the capabilities of the ISS by providing investigators another means to conduct research that could lead to Earth-based applications, such as improvements in medicines to treat salmonella infection and vaccines against Streptococcus pneumonia. In September 2012, CASIS announced a request for proposal for “Materials Research in the Extreme Environment of Space” that will utilize the NanoRacks’ External Platform in order to understand and make use of the physical and chemical properties influenced by microgravity, atomic oxygen, low pressure, and vast temperature variations.

Finally, NASA research efforts on the ISS are not limited to the allocated internal space or external sites. For example, the Alpha Magnetic Spectrometer constructed, tested, and operated by an international team of 56 institutes from 16 countries and organized under the auspices of the U.S. Department of Energy is attached to a nonstandard site outside the ISS. The Spectrometer is providing data to advance knowledge of space radiation and better understand the origin and structure of the universe. In April 2013, NASA announced that the Alpha Magnetic Spectrometer had collected data that may evidence dark matter particles colliding with each other, which would be a significant discovery in astrophysics research.[22]

## Objectives

Given NASA's substantial investment in the ISS, we reviewed NASA's efforts to maximize utilization of the Station for scientific research. Specifically, we examined:

- current level of Station research,
- CASIS's efforts to facilitate non-NASA research aboard the ISS, and
- transportation challenges that could hinder full research utilization of the ISS.

See Appendix A for details of the audit's scope and methodology, our review of internal controls, and a list of prior coverage.

[22] Stars and other visible matter in the Universe make up less than 5 percent of the total mass known to exist. The other 95 percent is either dark matter (estimated at 20 percent of the Universe by weight) or dark energy. The exact nature of both substances is unknown.

# MAXIMIZATION OF ISS RESEARCH OPPORTUNITIES IS DEPENDENT ON ATTRACTING PRIVATE FUNDING AND ENSURING RELIABLE CARGO AND CREW TRANSPORTATION

NASA has made progress over the past 14 years in increasing the use of the ISS as a research laboratory, but opportunities exist for greater utilization to more fully realize the Station's research potential and maximize the value of the United States' investment in building and maintaining the structure. However, further progress in maximizing the Station's research capabilities depends on (1) CASIS's ability to attract private funding to support research and to encourage companies and other organizations to conduct self-funded research and (2) the success of NASA's Commercial Cargo and Crew Programs.

## NASA Has Increased Research on the ISS but Opportunities Exist for Greater Utilization

Because no one measure provides a complete picture of utilization rates, NASA uses three primary data points to assess utilization of ISS research capabilities: average weekly crew time, number of investigations, and use of allocated space.[23] Since completion of ISS assembly in 2011, all three of these measures have increased, but opportunities exist to further increase utilization of the Station's research capabilities.

**Average Weekly Crew Time.** By 2009, the ISS was capable of housing six crew members and NASA set a goal that the crew should spend an average of 35 hours per week on research-related activities.[24] Over the next 2 years, the number of hours the crew devoted to research ranged from 23 to 29 hours. NASA fell short of its 35-hour goal primarily because the crew was dedicating a significant amount of time to activities necessary to complete construction of the Station. Once construction was completed in July 2011, the hours available for research substantially increased. For example, as shown in Table 1, the average amount of time dedicated to research between September 2011 and April 2012 increased from 24.1 hours to 35.8 hours (48.5 percent) and reached 37.5 hours by February 2013.

[23] In addition to average weekly crew time, number of investigations, and use of allocated space, NASA also tracks upmass, downmass, and power, thermal, and data usage, but does not consider these measures primary indicators of research utilization.

[24] This refers to both U.S. crew and crew from the international partners. At any one time, there could be two to three U.S. crew members onboard the ISS.

| Table 1. Average Crew Time Used for Scientific Research | | |
|---|---|---|
| **Expeditions** | **Dates** | **Hours (weekly average)** |
| 21/22 | 10/2009 to 3/2010 | 28.9 |
| 23/24 | 3/2010 to 9/2010 | 23.4 |
| 25/26 | 9/2010 to 3/2011 | 23.7 |
| 27/28 | 3/2011 to 9/2011 | 24.1 |
| 29/30 | 9/2011 to 4/2012 | 35.8 |
| 31/32 | 4/2012 to 9/2012 | 36.3 |
| 33/34 | 9/2012 to 4/2013 | 37.5[a] |

[a] Data through February 28, 2013.
Source: NASA Office of Inspector General (OIG) analysis of NASA data.

**Number of Investigations**. NASA has shown an upward trend in the number of active investigations conducted over time. For example, between December 1998 and March 2001, NASA performed 36 investigations aboard the ISS. In comparison, between October 2007 and October 2008, that number increased to 62 investigations, and for the 12 months ending September 2012, to 115 investigations. Overall, between December 1998 and September 2012, NASA performed 527 total investigations aboard the ISS.

A number of entities sponsor investigations aboard the ISS and these investigations vary considerably in terms of duration, complexity, and research goals. For example, the *Sleep-Wake Actigraphy and Light Exposure During Spaceflight* investigation continued for 13 expeditions, while the *Forward Osmosis Bag* investigation was completed during two expeditions in 2011.[25] Given these variables, NASA does not set goals to complete a set number of investigations over a specific period.

**Use of Allocated Space.** As shown in Table 2, the internal space allocated for research in the U.S. portion of the ISS was about 70 percent occupied as of April 2012. ISS Program officials expect that this rate will increase to 75 percent during FY 2013. NASA management told us that their goal is to accommodate all research needs, not to reach full occupancy. They also noted that 100 percent occupancy may not be feasible or desirable given the power, thermal, and data usage constraints this would place on the ISS.

[25] *Sleep-Wake Actigraphy and Light Exposure During Spaceflight* examines how sleep patterns are affected by space flight and is designed to aid the treatment of insomnia on Earth. *Forward Osmosis Bag* is an experiment designed to convert dirty water into a safe-to-drink liquid by comparing ground-based results to those conducted in space.

| Table 2. Internal Occupancy Rates | | |
|---|---|---|
| **Expeditions** | **Dates** | **Percentage occupied** |
| 21/22 | 10/2009 to 3/2010 | Not tracked |
| 23/24 | 3/2010 to 9/2010 | Not tracked |
| 25/26 | 9/2010 to 3/2011 | Not tracked |
| 27/28 | 3/2011 to 9/2011 | Not tracked |
| 29/30 | 9/2011 to 4/2012 | 70% |
| 31/32 | 4/2012 to 9/2012 | 70% |
| 33/34 | 9/2012 to 4/2013 | 70% |
| 35/36[a] | 4/2013 to 9/2013 | 75% |

[a] Expeditions 35/36 occupancy rate is planned.
Source: OIG analysis of NASA data.

As shown in Table 3, NASA's external sites were about 27 percent occupied as of April 2012, and ISS program officials expect this rate will increase to 40 percent during FY 2013.

| Table 3. External Occupancy Rates | | |
|---|---|---|
| **Expeditions** | **Dates** | **Percentage occupied** |
| 21/22 | 10/2009 to 3/2010 | Not tracked |
| 23/24 | 3/2010 to 9/2010 | 13% |
| 25/26 | 9/2010 to 3/2011 | 13% |
| 27/28 | 3/2011 to 9/2011 | 27% |
| 29/30 | 9/2011 to 4/2012 | 27% |
| 31/32 | 4/2012 to 9/2012 | 33% |
| 33/34 | 9/2012 to 4/2013 | 33% |
| 35/36[a] | 4/2013 to 9/2013 | 40% |

[a] Expeditions 35/36 occupancy rate is planned.
Source: OIG analysis of NASA data.

## CASIS's Early Performance Metrics Primarily Measured Organizational Goals Rather than Station Research Utilization

The primary way NASA expects to increase utilization of ISS research capabilities is by working with CASIS to solicit non-NASA research. Currently, NASA intends to provide CASIS with $15 million in funding each year and is counting on the organization to raise additional funding through membership fees and donations and to work to encourage others to conduct self-funded research on the Station. However, CASIS suffered a series of organizational issues early on that may have affected its initial fundraising efforts. Moreover, although CASIS met most of its early performance metrics, these metrics were focused primarily on achieving organizational milestones rather than measuring how successful CASIS has been in encouraging research on the Station.

**Fostering a Market for ISS Research Remains a Significant Challenge for CASIS.** Attracting private funding is essential to supplement the relatively limited funding NASA provides to CASIS. Although NASA received $225.5 million in FY 2012 to conduct research aboard the ISS, only $15 million went to CASIS. As shown in Table 4, CASIS must allocate at least $3 million of its annual allotment to fund research experiments. CASIS is planning to supplement this money with private funding raised through membership fees and direct donations. In addition, the organization plans to match outside funding sources with researchers and encourage self-funded research by corporations and other institutions.

**Table 4. CASIS Funding Sources**

| Source of Funding | Direct or Indirect | Significance of Funding Source | Example |
|---|---|---|---|
| **NASA** | Direct | Provides funding for operations, human resources, marketing, and solicited research experiments. | Of the $15 million awarded annually, approximately $3 million is set aside for funding research experiments. |
| **Membership Fees** | Direct | Membership fees provide CASIS with additional funds to allocate towards solicited and unsolicited research experiments. | CASIS has three membership categories –individuals, educational institutions, and corporations – with annual fees ranging from $35 to $50,000. |
| **Donors** | Direct | Funds from donors provide CASIS with additional resources to allocate toward research experiments. | CASIS plans to perform outreach activities as a means to solicit funds from foundations, individuals, and other funding organizations. |
| **Private Investors** | Indirect | Match private investors with scientists in need of research funds and encourage self-funded research by companies and other organizations. | CASIS plans to facilitate communication and funding between investors and researchers by leveraging the professional networks of its Board of Directors and Executive Director as a means to connect interested parties as well as through outreach activities that highlight the potential of the ISS. |

Source: OIG analysis of CASIS documentation.

According to an April 2011 NASA report, several factors make attracting private funding and research to the ISS a challenge.[26] First, NASA historically has received little interest from private entities for ISS research unless there was a substantial infusion of government funds. Of the experiments conducted aboard the U.S. segment of the ISS between December 1998 and September 2010, 81 percent were funded by NASA, 10 percent by the Department of Defense, and only 9 percent by commercial entities.[27] Moreover, the commercial entities paid only for the cost of the investigators while NASA covered the cost of payload integration, transportation, and ISS resources. According to NASA, it is unlikely that any of these commercial experiments would have taken place in the absence of the Agency's in-kind contributions and assistance.

A second challenge is that in some cases ground-based research provides similar results at significantly less expense than conducting research on the ISS.[28] The cost of testing, evaluating, and documenting payloads in order to ensure flight and mission safety on the ISS can exceed $250,000. Additional limitations to conducting research aboard the ISS include the frequency of tests and time dedicated to the experiment, the number of samples that can be conducted concurrently and repeatedly, and the availability of timely sample returns. On the other hand, unlike ground-based research options, the ISS offers the ability to conduct research in a sustained microgravity environment. CASIS's challenge is to demonstrate that this advantage is worth the extra cost.

Finally, a vast majority of the research activities conducted aboard the ISS have related to basic research as opposed to applied research.[29] While discoveries made as a result of basic research may eventually contribute to "real world" applications, investors and for-profit companies may be reluctant to allocate funds to basic research, especially when the likelihood of profitable results is unknown. If CASIS is unable to demonstrate the benefits of basic research or how those results can be transitioned to applied research – and therefore increase the potential to generate a return on investment to commercial partners – it will be difficult for the organization to attract significant private funding.

[26] "Commercial Market Assessment for Crew and Cargo Systems Pursuant to Section 403 of the NASA Authorization Act of 2010," (NASA, April 27, 2011).

[27] This data represents a period of time when the major focus of ISS activities was assembly. Therefore, it may not be predictive of private utilization statistics in the future.

[28] For example, researchers conducted experiments on protein crystallization in space for several years because microgravity afforded researchers the optimal environment in which to crystalize proteins. However, methods to conduct such research have improved to the point that some protein crystallizations can be performed in ground-based labs.

[29] Basic research increases the understanding of fundamental science, such as physics and biology. Applied research facilitates the practical application of science in a product, such as more efficient materials and improved performance.

In our discussions with CASIS officials, they acknowledged these challenges and emphasized their organization's important role in educating potential users who may have not considered conducting research in a microgravity environment. The officials explained that many industry leaders were unaware of the capabilities, potential, and past successes derived from conducting research aboard the ISS.

**Despite Organizational Disruptions CASIS Has Met Most Early Performance Metrics.** From its creation, CASIS has had a difficult time filling key senior management positions. For example, CASIS signed the cooperative agreement with NASA and appointed its first Executive Director in August 2011. Seven months later the Executive Director resigned and as of May 2013, CASIS had no permanent Executive Director. Additionally, only seven of the 15-member Board of Directors have been selected.[30] These seven Board members will select a permanent Executive Director and the remaining eight Board members. A permanent Executive Director and a full complement of Directors are critical for establishing CASIS's credibility as it begins fundraising activities in the third quarter of FY 2013. CASIS officials explained that Directors are expected to draw on their experience and call on their network of contacts in business, science, and academia to help attract non-NASA research to the ISS.

Despite the delay in filling key senior management positions, CASIS met its early performance metrics. According to NASA program officials, CASIS satisfied each of these performance metrics in FY 2012:

- *Establish a payload prioritization process and demonstrate its functionality for Expeditions 37 and 38, scheduled to launch in September 2013.* CASIS has developed this process and selected 17 experiments for Expeditions 37 and 38. In addition, CASIS has selected 21 experiments to be performed on expeditions prior to Expeditions 37 and 38.
- *Obtain full funding for three flight research projects from outside capital sources.* CASIS reported obtaining at least three self-funded research projects: a pharmaceutical company funding protein crystallization research, a private institute funding earth observation research, and a sport equipment company funding material science research.
- *Demonstrate functioning of the membership model by enrolling 50 paid members.* In FY 2012, CASIS enrolled 52 paid members and raised a total of $3,200 in membership fees. CASIS's membership model is organized into three categories: individuals, educational and nonprofits, and corporations. Each category has multiple levels of membership that vary in both cost and benefits provided. For example, an individual can choose to register as an "E-Member" at no cost and receive access to CASIS online forums, e-mail updates, and an electronic

[30] The individuals serving on the Board have a wide range of experiences and appear well qualified. One board member received the National Medal of Science for establishing an organization that researches the molecular basis of disease. Other members include current and former university presidents, human nutrition experts, and biomedical engineers.

membership card or as a "Commander" at the cost of $250 for additional benefits, including recognition in CASIS's Annual Report and special promotions and discounts from CASIS partners. Similarly, a corporate member can join at the "General" level for $5,000 and receive recognition in the Annual Report, a quarter-page advertisement in the program for CASIS's annual conference, and specific promotions and discounts from CASIS partners, or join at the "CASIS Founder's Circle" level for $50,000.

- *Develop transparent economic evaluation framework, tools, and processes and establish functionality in test cases.* CASIS created the evaluation framework described earlier in this report and applied it to a number of test cases and to selected projects slated to be launched in September 2013. CASIS designed the economic evaluation framework to attract users to the ISS who have not considered conducting microgravity research in the past. For example, CASIS may use the economic evaluation to demonstrate to a pharmaceutical company the benefits of conducting protein crystallization research in microgravity as a means to improve the functionality of their product thus increasing their profit potential.
- *Establish a focused marketing and outreach campaign.* CASIS has been the subject of a number of print and online media reports, including a portion of a 60-minute program on Clear Channel Radio dedicated to science and space. In addition, CASIS has launched a website and is active on Facebook and Twitter. CASIS has also designed an awareness campaign called "Space Is In It" designed to entice American companies and manufacturers to consider doing product development and testing aboard the ISS.

**FY 2013 Performance Metrics Are Not Clearly Defined.** CASIS's general goals for FY 2013 are to award research grants from funds raised through donations and approve more self-funded investigations for the Station. CASIS's FY 2013 Program Plan states that it will work to better position individuals, educators, and corporations to conduct research on the ISS by leveraging its own growing network of experienced researchers, companies, and other potential users.

While these goals are positive first steps toward developing a market for non-NASA research aboard the ISS, CASIS and NASA have yet to create specific, quantifiable metrics to measure CASIS's ability to meet these goals. NASA officials told us that establishing specific metrics were postponed until the fourth quarter of FY 2013 because CASIS's new Board of Directors wanted additional time to familiarize themselves with the organization before agreeing to such metrics. As a result, less than 3 months before NASA is scheduled to assess CASIS's performance for FY 2013 the metrics for each of the organization's goals is listed as "to be determined." Until NASA and CASIS establish precise metrics that reflect the degree to which CASIS is increasing non-NASA research on the ISS, it will be difficult to determine if CASIS is meeting the objectives of its agreement with NASA.

## Maximizing Use of the ISS for Research is Dependent on Evolving Transportation Capabilities

Dependable cargo and crew transportation is essential to maximizing the research capabilities of the ISS. At present, the Russian Soyuz is the only means of transporting crew to and from the ISS. Cargo providers currently include the Japanese, European, and Russian space agencies, and two private U.S. companies – SpaceX and Orbital. As of May 2013, SpaceX has flown two resupply missions to the ISS and the first Orbital resupply mission is scheduled for November 2013.

**Cargo Transportation.** With the retirement of the Space Shuttle in July 2011, NASA lost its in-house capability to transport cargo to and from the ISS. As shown in Figure 9, four cargo vehicles currently support the ISS – SpaceX's Dragon, the Russian Progress, the European Automated Transfer Vehicle, and the Japanese H-II Transfer Vehicle. A fifth vehicle, Orbital's Cygnus, is expected to begin cargo flights in late 2013. All but the Progress carry NASA payloads to the Station, but only the Dragon can return experiments and other cargo to Earth. The other vehicles burn up during atmospheric reentry and therefore are suitable only for trash disposal. The Dragon's return capability is critical to maximizing the Station's research capabilities as many experiments require samples be brought back to Earth for analysis and examination.

**Figure 9. ISS Cargo Mission Schedule as of May 2013**

| | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|
| Orbital Cargo Missions (Cygnus) | | *D* Sep, 1 Nov | 2 Jan, 3 May, 4 Oct | 5 Feb, 6 Sep | 7 Mar, 8 Sep |
| SpaceX Cargo Missions (Dragon) | *D* May, 1 Oct | 2 Mar, 3 Nov | 4 Apr, 5 Aug, 6 Nov | 7 Feb, 8 Apr, 9 Aug | 10 Jan, 11 Apr, 12 Aug |
| European Cargo Missions (ATV) | 3 Mar | 4 June | 5 Apr | | |
| Japanese Cargo Missions (HTV) | 3 Jul | 4 Aug | 5 Jul | 6 Jul | 7 Jul |
| Russian Cargo Missions (Progress)* | 46 Jan, 47 Apr, 48 Aug, 49 Oct | 50 Feb, 51 Apr, 52 Jul, 53 Oct | 54 Feb, 55 Apr, 56 Jul, 57 Oct | 58 Feb, 59 Apr, 60 Jul, 61 Oct | 62 Feb, 63 Apr, 64 Jul, 65 Oct |

*At this time, the United States does not procure cargo resupply services from the Russians.

ATV – Automated Transfer Vehicle
HTV – H-II Transfer Vehicle

Numbers represent launch number.
D is for demonstration launch.

Source: OIG analysis of NASA data.

Dragon can transport approximately 3,310 kilograms (kg) of cargo to the ISS and return approximately 2,500 kg of cargo to Earth. Cygnus can transport approximately 2,000 kg of cargo to the ISS. The Russian Progress visits the ISS roughly four times a year and carries up to 3,200 kg of supplies and experiments. The European Automated Transfer Vehicle launches approximately once per year with 7,667 kg, while the Japanese H-II Transfer Vehicle supplies the ISS once per year with 6,000 kg of materials. This information is presented in Table 5.

**Table 5. ISS Cargo Resupply Vehicles**

| | Company or Agency | Vehicle | Missions per year | Upmass[a] | Downmass |
|---|---|---|---|---|---|
|  | SpaceX | Dragon | 3 | 3,310 kg | 2,500 kg |
|  | Orbital | Cygnus | 2[b] | 2,000 to 2,700 kg[c] | |
|  | Roscosmos | Progress | 4 | 3,200 kg | |
|  | European Space Agency | Automated Transfer Vehicle | 1 | 7,667 kg | |
|  | Japan Aerospace Exploration Agency | H-II Transfer Vehicle | 1 | 6,000 kg | |

[a] Upmass is sometimes limited by volume within the vehicle.
[b] Missions to begin late in calendar year 2013.
[c] Improved capability planned for 2014.

Source: OIG analysis of NASA data.

**Crew Transportation.** The Russian Soyuz carried the first ISS crew in November 2000. From 2000 to 2006, NASA acquired seats for its astronauts on the Soyuz by bartering – for example, trading a seat or cargo space on a Space Shuttle mission for a seat on a Soyuz. The Space Shuttle also transported crew members to and from the ISS until 2009. After NASA retired the Space Shuttles in 2011, the Soyuz became the only vehicle capable of transporting crew to the ISS. Between 2006 and 2008, NASA purchased one seat per year. Beginning in 2009, NASA started purchasing six seats per year. The price per seat has increased over the years from $22 million in 2006, to $25 million in 2010, to $28 million in the first half of 2011. During the second half of 2011, the price per seat jumped to $43 million.[31] The price has continued to increase. For example, the price of purchased seats for launches in 2014 and 2015 are $55.6 million and $60 million, respectively. In April 2013, NASA signed another deal with Russia valued at $424 million for six additional seats to carry NASA astronauts to the Station during 2016 through June 2017, and the price per seat has increased to $71 million.

NASA began the Commercial Crew Program in 2010 in part to end its reliance on the Soyuz for crew transportation to the ISS. The goal of the Commercial Crew Program is to facilitate the design and development of safe, reliable, and cost effective crew transportation to the ISS and low Earth orbit. In August 2012, NASA awarded the third round of development agreements for approximately $1.1 billion to three commercial partners.[32] Following the design and development stages, NASA hopes to select at least two companies to conduct certification tasks to ensure the vehicles meet NASA safety standards. Once a company is certified, NASA will award at least one company a service contract to transport astronauts to and from the ISS.

NASA expects at least one commercial partner to achieve certification and provide crew transportation services to the ISS in 2017. However, NASA has not received the full amount of funds it requested for the Program since 2011, and the Program continues to face an uncertain funding stream. For example, NASA requested $850 million for FY 2012 and $830 million for FY 2013 for its Commercial Crew Program, but received only $406 million and $489 million, respectively. If this trend continues in the future, NASA likely will not meet its goal of having at least one vehicle transporting crew to the ISS in 2017. In that case, NASA would have to purchase additional seats on Soyuz vehicles. Soyuz manufacturing and assembly requirements require NASA to procure Soyuz seats at least three years in advance to avoid a gap in ISS crew transportation.

**Crew Transportation and Research Time.** The lack of crew transportation vehicles other than the Soyuz limits the amount of research that can be conducted on the ISS. Although the Station is capable of supporting a seven-member crew, each Soyuz has a three-person capacity and only two Soyuz vehicles can be docked at the ISS at one time. This means that only six crew members can safely be aboard the ISS at a time to allow for evacuation in case of an emergency.

[31] The largest increase occurred for launches planned for the latter portion of 2011, when retirement of the Space Shuttle and the lack of a U.S. domestic transportation capability increased NASA's previous demand for Soyuz seats. According to the Space Station External Integration Office, meeting this increased demand required upgrades to and modernization of Russia's manufacturing infrastructure, which resulted in a 57 percent increase in the cost per seat – from $28 million for launches in the first half of 2011 to $43 million for launches in the latter half of 2011.

[32] SpaceX received $440 million for its Dragon capsule; the Boeing Corporation received $460 million for its CST-100 capsule; and Sierra Nevada Corporation received $212.5 million for its Dream Chaser capsule.

The commercial vehicles currently under development will be capable of transporting a minimum of four astronauts. Accordingly, once one of these vehicles is operational the ISS can be staffed with its full complement of seven. According to the ISS Program Office, a seventh astronaut could increase crew time devoted to research by more than 33 hours per week – a 94 percent increase over current rates.

## Conclusion

Given its $60 billion construction price tag and almost $3 billion in annual operating costs, it is essential that NASA make a concerted effort to maximize the research capabilities of the ISS. The success of this effort largely hinges on two factors: the ability of CASIS to attract sufficient interest and funding from private users and investors, and the availability of reliable transportation to and from the Station for crew and cargo.

CASIS's task is particularly challenging given the historic lack of interest from private entities in conducting research aboard the ISS in the absence of government funding. While CASIS's general goals for FY 2013 to award research grants from funds raised through donations and approve more self-funded investigations are positive first steps toward enhancing a market for non-NASA research aboard the ISS, neither CASIS nor NASA have developed specific, quantifiable metrics to measure CASIS's ability to meet these goals. Without more precise metrics that reflect the degree to which non-NASA research is conducted on the ISS, it will be difficult to determine if CASIS is achieving its goal of improving the return on investment in the ISS by increasing use of the National Lab.

In addition to the challenges facing CASIS, the effort to maximize research capabilities aboard the ISS depends significantly on the success of NASA's Commercial Cargo and Crew Programs. The ability to return experiments to Earth and to fully staff the ISS with seven crew members both depend on the success of these efforts.

## Recommendation, Management's Response, and Evaluation of Management's Response

We recommended that the NASA Associate Administrator for the Human Exploration and Operations Mission Directorate work with CASIS to develop precise annual performance metrics that measure CASIS's success at fostering private research on the ISS.

**Management's Response.** The Associate Administrator concurred with our recommendation, stating that CASIS plans to provide suggested metrics to NASA in the fourth quarter of FY 2013 and that NASA will evaluate the proposed metrics and work with CASIS to incorporate more precise metrics into CASIS's execution plans.

**Evaluation of Management's Response.** Management's proposed actions are responsive; therefore, the recommendation is resolved. We will close the recommendation upon verification that NASA is using performance metrics that measure CASIS's success at fostering private research on the ISS.

In his response, the Associate Administrator also noted that CASIS is just one avenue to maximize ISS utilization, citing other ways in which NASA has expanded NASA-related research on the Station. Although we acknowledge these efforts, our report focused on increasing utilization of the National Lab by entities other than NASA, and CASIS is the primary mechanism through which NASA will pursue this goal. Accordingly, we continue to believe that CASIS's success is critical to maximizing the research capabilities of the ISS.

## Scope and Methodology

We performed this audit from November 2011 through May 2013 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, 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.

During the audit's survey phase, we focused on NASA's implementation of requirements stipulated by the NASA Authorization Acts of 2005, 2008, and 2010 that would enhance ISS utilization.

We assessed the steps NASA had taken to ensure it was maximizing the productivity and innovative use of the ISS National Lab with respect to scientific and technological research and development, advancement of space exploration, and international collaboration. We also analyzed data (crew research time, upmass, and downmass) reported in a recent Composite Operations and Utilization Plan approved by the Systems Operations Panel and User Operations Panel on February 24, 2012. We reviewed NASA's cooperative agreement with CASIS and CASIS's first Annual Program Plan; reviewed NASA's semiannual and monthly utilization reports; and held separate interviews with the NASA Cooperative Agreement Technical Officer, the first CASIS Executive Director before she resigned, the NASA Manager of the ISS National Lab, the NASA Manager of the ISS Payloads, and the ISS Program Scientist.

To determine whether management and utilization of the ISS National Lab provided opportunities for collaboration with other research programs and cooperation with commercial suppliers, users, and developers, we identified and reviewed Space Act Agreements and Memorandum of Understandings that NASA had entered into with nonexploration users of the National Lab and discussed with CASIS officials how they planned to carry out the requirements of the cooperative agreement.

To determine whether NASA had ensured CASIS will consider the recommendations of the National Academies Decadal Survey on Biological and Physical Sciences in Space in establishing ISS National Lab research priorities, we reviewed the National Academies Decadal Survey, the NASA Authorization Act of 2010, and the cooperative agreement, and interviewed the NASA Manager of the ISS National Lab, the ISS Program Scientist, NASA Manager of ISS Payloads, and the CASIS Executive Director and Director of Administration. For the audit phase, we identified and reviewed challenges to full utilization of the ISS National Lab and NASA's and CASIS's efforts to effectively manage these challenges.

We interviewed officials with five private companies, universities, and Federal agencies that had ongoing or past scientific experiments conducted on the ISS. We asked the organizations what facilitated the success of their research and what were the impediments to success; if they were impacted by the availability of resources like upmass, downmass, and crew time; and whether they felt CASIS going forward would be successful in retaining them and motivating other organizations to use the ISS. Also, we interviewed the former NASA Director of Space Station Freedom and the President of Space and Technology Policy Group, LLC, to obtain their views on the prospect for full utilization of the ISS.

We met with key staff members in NASA Headquarters Human Exploration and Operations Mission Directorate, the Science Mission Directorate, the Office of the Chief Technologist, and the Office of the Chief Scientist to discuss and increase our knowledge of the NASA research and the process and metrics used to maximize the NASA research conducted on the ISS.

We attended the first annual ISS Research and Development Conference co-sponsored by the American Astronomical Society, NASA, and CASIS to experience first-hand the dissemination of information and outreach to nonexploration customers interested in conducting scientific research on the ISS National Lab.

We met with the CASIS executive team and discussed CASIS's significant activities and processes (completed, ongoing, and planned) that promote maximum utilization of the ISS National Lab by nonexploration users. In addition, we asked CASIS to describe their challenges and mitigation plans.

**Use of Computer-Processed Data.** We did not use computer-processed data to perform this audit, but did use data provided by the Johnson Space Center Research Integration Office (formerly the ISS Payloads Office) for historical information on ISS assembly and utilization. We did not verify that data to source documents, but considered it reliable for the purposes of the review.

## Review of Internal Controls

We performed a preliminary assessment of the internal controls associated with our audit, including identifying controls that are in place to monitor and increase ISS utilization. Throughout the audit we reviewed controls associated with the audit objectives and identified that NASA monitors and reports ISS utilization data in its monthly Manager's Level Performance Indicators for utilization of ISS research facilities and achieving requirements and commitments for research crew time and research resupply upmass.

Further, NASA monitors and reports ISS utilization data in its quarterly Key Program Performance Indicators for meeting planned expectations of ISS utilization operations. Based on the results of our review, we considered the internal controls over the utilization of the ISS for research to be adequate.

## Prior Coverage

During the last 5 years, the NASA OIG and the Government Accountability Office have issued six reports of particular relevance to the subject of this report. Unrestricted reports can be accessed over the Internet at http://oig.nasa.gov/audits/reports/FY13 and http://www.gao.gov.

NASA Office of Inspector General

"Commercial Cargo: NASA's Management of Commercial Orbital Transportation Services and ISS Commercial Resupply Contracts" (IG-13-016, June 13, 2013)

"NASA's Challenges Certifying and Acquiring Commercial Crew Transportation Services" (IG-11-022, June 30, 2011)

Government Accountability Office

"NASA: Significant Challenges Remain for Access, Use, and Sustainment of the International Space Station" (GAO-12-587T, March 28, 2012)

"National Aeronautics and Space Administration: Acquisition Approach for Commercial Crew Transportation Includes Good Practices, but Faces Significant Challenges" (GAO-12-282, December 15, 2011)

"International Space Station: Significant Challenges May Limit Onboard Research" (GAO 10-9, November 2009)

"NASA: Commercial Partners Are Making Progress, but Face Aggressive Schedules to Demonstrate Critical Space Station Cargo Transport Capabilities" (GAO-09-618, June 16, 2009)

# MANAGEMENT COMMENTS

National Aeronautics and
Space Administration
**Headquarters**
Washington, DC 20546-0001

JUL 2 2013

Reply to Attn of: Human Exploration and Operations Mission Directorate

TO: Assistant Inspector General for Audits

FROM: Associate Administrator for Human Exploration and Operations

SUBJECT: Response to OIG Audit Report, "NASA's Efforts to Maximize Research on the International Space Station" (Assignment No. A-12-008-00)

The Human Exploration and Operations Mission Directorate (HEOMD) appreciates the opportunity to review your audit report entitled "NASA's Efforts to Maximize Research on the International Space Station" (Assignment No. A-12-008-00).

The report has numerous positive aspects that deserve mention. The description of the Center for Advancement of Science in Space's (CASIS) evaluation processes is thorough. NASA's methods for quantifying International Space Station (ISS) utilization are unavoidably complex, and the report conveys the significance of the metrics NASA uses. The review of ISS transportation capabilities accurately summarizes the status of U.S. and international capabilities and the connections between transportation capabilities and utilization needs.

However, the report states on page 16 that "the primary way NASA expects to increase utilization of ISS research capabilities is by working with CASIS." CASIS is just one avenue to maximize ISS utilization. In addition to CASIS, NASA is maximizing utilization by increasing subscribers from its own broad portfolio of research and technology development on board the ISS. Among the many areas of research, NASA's research into human health and performance is critical to achieving the Agency's goals of sending humans on long duration spaceflight beyond low-Earth orbit. Also, NASA has an ongoing program in space biology and physical sciences, which provides many of the research projects currently underway or in the pipeline for ISS utilization. NASA has expanded ISS utilization, by the Science Mission Directorate, in the areas of Earth and space science. ISS is also cooperating with the Space Technology Mission Directorate and Advanced Exploration Systems to perform technology and systems demonstrations to advance spacecraft and human exploration systems such as thermal technology and environment control systems for long-duration deep space missions. The ISS enables researchers from all over the world to put their talents to work on innovative experiments that could not be done anywhere else. Researchers, educators, and students from 68 different countries have participated in ISS utilization activities. In addition, NASA works cooperatively with the other four ISS international partners on scientific research and overall integrated utilization. Although each ISS partner has distinct agency goals for ISS research, each partner shares a unified goal to maximize utilization of the ISS. We are working toward integrating the research on ISS to enhance and optimize the effectiveness of flight crew utilization. When commercial crew capabilities are available, the ISS crew complement will be increased to seven crewmembers, thereby, increasing available crew time for utilization.

NASA also maximizes utilization by increasing the throughput of science data generation with major on-board system upgrades and major upgrades in the commercial cargo program. NASA has instituted modifications that will significantly enhance the powered middeck and cold stowage capability in the Dragon capsule and have upgraded the Dragon life support capability to be able to transport animal subjects and broaden the science spectrum being accomplished. Increased research capabilities are also being considered for the Cygnus vehicle, such as powered middeck locker accommodations.

The ISS program also has improved program processes and reorganized from a single research office to a structure where research and utilization are embedded in each and every office that manages, plans, and executes the program to shorten the life cycle of scientific data generation. These changes, combined with a philosophy where upmass and downmass are manifested with a "payload first" philosophy, are the core of the ISS program. NASA even modified planned operational timelines for the SpaceX 2 mission to allow for the operation of the Coarsening in Solid Liquid Mixtures payload. From the beginnings of the ISS program 30 years ago, NASA has had an evolving and multiple-pronged plan to achieve mission success, and this philosophy lives vibrantly today in the ISS program.

As tables two and three of the OIG report show, internal and external occupancy rates are expected to be 75 and 40 percent by September 2013, respectively. NASA acknowledges that this represents available occupancy capacity, but not necessarily utilization availability given other constraining resources (crew time, power, etc.) NASA is pursuing all avenues (NASA and CASIS) to ensure full usable occupancy is fully engaged. The report's sole focus on CASIS, as written, is short-sighted.

The OIG report includes the following recommendation, which is addressed to the Associate Administrator for HEOMD:

**Recommendation 1:** We recommend that the NASA Associate Administrator for HEOMD work with CASIS to develop precise annual performance metrics that measure CASIS's success at fostering private research on the ISS.

**Management's Response:** NASA concurs with the recommendation. NASA and CASIS have always had a plan to collect data in a number of areas that will support whatever set of metrics the two parties select. Although the exact metrics have not been defined, data is available now and this data will be used to define CASIS success. The baseline plan is for CASIS to provide their suggested metrics to NASA in the fourth quarter of FY13, and we are on schedule to meet that goal. NASA will evaluate the proposed metrics and work with CASIS to incorporate the agreed-upon metrics into the CASIS execution plans.

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Again, thank you for the opportunity to review and comment on the subject report. If you have any questions or require additional information regarding this response, please contact Michelle Bascoe at (202) 358-1574.

William H. Gerstenmaier

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JULY 8, 2013

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