Aeronautics and Space Report of the President

Fiscal Year 2011 Activities

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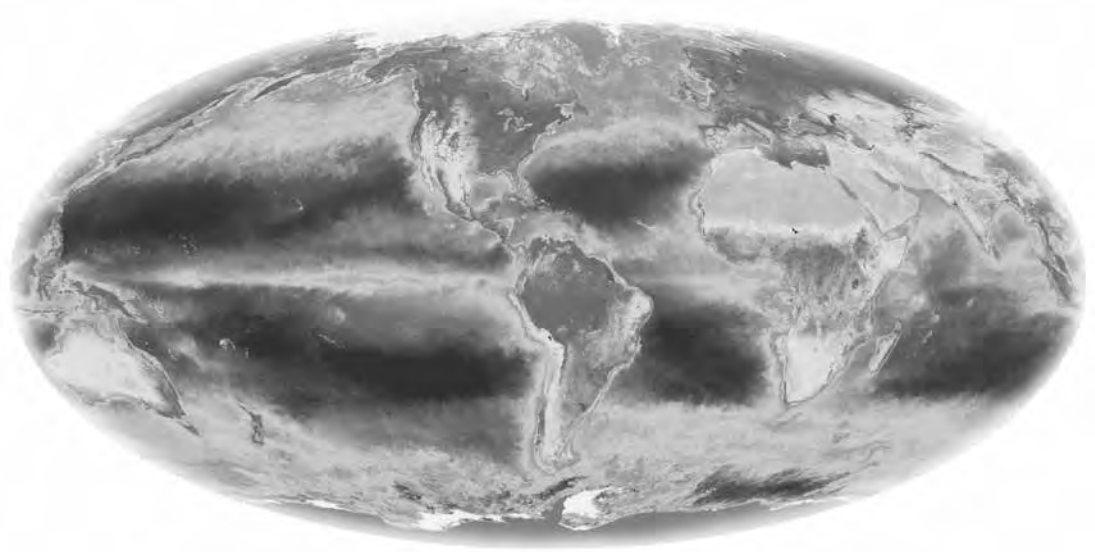


Fiscal Year 2011 Activities

The National Aeronautics and Space Act of 1958 directed the annual Aeronautics and Space Report to include a "comprehensive description of the programmed activities and the accomplishments of all agencies of the United States in the field of aeronautics and space activities during the preceding calendar year." In recent years, the reports have been prepared on a fiscal-year basis, consistent with the budgetary period now used in programs of the Federal Government. This year's report covers activities that took place from October 1, 2010, through September 30, 2011.

Table of Contents

National Aeronautics and Space Administration

NASA

Human Exploration and Operations Mission Directorate

The Human Exploration and Operations (HEO) Mission Directorate was newly formed in August 2011. It merged the Exploration Systems and Space Operations Mission Directorates, creating an organization dedicated to enabling human and robotic space exploration. HEO operates the International Space Station (ISS) and is developing technologies and capabilities for human exploration beyond low-Earth orbit (LEO). It manages the commercial crew and cargo developmental programs, the construction of the Orion Multi-Purpose Crew Vehicle (MPCV), the development of a new heavy-lift rocket known as the Space Launch System (SLS), launch operations, space communications, rocket propulsion testing, human health and safety, and exploration technology development, the last of which enables human exploration of deep space.

Space Operations

Space Shuttle/International Space Station

The Space Shuttle flew its final three missions and the last flights of each of the three orbiters in fiscal year (FY) 11, capping 32 years of operations and 135 missions by completing the assembly and outfitting of the International Space Station. Altogether, these three flights carried nearly 120,000 pounds of hardware, equipment, and supplies to the ISS.

The ISS began FY 11 with Expedition 25 crewmembers Douglas Wheelock (U.S.), Shannon Walker (U.S.), and Fyodor Yurchikhin (Russia) living on board. They were joined on October 10, 2010, by Scott Kelly (U.S.), Alexander Kaleri (Russia), and Oleg Skripochka (Russia), who launched on a Russian Soyuz rocket from Baikonur Cosmodrome, Kazakhstan. A Russian Progress cargo vehicle carrying several tons of supplies docked with the ISS on October 30, 2010. On November 2, 2010, the ISS program celebrated 10 continuous years of human occupation in low-Earth orbit. On November 15, 2010, Russian crewmembers Fyodor Yurchikhin and Oleg Skripochka conducted a spacewalk in Russian Orlan spacesuits, doing maintenance activities and replacing science experiments over the course of more than 6 hours on the outside of the Russian segment. On November 25, 2010, Wheelock, Walker, and Yurchikhin undocked their Soyuz return vehicle from the ISS and returned to Earth, landing on the steppes of Kazakhstan and ending Expedition 25.

Expedition 26 began on November 25, 2010. Astronaut Kelly (now ISS commander) and cosmonauts Kaleri and Skripochka remained on board and were joined by the rest of Expedition 26 on December 17, 2010, when a Russian Soyuz vehicle carrying Catherine Coleman (U.S.), Paolo Nespoli (European Space Agency [ESA]), and Dmitri Kondratyev (Russia) docked with the ISS. Skripochka and Kondratyev conducted two Russian Orlan spacewalks, on January 21, 2011, and February 16, 2011, which focused on maintenance on the Russian segment, as well as removing and replacing several external science experiments. The Japanese H-II Transfer Vehicle-2 (HTV-2) Kounotori berthed to the ISS Node 2 nadir port on January 27, 2011, carrying more than 5,300 kilograms of both pressurized and unpressurized supplies to the ISS. Due to the arrival of Space Shuttle Discovery, the HTV-2 had to be moved to the Node 2 zenith port during Shuttle docked operations and then moved back to the nadir port after the Shuttle's departure. The HTV-2 remained at the ISS until March 28, 2011. A Russian Progress vehicle docked with the ISS on January 30, 2011, carrying some 2,600 kilograms of cargo. On February 24, 2011, the ESA-provided Automated Transfer Vehicle-2 (ATV-2), named Johannes Kepler, docked with the ISS, carrying more than 7,000 kilograms of supplies and equipment. The ATV-2 remained at the ISS until June 20, 2011, when it undocked and then burned up in the atmosphere. February 2011

marked the first time that each ISS partner with a flight vehicle had one at the ISS at the same time: Space Shuttle, ATV, HTV, Progress, and Soyuz.

The first Space Shuttle flight of the fiscal year, which was the final mission of Space Shuttle Discovery, launched on February 24, 2011, following about four months of delays due to weather scrubs and technical reviews of a cracked stringer on the external tank. STS-133 commander Steve Lindsey; pilot Eric Boe; and mission specialists Alvin Drew, Steve Bowen (whose flights on STS-132 and STS-133 made him the first American astronaut to fly back-to-back missions), Michael Barratt, and Nicole Stott delivered the last U.S. pressurized module (the Permanent Multipurpose Module, or PMM) and an external stowage platform (the EXpedite the PRocessing of Experiments to the Space Station [EXPRESS] Logistics Carrier 4, or ELC 4) to the ISS, as well as equipment and supplies. During Discovery's almost nine days at the Station, Bowen and Drew performed two spacewalks for maintenance work and installation of new components. Discovery's visit to the Station was extended by two days so that its crew could help outfit the PMM, which previously had served as the reusable Multi-Purpose Logistics Module (MPLM) Leonardo. Leonardo had visited the Station seven times previously as a cargo carrier before being refurbished to serve as a permanent 2,472-cubic-foot addition to the orbiting laboratory. Among the 6,000 pounds of Leonardo cargo was Robonaut 2, a human-upper-torso-like robot that could be a precursor of devices to help during spacewalks. About 2,000 pounds of additional cargo for the Station was carried on the Shuttle's mid-deck. Space Shuttle Discovery returned to Earth on March 9, 2011, after which Discovery began nearly a year of safing activities in preparation for permanent display at the National Air and Space Museum's Steven F. Udvar-Hazy Center in Chantilly, Virginia.

Expedition 26 ended on March 16, 2011, when Kelly, Kaleri, and Skripochka left the ISS on their Soyuz vehicle and returned to Earth. Kondratyev, Coleman, and Nespoli remained on board to begin Expedition 27, which was joined by Ron Garan (U.S.), Andrei Borisenko (Russia), and Aleksandr Samokutyayev (Russia) when their Soyuz docked with the ISS on April 6, 2011. On April 12, 2011, the crew celebrated the 50th anniversary of the launch of Yuri Gagarin (the first man in space) as well as the 30th anniversary of the first launch of the Space Shuttle.

A Progress cargo ship carrying approximately 2,600 kilograms of cargo docked with the ISS on April 29, 2011, where it remained until October 29, 2011.

Space Shuttle Endeavour began its final mission, STS-134, with a morning launch on May 16, 2011. The six-person crew included commander Mark Kelly; pilot Gregory H. Johnson; and mission specialists Michael Fincke, Greg Chamitoff, Andrew Feustel, and European Space Agency astronaut Roberto Vittori. One of Endeavour's primary mission objectives was the delivery and installation of the $2 billion Alpha Magnetic Spectrometer 2 (AMS-02) to the ISS. AMS-02 is a particle physics detector designed to search for dark matter and for antimatter, which was first proposed by British physicist Paul Dirac in the 1920s. Endeavour also delivered spare parts for ensuring continued safe operations of the ISS after the Shuttle fleet was retired, including two S-band communication antennas, a high-pressure gas tank, and additional spares for the Station's Special Purpose Dexterous Manipulator (SPDM), or Dextre. Endeavour also transferred its Orbiter Boom Sensor System (OBSS) to the ISS. Following the loss of Space Shuttle Columbia, two OBSS systems were developed from systems similar to those used to build the orbiter's robotic arm; the new systems allowed the orbiters to inspect their thermal protection systems to ensure that they could return home safely. As part of the crew's work on the ISS, Shuttle astronauts Feustel, Chamitoff, and Fincke conducted the last four extravehicular activities (EVAs) by a Shuttle crew. Mike Fincke also surpassed Peggy Whitson's record for time spent by an American in space, logging a total of 382 days in orbit. Endeavour touched down nominally at the Kennedy Space Center on June 1, 2011. Afterward, like Discovery, Endeavour began a yearlong safing process. Endeavour would eventually be delivered for permanent display at the California Science Center in Los Angeles.

During Endeavour's docked period, ISS crewmembers Coleman, Kondratyev, and Nespoli undocked their Soyuz vehicle for return to Earth, ending Expedition 27. This marked the first time that a Soyuz had undocked from the ISS while a Shuttle was present. The Soyuz crew conducted a flyaround, capturing the first up-close and detailed pictures of a Space Shuttle orbiter docked with the Station.

Expedition 28 began with crewmembers Garan, Borisenko, and Samokutyayev watching the departure of Endeavour from the ISS. On June 9, 2011, they were joined on the ISS by Mike Fossum (U.S.), Satoshi Furukawa (Japan), and Sergey

Volkov (Russia), arriving on a Soyuz vehicle. A Russian Progress vehicle arrived on June 21, 2011, carrying food, water, supplies, and scientific research.

The final chapter in the 30-year history of Space Shuttle began on a hot Florida morning on July 8, 2011. Space Shuttle Atlantis was prepped and ready for launch, but a 70 percent chance of inclement weather made it likely that the launch would be postponed. Nevertheless, the countdown proceeded smoothly until a last-minute glitch held the clock at T-31 seconds. The issue—whether the gaseous oxygen vent arm had fully retracted—was quickly resolved by the experienced team inside the Launch Control Center at NASA's Kennedy Space Center in Florida, and the clock began counting down the final seconds. Atlantis roared off historic launch pad LC-39A at 11:29 a.m. eastern daylight time. The crew of four veteran astronauts aboard Atlantis—commander Chris Ferguson, pilot Doug Hurley, and mission specialists Sandy Magnus and Rex Walheim—set off on the STS-135 mission to deliver a stockpile of supplies and parts to the ISS. The MPLM Raffaello was berthed to the nadir port on the ISS Harmony node, and the Space Shuttle and ISS crews spent the next eight days transferring over 11,600 pounds of supplies and equipment. Two days after Atlantis arrived at the Station, the only spacewalk during the mission was performed—not by Shuttle astronauts, but by two ISS residents who, three years earlier, had collaborated on three spacewalks when they were STS-124 Shuttle crewmates. Now, as Expedition 28 flight engineers, Fossum and Garan were paired again as they spent 6 hours and 31 minutes working outside the Station. Among the spacewalkers' tasks was retrieving the Station's failed 1,400-pound cooling system pump module, which was replaced after it stopped working in 2010. The astronauts removed the pump from its temporary storage location and packed it in the Shuttle's cargo bay. Returning the pump to Earth allowed engineers to look into what caused its failure and then refurbish it for use as a spare in the future. The pair installed the Robotic Refueling Mission experiment, which would test whether remote-controlled robots could perform satellite refueling tasks in orbit using commands sent from controllers on Earth. The capability is expected to reduce costs and risks and lay the foundation for future robotic servicing missions. One week into Atlantis's mission, President Barack Obama radioed the combined Shuttle and ISS crews to help mark the final Shuttle flight. The President told them, "We're all watching as the 10 of you work together as a team." He added, "Your example means so much not

just to your fellow Americans, but also your fellow citizens on Earth. The space program has always embodied our sense of adventure and explorations and courage." Ferguson presented the ISS crew with a U.S. flag flown on the first Space Shuttle mission, STS-1. The flag will remain displayed on board the ISS until the next crew launched from the United States retrieves it for return to Earth so that it can be carried by the first crew launched from the United States on a journey of exploration beyond Earth orbit. Weather on landing day proved more predictable than it was for launch, and Mission Control in Houston gave the STS-135 astronauts the "go" for a deorbit burn that would bring them home on their 200th orbit of Earth. At 5:57 a.m. on July 21, Space Shuttle Atlantis dropped out of the predawn darkness and landed at Kennedy's Shuttle Landing Facility Runway 15. Caught in the last seconds by the brilliant xenon lights, a Space Shuttle rolled to a stop for the final time. But Atlantis's work was not complete. Like her sister ships, Atlantis began the process of being safed of hazardous materials and prepared for permanent display only a few miles from where all American crewed space missions were launched, in a new exhibit at the Kennedy Space Center Visitor Complex.

On August 3, 2011, Expedition 28 crewmembers Volkov and Samokutyayev conducted a Russian Orlan spacewalk outside the Russian segment. The pair performed a variety of maintenance and documentary activities and began relocating a Strela cargo boom from one docking compartment to another. On September 16, 2011, Garan, Borisenko, and Samokutyayev returned to Earth in their Soyuz descent vehicle, marking the end of Expedition 28 and the beginning of Expedition 29.

Launch Services

The first launch for the Launch Services Program (LSP) in FY 11 was the Glory climate observatory mission launching on an Orbital Sciences Corporation Taurus XL launch vehicle on March 4, 2011. Unfortunately, the mission did not achieve orbit due to the Taurus XL's payload fairing's failure to separate from the launch vehicle. LSP then went on to conduct four successful launches of four NASA missions during FY 11. LSP launched NASA's Aquarius instrument into low-Earth orbit aboard the Space Agency of Argentina's (Comisión Nacional de Actividades Espaciales, or CONAE) Satelite de Aplicaciones Cientificas-D (SAC-D) spacecraft on June 10 and launched Juno toward its path to Jupiter on August 5. The Gravity

Recovery and Interior Laboratory (GRAIL) mission, designed to increase knowledge of Earth's moon, launched on September 10. LSP also continued to provide launch-related systems engineering, launch integration, and mission design and analysis support to approximately 35 NASA-sponsored missions in various phases of development. To find out more about these and other NASA science missions, see the Science Mission Directorate section in this report.

Working to expand the selection of launch vehicles, LSP is working across the launch vehicle industry to support the emergence of a U.S. commercial space sector by providing competitive opportunities to U.S. commercial launch providers. In FY 11, LSP executed a procurement that allows new providers to be added and existing providers to "on-ramp" (put on contract) additional launch vehicles within an existing contract. In September 2011, LSP modified its NASA Launch Services (NLS) II contract with United Launch Services (ULS) of Littleton, Colorado, to add the Delta II rocket launch service in accordance with the contract's on-ramp provision. This modification will enable ULS to offer as many as five Delta II rockets for future NASA missions. Two other on-ramp proposals for additional launch vehicles were still under evaluation at the end of FY 11.

In FY 2011, Launch Services was also active on the launch-policy front. Efforts resulted in the development and signing of two major agreements with our Government Expendable Launch Vehicle (ELV) partners (i.e., the U.S. Air Force and the National Reconnaissance Office) that included a Memorandum of Understanding (MOU) on Evolved ELV (EELV) acquisition coordination, as well as an MOU on cooperative investments in launch range infrastructure.

Lastly, LSP actively supported the Taurus XL T9 Mishap Investigation Board (MIB) that is reviewing the cause for the March 4, 2011, launch failure of the Orbital Sciences Corporation Taurus XL launch vehicle. At the end of FY 11, the MIB was still ongoing. A Corrective Action Plan (CAP) will be developed and executed upon completion of the investigation.

In 2010, the Rocket Propulsion Test (RPT) Program continued to facilitate the Agency's ability to safely test rocket propulsion systems for NASA and the Nation by focusing its energies and limited resources on key needs. To ensure that the appropriate rocket test capabilities were understood, the RPT Program maintained close coordination with the Space Shuttle Program, the Exploration Systems

Mission Directorate, and the Department of Defense. Additionally, Stennis Space Center's Test Operations Contract (TOC) completed its final contract period in August 2010. To accommodate the competitive process and cover the transition from the old to a new TOC contract, a six-month extension was granted through the end of February 2011.

Space Communications and Navigation

In FY 11, NASA's Space Communications and Navigation (SCaN) Program Office focused on the critical sustainability and development of the ground and space components of the networks that provide space communications for NASA's missions. The three networks—the Near Earth Network (NEN), the Space Network's (SN) Tracking and Data Relay Satellite System (TDRSS), and the Deep Space Network (DSN)—continued to meet the space communications needs, such as Earth monitoring and support of deep space exploration missions, of a wide range of customers, both internal and external to NASA.

In FY 11, SCaN maintained at least 99 percent proficiency of all of its networks, providing communication and navigation services to 29 spacecraft using the DSN, 35 spacecraft using the SN, and 33 spacecraft using the NEN. The Near Earth Network also provided communication and navigation services to 33 launches during launch and early orbit phases.

The Deep Space Network is an international network of antennas that supports interplanetary spacecraft missions and radio and radar astronomy observations for the exploration of the solar system and the universe. The network also supports selected Earth-orbiting missions. The Space Network consists of a space segment, composed of TDRSS, and a ground segment, which includes the White Sands Complex and the Guam Remote Ground Terminal. Data from the satellites are downlinked to the ground segment. Using antenna assets located around the world, the Near Earth Network provides tracking, telemetry, and communications services for orbital missions and, occasionally, suborbital missions.

SCaN continued the sustaining and engineering of its aging networks, including the completion of upgrades to the NEN assets at McMurdo Ground Station in Antarctica. The Deep Space Network Aperture Enhancement project broke ground for adding 34-meter (110.5-foot) antennas at the Canberra Deep Space

Communications Complex in Canberra, Australia. The program also made significant progress in technology development. The Communication, Navigation and Networking re-Configurable Testbed (CoNNeCT) made significant progress and was readied for System Acceptance Review in early FY 12.

SCaN completed some key milestones for its development projects during FY 11:

- The Space Network Ground Segment Sustainment project completed its System Requirements Review (SRR). The goal of the project is to implement a flexible and extensible ground segment that will allow the Space Network to maintain the high level of service in the future and accommodate new users and capabilities while reducing the effort required to operate and maintain the system. The SRR examines the functional and performance requirements defined for the system and the preliminary project plan and ensures that the requirements and the selected concept will satisfy the needs of the Space Network.
- The Tracking and Data Relay Satellite (TDRS) project completed its System Integration Review (SIR) for the TDRS K satellite, which will become part of the space segment of the Space Network. The SIR evaluates the readiness of the project to start flight system assembly, testing, and launch operations.

Exploration Systems

FY 11 saw the continued transition for NASA's Exploration Systems Mission Directorate (ESMD) as NASA continued the development of the next generation of space vehicles to support human exploration beyond low-Earth orbit. The President's FY 11 budget continued recently initiated activities to develop the capabilities to send humans to a near-Earth asteroid and other development activities.

Advanced Capabilities Division

The Advanced Capabilities Division (ACD) is responsible for pursuing innovative knowledge and technology to reduce operational risks and costs associated with NASA's current and future exploration systems. ACD manages three programs: the Human Research Program, the Exploration Technology Development Program, and the Lunar Precursor Robotics Program. These programs focus on

high-priority activities, such as conducting basic research in life and physical sciences, meeting technology requirements for long-duration spaceflight, and developing robotic missions as precursors for future human missions.

Human Research Program

The Human Research Program (HRP) supported NASA's exploration goals by investigating and mitigating risks to astronaut health and performance during exploration missions. Risks include physiological effects from radiation, reduced gravity and microgravity, and terrestrial environments, as well as unique challenges in medical support, human factors, and behavioral health support. HRP has developed the Human Research Roadmap Web site for communicating the program's integrated approach and research activities needed to address these risks (see *http://humanresearchroadmap.nasa.gov/*).

In FY 11, HRP made extensive use of the ISS to perform research on maintaining human health and performance during and after long-duration spaceflight. HRP flew 11 major medical experiments to evaluate the immune system and other human health areas to make exploration missions healthier, safer, and more productive. HRP also added new ISS biomedical capabilities, including the second-generation ultrasound for medical imaging, the Urine Monitoring System, and the jointly developed ESA-NASA Muscle Atrophy Research and Exercise System. Additionally, HRP developed programmable lighting to aid in astronaut adaptation to the work, rest, and sleep cycle while living on the ISS. For summaries of HRP ISS experiments spanning FY 11, see Expeditions 25–26 (September 2010 through March 2011) and Expeditions 27–28 (March 2011 through September 2011) at the following ISS Program Web site: *http://www.nasa.gov/mission_pages/station/research/experiments/experiments_by_expedition.html*.

During the fiscal year, the program also delivered significant research products that will help take human space explorers far beyond low-Earth orbit, including an update to the space radiation cancer risk model that predicts the lifetime cancer health risk from exposure to deep space radiation—a vital tool in planning safe exploration missions. The updated model was delivered to the Space Studies Board of the National Academies for assessment to identify any gaps in NASA's approach to protecting astronauts from the effects of space radiation. Additionally, under

the leadership of HRP, NASA collaborated with ESA in January 2011 to develop and deploy a highly successful international outreach program called "Mission X," which brought together 14 space agencies and various partner institutions to work together to address health and fitness education for young people around the globe.

Finally, HRP released two NASA Research Announcements (NRAs) in FY 11 to engage the national biomedical research community: the Space Radiobiology NRA to address space radiation health effects and the Joint NASA and National Space Biomedical Research Institute's NRA on Crew Health and Performance in Space Exploration Missions to solicit innovative research addressing risks identified in NASA's human research roadmap.

Exploration Technology Development Program

In FY 11, the Exploration Technology Development Program (ETDP) tested a breadboard portable life-support system for an advanced spacesuit in the laboratory. This system incorporated new technology components for spacesuit thermal control, pressure regulation, and carbon dioxide removal. Advanced spacesuits with greater mobility, operational flexibility, and extravehicular activity duration are needed to replace the aging spacesuits used on the ISS and to enable the exploration of planetary surfaces.

In a desert field test, the program tested a mock-up habitat that included an airlock, a hygiene module, crew workstations, modules for growing plants, and an inflatable loft to provide greater living space. The test allowed designers to evaluate different habitat subsystems and configurations for a future deep space habitat in which the crew would live and work on missions lasting over a year.

The program delivered a radiation assessment detector for launch on the Mars Science Laboratory mission. This detector will measure the interplanetary radiation environment during the trip to Mars, as well as the radiation on the planet's surface. Characterizing the Mars radiation environment will increase our understanding of the risks that future human explorers will face and will help us to develop more effective countermeasures and radiation shielding.

In order to simulate asteroid mission operations, the program conducted the NASA Extreme Environment Mission Operations (NEEMO) underwater test.

Divers in spacesuits demonstrated various methods of anchoring to and translating across the surface of an asteroid in low gravity. A submersible simulated a crew excursion vehicle that flies around the asteroid. Such early testing of prototype systems and validation of operational concepts in analog tests helps to reduce mission risk and cost.

The humanlike Robonaut 2 hardware was launched to the ISS on STS-133. The 330-pound Robonaut 2 consists of a head and a torso with two arms and two dexterous hands. Engineers monitored how it operated in near microgravity with the objective of using it as a robotic assistant that can work alongside the crew. Currently, Robonaut is confined to operations in the ISS Destiny laboratory. Future enhancements and modifications may allow it to move more freely around the interior or outside the complex.

In support of future technology activities, ETDP issued broad agency announcements for cryogenic propellant storage and transfer and solar electric propulsion mission concept studies. NASA selected four companies to perform cryogenic propellant storage and transfer mission concept studies and five companies to perform solar electric propulsion mission concept studies. The concept studies will test and validate key capabilities and technologies required for future exploration elements such as large cryogenic propulsion stages, propellant depots, and high-power solar electric tugs.

Lunar Precursor Robotic Program

NASA created the Lunar Precursor Robotic Program (LPRP) to execute precursor robotic missions to support planned human missions to the moon, making the program critical to the Constellation Program's efforts. The goal of these robotic missions was to gather data essential for reducing risks to astronauts, identify resources and landing sites, and refine the requirements for lunar surface hardware. With the shift from lunar exploration to an advanced capabilities framework, the program was phased out in FY 11, culminating in the transfer of the Lunar Reconnaissance Orbiter (LRO) to the Science Mission Directorate.

Launched in June 2009, LRO operated flawlessly throughout FY 11, contributing to a range of discoveries that enhanced researchers' understanding of the moon. The LRO spacecraft provided data for high-resolution mapping of the moon,

conducted investigations on lunar radiation and thermal environments, and identified lunar resource availability. In October 2009, the Lunar CRater Observation and Sensing Satellite (LCROSS), a spacecraft comanifested with LRO, impacted a permanently shadowed crater at the lunar South Pole to investigate the possible presence of water and other volatiles. LRO imagery provided unprecedented high-resolution topography of the moon, while LCROSS data identified the presence of water and a variety of volatiles on the lunar surface. These two missions, with the data from previous NASA and international missions, have revolutionized our understanding of lunar volatiles and the geologic history of the moon. After its transition to NASA's Science Mission Directorate at the end of FY 10, the LRO mission has continued to operate flawlessly.

Another key component of LPRP was the Lunar Mapping and Modeling Project (LMMP), an initiative to ensure that results of precursor robotic missions are accessible to lunar exploration planners. LMMP data are accessed through a single, common NASA portal designed for convenient dissemination of lunar mapping and modeling data, products, and tools. The Web portal went live for public access in early FY 11 and provides public access to, among other products, LRO lunar images and maps.

Constellation Program and Its Relevance to SLS and MPCV

In moving forward, NASA is committed to meeting the goals and requirements of the NASA Authorization Act of 2010 by developing an affordable, sustainable, and realistic next-generation human spaceflight system that will enable human exploration, scientific discovery, broad commercial benefits, and inspiration missions that are in the best interest of the Nation. NASA is working to build a bridge between the past and the future by transitioning previous and ongoing development work, best practices, and lessons learned from the Constellation Program to the SLS and MPCV Programs and by transitioning and leveraging hardware and technology investments wherever possible.

Through April 2011, NASA spent $13.1 billion on the Constellation Program. That amount includes money spent on labor, infrastructure, acquisition, and testing of hardware elements and software systems, among other things. Much of what Constellation has accomplished is indeed transferable to the SLS and MPCV programs, not just in terms of hardware, validated requirements, and infrastructure

elements, but also in terms of less tangible items such as knowledge and experience gained by our team with the Constellation systems being developed. Therefore, as NASA works to close out the Constellation Program, we are also taking care to capture and build upon program accomplishments, especially those technologies that have a high likelihood of feeding into the SLS and MPCV programs. From the beginning, the Constellation Program used electronic records and a centralized database to capture and manage all data, risks, and knowledge learned, including information from test flights, hardware and software tests, and programmatic reviews. Therefore, there is a wealth of information that the program will be able to pass on to future human spaceflight developers, including those at NASA and those in the U.S. aerospace industry, when allowable by law. Since completing the technical portion of the program-level Preliminary Design Review (PDR) in March 2010, and after previously having completed the project-level PDRs for Ares and Orion in 2008 and 2009 respectively, the program has been working to finalize its technical library, thus ensuring that historical data from Constellation work are documented, preserved, and made accessible to future human spaceflight designers.

The Constellation Program enabled us to relearn how to build a crew launch system, beginning from the earliest stages of viewgraphs and Tradespace and advancing through multiple key project review checkpoints and ultimately to the point where NASA, along with its industry partners, had built hardware and integrated systems that were used on two major test flights, the Ares I-X flight and the Pad Abort 1 (PA-1) flight for the Orion Launch Abort System (LAS)—both of which resulted in substantial data that will be of great use to the MPCV and SLS programs. Additionally, the Constellation Program allowed us to incorporate new engineering models, technologies, and testing methods that will certainly become the norm as we move forward with SLS and MPCV. Historically speaking, during the Apollo era, NASA had comparatively little experience with in-flight aborts and limited computational capability. Today, however, flight tests are being combined with advanced simulation tools and advanced computers, thereby allowing NASA to conduct a more thorough analysis of hardware and software elements and operating processes. The Orion integrated abort system's effectiveness can now be calculated using computer models of the blast environment by employing more realistic, physics-based simulations of abort conditions

with remarkable speed and accuracy, given NASA's evolved engineering expertise and the computational power of modern computers. In comparison, during the Apollo era, abort effectiveness was estimated by comparison to escapes from high-performance military aircraft combined with the results of a few escape system tests. In fact, our current computer modeling scenarios are so accurate that we were able to forgo more expensive ground tests in some cases. We expect this trend to continue with the SLS and MPCV whenever possible, without sacrificing safety. For example, designing the Ares I allowed NASA to make an important technology leap in the design process by transitioning from a 2D, paper-based vehicle design and verification process to a 3D model-based design environment. NASA was able to gain valuable experience with a state-of-the-art design system that can reduce costs while also increasing system reliability—benefits that will feed into the SLS.

It is also important to note that there are Constellation technologies that are transferable to the U.S. aerospace industry. For example, one of NASA's commercial cargo partners, Space Exploration Technologies, has already incorporated Orion's Thermal Protection System and its parachute development technologies into the company's Dragon capsule, which successfully launched last year.

Over the past year, NASA continued to implement the Constellation Program and associated projects while prioritizing Constellation funding on work that was most related to the SLS and the MPCV, thus maximizing the effective use of taxpayer dollars.

The Ares project has worked closely with the SLS planning team to focus its development efforts on technologies and processes that could be utilized in the eventual SLS configuration. These include vehicle avionics, J-2X engine testing, first stage engine testing (development motor-3) and installation of upper stage tooling applicable to large-diameter tanks. At the same time, Ares deferred activities that were highly vehicle-configuration dependent, including a ground-vibration test article and the design of upper stage component hardware, such as the reaction control system.

The Orion project has focused its development efforts on crew safety, targeting an orbital test flight, Exploration Flight Test (EFT-1), in December 2014 to validate 10 of the top 13 analyzed crew safety risks in the real flight environment—risks

primarily in the areas of entry, descent, and landing. At the same time, Orion deferred efforts in areas posing relatively small risk to crew safety, such as life support, communications, crew-support systems, and the LAS. NASA has deferred further work on the LAS for the near term because it is ahead of other Orion systems in its design and testing phases.

The extravehicular activity (EVA) project has coordinated with Orion to focus its development efforts on suit architecture trades in light of the new beyond-LEO mission timetable, including a modified Advanced Crew Escape System (Shuttle launch and entry suit) that has been part of a launch and entry suit trade study. Concurrently, the project has deferred efforts on beyond-LEO suit design and commonality with the launch and entry suit.

Exploration Ground Systems has coordinated with the SLS team and focused its ground operations work on items that would most likely be needed by heavy-lift launches—including improvements to launch pad construction, launch control center construction at JSC, and crawler overhauls. (The crawler is the vehicle that transports a launch vehicle stack from an integration building to the launch site.) Also, Ground Operations deferred Vehicle Assembly Building modifications at Kennedy Space Center (KSC) until the dimensions of the new heavy-lift vehicle are known.

Mission Operations has coordinated with the Orion project to focus its efforts on activities required for general human spaceflight mission support, with efforts concentrated on the mission control center and training systems. Efforts have also been deferred on highly configuration-dependent activities such as a high-fidelity Orion mockup or docking adapter trainer.

Currently, NASA is finalizing its Constellation Transition Plan, which will provide the framework for moving ahead on the SLS and MPCV. NASA has procurement teams who are mapping SLS requirements (those outlined in the NASA Authorization Act of 2010, which are under development) against the Ares contracts to determine if the new requirements fit the scope of the existing contracts. For the SLS, NASA is reviewing each element of Ares (first stage, upper stage, upper stage J-2X engine, and avionics) to determine whether the new SLS requirements are within the scope of the current contract. For the MPCV, NASA recently announced that the Orion Crew Exploration Vehicle and its associated contract would be used for at least the development phase of the MPCV.

NASA Awards Second Round of Commercial Crew Development Awards

To further stimulate efforts within the private sector for the development and demonstration of safe, reliable, and cost-effective space transportation capabilities, NASA awarded approximately $270 million to four commercial companies in April 2011 and approximately $46 million in September 2011 in optional milestones.

This investment by NASA continues and expands the 2009 Commercial Crew Development (CCDev) initiative in which NASA used American Recovery and Reinvestment Act funds to develop and demonstrate human spaceflight capabilities. Through this new effort, CCDev2, NASA's commercial partners will further advance commercial crew space transportation system concepts, maturing the design and development of system elements such as launch vehicles and spacecraft. These investments will spur economic growth as capabilities for new, cost-effective space markets are created. NASA and the Nation will benefit from a reduced gap in U.S. human spaceflight capability.

For the second round of agreements, proposals selected were as follows:

- Blue Origin: $22 million. The company is developing a space vehicle design for their biconic New Shepard spacecraft, designed to take off and land vertically.
- Sierra Nevada Corporation: $80 million. Sierra Nevada is designing a lifting body called Dream Chaser.
- Space Exploration Technologies (SpaceX): $75 million. SpaceX plans to use the award to develop an escape system for a crewed version of its Dragon capsule, an uncrewed version of which has already flown.
- The Boeing Company: $92.3 million. Boeing will continue development of the CST-100 crew capsule, including maturation of the design and integration of the capsule with a launch vehicle.

Setting Requirements for Commercial Services

During the fiscal year, NASA has been developing the acquisition strategy and long-term planning for investment in end-to-end commercial crew transportation capabilities. In December 2010, NASA released the Commercial Crew

Transportation System requirements for NASA low-Earth orbit missions, which provide a consolidated set of requirements, standards, and processes that will be applied to the certification of a specific commercial crew transportation system for low-Earth orbit missions.

NASA developed a series of documents to communicate roles and responsibilities, technical management processes supporting certification, crew transportation system and ISS services requirements, ISS interface requirements, and the application of technical and operations standards for potential commercial partners. Over the year, these documents have been reviewed within NASA and by members of the industry. NASA's overarching strategy for the development of these documents is to ensure that the requirements meet NASA safety and performance standards, but the strategy is not overly prescriptive and allows commercial industry maximum flexibility to develop safe, reliable, and cost-effective human space transportation systems.

Commercial Spaceflight

The Commercial Spaceflight Theme creates incentives for commercial providers to develop and operate safe, reliable, and affordable commercial systems to transport crew and cargo to and from the ISS and LEO. This approach will supply assured access to the ISS, strengthen America's space industry, and provide a catalyst for future business ventures to capitalize on affordable access to space. Programs include Commercial Cargo and Commercial Crew.

Science Mission Directorate

NASA's Science Mission Directorate (SMD) conducts scientific exploration enabled by the use of space observatories and space probes that view Earth from space, observe and visit other bodies in the solar system, and peer out into our galaxy and beyond. NASA's science program seeks answers to profound questions that touch us all: How and why are Earth's climate and environment changing? How and why does the sun vary and affect Earth and the rest of the solar system? How do planets and life originate? How does the universe work, and what are its origin and destiny? Are we alone?

SMD has five program divisions: Astrophysics, Planetary Science, Heliophysics, Earth Science, and the Joint Agency Satellite Division. SMD also has a James Webb Space Telescope (JWST) program office. In FY 11, SMD successfully launched three new space and Earth science missions designed to improve our understanding of the Earth system and the history of the solar system. NASA's science vision is to achieve a deep scientific understanding of our planet, other planets and solar system bodies, our star system in its entirety, and the universe beyond. SMD lays the intellectual foundation for the robotic and human expeditions of the future while meeting today's needs for scientific information to address national concerns on climate change, space weather, and education.

Planetary Division

NASA extends humankind's virtual presence throughout the solar system via robotic space probes to other planets and their moons, to asteroids and comets, and to icy bodies of the outer solar system. SMD is completing humankind's first basic reconnaissance of the solar system by sending one mission to fly by Pluto and another to arrive at the asteroid Ceres in 2015; the latter mission visited one of the largest asteroids in our solar system—Vesta—in 2011. SMD is also in the midst of a large-scale investigation of Mars, with an ever-more-capable set of orbiters, landers, and rovers exploring the planet; the long-term goal is a sample return mission. Further, SMD is focusing on certain moons of the giant planets where current NASA missions see intriguing signs of surface activity and of liquid water within, knowing that on Earth, where there is water and an energy source, there is also life.

On October 21, 2010, nearly a year after announcing the discovery of water molecules on the moon, scientists revealed new data from NASA's Lunar CRater Observation and Sensing Satellite (LCROSS) and Lunar Reconnaissance Orbiter (LRO) that confirmed the discovery. The missions found evidence that the lunar soil within shadowy craters was rich in materials and that the moon was chemically active and had a water cycle.

On November 4, 2010, NASA's EPOXI mission spacecraft successfully flew past comet Hartley 2. EPOXI was an extended mission that used the already-in-flight Deep Impact spacecraft to conduct its new

mission. Images from the EPOXI mission revealed comet Hartley 2 to have 100 times less volume than comet Tempel 1, the first target of Deep Impact. Initial estimates indicated that the spacecraft was about 435 miles from the comet at its closest approach.

On December 14, 2010, NASA's Cassini spacecraft found possible ice volcanoes on Saturn's moon Titan that were similar in shape to those on Earth that spew molten rock. Topography and surface composition data had enabled scientists to make the best case yet in the outer solar system for an Earth-like volcano landform that erupted in ice. Scientists debated for years whether ice volcanoes, also called cryovolcanoes, existed on ice-rich moons and, if they did, what their characteristics were. The working definition assumed that some kind of subterranean geological activity warmed the cold environment enough to melt part of the satellite's interior and sent slushy ice or other materials through an opening in the surface. Volcanoes on Jupiter's moon Io and on Earth spew silicate lava. But when such flows were spotted on Titan in the past, theories explained them as nonvolcanic processes, such as rivers depositing sediment. At Sotra, however, cryovolcanism was the best explanation for two peaks more than 3,000 feet high with deep volcanic craters and fingerlike flows. Data from Cassini's visual and infrared mapping spectrometer revealed that the lobed flows had a composition different from that of the surrounding surface. Cassini launched on October 15, 1997, and began orbiting Saturn in 2004. Saturn has more than 60 known moons, with Titan being the largest.

On December 15, 2010, NASA's Mars Odyssey, which had launched in 2001, broke the record for longest-serving spacecraft at the Red Planet. The probe began its 3,340th day in Martian orbit at 8:55 p.m. EST to break the record set by NASA's Mars Global Surveyor, which orbited Mars from 1997 to 2006. Odyssey's longevity has enabled continued science, including the monitoring of seasonal changes on Mars from year to year and the most detailed maps ever made of the planet. Odyssey also served as a communication relay, handling most of the data sent home by NASA's Phoenix lander and Mars Exploration Rovers (Spirit and Opportunity). Odyssey became the middle link for continuous observation of Martian weather by NASA's Mars Global Surveyor and NASA's Mars Reconnaissance Orbiter (MRO). Odyssey will support the 2012 landing of the Mars Science Laboratory (MSL)/Curiosity and surface operations of that mission.

On February 15, 2011, the Stardust-NExT (New Exploration of Tempel 1) mission observed surface features on Comet Tempel 1 that had changed in areas previously seen during the 2005 Deep Impact mission, imaged new terrain, and viewed the crater generated when the Deep Impact mission propelled an impactor at the comet. The images also showed that the comet has a fragile and weak nucleus. The spacecraft made its closest approach to comet Tempel 1 on February 14 at a distance of approximately 111 miles. It also accumulated data about the dust in Tempel 1's coma.

On March 15, 2011, NASA's LRO team released the final set of data from the mission's exploration phase along with the first measurements from its new life as a science satellite. With this fifth release of data, striking new images and maps were added to the already comprehensive collection of raw lunar data and high-level products, including mosaic images, that LRO made possible. The spacecraft's seven instruments delivered more than 192 terabytes of data with an unprecedented level of detail. LRO's Diviner Lunar Radiometer Experiment provided new data relating to the moon's surface. These included maps of visual and infrared brightness, temperature, rock abundance, nighttime soil temperature, and surface mineralogy.

On March 18, 2011, NASA's MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft successfully achieved orbit around Mercury. This marked the first time a spacecraft had accomplished this engineering and scientific milestone at our solar system's innermost planet. MESSENGER continues to gather data about Mercury, including the recent discovery that water ice exists in permanently shaded areas at the planet's poles.

On May 21, 2011, new data analysis from NASA's Galileo spacecraft revealed a subsurface ocean of molten or partially molten magma beneath the surface of Jupiter's volcanic moon Io. The finding heralded the first direct confirmation of this kind of magma layer on Io and explained why the moon was the most volcanic object known in the solar system. Io produces about 100 times more lava each year than all the volcanoes on Earth. Before Galileo's findings, NASA's Voyager spacecraft discovered Io's volcanoes in 1979, making that moon the only body in the solar system other than Earth known to have active magma volcanoes. The energy for the volcanic activity came from the squeezing and stretching of the moon by Jupiter's gravity as Io orbited the largest planet in the solar system. Galileo was

launched in 1989 and began orbiting Jupiter in 1995. After a successful mission, the spacecraft intentionally was sent into Jupiter's atmosphere in 2003.

On July 17, 2011, NASA's Dawn spacecraft became the first probe ever to enter orbit around an object in the main asteroid belt between Mars and Jupiter. Dawn studied the asteroid, named Vesta, for a year before departing for a second destination, a dwarf planet named Ceres, in July 2012. Observations provided unprecedented data to help scientists understand the earliest chapter of our solar system. The spacecraft relayed information to confirm that it had entered Vesta's orbit. The asteroid's mass determined the strength of its gravitational pull. With Dawn now in orbit, the science team took more accurate measurements of Vesta's gravity and gathered more accurate timeline information. Dawn, which launched in September 2007, was on track to become the first spacecraft to orbit two solar system destinations beyond Earth.

On August 4, 2011, observations from NASA's MRO revealed possible flowing water during the warmest months on Mars. Dark, fingerlike features appeared and extended down some Martian slopes during late spring through summer, faded in winter, and returned during the next spring. Repeated observations tracked the seasonal changes in these recurring features on several steep slopes in the middle latitudes of Mars's southern hemisphere. Some aspects of the observations puzzled researchers, but flows of liquid brine (salty water) fit the features' characteristics better than alternate hypotheses. Sites with active flows got warm enough, even in the shallow subsurface, to sustain liquid water that was about as salty as Earth's oceans, while pure water would freeze at the observed temperatures. The features imaged were only about 0.5 to 5 yards or meters wide, with lengths of up to hundreds of yards. The width was much narrower than those of previously reported gullies on Martian slopes. However, some of those locations displayed more than 1,000 individual flows. Also, although gullies were abundant on cold, pole-facing slopes, these dark flows were on warmer, equator-facing slopes. These results were the closest scientists had come to finding evidence of liquid water on the planet's surface. Frozen water, however, was detected near the surface in the mid- to high-latitude regions. Fresh-looking gullies suggested slope movements in geologically recent times, perhaps aided by water. Purported droplets of brine also appeared on struts of the Phoenix Mars Lander. If further study of the recurring dark flows

supported evidence of brines, these could be the first known Martian locations with liquid water.

On August 5, 2011, NASA's solar-powered Juno spacecraft lifted off from Cape Canaveral Air Force Station to begin a five-year journey to Jupiter. Juno's detailed study of the largest planet in our solar system might reveal Jupiter's origin and evolution. As the archetype of gas giants, Jupiter could help scientists understand the origin of our solar system and learn more about planetary systems around other stars. The spacecraft would orbit the planet's poles 33 times and use its collection of eight science instruments to probe beneath the gas giant's obscuring cloud cover to learn more about its origins, structure, atmosphere, and magnetosphere; it would also look for a potential solid planetary core. With four large moons and many smaller moons, Jupiter could form its own miniature solar system. Its composition resembles a star's, and if it had been about 80 times more massive, the planet could have become a star instead.

On September 10, 2011, NASA's twin lunar Gravity Recovery and Interior Laboratory (GRAIL) spacecraft lifted off from Cape Canaveral Air Force Station in Florida to study Earth's moon in unprecedented detail. GRAIL-A reached the moon on New Year's Eve 2011, while GRAIL-B arrived on New Year's Day 2012. The two solar-powered spacecraft flew in tandem orbits around the moon to measure its gravity field. GRAIL answered long-standing questions about the moon and gave scientists a better understanding of how Earth and other rocky planets in the solar system formed. The straight-line distance from Earth to the moon is approximately 250,000 miles (402,336 kilometers). NASA's Apollo moon crews needed approximately three days to cover that distance. However, each spacecraft took approximately 3.5 months and covered more than 2.5 million miles (4 million kilometers) to arrive. This low-energy trajectory resulted in the longer travel time.

Earth Science Division

From space, NASA satellites can view Earth as a planet and enable its study as a complex, dynamic system with diverse components: oceans, atmosphere, continents, ice sheets, and life itself. The Nation's scientific community can thereby

observe and track global-scale changes, connecting cause to effects; study regional changes in their global context; and observe the role that human civilization plays as a force of change. Through partnerships with agencies that maintain forecast and decision-support systems, NASA improves national capabilities to predict climate change, weather, and natural hazards; manage resources; and craft environmental policy.

On March 4, 2011, NASA's Glory mission launched from Vandenberg Air Force Base in California but failed to reach orbit due to a launch-vehicle failure. The spacecraft separation was supposed to occur 13 minutes after launch. If the Glory mission had successfully launched, data from the mission would have allowed scientists to better understand how the sun and tiny atmospheric particles called aerosols affect Earth's climate.

On March 14, 2011, researchers and flight crew arrived in Thule, Greenland, for the start of NASA's 2011 Operation IceBridge, an airborne mission to study changes in Arctic polar ice. This year's plans included surveys of Canadian ice caps and expanded international collaboration. The state of Earth's polar ice sheets, glaciers, and sea ice is an important indicator of climate change and plays a key role in regulating global climate. With IceBridge, NASA is pushing ahead with its commitment to keep an eye on changes to polar ice to better understand the effects of climate change. Since 2009, Operation IceBridge has flown annual campaigns over the Arctic starting in March and over Antarctica starting in October. The missions extend the multi-year record of ice elevation measurements made by NASA's Ice, Cloud, and land Elevation Satellite (ICESat), which stopped collecting data in 2009, until the upcoming ICESat-2 launches in 2016. ICESat-2 will use a micro-pulse multi-beam approach. This approach will provide dense cross-track sampling to resolve surface slope on an orbit basis and improve lead detection for sea ice freeboard estimates.

On June 10, 2011, NASA's Aquarius/SAC-D observatory rocketed into space from Vandenberg Air Force Base in California. The SAC-D observatory is a collaboration between NASA and Argentina's space agency, Comisión Nacional de Actividades Espaciales (CONAE). Aquarius is providing NASA's first space observations of the salinity, or concentration of salt, at the ocean surface, a key missing variable in satellite studies of Earth. Variations in salinity influence deep ocean circulation, trace the path of freshwater around our planet, and help drive

Earth's climate. In addition to Aquarius, the observatory carries seven instruments that monitor natural hazards and collect a broad range of environmental data. Other mission partners include Brazil, Canada, France, and Italy. Aquarius is mapping the global open ocean once every seven days for at least three years with a resolution of 93 miles (150 kilometers). The maps show how ocean surface salinity changes each month, season, and year. Aquarius measures salinity by sensing thermal microwave emissions from the water's surface with three microwave instruments called radiometers. Because salinity levels in the open ocean vary by only about 5 parts per 1,000, Aquarius is able to detect changes as small as approximately 2 parts per 10,000, equivalent to about one-eighth of a teaspoon of salt in a gallon of water.

On June 23, 2011, two NASA research airplanes flew over the Baltimore-Washington region and northeast Maryland as part of a mission to enhance the capability of satellites to measure ground-level air quality from space. The campaign was called DISCOVER-AQ, which stood for Deriving Information on Surface conditions from COlumn and VERtically resolved observations relevant to Air Quality. It was one of the five Earth Venture class of investigations selected in 2010 as part of NASA's Earth System Science Pathfinder Program. These targeted science investigations complemented NASA's larger research missions. A fundamental challenge for spaceborne instruments monitoring air quality was to distinguish between pollution high in the atmosphere and pollution near the surface where people live. The new NASA field campaign made measurements from aircraft in combination with ground-based observation sites to help scientists better understand how to observe ground-level pollution from space in the future. A fleet of Earth-observing satellites called the Afternoon Constellation, or "A-train," passed over the DISCOVER-AQ study area each day in the early afternoon. The satellites' data, especially from the Aqua and Aura spacecraft, gave scientists the opportunity to compare the view from space with that from the ground and aircraft. The combined scientific resources made DISCOVER-AQ a rare opportunity for air-quality researchers.

Following the mission's first campaign in summer 2010, scientists embarked from Alaska on June 25, 2011, on the second and final NASA campaign to study how changing conditions in the Arctic affect the ocean's chemistry and ecosystems.

The Impacts of Climate on EcoSystems and Chemistry of the Arctic Pacific Environment (ICESCAPE) mission resumed its shipborne investigation of the impacts of climate change in the Chukchi and Beaufort seas along Alaska's western and northern coasts. Research teams departed from Dutch Harbor, Alaska, and boarded the U.S. Coast Guard Cutter Healy. The field campaign took 47 scientists for five weeks to the Arctic Ocean, where a variety of instruments were used on board the Healy and deployed into the ocean and on the sea ice. The second year of sampling sought to find year-to-year differences and provided data for new lines of investigation. Combined observations from the field and from NASA satellites were critical to understanding the Arctic, where the signals of climate change were amplified. The accelerated decline of Arctic sea ice extent and thickness exemplified this trend, and scientists wanted to know how this change affected other ocean processes and marine life. Phytoplankton, microscopic organisms found in watery environments, was a key focus of the campaign. They formed the base of the aquatic food web, participated in cycling Earth's carbon between the atmosphere and the ocean, and were susceptible to climate change. NASA monitored changes in phytoplankton from space worldwide with the Moderate Resolution Imaging Spectroradiometer instrument on the Aqua satellite and the Sea-viewing Wide Field-of-view Sensor, which ended observations in 2010.

Heliophysics Division

Our solar system is governed by the sun, a main-sequence star midway through its life. The sun's influence is wielded through its gravity, radiation, solar wind, and magnetic fields as they interact with the masses, fields, and atmospheres of planetary and small bodies. Through the eyes of multiple spacecraft, the scientific community sees the solar system as a "heliosphere," another kind of interconnected system with diverse components. Using a fleet of sensors on various spacecraft in Earth orbit and throughout the solar system, SMD seeks to understand how and why the sun varies, how planetary systems respond, and how human activities are affected. The science of heliophysics enables the space weather predictions necessary to safeguard the outward journeys of human and robotic explorers.

On June 9, 2011, observations from NASA's Voyager spacecraft, humanity's farthest deep space sentinels, suggested that the edge of our solar system might not be smooth, but filled with a turbulent sea of magnetic bubbles. While using a new computer model to analyze Voyager data, scientists found that the sun's distant magnetic field was made up of bubbles approximately 100 million miles wide. The bubbles were created when magnetic field lines reorganized. The new model suggested that the field lines were broken up into self-contained structures disconnected from the solar magnetic field. The Voyager spacecraft, more than nine billion miles away from Earth, was traveling in a boundary region. In that area, the solar wind and magnetic field were affected by material expelled from other stars in our corner of the Milky Way Galaxy. Understanding the structure of the sun's magnetic field allows scientists to explain how galactic cosmic rays enter our solar system and helps define how the star interacts with the rest of the galaxy.

On July 19, 2011, two small NASA probes were orbiting the moon to study its interior and surface composition. The spacecraft, called Acceleration, Reconnection, Turbulence and Electrodynamics of the Moon's Interaction with the Sun (ARTEMIS), began their journey away from Earth's orbit in July 2009. The ARTEMIS mission was made possible by repurposing two spacecraft. The spacecraft were part of NASA's Time History of Events and Macroscale Interactions during Substorms (THEMIS) mission, launched in 2007, which consisted of five identical spacecraft that studied the magnetic environment around Earth, the aurora, and how these were affected by the sun. The first spacecraft entered lunar orbit on June 27, and the second on July 17. Engineers used complex orbit maneuvers to relocate the spacecraft to their new locations. The journey required many gravity-assists from the moon and Earth and used minimal amounts of fuel. The probes approached the moon's surface to within 60 miles every orbit. The data provided scientists with new information about the moon's internal structure. Both spacecraft were previously in areas called the Lagrangian points, areas on either side of the moon where the moon and Earth's gravity balance perfectly. These locations were ideal spots to study Earth's distant magnetic field and how the solar wind, made up of ionized gas known as plasma, flew past the moon and tried to fill in the vacuum on the other side.

On August 18, 2011, NASA spacecraft observations and new data-processing techniques were giving scientists better insight into the evolution and development of solar storms that could damage satellites, disrupt communications, and cause power grid failures on Earth. The solar storms, called Coronal Mass Ejections (CMEs), were being observed from NASA's twin Solar TErrestrial RElations Observatory (STEREO) spacecraft, launched in 2006. The duo represented a key component within a fleet of NASA spacecraft that enhanced the capability to predict solar storms. Previous spacecraft imagery did not clearly show the structure of a solar disturbance as it traveled toward Earth. As a result, forecasters had to estimate when storms would arrive without knowing the details of how they evolve and grow. New processing techniques used on STEREO data allowed scientists to see how solar eruptions developed into space storms as they reached Earth. CMEs are billion-ton clouds of solar plasma launched by the same sun explosions that spark solar flares. When they sweep past Earth, they cause auroras, radiation storms that disrupt sensitive electronics on satellites, and in extreme cases, power outages. Better tracking of these plasma clouds and the ability to predict their arrival are important parts of space weather forecasting. The spacecraft's wide-angle cameras captured the images. They detected ordinary sunlight scattered by free-floating electrons in plasma clouds. These observations could pinpoint not only the arrival time of the CME, but also its mass. The brightness of the cloud enabled researchers to calculate the cloud's gas density throughout the structure and compare it to direct measurements by other NASA spacecraft. When this technique was applied to future storms, forecasters were able to say with confidence whether Earth was about to be hit by a small or large cloud and where on the sun the material originated.

On September 7, 2011, NASA's Solar Dynamics Observatory (SDO) provided scientists with new information indicating an increase in strength and longevity in solar flares that was more than previously thought. Solar flares are intense bursts of radiation from the release of magnetic energy associated with sunspots. They are the solar system's largest explosive events and are seen as bright areas on the sun. Their energy can reach Earth's atmosphere and affect operations of Earth-orbiting communication and navigation satellites. Using SDO's EUV (extreme ultraviolet) Variability Experiment (EVE) instrument, scientists observed that radiation from

solar flares continues for up to 5 hours beyond the main phase. SDO provided images 10 times clearer than high-definition television and more comprehensive science data faster than any solar observing spacecraft in history.

Astrophysics Division

Some of the greatest minds of the last century discovered wondrous things about our universe: the Big Bang and black holes, dark matter and dark energy, and the interrelated nature of space and time. Their theories challenge scientists and NASA to use observations from space to test the limits of our understanding of fundamental physics. Having measured the age of the universe, the scientific community now seeks to explore its ultimate extremes: its birth, the edges of space and time near black holes, and the mysterious dark energy filling the entire universe. Scientists also seek to understand the relationship between the smallest of subatomic particles and the vast expanse of the cosmos. With hundreds of planets around other stars now known, scientists are using current NASA missions in conjunction with ground-based telescopes to seek Earth-like planets in other solar systems.

On October 6, 2010, after nine years of scanning the sky, NASA's Wilkinson Microwave Anisotropy Probe (WMAP) space mission concluded its observations of the cosmic microwave background, the oldest light in the universe. The spacecraft had not only given scientists their best look at this remnant glow but also established the scientific model that described the history and structure of the universe. WMAP was designed to provide a more detailed look at subtle temperature differences in the cosmic microwave background that were first detected in 1992 by NASA's Cosmic Background Explorer (COBE). WMAP is in the Guinness World Records for "most accurate measure of the age of the universe."

On November 15, 2010, astronomers using NASA's Chandra X-ray Observatory found evidence of the youngest black hole known to exist in our cosmic neighborhood. The 30-year-old black hole provided a unique opportunity to watch this type of object develop from infancy. The black hole could help scientists better understand how massive stars explode, which ones leave behind black holes or neutron stars, and how many black holes there are in our galaxy and others. The

30-year-old object was a remnant of SN 1979C, a supernova in the galaxy M100 approximately 50 million light-years from Earth.

On December 15, 2010, NASA's scientific balloon program resumed flights after an extensive evaluation of its safety processes following a mishap during an earlier launch attempt from Australia in 2010. NASA's high-altitude balloons fly instruments for scientific and technological investigations that contribute to our understanding of Earth, the solar system, and the universe. NASA's scientific balloons are composed of a lightweight polyethylene film that is similar to sandwich wrap. Flying to altitudes of nearly 25 miles, many of the balloons inflate to almost the size of a football stadium and carry payloads weighing up to 6,000 pounds. In October 2010, a NASA mishap review board listed 25 causes that contributed to the accident, including insufficient risk analysis, contingency planning, personnel training, Government oversight, and public safety accommodations. To prepare for the resumption of flights, NASA developed a corrective action plan to address the recommendations from the mishap review.

On January 11, 2011, the Planck mission released a new data catalog from initial maps of the entire sky. The catalog included thousands of never-before-seen dusty cocoons where stars were forming, along with some of the most massive clusters of galaxies ever observed. Planck is a European Space Agency (ESA) mission with significant contributions from NASA. Planck launched in May 2009 on a mission to detect light from just a few hundred thousand years after the Big Bang, an explosive event at the dawn of the universe approximately 13.7 billion years ago. The spacecraft's state-of-the-art detectors surveyed the whole sky at least four times, measuring the cosmic microwave background, or radiation left over from the Big Bang. The data helped scientists decipher clues about the evolution, fate, and fabric of our universe. Similarly, the Herschel Space Observatory, on February 6, 2011, revealed how much dark matter it took to form a new galaxy bursting with stars. Herschel is also an ESA mission supported with important NASA contributions. Herschel's findings were a key step in understanding how dark matter, an invisible substance permeating our universe, contributed to the birth of massive galaxies in the early universe.

On January 26, 2011, astronomers pushed NASA's Hubble Space Telescope to its limits by finding what is likely to be the most distant object ever seen in the

universe. The object's light traveled 13.2 billion years to reach Hubble, roughly 150 million years longer than the previous record holder. The tiny, dim object was a compact galaxy of blue stars that existed 480 million years after the Big Bang. More than 100 such mini-galaxies would be needed to make up our Milky Way. The new research offered surprising evidence that the rate of star birth in the early universe grew dramatically, increasing by about a factor of 10 from 480 million years to 650 million years after the Big Bang. As with a developing embryo, astronomers knew there must have been an early period of rapid changes that would set the initial conditions to make the universe of galaxies what it is today.

On April 6, 2011, NASA's Stratospheric Observatory for Infrared Astronomy (SOFIA) completed its first science flight using the German REceiver for Astronomy at Terahertz Frequencies (GREAT) scientific instrument. GREAT is a high-resolution, far-infrared spectrometer that finely divides and sorts light into component wavelengths for detailed analysis. SOFIA is the world's largest airborne observatory. It is a joint program between NASA and the German Aerospace Center (DLR). The observatory is a heavily modified Boeing 747SP aircraft carrying a reflecting telescope with an effective diameter of 100 inches. Flying at altitudes between 39,000 and 45,000 feet, above the water vapor in Earth's lower atmosphere that blocks most infrared radiation from celestial sources, SOFIA conducts astronomical observations not possible with ground-based telescopes. Among its targets were IC 342, a spiral galaxy located 11 million light-years from Earth in the constellation Camelopardalis ("The Giraffe"), and the Omega Nebula (known as M17), 5,000 light-years away in Sagittarius. The team captured and analyzed radiation from ionized carbon atoms and carbon monoxide molecules to probe the chemical reactions, motions of matter, and flows of energy occurring in interstellar clouds. Astronomers had evidence that such clouds in both IC 342 and M17 were forming numerous massive stars. GREAT focused on strong far-infrared emissions from interstellar clouds that cooled the clouds. The balance between heating and cooling processes regulates the temperature of the interstellar material and controls initial conditions for the formation of new stars.

On April 12, 2011, the famous Crab Nebula supernova remnant erupted in an enormous flare five times more powerful than any flare previously seen from the object. NASA's Fermi Gamma-ray Space Telescope first detected the outburst,

which lasted six days. The nebula was the wreckage of an exploded star that emitted light, which reached Earth in the year 1054. It was located 6,500 light-years away in the constellation Taurus. At the heart of an expanding gas cloud lies what is left of the original star's core, a superdense neutron star that spins 30 times a second. Based on the rise and fall of gamma rays during the April outbursts, scientists estimated that the size of the emitting region must be comparable in size to the solar system.

On April 20, 2011, to celebrate the 21st anniversary of the Hubble Space Telescope's deployment into space, astronomers at the Space Telescope Science Institute in Baltimore, Maryland, pointed Hubble's eye at an especially photogenic pair of interacting galaxies called Arp 273. The newly released Hubble image showed a large spiral galaxy, known as UGC 1810, with a disk that was distorted into a rose-like shape by the gravitational tidal pull of the companion galaxy near it, known as UGC 1813. The image showed a tenuous tidal bridge of material between the two galaxies that were separated from each other by tens of thousands of light-years.

On May 3, 2011, NASA's Gravity Probe B (GP-B) mission confirmed two key predictions derived from Albert Einstein's general theory of relativity, which the spacecraft was designed to test. The experiment, launched in 2004, used four ultra-precise gyroscopes to measure the hypothesized geodetic effect, the warping of space and time around a gravitational body, and frame-dragging, the amount a spinning object pulls space and time with it as it rotates. GP-B was one of the longest-running projects in NASA history, with Agency involvement starting in the fall of 1963 with initial funding to develop a relativity gyroscope experiment. Innovations enabled by GP-B had been used in Global Positioning System (GPS) technologies that allowed airplanes to land unaided. Additional GP-B technologies were applied to NASA's Cosmic Background Explorer mission, which accurately determined the universe's background radiation. That measurement was the underpinning of the Big Bang theory and led to the Nobel Prize for NASA physicist John Mather.

On May 26, 2011, NASA's Spitzer Space Telescope observed that tiny crystals of a green mineral called olivine were falling down like rain on a burgeoning star. This was the first time such crystals had been observed in the dusty clouds of gas that collapsed around forming stars. Spitzer's infrared detectors spotted the

crystal rain around a distant, sunlike embryonic star, or proto-star, referred to as HOPS-68, in the constellation Orion. The crystals were in the form of forsterite. They belonged to the olivine family of silicate minerals and could be found everywhere from a peridot gemstone to the green sand beaches of Hawaii to remote galaxies. Forsterite crystals had been spotted before in the swirling planet-forming disks that surround young stars. The discovery of the crystals in the outer collapsing cloud of a proto-star was surprising because of the cloud's cold temperatures, about minus 280 degrees Fahrenheit (minus 170 degrees Celsius), whereas they are formed in regions at temperatures of 1,300 degrees Fahrenheit (700 degrees Celsius). This led the team of astronomers to speculate that the jets might in fact be transporting the cooked-up crystals to the chilly outer cloud.

On July 27, 2011, astronomers studying observations taken by NASA's Wide-field Infrared Survey Explorer (WISE) mission discovered the first known "Trojan" asteroid orbiting the sun along with Earth. Trojans are asteroids that share an orbit with a planet near stable points in front of or behind the planet. Because they constantly lead or follow in the same orbit as the planet, they never collide with it. In our solar system, Trojans also share orbits with Neptune, Mars, and Jupiter. Two of Saturn's moons share orbits with Trojans. Scientists had predicted that Earth should have Trojans, but they are difficult to find because they are relatively small and appear near the sun from Earth's point of view. The WISE telescope scanned the entire sky in infrared light from January 2010 to February 2011. Scientists began their search for an Earth Trojan using data from NEOWISE, an addition to the WISE mission that focused in part on near-Earth objects (NEOs), such as asteroids and comets. The NEOWISE project observed more than 155,000 asteroids in the main belt between Mars and Jupiter and more than 500 NEOs, discovering 132 that were previously unknown. The team's hunt resulted in two Trojan candidates. One, called 2010 TK7, was confirmed as an Earth Trojan after followup observations with the Canada-France-Hawaii Telescope on Mauna Kea in Hawaii.

On September 15, 2011, the existence of a world with a double sunset, as portrayed in the film *Star Wars* more than 30 years ago, was proven as a scientific fact. NASA's Kepler mission made the first unambiguous detection of a circumbinary planet—a planet orbiting two stars—200 light-years from Earth. Unlike *Star Wars'* Tatooine, the planet was cold, gaseous, and not thought to harbor life, but its

discovery demonstrated the diversity of planets in our galaxy. Previous research had hinted at the existence of circumbinary planets, but clear confirmation proved elusive. Kepler detected such a planet, known as Kepler-16b, by observing transits, during which the brightness of a parent star dims when the planet crosses in front of it. Kepler was the first NASA mission capable of finding Earth-size planets in or near the "habitable zone," the region in a planetary system where liquid water could exist on the surface of the orbiting planet. Scientists detected the new planet in the Kepler-16 system, a pair of orbiting stars that eclipsed each other from our vantage point on Earth. When the smaller star partially blocked the larger star, a primary eclipse occurred, and a secondary eclipse occurred when the smaller star occulted, or completely blocked, the larger star. Astronomers further observed that the brightness of the system dipped even when the stars were not eclipsing one another, hinting at a third body. The additional dimming in brightness events, called the tertiary and quaternary eclipses, reappeared at irregular intervals of time, indicating that the stars were in different positions in their orbit each time the third body passed. This showed that the third body was circling not just one, but both, stars in a wide circumbinary orbit.

James Webb Space Telescope Program

The James Webb Space Telescope (JWST) will be a large, infrared-optimized space telescope. JWST will discover the first galaxies that formed in the early universe, connecting the Big Bang to our Milky Way Galaxy. JWST will peer through dusty clouds to see stars forming planetary systems, connecting the Milky Way Galaxy to our own solar system. JWST's instruments will be designed to work primarily in the infrared range of the electromagnetic spectrum, with some capacity in the visible range.

On September 13, 2011, JWST reached a major milestone in its development. The mirrors finished undergoing the coating process at Quantum Coating, Inc., in Moorestown, New Jersey. The Webb telescope has 21 mirrors, with 18 mirror segments working together as one large 21.3-foot (6.5-meter) primary mirror. The mirror segments are made of beryllium, which was selected for its stiffness, light weight, and stability at cryogenic temperatures. Bare beryllium is not very reflective

of near-infrared light, so each mirror was coated with a microscopically thin layer of gold, selected for its ability to properly reflect infrared light from the mirrors into the observatory's science instruments. The coating will allow the Webb telescope's "infrared eyes" to observe extremely faint objects in infrared light. The last full-size (4.9-foot/1.5-meter) hexagonal beryllium primary mirror segment was coated, completing this stage of mirror production.

Aeronautics Research Mission Directorate

Aviation is an integral part of our daily lives, a critical part of the Nation's economy, and a source of strength in the global market. Airlines in the United States transport over one million people daily, but during peak travel times, the air traffic and airport systems in the United States are stretched to capacity. Environmental concerns, such as aircraft noise and emissions, limit increased operations and the expansion of airports and runways. Technological superiority is a key enabler for the U.S. industry to continue in its position as the world leader in the aviation sector, which has been bringing a positive trade balance of over $40 billion per year. The critical challenge—and opportunity—facing the U.S. aviation industry is to retain this leadership in a growing, complex, and increasingly global market through the infusion of new technology. NASA's aeronautics research portfolio is the Nation's most comprehensive civil aeronautics research and development effort. While improving the safety of the system that is already the safest mode of transportation, NASA's Aeronautics Research Mission Directorate (ARMD) works to solve these critical challenges that affect the Nation's air transportation system and limit growth of the economy.

ARMD's four research programs—Aviation Safety, Airspace Systems, Fundamental Aeronautics, and Integrated Systems Research—conduct cutting-edge research at the fundamental and integrated systems levels to address these national challenges. This research supports current and emerging applications, as well as revolutionary concepts and technologies that could one day change the face of air transportation. ARMD's research is also enabled by its Aeronautics Test Program, which provides critical support to NASA's ground and flight test infrastructure needs. The Aeronautics Test Program manages and makes strategic investments in the NASA-owned state-of-the-art ground test facilities and flight

research assets to ensure ready access for NASA programs, other Federal agencies, and the private sector to test and evaluate research concepts and technologies.

ARMD's research portfolio is well aligned with the principles, goals, and objectives of the National Aeronautics Research and Development Policy and Plan and directly supports the development of the Next Generation Air Transportation System (NextGen), a national initiative to transform America's air traffic control system from an aging ground-based system to a satellite-based system. NextGen technology will provide advanced levels of automated support to air navigation service providers and aircraft operators, thereby permitting controllers to monitor and manage aircraft with greater safety margins and enabling shortened routes for time and fuel savings, reduced traffic delays, and increased capacity. This transformation has the aim of reducing gridlock, both in the sky and at airports.

ARMD's partnerships with other Federal agencies, academia, and industry are critical to our ability to expand the boundaries of aeronautical knowledge for the benefit of the Nation. These partnerships foster a collaborative research environment in which ideas and knowledge are exchanged across all communities and help to ensure the future competitiveness of the Nation's aviation industry. As a member agency of the multi-agency Joint Planning and Development Office (JPDO), NASA, along with partner Federal agencies including the Federal Aviation Administration (FAA) and the Department of Defense (DOD), plans and coordinates the development of concepts and technologies required for NextGen. Through the research conducted in-house and sponsored with academia and industry, ARMD helps to develop the technology that enables continuous innovation in aviation. U.S. companies are well positioned to build on discoveries and knowledge resulting from NASA research, turning them into commercial products benefiting the quality of life for our citizens, providing new high-quality engineering and manufacturing job opportunities, and enabling the United States to remain competitive in the global economy.

Results from ARMD's fundamental research into high-efficiency, low-emissions combustion and light, high-temperature materials for jet engines from the 1990s and early 2000s have been incorporated by U.S. jet engine manufacturers Pratt & Whitney (P&W) and General Electric (GE) in their next-generation aircraft engines. The P&W Geared Turbofan (GTF) engine and the GE LEAP-X (leading

edge aviation propulsion) engines feature a reduction of more than 15 percent in fuel burn and harmful emissions, and these competitive edges enabled P&W and GE to dominate the two global engine replacement programs: the Boeing 737 MAX and the Airbus A320NEO. In the case of P&W, all new Bombardier C-Series and Mitsubishi Regional Jets selected the GTF engine as their launch product. As noted in the May 30, 2011, issue of *Time* magazine, job creation associated with the P&W GTF engine is estimated to be in the hundreds of jobs per year in the high-paying manufacturing sector. The same competitive edges that these engines present in decreased fuel burn, reduced emissions, and lower noise will directly benefit the flying public and communities adjacent to the Nation's airports and will help to ensure the long-term viability of the U.S. air transportation system. By addressing a current problem and making a timely transfer of the needed technology, NASA is helping the FAA realize NextGen benefits through near-term applications.

ARMD collaborates with universities for conducting cutting-edge, fundamental research with built-in support for science, technology, engineering, and mathematics (STEM) education. For example, ARMD's NASA Research Announcements represent a significant investment in university research, which encourages participating undergraduate and graduate students to work with NASA researchers and its industry partners. The NASA Aeronautics Scholarship Program provides tuition support and pays for student recipients to spend a summer working with NASA researchers at NASA research centers. These direct interactions and hands-on experiences have been helping to inspire students to pursue future careers in the STEM professions.

NASA pursues very challenging and high-payoff aeronautics research goals to bring about revolutionary advancement, not incremental improvement, in technologies and concepts. With inherently high-risk research, the potential for not meeting any specific research metric is always present. NASA is still committed to performing such research and seeks to ensure that our research—even in those cases where the intended results are not achieved—provides valuable knowledge. We mitigate these risks by making certain that NASA's work is relevant to national needs, closely coordinating and collaborating with external partners, and ensuring technical excellence and rigorous technical and program management.

During FY 11, the ARMD programs made significant progress toward their research goals. Specific examples from each program are provided below.

Aviation Safety Program

The extremely high safety record of the National Airspace System (NAS) is a credit to the ongoing vigilance of operators, manufacturers, and regulators and past investments in technology. But even with very low accident rates, the United States always strives to improve this record, and NASA contributes to this continuous improvement through innovation to meet the remaining and emerging safety challenges. The Aviation Safety Program develops innovative algorithms, tools, concepts, and technologies that will improve the safety attributes of current and future aircraft operating in the NAS; identify and control emerging hazards; and overcome aircraft safety–related barriers that could impede full realization of NextGen. During FY 11, the program developed a highly capable data-mining algorithm to identify flight anomalies that could be precursors to safety issues and demonstrated "self-healing" concepts that can mitigate damage in aircraft structural components.

The data-mining algorithms enable the discovery of flight operations and aircraft maintenance issues through automated analysis of the vast amounts of data generated during flight operations and by sensors on board the aircraft. These methods have enabled the development of new software for aircraft central maintenance computers on both business jets and large commercial aircraft that can identify the early stages of hardware faults 30 to 50 flights earlier than previously possible. This enables airline maintenance personnel to address equipment issues before they cause a disruptive maintenance delay at the airport gate. Anomalous flights contain data points that are significantly different from those of other, comparable flights. These events, known as anomalies, could be due to a pilot configuring the airplane for landing (setting flaps and gear) at an inappropriate time or carrying out excessive maneuvering close to the ground, or something that causes unexpected readings from an airplane system. Anomalies may signify operationally significant events that can have a potential impact on flight safety. However, they are contained within massive datasets, and it would be too time-consuming for human analysts to find them without support from highly capable algorithms. These algorithms will detect anomalous flights from within these large datasets, helping analysts identify potential safety issues and conduct targeted studies. The

program developed a highly capable data-mining algorithm that searches data from thousands of flights to discover unusual events that could be precursors to safety issues. The algorithm successfully detected three operationally significant anomalies, data points that are significantly different from the majority of the data, across 177,000 flights. When anomalies are detected, airlines investigate the events and take corrective action if needed.

NASA open-sourced key data-mining software for analyzing flight data recorder output through a collaborative Web site with over 300 members, known as DASHlink. Southwest Airlines (SWA) acquired sequenceMiner and Orca, two advanced anomaly-detection techniques, through DASHlink. Early application of these techniques to data from 7,200 SWA flights uncovered flight anomaly events that were not detected by SWA's existing analysis methods. Events flagged by these software tools are being added to SWA's daily operations review to improve operational performance. Southwest Airlines plans to incorporate these software tools into daily use to better manage their fleet of 305 planes, which fly over 1,600 flights per day.

Self-healing concepts were successfully demonstrated by the program to mitigate damage in aircraft structural elements, helping to improve aircraft safety. Initiation and propagation of damage generally results in the failure of aircraft structural components. Additionally, typical structural repairs often result in damaging practices in which material is ground away and holes are drilled to secure patches, which can act as new sites for damage. The proposed self-healing system provides a nonintrusive means to mitigate damage and is a significant foundation for future self-healing systems. Demonstration results have shown the ability to mitigate fatigue crack spread in metals and to mitigate the effects of impacts on compressive strength in composites. For metals, a heat-activated self-healing material was drawn into fatigue cracks. The material successfully reduced the crack tip driving force of two aerospace materials (aluminum and titanium alloys), dramatically slowing the spread of the crack. For composites, the program developed a carbon-fiber-reinforced composite with a commercially available thermoplastic resin, which self-heals after ballistic impact and through penetration. A healing effect was demonstrated in the developed composite materials by heating these materials under pressure. These capabilities suggest that a healing system can

be scaled up to provide self-healing to damaged structural aircraft components. Work supporting this research and other program accomplishments was done in close cooperation with the program's many partners from industry, academia, and other Federal agencies. The program personnel also published numerous technical papers, gave presentations at conferences, and worked with partners to transfer key technologies.

Airspace Systems Program

The Airspace Systems Program addresses the fundamental air traffic management research needs of increasing capacity, improving efficiency, and reducing the environmental impact of aviation in NextGen in collaboration with its partners in Government, industry, and academia. The program works to directly benefit the flying public by moving key concepts and technologies from the laboratory into the field to facilitate the transfer of technology to end users. Concept simulations and field trials of NASA-developed technologies in real flight environments have demonstrated potential annual savings of tens of millions of dollars to airspace users through reduction in flight delays and fuel usage. During FY 11, the Airspace Systems Program completed a joint NASA-FAA study that demonstrated an effective process called Flow-Based Trajectory Management (FBTM) for managing future aircraft operations; developed a promising technology called Terminal-Tactical Separation Assured Flight Environment (T-TSAFE), which is able to predict the future positions of aircraft; supported testing of the NASA-developed Ground Delay Program (GDP) Parameters Selection Model, which combines National Weather Service real-time data with Air Traffic Control departure scheduling; and made significant progress in the Efficient Descent Advisor (EDA) tool, which will allow efficient aircraft arrival profiles.

The program conducted work in tools and methods for in-flight FBTM in the NextGen. FBTM is a process for solving local airspace problems by modifying flightpaths, or trajectories, of one or more aircraft. These operations provide a practical way to maintain efficient operations in the face of changing local and downstream conditions. Solving the technical challenge of managing in-flight trajectories that extend beyond currently available planning horizons provides one

step toward accommodating increasing airspace capacity. The concept of FBTM has evolved through a series of studies that began in 2006 and culminated in 2011 with a study completed by the joint NASA–FAA FBTM Research Transition Team (RTT). NASA uses the joint agency RTT to conduct research and field trials to accelerate the acceptance of new air traffic management procedures. For the study, the RTT modified current air traffic management procedures to distribute FBTM responsibilities within a "planning team" composed of traffic management and area supervisors. The RTT successfully managed air traffic levels 30 percent greater than today's level. FBTM also can be integrated effectively into today's operations without additional resources. The RTT provided simulation results and tool requirements to the FAA as technology transfer to inform FAA acquisition planning. The results also inform 10 out of 50 Operation Improvements as described in the FAA's NextGen Implementation Plan. The study is an example of successfully transitioned research results from NASA to the FAA and Government collaboration using the RTT model.

The concept and algorithms for T-TSAFE were developed by the program. T-TSAFE uses a trajectory algorithm based on available flight intent information that includes flight plans, area navigation departure routes, speed restrictions, and altitude clearances. Terminal airspace surrounds airports to a radius of about 40 miles. Air traffic controllers managing this airspace guide aircraft as they approach or depart and must maintain separation standards. Separation standards can change depending upon factors such as aircraft weight class, type of approach, visual versus instrument flight rules, and whether the aircraft is transitioning to or from en route airspace. T-TSAFE is able to predict the future positions of aircraft and check them for possible conflicts with significantly fewer false alerts. NASA continues to address additional T-TSAFE challenges to include traffic density, turning angle, and flight plan data availability.

NASA provided support to the FAA to conduct trials of the GDP Parameters Selection Model at San Francisco Airport. A significant reduction in ground delays due to morning fog was demonstrated compared with the airport's current ground delay policy, which often leads to excessive and unrecoverable delays affecting the entire country.

The program also successfully field-tested the EDA tool, which provides air traffic controllers with speed and path changes that will allow efficient aircraft arrival profiles. Current air traffic control operations require an air traffic controller to generate and provide clearances manually (that include path and speeds) so aircraft can arrive at an established point on a route and to time-regulate the aircraft's entry into an airport's terminal area at a scheduled time during the arrival phase of flight. This manual process often results in inefficient paths for an aircraft's flight and descent (particularly during higher traffic density operations), restricting the number of aircraft that can be processed for arrival operations while increasing noise and fuel consumption. EDA's innovation is its transformation of operations from existing procedures to ones that reduce flight time, fuel consumption, noise, and emissions, thus resulting in more environmentally friendly en route and terminal operations. By enabling aircraft to descend on the optimal continuous path, NASA estimates $300 million in fuel savings per year if EDA is implemented fleetwide at the Nation's busiest airports. This type of capability not only will contribute to more efficient operations but also will show the airlines the return on investment they can achieve by equipping their aircraft with NextGen avionics.

Fundamental Aeronautics Program

The Fundamental Aeronautics Program develops knowledge, technologies, tools, and innovative concepts to enable new aircraft that will be faster, cleaner, and quieter and use fuel far more efficiently. The program conducts research on advanced vehicle configurations and concepts; lighter, stronger materials and structures; fuel-efficient, less polluting propulsion systems; advanced concepts for increasing lift and reducing drag; advanced computational tools and capabilities; and modeling and simulation for efficient future air vehicle design. Future air vehicles will demand environmentally sensible and innovative aeronautics technologies and concepts to achieve significantly better performance, higher fuel efficiencies, and reductions in noise and emissions. During FY 11, the program validated a tool used to develop future aircraft configurations and technologies; demonstrated advances in rotorcraft safety and performance; verified supersonic aircraft model

configurations that produce significantly less sonic boom; and completed significant hypersonic engine inlet model testing.

The program confirmed the accuracy of its second-generation aircraft system analysis code used to evaluate and compare future subsonic fixed-wing aircraft designs with respect to predicted noise, emissions, and performance. This tool enables the design of future aircraft that break the mold of current configurations, allowing designers to conceive advanced, unconventional aircraft configurations and evaluate performance with a higher degree of confidence than ever before. Project personnel confirmed the accuracy of this computer code by developing analytical aircraft performance predictions for both conventional and unconventional configurations (ones that are not a tube-and-wing shape) and then verifying the accuracy of these predictions against publicly available data and/or other independent data sources. The code is also used to assess the introduction of new technologies that allow significant improvements in performance for future aircraft and help guide future research to help select and develop the technologies that will have the most impact on an integrated design.

The program made advances in computational modeling for understanding and designing crashworthy rotorcraft by using test data obtained from full-scale crash tests of an MD-500 helicopter, conducted in December 2009 and March 2010. These data were used to calibrate and validate finite element models that contained detailed representations of airframe, seats, occupants, and external energy absorbers. Results and comparisons were very encouraging: the models predicted the pilot floor acceleration response within ±10 percent of the target. The significance of this result is that survivability for helicopter crashes can be predicted to a higher degree of confidence, which in turn can be used to produce safer designs. As the technology evolves to efficiently incorporate more modeling and simulation into the design process, next-generation rotorcraft will contain more crashworthy features without sacrificing weight and performance.

Using wind tunnel tests, the program verified advanced supersonic aircraft models that produce significantly lower sonic booms. These aircraft concepts were designed using NASA-developed computer-based tools for predicting aircraft shape and performance. These tools allow designers to accurately and quickly assess supersonic aircraft shapes and other key attributes of successful supersonic aircraft

flight, such as aircraft efficiency and control, thereby helping to enable new designs that may make much faster forms of transportation possible in the future.

Additionally, program researchers completed significant testing of the changing shape of a hypersonic engine inlet model as airspeed increased to Mach 4. The test results and the associated data analysis, as well as propulsion prediction and design tool developments, establish key knowledge for future applications of turbine-based combined-cycle engines for hypersonic vehicles. This work culminates several years of wind tunnel combined-cycle engine inlet model design and build, small-scale inlet testing, inlet performance tool development, and experimental data analysis.

Integrated Systems Research Program

One of the greatest challenges that NASA faces in transitioning advanced technologies into future aeronautics systems is closing the gap caused by the difference between the maturity level of technologies developed through fundamental research and the maturity required for technologies to be infused into future air vehicles and operational systems. The Integrated Systems Research Program's (ISRP) goal is to demonstrate integrated concepts and technologies to a maturity level sufficient to reduce the risks associated with implementation for stakeholders in the aviation community. The research in this program is coordinated with ongoing, long-term fundamental research within the other three aeronautics research programs, as well as efforts of other Government agencies. This coordination helps to ensure that the most promising research is transitioned between the fundamental research programs and ISRP. The program conducts integrated system-level research on those promising concepts and technologies to explore, assess, and demonstrate the benefits in an operationally relevant environment. The program matures and integrates technologies for accelerated transition to practical applications. One of the program's goals is to reduce the impact of aviation on the environment through the development of vehicle concepts and technologies that can simultaneously reduce aircraft fuel burn, noise, and emissions. During FY 11, the program completed a major design study by three aircraft manufacturers that developed advanced vehicle concepts and associated technology suites capable of simultaneously meeting NASA's environmental goals in aircraft entering service in

2025. The program also achieved significant results related to fuel injector design concepts; a highly fuel-efficient jet engine concept; and low-weight, damage-tolerant composite structures.

The program demonstrated fuel injector design concepts that achieved a significant reduction in nitrogen oxides (NOx) emissions. NOx forms quickly from emissions from aircraft engines (as well as from automobiles, trucks, power plants, and industrial plants) and contributes to the formation of ground-level ozone (smog) and fine-particle pollution. These concepts were developed to efficiently mix the fuel and air to maintain a stable combustion process and minimize the formation of NOx emissions. The program worked collaboratively with industry to develop and test several new combustor concepts that have the potential to reduce NOx emissions by as much as 75 percent compared to emissions from aircraft flying today.

As part of its research on future aircraft engine designs that aim to dramatically reduce the impact of the aviation industry on the environment, the program demonstrated lower noise, high-propulsive-efficiency counter-rotating "open rotor" systems. This engine concept called "open rotor" does not encase the engine fan blades in an engine housing, which is typical in traditional jet engine designs. Research has shown that this concept has great potential to dramatically reduce fuel burn.

The program successfully demonstrated a Pultruded Rod Stitched Efficient Unitized Structure (PRSEUS) panel. This low-weight, damage-tolerant stitched composite structural concept on a curved panel represented the first demonstration of the PRSEUS configuration for conventional-type aircraft fuselage structure, capable of being fabricated and supporting the required combined pressure and tension loading condition. In addition, a successful test of a PRSEUS pressure cube demonstrated that low-weight, damage-tolerant joints in stitched composite structures with fewer fasteners were capable of being fabricated and supporting the required pressure loading.

In FY 11, the program began a new project that will contribute capabilities that reduce technical barriers related to the safety and operational challenges associated with enabling routine civil unmanned aircraft system (UAS) access to the NAS. There is an increasingly urgent need to fly UAS in the NAS to perform missions of vital importance to national security and defense, emergency management, and

science, as well as to enable commercial applications. As part of the UAS integration into the NAS efforts in FY 11, the program worked with JPDO and associated Government agencies to deliver a research, development, and demonstration roadmap for UAS access to the NAS. It also provided a rationale for international support for a radio-frequency spectrum allocation to be addressed at the 2012 World Radiocommunication Conference.

Aeronautics Test Program

The Aeronautics Test Program manages and ensures the strategic availability of a minimum, critical suite of aeronautical test facilities (like wind tunnels and jet engine test facilities), support aircraft, laboratories, and the Western Aeronautical Test Range, which are necessary to meet the long-term aeronautical test requirements of the Nation. The Aeronautics Test Program's ground test facilities consist of various categories of wind tunnels located at Ames Research Center, Glenn Research Center, and Langley Research Center; the flight operations and test infrastructure are located at Dryden Flight Research Center and include the Western Aeronautical Test Range, support aircraft, and the Simulation and Flight Loads Laboratories.

In FY 11, the program successfully executed more than 9,000 hours of ground testing and approximately 1,000 hours of flight testing for NASA and the Nation, achieving high overall customer satisfaction ratings and good facility availability and performance. Strategic initiatives accomplished by the program include investments and upgrades at five major wind tunnels across its portfolio to provide new capabilities, improved facility reliability, and investments in flight assets to enable a new flight research capability.

The program performed critical testing in the Ames Research Center Unitary Plan Wind Tunnel to validate design processes and predictions for a new supersonic low-boom, low-drag design for ARMD's Fundamental Aeronautics Program. Flight testing was performed at Dryden Flight Research Center to execute its Superboom Caustic Analysis and Measurement project, validating computer prediction tools to be used in design of future quieter supersonic aircraft. The program performed several critical tests for DOD, including testing at the Glenn Research Center Icing

Research Tunnel for the Office of Naval Research and at the Langley Research Center 14×22-Foot Subsonic Wind Tunnel for the U.S. Army.

Included in program investments were a new engine icing test capability at the Propulsion Systems Laboratory at Glenn and an acoustic measurement capability at the 14×22-Foot Subsonic Wind Tunnel at Langley that will enable researchers to measure noise signatures from novel aircraft designs at a fraction of the cost of flying real aircraft over airport microphone arrays. The program also modified an existing G-III subsonic research aircraft test bed to enable ARMD flight testing at Dryden, which will result in new experimental flight test capability to assess emerging flight technologies. One of the first intended uses of the aircraft is to enable NASA to explore and mature alternative unconventional aircraft designs with the potential to simultaneously meet research goals for community noise, fuel burn, and nitrogen oxides emissions. Program investments also led to the development and implementation of new and improved test technologies to increase productivity and efficiency and improve research data quality, including investments in the National Force Measurement Technology Capability. The program also finalized a Capability Reliance Framework, a top-level decision-analysis instrument that provides a view of the entire suite of the program's ground test capabilities and includes similar test assets owned and operated by DOD. This decision-analysis tool will inform decision makers about capability needs, the facilities and resources operated by NASA and other entities that could serve those needs, reliance opportunities, condition and life-cycle costs, and other related issues.

Department of Defense

DOD

Aeronautics Activities

Fixed-Wing Vehicles

The Department of Defense (DOD) continued flight test evaluations of the three F-35 Joint Strike Fighter (JSF) variants: the F-35A conventional takeoff and landing, the F-35B short takeoff/vertical landing, and the F-35C aircraft carrier variant. The F-35 completed its 1,000th test flight. The F-35B has performed more than 122 vertical landings, including one on the USS Wasp. The F-35C also completed jet-blast deflector testing and initiated catapult launch testing.

The E-2D Advanced Hawkeye, the Navy's newest airborne early warning and command and control aircraft, completed carrier suitability testing.

The Air Force awarded Boeing the contract to develop its next-generation aerial refueling tanker, the KC-46A, based on the 767-200 platform.

The Air Force Research Laboratory (AFRL) and the Air Mobility Command (AMC) performed flight tests to validate potential fuel savings that might be realized by retrofitting C-130H/J aircraft with drag-reduction devices that have been shown to improve fuel efficiency. The tests indicated the potential for a savings of up to $30 million per year and revealed no adverse effects on the airframe as a result of the change. The first phase of testing assessed the compatibility of microvanes with airdrop missions.

The AFRL and AMC also flight tested a Flight Formation System aboard the C-17. The Defense Advanced Research Projects Agency (DARPA) began developing this system in 2010, and the AFRL continued the project with the goal of

reducing fuel consumption through formation flying. The tests showed a fuel savings of between 8 and 13 percent. Because the C-17 fleet consumes approximately one-quarter of the fuel used by the Air Force each year, savings of 8 to 13 percent are potentially significant.

The Speed-Agile Concept Demonstration, performed at the National Transonic Facility (NTF) and the National Full-Scale Aerodynamics Complex (NFAC) at NASA Ames Research Center, validated a cruise-efficient powered lift system that produced double the lift per unit thrust of a conventional C-17, resulting in a 30 percent improvement in range. The lift system can be employed with commercially available bypass ratio engines and uses bypass airflow to drive circulation control wing flaps. Employing this design approach reduces engine size requirements.

Rotorcraft

The Army demonstrated the performance, vibration, and noise improvements of a helicopter rotor system with active trailing-edge flaps at the NFAC. In related efforts, DARPA's Mission Adaptive Rotor (MAR) program investigated various methods to increase helicopter payload, range, and availability and reduce acoustic signature and vibration by actively morphing the shape and other properties of the rotor system. MAR also uses active rotors with on-blade control in order to eliminate the need for a rotor swash plate. Adaptive features include modification to blade slope, control of individual blades, and variation in rotor speeds.

The Army and NASA began analysis of data acquired during the 2010 UH-60A air loads wind tunnel test at Ames. This test program provided unique measurements on a full-scale UH-60A rotor system under challenging flight circumstances, including high-speed, high-thrust, and slowed-rotor conditions. Measurements included blade pressures and loads, rotor condition, blade displacement and deformation, and rotor wake velocity. Initial analysis verified the quality of the data and identified defects in the computational fluid dynamical models.

The Computational Research and Engineering Acquisition Tools and Environments (CREATE) program released the rotorcraft design tool HELIOSv2.0 in FY 11. HELIOSv2.0 enables off-body adaptive mesh refinement and the ability to handle multiple rotorcraft components.

Balloon Flight Systems

Marines from the 26th Marine Expeditionary Unit used a balloon-based communications system, Lofted Comms, during counterinsurgency operations in Helmand province, Afghanistan. They also launched Lofted Comms balloons from the USS Kearsarge to relay messages to AV-8B Harrier jump jets flying strike missions over Libya.

The Army is in the process of developing a first-of-type, state-of-the-art hybrid airship, the Long Endurance Multi-intelligence Vehicle (LEMV), to provide persistent intelligence, surveillance, and reconnaissance capability. The LEMV hybrid aircraft is designed to generate 40 percent of its lift using aerodynamic forces to increase endurance. The airship was inflated in September 2011 at the integration facility in Lakehurst, New Jersey. After completion of integration and testing, LEMV will be ready for deployment to Afghanistan.

Hypersonics

The second flight of the X-51A Waverider in June 2011 resulted in the loss of the flight vehicle. Despite the loss of the vehicle, data were obtained that identified modifications to the vehicle for another flight. Many of the subsystems worked as expected, including B-52 safe separation, boost, booster separation, guidance and control, flight actuators, battery power, fuel system pressurization, and flight test instrumentation.

A second test flight of DARPA's experimental Falcon Hypersonic Technology Vehicle 2 (HTV-2) on August 11, 2011, ended prematurely when the aircraft failed and stopped sending back real-time data to engineers and scientists who were monitoring the mission. After booster separation, the HTV-2 was designed to maneuver to perform a ballistic atmospheric reentry, execute a pull-up after pierce-point, then fly a long-endurance, in-atmosphere powered glide phase that included maneuvers to help characterize its aerodynamic properties in high-speed regimes. HTV-2 provided data through boosting, apogee reorienting, ballistic return, and atmospheric reentry. Ground control lost contact with the vehicle during its aerodynamic glide phase. The aircraft plunged into the Pacific Ocean after reaching a top speed of approximately Mach 20 on this flight, the second and last scheduled flight for the Falcon program, which began in 2003. For the test, the Falcon was launched from

Vandenberg Air Force Base (AFB) aboard a Minotaur IV. HTV-2 had been modified after its first flight; the changes moved its center of gravity, reduced its angle of attack to increase controllability, and augmented its aerodynamic control surfaces with reaction control system (RCS) steering jets.

The Air Force Office of Scientific Research, DARPA, and the Arnold Engineering Development Center (AEDC) refined and integrated a suite of scientific research tools in AEDC's Tunnel 9; they have been used to measure the performance of hypersonic flight vehicles. Until this development, hypersonic systems were tested and evaluated by measuring integrated forces and moments. These tools provide a new capability in aerothermal analysis. Engineers combined high-frequency pressure measurement practices and computation techniques from academia with surface-temperature-sensitive paint measurements from AEDC. This combination enables developers to predict, measure, and document the global impact of boundary layer instabilities that drive significant heating phenomena on hypersonic systems.

The National Center for Hypersonic Combined Cycle Propulsion (CHCCP), funded by the Air Force Office of Scientific Research and NASA, completed its second year of research. Consisting of teams from industry, Government, and academia, CHCCP is seeking to improve our understanding of the physics and to model three combined-cycle flow regimes: turbine-to-ramjet mode transition, ramjet-to-scramjet mode transition, and hypervelocity operation. Researchers developed a dual-mode combustion wind tunnel to simulate Mach 5 flight conditions, incorporating new laser diagnostic tools such as tunable diode laser absorption spectroscopy and particle image velocimetry. Modeling of experimental data continues using both Reynolds-averaged Navier-Stokes (RANS) and large-eddy simulation/RANS methods. Advanced filter density function and chemical kinetic models are being developed to compute hypersonic turbulent reacting flows.

Unmanned Aerial Systems (UASes)

The X-47B Unmanned Combat Air System (UCAS) made its first flight in February 2011. The airframe's unique configuration combines a kite planform and

a flying wing (called a "cranked" wing) optimized for aircraft carrier operations. Stereolithograph models were used to analyze initial test results and implement design changes quickly. A modified F/A-18D (using the X-47B precision GPS guidance and control laws) successfully completed shipboard surrogate testing aboard the USS Dwight D. Eisenhower. The aircraft achieved a completely automated approach and trap using precision GPS and datalink systems, the first such approach and trap in naval history. The stealthy, tailless X-47B demonstrator made strides toward the long-held Navy goal of marrying persistent, autonomous unpiloted intelligence and strike aircraft with the reach of its fleet of aircraft carriers.

The Navy integrated the MQ-8B Fire Scout UAS into operations on the USS Halyburton. This UAS has been used to chase pirates in the Indian Ocean, watch over troops in Afghanistan, and provide reconnaissance in Libya.

A miniaturized version of the electro-optical portion of the Air Force Sense-And-Avoid (SAA) system was integrated into an Army Shadow and flown in January 2011. On April 25, 2011, the Army flew the Grey Eagle UAS during the first night SAA flights. The midair collision of a drone with a C-130 military cargo plane in eastern Afghanistan on August 15, 2011, highlighted the need for new control strategies and SAA systems. No crew injuries resulted, and the cargo plane was able to make an emergency landing with only minor damage.

The AFRL demonstrated a replacement lithium-ion battery for the Global Hawk Program and developed a derivative B-2 battery set for Global Hawk to replace the three nickel-cadmium batteries, saving approximately 170 pounds and providing additional volume and weight for sensor equipment.

The Air Force Institute of Technology's Department of Aeronautics and Astronautics is continuing research on the development and testing of flapping wing micro air vehicles (FWMAVs). Each wing is individually controlled using a piezo actuator and novel control technique: biharmonic amplitude and bias modulation control, which consists of three independent wing-stroke parameters per wing. Various micromanufacturing techniques were developed to create wing structures, hinge mechanisms, piezoelectric actuators, and support assembly.

DARPA's nano air vehicle program developed Nano Hummingbird, a 19-gram, 16-centimeter-wingspan UAS that can be independently controlled up/down, forward/backward, left/right, and in yaw by modulating the thrust and shape of the

wings using four electric motors. Nano Hummingbird can fly both indoors and out for up to 10 minutes, streaming video back to a palmtop base station. It has demonstrated hover, forward flight at up to 11 miles per hour (mph), and even a 360° autonomous lateral flip. Nano Hummingbird has shown stability of hover in lateral wind gusts of up to 5 mph.

Aircraft Engines, Subsystems, Components, and Other Aeronautical Developments

The AFRL ADaptive Versatile ENgine Technology (ADVENT) program completed risk-reduction tests that verified performance and structural characteristics of a variety of components intended to culminate in a variable cycle turbofan demonstrator engine. Key ADVENT components that were successfully tested include the adaptive fan, compressor, combustor, bearing, and heat exchanger. In addition, AFRL produced advanced high-pressure compressor test rigs under the Highly Efficient Embedded Turbine Engine (HEETE) program, which seeks significant improvements in engine thermal efficiency.

The Army tested upgraded engines for the UH-60 Blackhawk under its Advanced Affordable Turbine Engine program.

AFRL demonstrated a 2.5-megawatt, high-speed generator to industry and DOD. The demonstration showed a tenfold power improvement for its weight/package (360 pounds) over existing state-of-the-art generators. The generator is intended to supply power through a compact package for airborne directed energy applications and other special mission loads.

AFRL demonstrated a high-current silicon carbide power module in a joint Air Force–Army program that led to the first commercial product of that class. This high-current solid-state switch replaces mechanical contactors in electric systems, providing fast reconfigurability and fault protection.

The Army's Joint Precision Airdrop System demonstrated prototype software that enables clusters of guided parachutes to avoid terrain, and each other, during descent. The parachutes are fully autonomous during their entire descent; advanced on-board optimization-based guidance algorithms enable them to fly for several miles using on-board terrain databases for guidance around obstacles and for highly precise landings.

A single 150-foot-diameter Ares main parachute was successfully tested at the Army's Yuma Proving Ground. The 72,000-pound Jumbo Drop Test Vehicle (JDTV) was extracted from a C-17 aircraft at an altitude of 25,000 feet. The JDTV descended under a programmer chute until main parachute deployment. The total extracted weight was 85,000 pounds, a record for C-17 single-payload extraction.

The Navy completed its first aircraft launch using the electromagnetic aircraft launch system designed to replace today's steam-catapult system on next-generation aircraft carriers to reduce maintenance and personnel costs.

The AFRL demonstrated the Automatic Ground Collision Avoidance System (Auto-GCAS). Auto-GCAS performs an automatic avoidance maneuver in order to save the pilot's life, even if the pilot has lost consciousness because of g-induced maneuvers, has become disoriented, or has lost situation awareness. Auto-GCAS performs the automatic recovery maneuver between the point when the pilot normally gets the warning alert and the point of nonrecovery. This capability has been transitioned to the F-16 Block 40 and is being targeted to transition to the remainder of the F-16 fleet and to F-22s and F-35s.

Airborne Weapons Systems and Missiles

The Army's high-energy laser tactical demonstrator was completed and delivered to the Army Space and Missiles Defense Command.

The Missile Defense Agency's Airborne Laser Testbed continued in-flight testing of the laser weapon, building on its missile shoot-down successes in 2010. Working along a similar path, researchers at the Air Force Academy, AFRL, and Lawrence Livermore National Laboratory demonstrated further improvements in the hybrid gas-electric diode pumped alkali laser technology, which has the potential to supersede both solid-state and chemical laser technology with lower logistics footprints and higher efficiencies.

The Airborne Laser (ABL) platform was used this year as a test bed and successfully flew numerous missions in that capacity without engaging in high-power tests. Significant advances were made in different types of chemical oxygen iodine laser efficiencies promising output performance increases of an order of magnitude. DARPA pursued acquisition of the 100-kilowatt-class solid-state high-energy

liquid laser area defense system (HELLADS) for potential applications for future Air Force airborne high-energy demonstrators. The Air Force Research Laboratory conducted preliminary ground demonstrations with its high-power microwave system on a cruise missile named CHAMP (Counter-electronics High-powered Microwave Advanced Missile Project).

In April, the Navy completed the first flight test of a Standard Missile-3 (SM-3) Block IA against an intermediate-range ballistic missile, marking the 19th successful SM-3 intercept. In August, Aerojet accomplished key developmental milestones on its SM-3 Block IB throttleable divert and attitude-control system by completing a series of full-up system tests.

In March 2011, the enhanced version, the Patriot Advanced Capability 3 Missile Segment Enhancement, successfully intercepted a tactical missile target at White Sands.

In March, the Navy conducted a successful test flight of a Trident II D5 fleet ballistic missile. The three-stage, solid-propellant D5 was launched from the submerged submarine USS Nevada in the Pacific Ocean, marking the 135th consecutive successful test flight of the D5 missile since 1989—a 22-year record of reliability unmatched by any other large ballistic missile or space launch vehicle.

The Navy carried out the 25th launch of its Coyote supersonic sea-skimming target vehicle in July 2011, supporting ongoing ship self-defense exercises.

In May, the Air Force completed a series of tests of the next-generation joint air-to-ground missile (JAGM), a single-motor solution for fixed- and rotary-wing platforms. The rockets were subjected to 5 to 20 thermal cycles of –45 to 160°F and successfully fired, meeting all test objectives. In August, the JAGM conducted a demonstration firing of a minimum-smoke rocket motor in fixed-wing aircraft operating in severe weather environments.

Aircraft Survivability

At Wright-Patterson AFB, the Air Force recently investigated laser effects on fuel-backed aircraft composite materials immersed in a high-velocity airstream. The goal was to conduct a test, the first of its kind, of a composite wing box under fully controlled test conditions that included laser engagement during simulated

flight. In order to obtain the necessary test approvals for these weapons, in-lab tests supported by modeling addressed fundamental questions concerning target surface reflectivity, laser burn-through time, energy absorption due to the fluid-backing, and the presence of an airstream. Simultaneously, the Air Force's airflow test facility was reconfigured to create a fully enclosed test operation, complete with laser energy locks. After the approval was granted, three laser tests were performed on a single composite wing box from a UAS. The first two of these tests avoided the fuel tank and were performed merely to verify laser system stability and burn-through times in the presence of an airstream. The final test involved direct impingement on the fuel tank. The test procedure will now transition to assessing the survivability of other military assets against this threat.

Large turbofan engines of both civilian and military aircraft are vulnerable to manportable air defense system (MANPADS) missiles. An important first step toward countering this threat is to understand and determine likely engagement outcomes. Thus the Air Force, the Navy, the Department of Homeland Security, and NASA Langley Research Center have teamed to assess the missile's encounter with a large transport aircraft. Testing involved firing live-warhead missiles into each of two turbofan engines operating at full thrust. Work completed during the past year includes generating high- fidelity predictions of the engine damage and provisioning for the test. This effort also included preparing the test plan, fabricating the test fixture, designing an engine controller, preparing and instrumenting engine test articles, and conducting system checkout tests. Upon the conclusion of each engine test, thrust degradation characteristics and end damage states will be assessed, correlated with damage predictions, and used to evaluate the aircraft's controllability and its ability to perform a safe landing.

Space Activities

The first Defense Space Council (DSC) was held on December 20, 2010. The DSC, chaired by the Department of Defense Executive Agent for Space, serves as the principal advisory forum on all Defense space matters to include providing recommendations regarding Defense space and Defense elements of National Security Space (NSS) to streamline space governance while allowing appropriate interagency

participation; developing, coordinating, and recommending Defense space priorities and strategic guidance for Defense space systems and for Defense space planning and programming; assessing and guiding Defense space requirements, plans, programs, and architectures; promoting cooperation between the Defense and Intelligence Community (IC) space sectors to create effectiveness and efficiency in Defense and IC space programs; aligning DOD requirements, Planning, Programming, Budgeting and Execution (PPBE) guidance, and acquisition with Defense and NSS strategy, policy, and resources; synchronizing Defense space activities; and promoting unity of effort within DOD and the U.S. Government, consistent with NSS strategic objectives.

Launch and Range Operations and Spacelift Developments

The Air Force, through partnership with the United Launch Alliance (ULA), launched eight Evolved Expendable Launch Vehicles to extend the program's record to 43 successful launches out of 43 attempts. Atlas V launch vehicles launched the military's X-37B in March, the NROL-34 spacecraft in April, Space Based Infrared System (SBIRS) Geosynchronous Earth Orbit (GEO) 1 in May, and NASA's Juno spacecraft to Jupiter in August. Delta II launch vehicles launched Argentina's SAC-D satellite with the Aquarius instrument for NASA, the GRAIL mission for NASA, and the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project (NPP) weather satellite for NASA and the National Oceanic and Atmospheric Administration (NOAA), along with six CubeSats. Delta IV launch vehicles launched the NROL-27 satellite and the Air Force's second Block IIF navigation satellite for the GPS. Finally, a Delta IV-Heavy launched the NROL-49 payload. ULA also signed a Space Act Agreement with NASA to collaborate on human rating for crewed flights.

DOD also supported NASA launch events for the second launch of SpaceX's Falcon 9 launch from Cape Canaveral. The Air Force's Eastern Test Range provided vital tracking assets in support of range safety. This successful launch occurred on December 8, 2010.

AFRL successfully tested a hydrogen turbopump under the Upper Stage Engine Technology effort. This project also successfully validated a new set of physics-based modeling, simulation, and analysis tools for liquid rocket engines that the industry is already using in developing new designs and analyzing existing designs. These tools have the potential to save new engine development programs $1 billion compared to how the United States developed the Apollo F-1 and Space Shuttle main engine.

For the U.S. Government, the National Reconnaissance Office successfully launched six satellites over an eight-month period, a launch tempo not seen by them in 25 years.

Also of note was the Army's launch of several CubeSats on a Falcon 9. SpaceX developed and produced the Merlin rocket engine to power the Falcon 9 launch vehicle using liquid oxygen and rocket-grade kerosene propellants.

Global Positioning System

The Air Force launched the second of the GPS Block IIF satellites in 2011 to maintain the constellation as a global utility, providing improved accuracy and enhanced performance for GPS users worldwide.

Satellite Communications

The first Advanced Extremely High Frequency (AEHF) space vehicle, launched on August 14, 2010, overcame a main propulsion subsystem failure during 2011. In 2011, an ad hoc satellite recovery team with representatives from the Space and Missile Systems Center, 14th Air Force, 50th Space Wing, Headquarters Air Force Space Command, as well as the Aerospace Corporation and Lockheed Martin, successfully averted an AEHF-1 mission failure by using on-board propulsion systems, which were not designed for orbit placement, to ease the satellite into its planned orbit.

DOD launched the Tactical Satellite-4 (TacSat-4) space vehicle, which was developed by the Naval Research Laboratory for the Office of Naval Research and the Operationally Responsive Space (ORS) Office. TacSat-4 will enable deployed military members utilizing handheld radios to contact and task the experimental

asset even in many now-problematic mountainous and urban areas. In September, the TacSat-4 satellite was launched from the Kodiak Launch Complex on a Minotaur-IV. The Navy-led joint tactical microsatellite mission features a 12-foot-diameter deployable antenna with 10 ultrahigh-frequency (UHF) channels battlefield commanders can use with a multitude of existing communications systems. Placed in a low, highly elliptical orbit, TacSat-4 can provide long dwell times over intended theaters of operations to enable communications on the move, blue force tracking, and data exfiltration.

Space-Based Intelligence, Surveillance, and Reconnaissance

The Air Force launched the first SBIRS GEO satellite, a long-anticipated milestone in upgrading our Nation's missile warning capability. SBIRS GEO-1 will provide missile warning, missile defense, battlespace awareness, and technical intelligence products to deployed warfighters, national leadership, and U.S. allies. The satellite employs staring and scanning infrared (IR) sensors, supporting revolutionary simultaneous strategic and theater surveillance.

DOD launched the ORS-1 satellite. The ORS-1 effort stemmed from an urgent request by U.S. Central Command for additional space-based intelligence, surveillance, and reconnaissance capabilities.

The Air Force launched the Commercially Hosted Infrared Payload (CHIRP) in September 2011 as part of the SES-2 telecommunications satellite on an Ariane 5 rocket out of Kourou, French Guiana. CHIRP is a technology-maturation and risk-reduction experiment to collect real-world data, investigate spacecraft-sensor interactions and sensor behavior in the space environment, explore operational issues relevant to these sensors, and evaluate long-term suitability of commercially hosted payloads. This effort marks the first time the Air Force has integrated a payload into a commercial satellite.

Air Force Space Command continued operational control of AFRL's TacSat-3 and demonstrated the capability to provide space-based hyperspectral images and information that meets the needs of U.S. tactical warfighters. The spacecraft delivered over 2,100 hyperspectral images and demonstrated the ability to transmit processed data to a tactical ground station within 10 minutes.

Satellite Control and Space Situation Awareness

DOD launched the Space-Based Space Surveillance (SBSS) satellite to enhance awareness of deep space objects of interest for safety of flight, threat detection, and warning. This system was launched on September 25, 2010, and became operational during 2011. SBSS significantly improves the timeliness of data on space objects in transit to deep space orbits and is exceeding performance expectations, demonstrating excellent focus, high stability, and superb photometric sensitivity.

In 2011, space professionals used the Air Force Satellite Control Network to conduct over 159,000 satellite contacts and to support 15 launches and more than 20 space vehicle emergencies, averaging 450 satellite contacts per day. The Air Force Satellite Control Network provides launch support, the capability to receive satellite telemetry and command and control of U.S. Government and allied spacecraft once on orbit.

The Space Surveillance Telescope (SST) achieved first light (began operating) on February 15, 2011, delivering the capability to routinely maintain the entire deep space catalog.

Space Situation Awareness (SSA) partnership agreements were signed between the United States and France in February 2011 and between the United States and Canada in March 2011. These documents, signed by the U.S. Secretary of Defense and the respective countries' ministers of defense, provide overarching policy, guidance, and emphasis for SSA cooperation between these countries.

The first reentry of the ReEntry Breakup Recorder (REBR) occurred on March 29, 2011, while the instrument was attached to the Japanese HTV-2 supply vehicle. The REBR is a small, autonomous device that records temperature, acceleration, rotational rate, and other data during the reentry of space hardware into Earth's atmosphere and during the subsequent breakup due to aerodynamic heating and loads. REBR includes a heat shield that protects the instrument and its recorded data from the severe reentry heating environment. Recorded data are transmitted through the Iridium satellite network, and REBR recovery is not needed. The first-ever recorded data from an intentionally destroyed spacecraft enables the validation of reentry hazard models in support of DOD safety requirements. Future collection of additional REBR data will enable spacecraft and launch stages to be designed to minimize risks from surviving debris.

The Air Force's multi-mission spacecraft operations center began operations at the beginning of 2011, marking a new milestone for responsive space missions. The Army opened a new Wideband Space Operations Center in Hawaii in February 2011.

Other Space Developments

A second X-37B Orbital Test Vehicle (OTV) was launched aboard an Atlas V on March 5, 2011, and landed safely during FY 12. The OTV mission is to test new space technologies. The X-37B was launched on its first orbital flight on an Atlas V rocket in April 2010. The spacecraft was placed into LEO for testing. As scheduled, the X-37B deorbited, reentered Earth's atmosphere, and landed at Vandenberg AFB on December 3, 2010.

The Naval Research Laboratory is nearing completion of two tethered satellite systems to demonstrate electrodynamic-tether (EDT) propulsion in LEO. TetherSat, being built in conjunction with the Naval Academy, will test the deployment of a 1-kilometer tether connecting two 1.5-unit CubeSat end masses. (A CubeSat unit is a volume of 10 by 10 by 10 centimeters.) The Tether Electrodynamic Propulsion CubeSat Experiment (TEPCE) will perform orbit maneuvers. Extensive testing this year included tether deployment experiments in vacuum chambers and by freefall in air. These tests validated tether deployment driven by a long-stroke spring called a stacer, which pushes the end masses apart at 4 meters per second and then stabilizes the deployer attitude. The launch of TetherSat and TEPCE by the Air Force's satellite test program is expected in 2012.

An Air Force Office of Scientific Research–funded team from academia and industry continued its research on the use of energy-harvesting EDT systems. Such systems can generate power and propulsion on spacecraft using EDTs by storing energy in and deriving energy from the "orbital battery."

Federal Aviation Administration

FAA

The Federal Aviation Administration's (FAA) Next Generation Air Transportation System (NextGen) is a wide-ranging transformation of the entire NAS to meet future demand and support the economic viability of the system while reducing delays, improving safety, and protecting the environment. NextGen is not a single piece of equipment or a program or a system that will instantaneously transform the NAS. It is an evolutionary process, and existing systems must be sustained in the transition. NextGen builds on legacy systems to increase capability in today's airspace system, adds new performance-based procedures and routes, and ultimately delivers programs that will transform the NAS.

In FY 11, NextGen continued improving safety and adding real dollars to the bottom line. Using Automatic Dependent Surveillance-Broadcast (ADS-B), a GPS-based technology, aircraft are able to fly more safely and efficiently in previously challenging areas. ADS-B–equipped helicopters flying over the Gulf of Mexico benefited from radar-like air traffic services for the first time. ADS-B radio stations deployed along the shoreline and on oil platforms blanket the area with air traffic surveillance, increasing the safety of all operations. This same surveillance improved efficiency in the Gulf through more direct routing of ADS-B–equipped helicopters, reducing both their operating cost and their environmental impact. In Colorado, new surveillance technologies enabled controllers to track aircraft flying through challenging mountainous terrain. Currently, over half of the ADS-B ground infrastructure has been deployed.

Several airlines began using GPS-based Required Navigation Performance (RNP) approaches at a dozen airports in 2011. In Alaska, airlines using RNP approach procedures at Juneau International Airport are able to fly precisely through mountainous terrain in low-visibility conditions thanks to the higher navigational accuracy of GPS.

In Atlanta, using more efficient descent procedures designed under NextGen, airlines saw savings in fuel costs. Aircraft descend continually to the runway with engines idle, as opposed to descending in a stair-step fashion and using the engines and burning fuel to power up at each level-off point. One airline is equipping its fleet with NextGen technology to help save time and money as pilots transport goods in and out of its hub, estimating a 25 percent to 30 percent savings in fuel burn on arrival.

The FAA conducted Initial Tailored Arrival (ITA) flight demonstrations at San Francisco, Los Angeles, and Miami. ITAs are pre-negotiated arrival paths through airspace of multiple air traffic control facilities; they limit vectoring and minimize the time the aircraft spends maintaining level flight during its descent. ITAs differ from other types of Optimized Profile Descents (OPDs) in that they are assigned by controllers to specific approaches and tailored to the characteristics of a limited number of Future Air Navigation System (FANS)-equipped aircraft types—747s, 777s, A330s, A340s, and A380s. The agency estimates that the 747s saved an average of 176 gallons of fuel per arrival in ITAs and 78 gallons per flight in partial ITAs, compared with fuel usage in conventional approaches. For 777s, the corresponding savings were 99 gallons in full ITAs and 43 gallons in partial ITAs.

NextGen operational capabilities will make the NAS safer. ADS-B improvements in situational awareness—on the ground and in aircraft—will increase controllers' and pilots' individual and combined ability to avoid potential danger. Among other benefits, these improvements could provide valuable time savings in search-and-rescue efforts. Appropriately equipped aircraft will be able to receive, displayed directly to the flight deck, information about nearby traffic, weather, and flight-restricted areas.

More precise tracking and information sharing will improve the situational awareness of pilots, enabling them to plan and carry out safe operations in ways they cannot today. Air traffic controllers will become more effective guardians of

safety through automation and simplification of their most routine tasks, coupled with better awareness of conditions in the airspace they control. Additionally, NextGen will facilitate the implementation of Safety Management System processes for the air traffic controllers' use.

Advances in tracking and managing operations on airport surfaces will make runway incursions less likely. Fusing surface radar coverage from Airport Surface Detection Equipment-Model X (ASDE-X) with ADS-B surveillance of aircraft and ground vehicles will increase situational awareness, particularly when linked with runway status lights.

Collaborative decision making will increase everyone's understanding of what others are doing.

Starting with pre-takeoff advisories, departure instructions, and reroutes for pilots, we will use data messages increasingly instead of voice communications between pilots and controllers, reducing opportunities for error or misunderstanding. Voice channels will be preserved for the most critical information exchange.

As with safety, the agency's work to mitigate aviation's influence on the environment also benefits—and is a beneficiary of—NextGen. The operational improvements that reduce noise, carbon dioxide, and other greenhouse-gas emissions from aircraft are the tip of the FAA's environmental iceberg. Equally important are the other four-fifths of the agency's environmental approach—aircraft and engine technology advances, sustainable fuels, policy initiatives, and advances in science and modeling.

Environmental benefits of operational improvements are simple and direct. When efficiency in the NAS is improved, time and fuel savings will improve. Burning less fuel produces less carbon dioxide and other harmful emissions. Some of the agency's NextGen improvements, notably landing approaches in which aircraft spend less time maintaining level flight and thus can operate with engines at idle, reduce ground noise too. But operational benefits go only so far; their net systemwide effect can be offset by growth of the aviation system.

To accommodate system growth, the FAA is supporting the development of aircraft, engine, and fuel technology. The agency's Continuous Lower Energy, Emissions and Noise (CLEEN) program continues its work to bring promising new airframe and engine technologies to maturity, ready to be applied to

commercial designs, within five to eight years. Similarly, the FAA is part of a Government-industry initiative, the Commercial Aviation Alternative Fuels Initiative, to develop sustainable low-emission alternative fuels and bring them to market.

The FAA developed and is using the NextGen Environmental Management System (EMS) to integrate environmental protection objectives into NextGen planning and operations. The EMS provides a structured approach for managing agency responsibilities to improve environmental performance and stewardship. The FAA also analyzed the effect of market-based measures, including cap-and-trade proposals, on aviation environmental policy and standards.

In FY 11, the FAA continued the expansion of its work on demonstrations, trials, and initial deployment of NextGen systems and procedures. NAS operators and users—particularly participants in the demonstrations and trials—continue to benefit from them.

Also in FY 11, the FAA's Office of Commercial Space Transportation (AST) continued to regulate the safety of U.S. commercial space transportation, as well as to encourage, facilitate, and promote industry growth.

A key area of AST activity involved issuing licenses and permits to commercial space transportation launch operators and launch sites. Two new launch-specific licenses were issued, involving the following:

- SpaceX's Falcon 9 vehicle, operating from Cape Canaveral Air Force Station (CCAFS), and
- Orbital Sciences Corporation's Taurus II at Wallops Flight Facility (WFF).

Five launch operator license renewals were granted, including

- Orbital Sciences Corporation's Pegasus at WFF,
- Orbital Sciences Corporation's Pegasus at CCAFS,
- Boeing's Delta II at CCAFS,
- Boeing's Delta IV at CCAFS, and
- SeaLaunch's (transferred to Energia Logistics) Zenit 3SL from a mobile launch platform in the Pacific Ocean.

Two launch-site (spaceport) operator license renewals occurred. These involved the Oklahoma Spaceport and the California Spaceport, colocated with Vandenberg Air Force Base (VAFB).

One new reentry launch license was issued for SpaceX's Dragon capsule. One new experimental permit was issued to Blue Origin to launch from its West Texas launch site.

Authorized by AST licenses and permits, a number of commercial spaceflights took place. Three licensed launches occurred, including a Delta II launch of an Earth observation satellite from VAFB; a Falcon 9 launch of the Dragon capsule from CCAFS, followed by the licensed reentry of the capsule; and a Zenit 3SL launch of a communications satellite from its mobile launch platform in the Pacific. Two suborbital flights took place under the authority of AST experimental permits, conducted by Blue Origin in West Texas.

Beyond this, AST supported NASA's three final Space Shuttle missions. AST provided real-time reentry support during these flights. In fact, following the Space Shuttle Columbia failure in 2003, AST supported all 22 remaining Shuttle missions. AST benefited from Shuttle mission experience in preparing for the reentries of the SpaceX Dragon and other commercial orbital transportation vehicles. Shuttle expertise contributed to developing a number of useful tools and procedures.

Also directly impacting public safety, AST carried out inspections associated with a multitude of AST-regulated activities. The goal of every safety inspection was to ensure safe operations by verifying licensee, permittee, and safety approval holder compliance with FAA regulations and license/permit/safety approval terms and conditions. Overall, in FY 11, AST conducted 52 safety inspections. Inspectors traveled to a variety of locations, including Florida (CCAFS and Jacksonville), California (VAFB, Mojave, Hawthorne, and Long Beach), Texas (McGregor and Caddo Mills), New Mexico (Upham and Las Cruces), Oklahoma (Burns Flat), Virginia (WFF), Alaska (Kodiak), Nevada (Black Rock), and the equator.

Another significant aspect of AST's public safety role involved environmental evaluations. Such evaluations supported eventual site license renewals and modifications. In FY 11, AST completed evaluations involving the California Spaceport, Oklahoma Spaceport, and Virginia Commercial Space Flight Authority. In addition, AST continued to monitor the New Mexico Spaceport Authority's compliance with Federal historic preservation requirements and other requirements related to biological resources for the development of Spaceport America. AST also carried out environmental evaluations associated with the eventual issuance

or renewal of launch operator licenses for Taurus II, Pegasus, Atlas V, Delta IV, Falcon 9, and Zenit 3SL, as well as reentry licenses involving the Dragon and Cygnus orbital cargo transportation vehicles. In addition, AST completed environmental evaluations pertaining to the issuance of experimental permits for vehicles developed by SpaceX (Grasshopper) and Blue Origin.

As for development of commercial space transportation infrastructure, AST continued to administer a grant program on behalf of the FAA. Space Transportation Infrastructure Matching Grants were solely discretionary; required matching contributions from other, non-Federal sources; and funded projects that directly developed and expanded infrastructure. In 2011, grant awards totaled $500,000. The three grant recipients were the New Mexico Spaceport Authority, the Alaska Aerospace Corporation, and the Virginia Commercial Space Flight Authority/Mid-Atlantic Regional Spaceport.

As for AST's research and development (R&D) portfolio, growing activities constituted a key part of the Office's mission to encourage, facilitate, and promote commercial space transportation. FY 11 involved the continuing consolidation of initiatives into a single programmatic effort. Activities entailed conducting research in four main areas: space traffic management and operations; space transportation operations, technologies, and payloads; human spaceflight; and space transportation industry viability. R&D activities were executed both in-house and by contractor and university (grantee) personnel. The most prominent R&D entity among these was the FAA Center of Excellence for Commercial Space Transportation (COE CST), a partnership of academia, industry, and government. The partnership was developed to address current and future challenges for commercial space transportation. In FY 11, COE CST began its first full year of operation with the selection and implementation of 25 tasks across the nine member universities, involving 27 principal investigators and 31 students. For the second year of operation, the number of tasks was expected to grow to 30, with results from the first year's efforts beginning to be published in the academic literature.

Another important initiative to encourage the growth of commercial space transportation was AST's 14th annual conference, held in February 2011. Cosponsored by the American Institute of Aeronautics and Astronautics (AIAA), the event took place at the Walter E. Washington Convention Center in

Washington, DC. Featuring high-level speakers and panels, the conference examined the state of technology and capabilities in the commercial space transportation sector, as well as economic and regulatory issues. Prominent speakers included Robert T. Bigelow, founder and president, Bigelow Aerospace; Brewster H. Shaw, vice president and general manager, Space Exploration, Boeing Defense, Space and Security; Joe Engle, former X-15 pilot and Space Shuttle astronaut; Michael C. Gass, president and chief executive officer, United Launch Alliance; and Wayne Hale, director of human spaceflight programs, Special Aerospace Services. Also speaking at the event were Ray LaHood, U.S. Secretary of Transportation, and J. Randolph "Randy" Babbitt, FAA Administrator. According to Dr. George C. Nield, FAA Associate Administrator for Commercial Space Transportation, the outstanding array of keynote speakers and panelists ensured that all attendees left the conference with a much better understanding of the issues confronting the U.S. commercial space transportation sector.

Also supporting commercial industry growth in FY 11 were several AST reports and publications, including the *Flight Safety Analysis Handbook, Version 1.0.* The *Handbook* was designed to help launch and reentry vehicle operators conduct flight safety analyses. The document reflected the results of a survey of common industry practices and identified those practices most appropriate to launch vehicles. In addition, AST continued to issue annual revisions of several ongoing reports, including *US Commercial Space Transportation Developments and Concepts: Vehicles, Technologies, and Spaceports*; *Semi-Annual Launch Reports*; *Commercial Space Transportation 2010 Year in Review*; and *2011 Commercial Space Transportation Forecasts*. The forecasts were prepared by the industry-led Commercial Space Transportation Advisory Committee in cooperation with AST. Projections for 2011 to 2020 included an average worldwide demand of about 16 launches per year to geosynchronous orbit and approximately 13 launches per year to nongeosynchronous orbits.

In summary, FY 11 represented another year of successful progress for the FAA's Office of Commercial Space Transportation, which worked effectively to protect public safety as well as to encourage, facilitate, and promote industry growth. Additional information about the Office is available at *http://ast.faa.gov*.

Department of Commerce

DOC

During FY 11, the Department of Commerce (DOC) participated in interagency efforts to implement elements of the 2010 National Space Policy and develop updated policies addressing specific aspects of space activity.

DOC continued to participate in the national management of the Global Positioning System (GPS) as a member of the National Executive Committee for Space-Based Positioning, Navigation, and Timing, the senior body that advises and coordinates Federal agencies on GPS matters. DOC hosted four meetings of the committee and its Executive Steering Group to discuss major policy issues, including protecting GPS users from potential interference due to a communications network (LightSquared) licensed to broadcast in frequencies next to GPS. Through the National Oceanic and Atmospheric Administration (NOAA), DOC participated in interference testing that showed harmful impacts to GPS users and conveyed its concerns to the Federal spectrum authorities. In testimony before Congress, NOAA Deputy Under Secretary Mary Glackin described a range of serious impacts to NOAA's daily operations if GPS interference were to become widespread.

DOC continued to host the offices of the National Executive Committee. DOC staff planned and executed a major redesign and relaunch of its Web site, *http://www.gps.gov*, as the central pillar of the Government's GPS outreach campaign. The site quickly became a top result in Internet searches for "GPS."

NOAA participated in bilateral consultations, led by the State Department, with Australia, Japan, and Europe to discuss cooperation on GPS issues. NOAA's Office of Space Commercialization continued to serve as the U.S. cochair of a U.S.-European working group on trade issues affecting satellite navigation markets.

DOC participated in an American Meteorological Society workshop on the effects of space weather on satellite navigation, culminating in the publication of an April 2011 report highlighting vulnerabilities and recommending steps to strengthen the integrity and robustness of GPS-based services.

National Oceanic and Atmospheric Administration

NOAA's environmental satellites are key tools for forecasting weather, analyzing climate, and monitoring hazards worldwide. In FY 11, a year full of exceptionally destructive natural disasters, these satellites helped scientists and meteorologists at NOAA monitor severe flooding of the Mississippi River; a devastating tsunami in Japan; and a particularly destructive tornado season that included a single outbreak of 358 tornadoes across the southeastern United States and, one month later, the catastrophic EF5 tornado in Joplin, Missouri. Twenty-four-hour global coverage from NOAA's satellites provides scientists and managers with a never-ending stream of information used in preparation for events that will impact our climate, weather, and oceans. NOAA manages and operates two groups of environmental satellites: Geostationary Operational Environmental Satellites (GOES) and Polar-orbiting Operational Environmental Satellites (POES).

NOAA's Geostationary Satellites

GOES satellites continuously monitor the Western Hemisphere by circling Earth in a geosynchronous orbit 22,000 miles above the equator, meaning they remain over one position on the surface by orbiting at a speed matching Earth's rotation. Information from GOES is used for short-term weather forecasting and severe-storm tracking. GOES imagery is also used to estimate rainfall during thunderstorms and hurricanes for flash-flood warnings, as well as to estimate snowfall accumulation and overall extent of snow cover. This information helps meteorologists issue winter storm warnings and spring snow-melt advisories. In FY 11, GOES-11 flew at 135°W and served as "GOES-West," while GOES-13 flew at 75°W and served as "GOES-East."

NOAA's Polar-Orbiting Satellites

POES satellites circle Earth in an almost north-south orbit at an altitude of approximately 517 miles, passing close to both poles. Earth constantly rotates counterclockwise underneath the path of the satellites, allowing a different view with each orbit. It takes a satellite approximately 1.5 hours complete a full orbit. In a 24-hour period, the 14 orbits of each polar-orbiting satellite provide two complete views of weather around the world. POES provides full global coverage with advanced sensors for weather and climate data, collecting information on temperature, atmospheric conditions, wind speed, cloud formation, and drought conditions over the entire planet. In FY 11, NOAA-19 served as NOAA's primary polar-orbiting satellite.

International Agreements

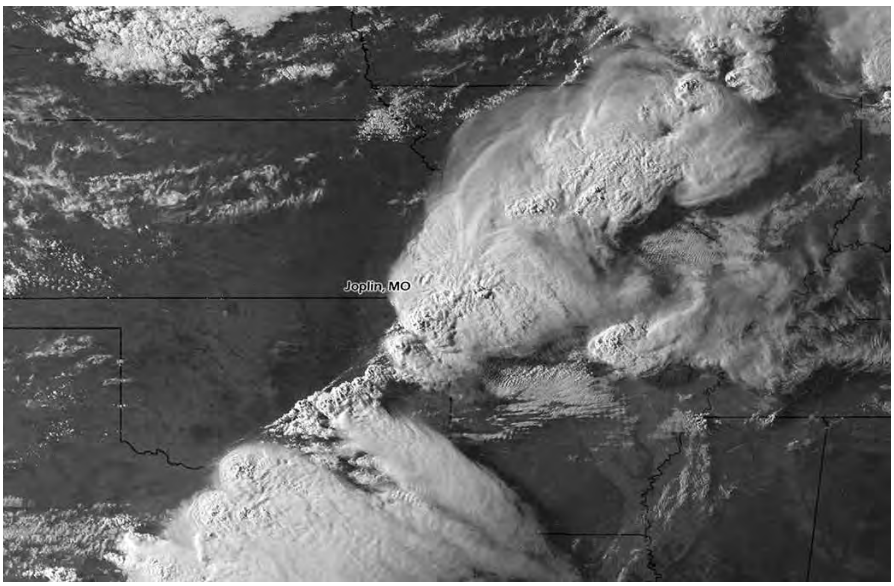
On July 18, 2011, NOAA entered into an agreement with the Japan Aerospace Exploration Agency (JAXA) for satellite information that will help scientists understand water circulation and climate change. Once launched in 2012, NOAA will receive access to data from the Global Change Observation Mission-Water 1 (GCOM-W1) satellite in exchange for ground system support for JAXA. GCOM-W1 will carry the Advanced Microwave Scanning Radiometer 2 (AMSR2) instrument, which observes water-related targets such as precipitation, water vapor, and snow depth. AMSR2 data will complement data from NOAA's future Joint Polar Satellite System (JPSS) and meet key NOAA observational requirements in areas such as total water vapor content, cumulative cloud and water volume, and rainfall. GCOM-W1 data will contribute to a range of environmental data products used routinely in weather forecasting. Access to the data will allow NOAA to have improved forecasting skill without having to build and launch a similar satellite.

Other Accomplishments

Antarctica Station Cuts Data Delivery Latency in Half

On June 10, 2011, the Antarctica Data Acquisition (ADA) Station successfully began receiving images from the European Organisation for the Exploitation of Meteorological Satellites' (EUMETSAT) Metop polar-orbiting satellites for the first

time in history, allowing NOAA to process and deliver information from the polar-orbiting satellites to weather data users in the United States and around the world approximately twice as fast as the previous rate. The Metop series records meteorological and environmental data used by U.S. and European weather services for analyses of fires, tropical cyclones, volcano plume, and precipitation and general weather pattern observations. NOAA's Office of Satellite and Product Operations (OSPO) implemented technology at the ADA Station—located at the U.S. National Science Foundation's (NSF) McMurdo Station—that lets it download images from a Metop satellite when it reaches the South Pole. Previously, images from a Metop satellite were downloaded only at the Svalbard Ground Station at the North Pole.

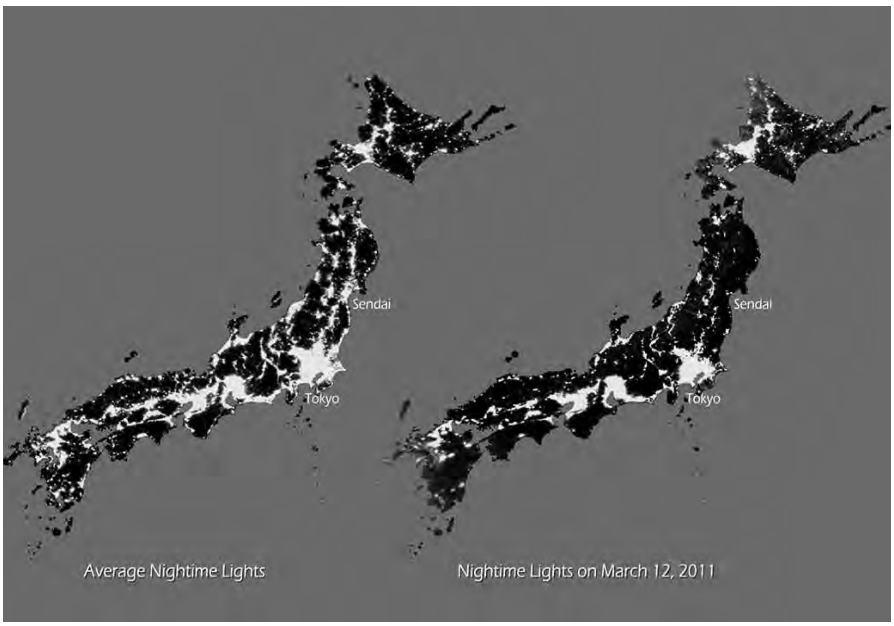


The city of Joplin, Missouri, was devastated by a powerful tornado that spun through a densely populated part of town. This image, from GOES-13 on May 22, 2011, shows the storm system moments before it spawned the tornado, estimated to have struck shortly before 6 p.m. CST. Many houses, many school buildings, and the St. John Medical Center sustained major damage.

NOAA Provides Flood Imagery for Major Disasters

NOAA's Center for Satellite Applications and Research (STAR) provided real-time flood maps to support emergency response to the March 2011 tsunami in Japan and the May 2011 flooding in the U.S. Midwest. The STAR Geostationary Operational Environmental Satellite Series R (GOES-R) land application team used satellite images to create a product to detect flooding and standing water.

The imagery was rapidly disseminated to decision makers and the public to permit informed flood response, which involves developing plans for disaster preparation when a threatening flood approaches and monitoring active floods. After the tsunami in Japan, STAR created a flood map for the coast line of Sendai, Japan, in a quick response to a request from the U.S. Government. NOAA, NASA, and other agencies used this map online through NOAA's Web sites. STAR also created a map of the levee breach near the confluence of the Ohio and Mississippi Rivers.



The earthquake and tsunami that impacted Japan on March 11, 2011, crippled the Nation's power supplies, leaving many areas without, or with less, electricity. On March 12, 2011, a U.S. Defense Meteorological Satellite Program (DMSP) satellite, a polar-orbiting Department of Defense satellite operated by NOAA, passed over Japan and was able to detect the nighttime lights from the region. The data are shown here in comparison to the average nighttime lights of Japan taken from several DMSP satellite passes during 2010. Much lower light levels can be seen in many areas of Japan. Sendai, near the 9.0 earthquake epicenter and also the area hardest hit by the tsunami, is almost completely blacked out.

NOAA manages the command, control, and data processing of the DMSP satellites. Data come from the Operational Linescan System sensors. Nighttime lights imagery is one of the many data products generated by DMSP. For example, the microwave sensors on board the satellite have provided meteorologists with the longest continuous data archive for many variables on Earth, including sea ice concentration and atmospheric moisture.

National Institute of Standards and Technology

In FY 11, the National Institute of Standards and Technology (NIST) continued to provide Federal agencies and the aerospace industry with the research, guidance, standards, products, and services needed to advance the presidential administration's space agenda. These wide-ranging outputs fall into four main categories: 1) validation, measurement, and calibration; 2) manufacturing technology; 3) observation and sensing; and 4) spacecraft and living environments.

NIST supported accurate and compatible measurements made by the aerospace industry by providing Standard Reference Materials (SRMs) and calibration services. Customers used these SRMs and services to ensure the accuracy of their own instrument calibrations and the validity of their measurement methods. In 2011, aerospace companies purchased 50 SRMs, including ferrous and nonferrous metals certified for chemical composition and for hardness, as well as artifacts certified for nanoscale dimensional properties. Additionally, in 2011, 94 aerospace companies from 21 states and 7 foreign countries requested 278 calibrations of 4,133 instruments or artifacts sent to NIST. These tests spanned NIST's entire calibration services offerings, including dimensional, force, vibration, ionizing and optical radiation, mechanical, thermodynamic, and time/frequency measurements, thus providing these companies with a source of metrological traceability for their primary measurement standards.

NIST continues to provide the tools, methodologies, standards, and measurement services needed by aerospace parts manufacturers, assemblers, and NASA to maintain their accurate and traceable use of the International System of Units (SI) units of length, mass, and time, as well as their derived units (force, acceleration, sound pressure, and ultrasonic power). For example, NIST performed calibrations of length standards for U.S. aerospace companies to ensure that the dimensions of their manufactured parts conform to design specifications. Traceable NIST measurements (mass, force, vibration, acoustics, electricity, thermometry, humidity, flow, pressure, viscosity, fluid density, radiometry, and length) are essential for aircraft manufacturing, according to a senior Boeing metrologist. Further, in the manufacture of the company's new 787 airplanes, every tool used in the assembly process was calibrated in Boeing's metrology laboratories with direct traceability

to NIST. Structural testing of the airplane is performed by scores of load cells with up to 3.54 meganewtons (800 kilopounds-force, or klbf) capacity. These load cells are central to the structural testing of the first full-scale composite wing/titanium wing box. The load cells, used to analyze the integrity of the wing box structure, are directly traceable to NIST either through direct comparison with NIST-calibrated load cells or through calibration in the Boeing 221-kilonewton (50-klbf) deadweight machine whose masses were calibrated at NIST. Other direct applications of NIST measurements included the use of NIST-calibrated weights to support wind tunnel applications; the weighing of airplanes; and torque, pressure, and force measurements.

NIST worked with EMCORE Corporation of Albuquerque, New Mexico, a leading developer of high-efficiency solar photovoltaic cells for space applications, to "space-qualify" their solar cells. EMCORE sent batches of solar cells for irradiation by an electron beam from the NIST Van de Graaff accelerator, where the equivalent electron fluency experienced by a satellite over several decades in Earth orbit may be delivered in less than 1 hour. Characterizing the degradation in performance of the solar cells as a result of irradiation is an important part of the qualification process, validating the performance of the cells in a space-radiation environment. The knowledge gained by the irradiation of these devices assisted EMCORE in the development of its technology in terms of product reliability and functionality.

NIST has recently begun work with DOD and with Boeing on the applicability of laser scanning technology for the dimensional measurement of aircraft components. This new technology offers potential cost savings and increased measurement throughput. The work includes the development of calibration methodologies and facilities for laser scanner systems and national and international standardization of their measurement accuracy.

NIST continues to develop and characterize measurement methods for advanced optics used in aerospace and space applications. Advanced optical elements are essential components of air- and space-borne imaging systems and telescopes. They must incorporate features that yield vastly improved performance but pose significant measurement challenges. Examples are complex, highly accurate optical surfaces that are neither flat nor spherical or ones that have micro- and nanoscale surface structures. In collaboration with NASA, NIST developed a method that

employs a mirror with a special height relief pattern to assess the capability of inspection equipment to measure fine surface features on optical surfaces. NIST furthermore collaborated with NASA, supported by funding through NASA's Innovative Partnerships Program, to develop a new interferometric method to precisely measure the form errors of mandrels needed for the fabrication of x-ray mirrors for future space-borne x-ray telescopes. The new method, based on a pair of computer-generated holograms, has the potential to meet the metrology requirements for the next generation of x-ray mirrors, which cannot be met with the current probe-based metrology for mandrels. These collaborations built on prior joint developments by NIST and NASA for the calibration of reference optical flats for precision interferometry.

NIST also continues to work in the development of nanometrology for nanomanufacturing. The aerospace industry is interested in the potential benefits of nanotechnology. The development of accurate nanometrology of small particles and structures is critical to the success of this effort. For example, a Reference Material has been made available for scale calibration of optical, scanning probe, and scanning particle beam instruments to the same dimensional standard. The use of this standard has also been extended to the measurement and monitoring of beam-induced contamination in scanned particle beam instruments. Using this standard and the methods developed, NIST has virtually eliminated the deposition of contamination on the specimen, which is a common artifact in these instruments (which are critical to imaging, measurement, and characterization for nanotechnology). In addition, these methods have applications in other areas, such as cleaning optical surfaces. NIST research is also being conducted to characterize and monitor instrumentation performance and standardization to ensure accurate dimensional metrology of carbon composites, carbon nanotubes, and cellulose nanocrystals. Nanocomposite material offers the advantage of lighter airframes, giving better fuel economy; however, it still needs to be determined if the material provides the necessary high strength and durability. To facilitate this, NIST developed a new scanning electron microscope imaging technique to help determine the carbon nanotube loading in composite materials.

Using instruments developed to help improve semiconductor electronics, NIST has worked with Johns Hopkins University and NASA to measure the optical

constants of iron and nickel. Iron metal is a key component of many planetary surfaces. It is present as macroscopic grains (larger than the wavelength of light) in a variety of meteorites and is inferred to exist in the asteroidal parent bodies (e.g., S- and M-types). In addition, much smaller (nanometer to micrometer) grains of metallic iron are produced to varying degrees in the surfaces of airless solar system bodies by exposure to the space environment. Space weathering (which includes solar wind sputtering and micrometeoroid impact melting and vaporization) results in the reduction of ferrous iron in silicates to the metallic state and the creation of nanophase blebs and coatings on and within regolith particles. The nanophase iron ($npFe^0$) is optically active and has a strong effect on the reflectance spectrum. For example, a mature lunar soil that has accumulated $npFe^0$ is much darker and has a steeper spectral slope than a freshly ground powder of the same lithology; diagnostic absorption bands are also greatly attenuated in space-weathered material. In support of Johns Hopkins University's efforts to analyze remote and laboratory spectra of planetary surfaces, NIST has undertaken a program to measure the optical constants of iron and nickel. The optical constants (n and k) are fundamental physical parameters that govern the reflectance (and transmission) of light from a material. NIST has measured n and k from extended wavelengths ranging from 150 nanometers to 4,000 nanometers for high-purity iron films using ellipsometry, including bare films exposed to the atmosphere and films protected from the atmosphere via a novel technique involving an iron coating on a fused silica prism. The air-exposed film exhibits optical constants that are markedly different from those of the protected film, despite the fact that the air-exposed film appears to the eye to be bright and mirrorlike. Analysis of the air-exposed film by x-ray photoelectron spectroscopy confirms the presence of oxidized iron (Fe_2O_3) on the surface, and NIST scientists conclude that oxidation layers form rapidly on the air-exposed metal and measurably alter the optical properties.

NIST provided quality assessment of atomic data used by astronomers who are interpreting observations from NASA's land- and space-based missions, including the Hubble Space Telescope, the Chandra X-ray Observatory, the Far Ultraviolet Spectroscopic Explorer, and the Spitzer Infrared Observatory. In 2011, NIST provided results for atomic sulfur, neon, titanium, chromium, nickel, barium, strontium, iron, silver, mercury, and other elements of particularly strong current

interest. For each type of atom, NIST provided a single, self-consistent set of best values from the frequently inconsistent, incomplete, and heterogeneous-quality data scattered across the open literature. NIST published these evaluated datasets in peer-reviewed scientific journals and disseminated them publicly through NIST's online Atomic Spectra Database (*http://physics.nist.gov/asd*). These data are used as standards across the astrophysics community and facilitate the comparison of results from different astronomers. This work was partially funded by NASA.

NIST measured atomic properties required to make use of observations from NASA's ultraviolet and infrared spaced-based observatories. Comprehensive data for iron and chromium atoms, two of the most important atoms for interpreting data from these observatories, were recently published by NIST. The NIST analyses provide over an order of magnitude increase in accuracy over the previous data, which were over 30 years old. Additional data for chromium and cobalt are currently being analyzed. This work was partially funded by NASA.

NIST provided a new release of its online Atomic Spectra Database, v.4.1.1. Following this release, the average volume of data downloaded per month by all users doubled compared to the amount downloaded using previous versions. This change indicates that data are of high importance. The new release features significant improvements to the spectral data on a range of elements critical to aerospace efforts. This work was partially funded by NASA.

NIST announced a new measurement service that provides accurate measurements of the area of optical apertures. This new service improves the operation of optical apertures that are used in a variety of remote sensing instruments, such as satellite sensors, that measure the amount of optical radiation coming from Earth or the sun, as well as apertures in various radiometric standards needed to calibrate remote sensing instruments.

NIST published a report in the *NIST Journal of Research* summarizing the discussions in the NIST workshop called "Bridging Satellite Climate Data Gaps." The report addresses the issue of data gaps in time series of satellite measurements of climate variables such as sea surface temperature, ocean color, vegetation level, soil moisture, and atmospheric temperature. Gaps can be caused by a satellite failure on launch or on orbit or by a satellite launch delay. The report provided a variety of

strategies to mitigate the impact of such a gap on maintaining accurate long-term climate variable time series.

NIST provided calibration support for the infrared and optical sensors for several satellite missions under development: JPSS, GOES-R, the Landsat Data Continuity Mission (LDCM), and the second Orbiting Carbon Observatory (OCO II). NIST activities included the provision of radiometric standards, the validation of radiometric standards used by the sensor development teams, and the calibration and characterization of satellite sensors.

NIST, in partnership with the University of New Mexico, Harvard University, and the Smithsonian Institution, continued a research program to improve the absolute radiometric calibration of stars for applications that include satellite sensor calibration, dark energy research, and nighttime aerosol monitoring.

Scientists from NIST, the Jet Propulsion Laboratory (JPL), and the California Institute of Technology collaborated on the pre-launch and post-launch calibration of the Cosmic Infrared Background Experiment (CIBER) which has flown three times: first in February 2009, again in July 2010, and finally in March 2012. CIBER is designed to characterize various properties of the near-infrared background, including its absolute photometric spectrum and spatial anisotropy. These are critical measurements that constrain the overall stellar content of the universe, particularly at very early epochs when the first generation of stars was formed. The CIBER calibrations were performed using a transportable version of the NIST Spectral Irradiance and Radiance Responsivity Calibrations using Uniform Sources (Traveling SIRCUS) facility. The SIRCUS calibration provided the most accurate available measurements of the CIBER absolute spectral response and has allowed several critical science topics to be addressed. Primarily, the NIST calibration has enabled a detailed analysis of the CIBER data, allowing the disentanglement of local contributions like the zodiacal diffuse galactic light from the much more faint and distant extragalactic background. Furthermore, the NIST calibrations are critical for allowing comparison of the CIBER data to previous measurements and models, some of which have already been excluded by the CIBER data. As a side-product of the exceptionally accurate calibration provided by SIRCUS, the CIBER team will release a catalog of several hundred calibrated stars to the astronomical

community; the catalog will be a unique and valuable dataset due to the lack of atmospheric extinction over a broad spectral range.

NIST developed calibration protocols for acoustic emission, a method used to detect subsurface macroscopic defects in fiber-based composites. A draft standard addressing these protocols is currently being balloted by American Society for Testing and Materials (ASTM) International. NIST also worked with several partners to develop protocols and reference specimens for calibrating nondestructive evaluation (NDE) instruments to enable more reliable detection of subsurface macro- and microscopic defects. Specifically, NIST established a noise-free calibration artifact for determining baseline performance in acoustic emission sensors. These sensors are widely used by NASA to detect breaks in fiber-reinforced structural composites. In addition to establishing the noise-free standard, NIST developed a protocol for calibration to specifically meet the needs of the aerospace industry. This documentary standard is currently under review by ASTM. NIST's continued development of calibration standards will improve the accuracy of the data obtained through acoustic emission while also providing key scientific insights into composite manufacturing that will enable long-term reliability of the structural materials used in military and commercial aircraft and long-duration spacecraft.

NIST worked with the Air Force, as well as industry and NASA, in fuels research geared toward developing alternative fuels and generating an understanding upon which to base innovative designs for jet and rocket propulsion systems. Major foci of the work involved combustion kinetics, chemical characterization, and thermophysical properties. In particular, NIST evaluated properties of synthetic Fischer-Tropsch fuels (including several renewable bio-based fluids) and rocket/jet fuels.

NIST's Synchrotron Ultraviolet Radiation Facility (SURF) III was used as a source of soft x rays and extreme ultraviolet (EUV) light to calibrate mirrors, detectors, and spectrometers used in NASA and NOAA spacecraft. These include calibrations of rocket-borne instruments to maintain the accuracy of the instrumentation for the EUV Variability Experiment (EVE) aboard NASA's Solar Dynamics Observatory (SDO) and others. NIST performed spectral irradiance measurements of the collimated output infrared beam from five separate space simulation chambers used in the aerospace industry for the calibration of infrared remote sensing systems for the Missile Defense Agency. One of these deployments

utilized the NIST-developed Ballistic Missile Defense Transfer Radiometer (BXR), and four other deployments utilized the NIST-developed Missile Defense Transfer Radiometer (MDXR). Both of these are portable cryogenic radiometers. The BXR is the legacy NIST portable infrared filter radiometer for this application, and the MDXR is an improved system that can be operated as an infrared filter radiometer or as an infrared spectral radiometer using a recently developed cryogenic Fourier-transform spectrometer. While the MDXR was constructed to meet the infrared calibration needs of the missile defense community, it also has applications in the calibration of test sources and calibration standards for infrared astronomy.

NIST collaborated with NASA on the calibration and characterization of the Ocean Radiometer for Carbon Assessment (ORCA), a hyperspectral ocean color imaging system under development at NASA through the Instrument Incubator Program.

NIST continued its collaboration with NOAA on the calibration of the Marine Optical BuoY (MOBY) used in the vicarious calibration of ocean color measurements provided by satellite sensors.

The NIST Fluid Metrology Group makes airspeed and hydrocarbon liquid flow measurements to support the aerospace sector. The airspeed calibration service performs calibrations of anemometers used at airports, on aircraft, and in wind tunnels used for testing new aircraft. The hydrocarbon liquid calibration service calibrates flow meters that are used to meter jet fuel, for example, turbine meters used to evaluate jet engine performance on test stands. During the past year, NIST worked to improve these measurements by researching the influence of fluid properties (density and viscosity) on turbine flow meter performance. This work will lead to the use of less toxic and inflammable surrogate fluids by NIST and secondary calibration labs in the aerospace calibration chain. The NIST Temperature and Humidity Group provides measurement services for traceable temperature and humidity to support NASA's missions. Additionally, the group is actively involved in accreditation activities, through the National Voluntary Laboratory Accreditation Program (NVLAP), with companies that support NASA (e.g., Wyle Laboratories). The NIST Pressure and Vacuum Group invented a revolutionary transfer pressure standard that can be used in an FAA-proposed project aimed at safely narrowing separation distances between aircraft, known as Reduced Vertical Separation Minima

(RVSM). This potentially exciting application would help to alleviate air traffic congestion around the Nation's airports.

NIST helped resolve long-standing discrepancies in the data used to determine temperature and other properties of hot astronomical objects observed by the Chandra X-ray Observatory and other x-ray missions. NIST created, in the laboratory, atoms in the same extremely hot form as that found in high-energy astrophysical environments. By analyzing x-ray emission from these atoms and comparing them to detailed calculations, NIST provided the basic data needed to understand observations from deep space. NASA partially funded this effort carried out in collaboration with the Harvard-Smithsonian Center for Astrophysics and the Argonne National Laboratory.

NIST began the construction of a new facility, the Controlled-Background System for Spectroradiometry and Spectrophotometry (CBS3). This facility will contain an evacuated, temperature-controlled infrared test chamber for studying the performance of sensors, calibration sources, and the optical properties of materials in the 5-micrometer to 50-micrometer infrared spectral region to provide the measurement standards and calibrations required for the next generation of infrared satellite sensors used for weather forecasting and climate research.

NIST initiated the construction of a new facility to permit more rapid and accurate measurements of the bidirectional reflectance distribution function (BRDF) of materials, including polarization sensitivity, in support of ground- and space-based remote sensing throughout the solar reflected region.

NIST is collaborating with NASA's Goddard Space Flight Center (GSFC) to develop photodetectors for space applications. With funding from NASA, NIST designed and fabricated nanotextured gallium nitride (GaN) and GaN nanowires that serve as raw material for photocathode detectors. Goddard collaborators activated the material with cesium and packaged the units into complete imaging systems. In FY 11, this collaboration tested GaN nanowires with magnesium (Mg) doping that varied with depth and found that these performed better than previously tested nanowire samples. They also concluded that nanowire samples performed better when cleaned with similar processes that had been developed for planar materials.

NIST is collaborating with the Jet Propulsion Laboratory (JPL) on the development of superconducting nanowire single photon detectors (SNSPDs). SNSPDs are a type of single photon detector with extremely low noise and very-high-speed

response. These devices are of interest to JPL for space communications and to NIST for various quantum information experiments. NIST characterized various JPL devices and also packaged some JPL devices with NIST's self-aligned single-mode optical fiber packaging scheme.

NIST is teaming with Northrop Grumman and the University of Maryland to develop the next generation of highly sensitive, solar-blind, ultraviolet (UV) photodetectors using robust wide-bandgap materials. This project successfully combines Northrop Grumman's expertise in nitride materials growth, NIST's exceptional nanofabrication and characterization capabilities, and the University of Maryland's device design and fabrication expertise. Such radiation-hard, ultra-sensitive ultraviolet photodetectors are intended for use in radiation monitors, satellite-based imaging, and other space applications.

With NASA funding, NIST is also developing Superconducting Quantum Interference Devices (SQUIDs) and SQUID-based multiplexers to read out large arrays of TES detectors in a manageable number of output channels. NIST is providing SQUID systems to many researchers, both those at NASA Centers (GSFC and JPL) and those in academia working on NASA-funded projects (including at the California State Polytechnic University; Stanford University; the Massachusetts Institute of Technology; the University of California, Berkeley; Princeton University; and Cornell University). SQUIDs and SQUID multiplexers developed at NIST are currently deployed in many ground- and balloon-based instruments (ACT, BICEP2/Keck, SPT, BLISS, GISMO, SPIDER, EBEX, and others) and will be used in most of NASA's future TES instruments. Recent developments for improved detector readout include the demonstration of TES readout with dissipationless microwave SQUID multiplexers, the demonstration of code-domain multiplexers for subframe sampling for measurement of fast x-ray pulses, and new low-power SQUID amplifiers for use at focal plane temperatures. Recently (in collaboration with the University of Colorado), NIST has developed a quantum limited Josephson parametric amplifier for use in the readout of microwave kinetic inductance detectors (MKID). NIST's work in detector readout and multiplexing creates a path for truly large (up to 1 million) pixel arrays of TES detectors for use in a variety of astronomical instruments. NIST is also using its SQUID expertise to assist Goddard in the development of magnetic micro-calorimeters.

NIST and international collaborators also successfully delivered eight imagers (10,240 total pixel count) for the Submillimeter Common-User Bolometer Array (SCUBA-2) camera. The SCUBA-2 instrument is currently in shared-risk observing mode, allowing preliminary scientific observation to be made concurrent with system startup. The new camera is based upon eight 1,280-pixel SQUID multiplexer chips and eight 1,280-pixel TES bolometer arrays fabricated at NIST. This ground-based instrument is not funded by NASA, but it is a technical pathfinder for a number of future NASA instruments. The SCUBA-2 instrument was commissioned for research in October 2011.

NIST continued work on new concepts to achieve on-chip electrical cooling of cryogenic detectors. These on-chip coolers, based on superconducting tunnel junctions, could greatly simplify spacecraft cryogenic requirements by providing a final on-chip stage of cooling from 0.3 kelvin (K) to 0.1 K. Researchers at NIST have developed large-area coolers fabricated using standard microelectronic processes. These devices have demonstrated cooling from 260 millikelvins (mK) to 115 mK with cooling power 100 to 1,000 times greater than previous demonstrations. In collaboration with researchers at GSFC, NIST also fabricated and operated devices that combine both TES detectors and electrical refrigerators on a single chip.

NASA Kennedy Space Center (KSC) was the first measurement laboratory to implement NIST's newly developed 10-volt programmable Josephson Voltage Standard. This system will be used for calibrating NASA standards and is the first in the world to provide stable voltages whose accuracy is determined by quantum behavior. It is also the first Josephson system capable of performing calibrations of alternating current (AC) voltages at 10 volts. NIST is collaborating with KSC to incorporate new software features and hardware that will make the system simpler to transport, including a compact microwave synthesizer and an on-board embedded controller.

In collaboration with Goddard (Microwave Sensors and Hydrological Sciences Branch), NIST demonstrated the world's first SI-traceable brightness-temperature or radiance calibration of a microwave black-body target, as used in space-based radiometers that monitor Earth's climate. NIST has designed the world's first facility to precisely measure the performance of millimeter-wave antennas using a robotic

arm. It will operate at first to 210 gigahertz (GHz) and ultimately to 600 GHz. This facility will allow NIST to perform accurate calibrations of radiometer antennas above 110 GHz, a capability currently not available to the aerospace community.

In collaboration with the University of Colorado (CU) Center for Astrophysics and Space Astronomy, NIST demonstrated a prototype easily portable new system to precisely measure the tiny changes in wavelength of infrared light emitted from stars caused by the orbit of Earth-like exoplanets. The NIST/CU system uses femtosecond laser frequency combs to make ultraprecise, ultra-stable wavelength references in the infrared spectrum around 1,600 nanometers (nm). About 80 percent of the exoplanets discovered so far have been identified by the radial velocity technique of measuring tiny changes in the wavelength of the star's emitted light over weeks to months as the orbiting exoplanet causes the star to "wobble" slightly. However, the great majority of exoplanets so far detected with the radial velocity technique are large gas planets closely orbiting hot stars that emit strong visible light. Thus, the detectable exoplanets are much too hot to support Earth-like conditions and life as we know it. Cooler stars emitting mostly infrared light are very common (comprising about 2/3 of the stars nearest our solar system) and could support Earth-like exoplanets orbiting much closer to the stars and detectable by the radial velocity technique. But no good, ultra-precise, ultra-stable infrared wavelength references have been available, in contrast to suitable visible light references. The NIST/CU team developed a prototype compact, portable, ultra-precise, ultra-stable infrared wavelength reference based on the technology of laser frequency combs that won NIST a share of the 2005 Nobel Prize in Physics. The NIST/CU frequency comb reference was transported to and tested at the Hobby-Eberly Telescope at the MacDonald Observatory in Texas. The initial prototype testing, done in collaboration with astronomers from the Pennsylvania State University (PSU), resulted in the first stellar spectra calibrated with a frequency comb. Following this successful demonstration experiment, the NIST/CU team is now building a fully autonomous, stand-alone frequency comb operating near 1,000 nm, which is the preferred wavelength band for observing the cooler stars mentioned above. In parallel, collaborators at PSU are developing the Habitable-Zone Planet Finder, which will be the world's most precise spectrograph for this same wavelength band. In 2015, the NIST/CU frequency comb and the PSU

spectrograph will come together again at the MacDonald Observatory to begin a systematic search for exoplanets around 300 nearby stars.

NIST also works with NASA on secure communications. The NIST Cryptographic Module Validation Program and the Cryptographic Algorithm Validation Program (CAVP) have had an ongoing relationship with NASA, specifically with NASA's Langley Research Center, in providing technical assistance with Federal Information Processing Standard (FIPS) 140-2: Security Requirements for Cryptographic Modules, as well as other cryptographic-based standards. NASA works with many vendors and other government space agencies, such as the Japan Aerospace Exploration Agency (JAXA), who develop cryptographic modules for unique environments (e.g., space-based or ground-based telemetry) where interpretation of FIPS 140-2 is critical to both development and conformance to the standard. As a result, the NIST programs have successfully validated vendor-developed cryptographic modules for conformance to FIPS 140-2 that are deployed for space-based imaging and communication systems. Recent cryptographic validations were in use on vehicles contracted to the International Space Station (ISS) under NASA's Commercial Resupply Services program. The ongoing NIST collaboration with NASA and suppliers continues with specific application to the Orion Multi-Purpose Crew Vehicle (MPCV) and NASA's Commercial Crew Development programs.

NIST supports NASA with its unique capabilities at the National Center for Neutron Research (NCNR). Polymer nanocomposites seek to enhance the thermal, mechanical, and electrical properties of the base polymeric matrix material. Electrical properties of nanocomposites are crucial in many aerospace applications, including lightning strike dissipation in air vehicles and electrical charge mitigations in space vehicles in the charged space environment. In addition, robust mechanical properties are necessary in a wide range of temperatures for fundamental structural material components. NIST partnered with Edwards Air Force Base to use small-angle neutron scattering (SANS) to measure electrically conducting polyaniline nanofiber/polyimide nanocomposites. The study determined that the level of electrical conductivity in these heterogeneous materials depends primarily on the concentration and geometry of the conductive filler particles. The observed critical filler content that marks the onset of increase in conductivity

in the majority of these composites falls between 15 and 25 percent (vol/vol). At such high filler concentrations, many of the desirable mechanical properties of the matrix polymer are either compromised or lost. However, when the conductive components are reduced in size from macro- to nano-sized, the concentration threshold for conductivity is dramatically reduced with the additional advantage of preserving the bulk mechanical properties of the matrix polymer.

An additional collaboration with NASA Glenn Research Center studied the synthesis and properties of several proton exchange membranes for fuel cell technology. SANS measurements were critical to understanding the morphology and distribution of small ionic clusters within these films that impart their ability to exchange protons. The goal of this partnership is to produce materials with lower costs, higher conductivity, and improved temperature stability.

As a part of the Materials Genome Initiative, NIST is exploring with Glenn methods to improve data informatics tools and accessibility for materials data.

With NASA funding from the Planetary Instrument Definition and Development Program (PIDDP), NIST has worked to develop microsensor technology for use in planetary exploration missions. The NIST sensing technology for the measurement of trace gas-phase compounds is inherently small, with low mass and low power consumption, and these features are well suited to extraterrestrial deployment and operation on rovers, atmospheric sampling balloons, trend-monitoring weather stations, or networks. The fabricated devices include silicon microelectromechanical systems (Si-MEMS) array platforms that are populated with varied chemiresistive materials. Rapid thermal modulation is employed to greatly enhance signal densities from sets of individually addressable "microhotplate" elements within the arrays to sense multiple analytes. Nanostructured oxide sensing materials provide the sensitivity required to detect targets of interest at relevant concentration levels. As a demonstration scenario, efforts were specifically directed to future exploration of the Martian surface that will seek to locate hot spots of methane and then determine if there is also proximal sulfur dioxide (suggesting volcanic activity) or ethane or hydrogen (possibly indicating a biological origin).

A critical aspect of NIST studies during FY 11 related to developing appropriate sensing, with the goal of demonstrating microsensor viability in the background conditions found on the Martian surface—which is dominated by carbon dioxide

and is very low in oxygen. Initial testing of the NIST technology was successful at measuring sub-µmol/mol target concentrations. In FY 11, NIST designed and constructed a testing facility that operates at the reduced pressures (7.5 hectopascals [hPa]) and temperatures (200 K) found in the Mars environment.

The NIST Manufacturing Extension Partnership (MEP) program maintains a network of 60 centers, with at least one in every state and Puerto Rico. These MEP centers offer business and technical assistance services to the Nation's manufacturers. The aerospace industry is experiencing a twofold challenge to meet the growing needs of domestic and worldwide government customers. These customers are demanding higher visibility in the supply chain while maintaining high-performance, lower-cost standards. These pressures are creating opportunities for small- and medium-sized manufacturers who are capable of moving beyond offering simple products to presenting differentiated product-service bundles based on innovative ideas. In FY 11, MEP centers engaged in 214 business improvement projects with 138 individual manufacturing companies designated with an aerospace North American Industry Classification System (NAICS) 3364 code. MEP aerospace clients reported 2,140 jobs created and retained for this time period. Some examples of MEP projects impacting aerospace companies include efforts of the Connecticut State Technical Extension Program (CONNSTEP) to improve supply-chain efficiencies in the Connecticut aerospace industry. Connecticut has one of the highest concentrations of small and mid-sized aerospace suppliers in the Nation. CONNSTEP, in conjunction with aerospace suppliers, is doing Two-Tier Value Stream Mapping projects. The maps cover the flow of product between companies. The first case was with an aircraft-bearing manufacturer and its heat-treating vendor. The second was with an external jet-engine tube manufacturer and its plating supplier. Both were extremely successful, and CONNSTEP has at least one additional project planned with one of these companies.

In Ohio, the Ohio MEP is working with Airbus on a supplier initiative. This initiative was developed to aid Airbus in the recruitment and development of small business, minority, and disadvantaged suppliers. The Ohio MEP has a similar initiative in place with GE Aviation.

Industry and Trade Policy

The International Trade Administration's (ITA) Office of Transportation and Machinery (OTM) participated in the development of administration policies on aeronautical R&D through the National Science and Technology Council's (NSTC) Aeronautics Science and Technology Subcommittee (ASTS). In FY 09, the ASTS completed the first biennial update to the National Aeronautics Research and Development Plan (R&D Plan), which establishes research goals and objectives for Federal aeronautics R&D investments in priority areas. To follow that exercise, in FY 10, the ASTS completed the first biennial update to the National Plan for Aeronautics R&D and Related Infrastructure, which establishes aeronautics R&D goals, objectives, and guidance outlining the path forward for implementing the R&D Plan. With the completion of the 2011 Progress Assessment, the ASTS completed its five-year national aeronautics R&D planning and assessment cycle. Following the completion of the 2011 assessment, the ASTS engaged in deliberations to define its next steps. These discussions led to a consensus among the ASTS membership that its future work program should encompass the following:

1. continuing integrated R&D planning across the Federal agencies;
2. developing and implementing, as appropriate, measures for improving the dissemination of R&D results;
3. facilitating technology transition from R&D to applications; and
4. identifying and promoting innovative policies and approaches that complement and enhance the Federal Government's aeronautics investments.

OTM participated in the planning and implementation process for the Next Generation Air Transportation System (NextGen) through the interagency Joint Planning and Development Office (JPDO) overseeing the initiative. OTM staff continued to represent the Department of Commerce on both the Global Harmonization Working Group (GHWG) and the Aviation Security Working Group. As part of the GHWG, OTM staff supported the GHWG Executive Committee and cochaired the Liaison Standing Committee (which is charged with collaborating with the other working groups on technological and procedural developments with global implications). Further, OTM staff coordinated the review of various JPDO documents, including the Harmonization Roadmap,

JPDO suggestions to International Civil Aviation Organization (ICAO) regarding air traffic management standard and recommended practices (SARP) and ICAO's Aviation System Block Upgrade initiative, the JPDO's Targeted NextGen Capabilities for 2025, and the Avionics Roadmap. The ICAO is a United Nations specialized agency, created in 1944 upon the signing of the Convention on International Civil Aviation (Chicago Convention). ICAO works with the Convention's 191 Signatory States and global industry and aviation organizations to develop international SARPs which are then used by States when they develop their legally-binding national civil aviation regulations. OTM staff also began work to form a NextGen Vendors Group to improve outreach to industry, garner market intelligence, create strategies for increased foreign market access, and build a catalog of NextGen-related products and services to help promote exports.

OTM continued its participation in aviation security activities, including work on the JPDO Aviation Security Working Group. As part of the Secure Aircraft Standing Committee, OTM staff contributed to the creation of the Secure Aircraft Scenario, which suggested optimal technological and operational standards that would allow for both secure and efficient in-flight operations. OTM staff took part in various security technology demonstrations and presentations to determine viability and provide perspective on the state of aviation security technology. OTM staff worked to ensure cooperation between the GHWG and the Aviation Security Working Group with regard to specific projects, such as the Flight Data Initiative (advanced flight data recorder technology) and the Security Integrated Tool Suite (for assessing the threat level of various flight objects), as well as to the integration of unmanned aircraft systems (UASes) into common airspace. OTM also assisted the Commercial Service in recruiting for aviation security–related trade missions to the Netherlands and Sweden in March 2011.

OTM updated market and policy assessments for civil-use UASes. OTM continued public outreach on UAS issues through meetings with major UAS manufacturers at the 2010 Farnborough International Air Show and other UAS conferences. OTM also met with FAA officials on their small-UAS rule to ensure that the future rule addresses industry concerns regarding airspace access.

In September 2010, ITA signed a Memorandum of Understanding with Embry-Riddle Aeronautical University's (ERAU) Worldwide Center for Aviation and

Aerospace Leadership to promote U.S. aerospace industry competitiveness through joint outreach, research, and other activities.

Throughout the year, OTM organized and led five meetings of the Industry Trade Advisory Committee for Aerospace Equipment (ITAC 1). The committee provides advice to the Secretary of Commerce and U.S. Trade Representative on aerospace-related trade policy issues.

ITA continues to support the Office of the U.S. Trade Representative on issues relating to the enforcement of U.S. rights under the World Trade Organization concerning trade in civil aircraft. In particular, OTM has provided support for the ongoing U.S.–European Union (EU) trade dispute over subsidies to manufacturers of large civil aircraft, providing industry expertise in areas relating to changes in the market and the actions of the major stakeholders.

ITA's OTM and Office of Financial Service Industries continued to participate in the Group on the Sector Understanding on Export Credits for Civil Aircraft (the "Aircraft Sector Understanding," or ASU) at the Organization for Economic Cooperation and Development (OECD). The governments of almost all countries with major aircraft manufacturers are signatories to the ASU, an annex to the OECD Arrangement on Officially Supported Export Credits, which establishes rules for export credit agencies. The OECD rules aim to ensure that government-provided export financing is not a competitive factor in civil aircraft sales competitions. In 2011, a new round of negotiations was concluded; it addressed several issues related to the 2007 ASU. As a member of the U.S. delegation, ITA helped ensure that the interests of industry were incorporated into the U.S. position and provided advice on how the Export-Import Bank of the United States (Ex-Im Bank) programs affect the aerospace industry.

ITA and NOAA continued their active participation in the implementation of the current National Space Policies, which include industrial base and competitiveness issues. ITA's OTM actively participated in the implementation of several actions that were identified in the June 2010 National Space Policy, which revised and updated several aspects of the previous policies. In order to ensure that commercial interests continue to be adequately addressed, OTM and NOAA continued to ensure that all of the policies' implementation actions would improve U.S. industry's competitiveness, stimulate the American economy, increase exports, and create U.S. jobs.

OTM continues to represent commercial remote sensing satellite industry interests within the Remote Sensing Interagency Working Group (RSIWG), led by the State Department. The RSIWG coordinates policy for the export of commercial remote sensing satellite systems and negotiates government-to-government agreements that address the safeguarding of those systems' technology. The RSIWG consulted with several foreign countries on satellite cooperation and met with industry representatives to understand the impact on industry.

ITA continued to play an important role in promoting U.S. aerospace trade interests as the industry faced mounting competition from abroad. ITA participated in and organized trade events and provided advocacy to support U.S. companies in international aerospace competitions, including commercial sales for aircraft, helicopters, airport construction, communications, remote sensing satellites, commercial projects, and air traffic management projects.

In June 2011, ITA organized and supported the Commerce Department's participation in the Paris Air Show and arranged senior-level meetings for the Under Secretary for International Trade and the Assistant Secretary for Manufacturing and Services with foreign government and industry officials as well as U.S. industry executives. ITA/OTM met with numerous U.S. and foreign government and industry officials to discuss ongoing policy issues impacting the competitiveness of U.S. industry.

OTM organized several meetings of the Civil Aviation Subcommittee of the U.S.-India High Technology Cooperation Group. The group provides a platform to discuss industry-specific trade issues in both business-to-government and government-to-government formats. Important topics of discussion included the expansion and upgrade of India's airport infrastructure and air traffic management system, as well as the development of India's domestic business aviation industry.

In FY 11, ITA's U.S. and Foreign Commercial Service Aerospace Team recorded 363 export successes valued at over $20 billion. An export success is an activity in which Department of Commerce personnel effectively assist a U.S. company with identifying new international sales channels or resolving an issue that is hindering an export sale. Commercial Service (CS) personnel impacted deals with small- and medium-sized companies, as well as larger corporations such as Boeing, Lockheed Martin, Raytheon, and Northrop Grumman.

The CS Aerospace Team held over 500 counseling sessions with U.S. aerospace companies, helping them to resolve international trade issues, identify new export markets, and develop strategies for entering those markets.

The CS Aerospace Team participated in 30 domestic and international aerospace trade events at which CS Aerospace Team members supported U.S. industry with one-on-one counseling sessions, arranged individualized business-to-business meetings with international business partners, and provided additional export counseling services. ITA trade show support generated hundreds of trade leads for participating companies, allowing them to enter or expand their exports to international markets. These international trade events included the Paris Air Show, Asian Aerospace, and an Aerospace Supplier Development Trade Mission to Russia, among others.

Department of the Interior

DOI

The many bureaus in the Department of the Interior (DOI) rely on remotely sensed data to assist them in fulfilling their mission to measure, monitor, and evaluate surface features on land for which they carry responsibilities. The bureaus use a wide range of remotely sensed data from Government-managed satellites, commercial satellite sources, elevation data, GPS, aerial photography, and unmanned platforms. The collective data complement and supplement field studies and eventual analysis and interpretation. Reports from the bureaus illustrate the importance and uses of the remotely sensed data resources.

The National Park Service

Alaska Region continued the use of remote sensing technologies to manage nearly 55 million acres of national park resources. Alaska is home to some of the Nation's most remote parklands, so there is perhaps no more appropriate place to highlight the utility and necessity of remote sensing technologies. Remotely sensed datasets were important for applications of aerial photography, satellite imagery, GPS, and digital elevation data as they were used by the Inventory and Monitoring (I&M) and other National Park Service (NPS) programs in various resource management disciplines, including wildlife monitoring, glacier and permafrost monitoring, vegetation and soils mapping, cultural resources, and hydrologic applications.

The Alaska Land Resources Program Center uses orthoimagery available from the Alaska Region's Geographic Information System (GIS) site. Prior to good high-resolution digital orthoimagery, the locations of many parcels were drawn using the U.S. Geological Survey (USGS) quads digital raster graphics (DRGs) or other data

that were often dated or of lower resolution. By using more recent orthoimagery in combination with the survey plat or legal descriptions, we are able to update tracts and boundaries with increased accuracy. The I&M Central Alaska Network stream monitoring program relies heavily on GPS and remote sensing technology. Remotely sensed imagery, particularly IKONOS and high-resolution aerial photography, is used extensively to evaluate the suitability and logistical feasibility of potential sampling locations prior to the field season. This is of particular importance in a large, remote landscape like the Central Alaska Network, where the cost of accessing sampling sites is particularly high. GPS is used daily to navigate to predetermined sampling coordinates and attach accurate location information to biological and habitat data collected in the field, including samples collected at stream reaches and anomalous permafrost features as part of an effort to construct a comprehensive dynamic database.

Digital Elevation Models (DEMs) are used to construct flow-accumulation grids for the sampled locations, a critical step in the delineation of point-specific drainage basins. IKONOS imagery is used to help confirm the accuracy of the resulting delineated basins. The derivation of spatially explicit basin descriptors for each sampling location is important for the ecological and hydrological modeling used to understand and quantify ecosystem status and trends across the landscape.

GPS data received by collars on caribou, moose, musk oxen, and wolves are relayed via communication satellites to the desks of wildlife biologists. This technology allows biologists to track these animals in the remote areas of Alaska even during inclement weather and darkness. These data help biologists study the movements, behavior, habitat use, and population dynamics of these animals. Each caribou migrates over 3,000 kilometers (1,800 miles) each year, and the herd utilizes five National Park units and roams over an area nearly the size of Montana.

In the Denali National Park and Preserve, GPS radio collars placed on grizzly bears and Dall sheep are designed to store the animals' location data several times per day and detach from the animals' necks on a preset date so that the collars can be retrieved and the data analyzed. These collars were used as part of the Denali Park Road study to help understand how animal movements were influenced by the presence of the road and by road traffic. Information from GPS collars on caribou helps to illuminate habitat use and food sources for the Denali Caribou Herd. The

collars used on wolves provide biologists with timely information on movements, mortality, and den occupancy.

Nearly every wildlife research or monitoring project conducted by staff at Kenai Fjords National Park relies on GPS and/or GIS/remote sensing technologies to document geospatial data and monitor change. Management decisions are often facilitated by GPS data analyzed and displayed on maps with satellite image backgrounds.

The Alaska Region I&M program uses a variety of remote sensing technologies to assist its efforts to inventory vegetation and soils within the region. As with other NPS programs, the inventory program uses GPS to establish ground control for satellite image analysis and to collect geolocation information about the study sites. During routine office work, transects, plot locations, and related geospatial data are overlaid on satellite and/or aerial photography. Remotely sensed imagery is also used as background data for GPS unit displays to aid navigation while in the field. Standard-scale hard-copy aerial image maps are generated for navigational and reference purposes while in the field. These hard-copy maps provide a backup to GPS units should they fail while in remote areas.

The Alaska Region's Exotic Plant Management Team also uses GPS technology as an important tool for invasive plant management, as it allows managers to map and monitor invasive plant populations and to document the success of control measures.

The Alaska Regional Cultural Resources program uses all available imagery to evaluate land areas for the presence of cultural sites and to assess the status of known sites. For example, an investigation to relocate Katmai Village in the Katmai National Park and Preserve involved the use of United States land survey records, NPS GIS data, and Google Earth imagery.

In support of the NPS Alaska Region Inventory and Monitoring Program, a sampling design of soil and vegetation in Lake Clark National Park and Preserve was developed through a contract with the private sector. As part of this effort, an extensive time series of Landsat imagery (1985–2010) was collected. The time-series data were used to characterize patterns of snow persistence on the landscape, which is related to snow depth and growing-season length—factors important for soil development. The 30-meter-resolution satellite image time series was analyzed

to determine the typical snow-free date for the Lake Clark soils study area. This analysis provided valuable information on local and regional snow regime patterns that will be useful for stratification and modeling of vegetation and soil distribution.

In FY 11, the I&M Arctic Network used IKONOS imagery from 2006 to 2008 to map slumps and small landslides caused by the thaw of permafrost in the Noatak National Preserve (2.6 million hectares). Over 1,000 features were located. The results of this analysis were compared to the 1977 color-infrared Alaska High-Altitude Photography (AHAP) of the same area to assess the volume of change in the landscape due to thawing permafrost.

NPS staff continued the trend to institutionalize the application of GPS and GIS technologies toward important and diverse park management needs. Routine workflows that survey and monitor wildlife and vegetation, assist with search-and-rescue operations, and document historic features now depend on GPS data and subsequent visualization and analysis of those data using GIS and recent orthoimagery.

- Glacier National Park's Integrated Pest Management (IPM) program documented exotic vegetation populations using GPS and monitored the effectiveness of treatments on these populations using GIS-based field maps and related descriptive notes.
- The park's first formal bat inventory in 2011 used a GIS analysis of vegetation/habitat and proximity to roads and trails to determine sample locations. Sample sites were then documented using GPS.
- A harlequin duck research project fitted female ducks with radio transmitters, yielding XY locations that were analyzed in GIS to assess habitat utilization. Harlequin ducks are listed as a species of concern in Montana, where they are at high risk of extirpation due to their very limited numbers, limited habitat, disturbance, and habitat loss or alteration. One bird was documented in the Puget Sound, hundreds of miles from their breeding grounds in Glacier.
- Ranger staff responded to two search-and-rescue events in 2011 assisted by GIS mapping products that show GPS track log paths of previous ground- and air-based search parties.
- Submeter GPS was used to document new cultural features and conduct condition assessments of existing cultural resource sites, greatly improving

the spatial resolution of feature mapping at those sites. Notable was the 2011 discovery and documentation of an abandoned adit from the brief heyday of copper mining in Glacier, ca. 1896.

Recently acquired National Agriculture Imagery Program (NAIP) and border area orthoimages are valuable backdrops for revisions to core geospatial base map datasets in Glacier National Park. The 2009 Montana NAIP data were used to revise hydrology data for stream reaches in Glacier that experienced channel shifting due to spring runoff events. The revised data will assist the Montana State Library's coordinated edits to the National Hydrography Dataset (NHD). More importantly, approximately 40 percent of the park boundary is defined by stream channel location, and revisions to those stream segments resulted in a current, or "working," park boundary theme in GIS. The NAIP-derived working boundary layer was used in 2011 to define a project area boundary for the park's Natural Resources Conservation Service (NRCS) soil inventory. NAIP and border area data also helped update park trails and building footprints in remote settings where ground-based GPS mapping efforts come at a great expense.

Grand Canyon staff and contractors used imagery from the U.S. Department of Agriculture (USDA) NAIP program and Landsat imagery to map vegetation in the inner canyon. A time series of Landsat images was used to generate life-form maps (deciduous versus evergreen and woodlands versus shrublands versus grasslands).

Grand Teton National Park is currently using historic color and color-infrared aerial photography, QuickBird satellite imagery, and Light Detection and Ranging (LIDAR) imagery for several wide-ranging and critical projects that range from resource protection (natural and cultural) to decision support for infrastructure and emergency planning. The GIS specialists lead the acquisition and analysis of the remotely sensed images, and vegetation ecologists, wildlife specialists, and project manager experts inform the analysis methodology and evaluate the results.

Park facilities management and resource management staff are very interested in the wider use of LIDAR imagery for project planning and other park management decisions. Specific future applications include characterizing the vertical structure of forested areas for fire fuels monitoring and sagebrush areas for their use by sage grouse and other wildlife species, as well as identification and documentation of historic and archaeological resources.

Vegetation post-fire updates used Landsat Thematic Mapper (TM)–derived burn severity and other fire data: park GIS staff assisted the Bridger-Teton National Forest in developing a process to update vegetation maps using Landsat TM–based burn severity models in association with vegetative change models. This process is being adapted to update the Grand Tetons vegetation map.

Each year, disturbance events such as avalanches, landslides, floods, fires, and clearcuts alter the landscape in and around the parks in the North Coast and Cascade Network (NCCN). These disturbances vary in duration, size, and severity, from a sudden small flood in a riparian zone to a fire that burns thousands of acres over several weeks.

Natural-disturbance events inside the park can have lasting effects on park ecosystems and can significantly impact cultural resources. Disturbances outside the parks, such as clearcuts and development, alter the ecological connections that tie resources within the park to the broader ecosystem in which each park is located. The NCCN landscape dynamics monitoring program was developed in order to track the location, type, severity, and duration of common landscape disturbances. Observations from the program will also provide a broader context for changes observed in other NCCN monitoring programs.

Due to advancements in satellite image–processing techniques, landscape changes can be efficiently detected over large areas at a relatively low cost. The NCCN landscape dynamics monitoring program uses satellite imagery, GIS, and statistical analyses to map and categorize disturbance events in and around NCCN parks. The study area for each park includes all watersheds inside and within 10 miles outside the park's boundary, as well as areas of particular detection and mapping areas within the NCCN study areas that are larger than 2.5 acres (0.5 hectares) and have experienced a minimum 10 percent loss in cover.

The Midwest Archeological Center (MWAC) maintains archaeological datasets for parks in the Midwest region and assists parks with archaeological issues. The Center's Archeological Information Management Team makes extensive use of GIS to maintain spatial location information on over 5,000 archaeological sites in the region. Remotely sensed data are an integral component of the archaeological base maps and are used in data analysis. The data, maintained in attribute and spatial databases, are used to aid in the preservation and protection of those sites.

Bureau of Reclamation

In 2011, the Bureau of Reclamation (BOR) continued its use of remote sensing to support its water resource management mission. Two specific application areas are highlighted: estimating consumptive water use and providing data necessary for river restoration activities.

Consumptive Water Use

Consumptive water use refers to water that is removed from a watershed by evapotranspiration (ET)—the loss of water from direct evaporation or plant transpiration—making it unavailable for other uses. BOR staff needs reliable estimates of consumptive water use to administer interstate and interbasin water compacts and to quantify and verify volumes of conserved water arising from fallowing and crop type substitution agreements.

BOR image analysts used Satellite Pour l'Observation de la Terre (SPOT) and Landsat Thematic Mapper imagery to map open water, crop types, and riparian vegetation for the Central and Imperial Valleys of California, as well as areas adjacent to the Lower Colorado River dividing California and Arizona. Multidate imagery was required to map the area because some of these areas produce agricultural crops year-round and up to four different crops could grow on a single agricultural field during the year. A GIS was used to assign the Landsat-derived crop types to vector-based maps of individual agricultural fields developed from high-resolution imagery. The GIS data were then used to calculate and analyze consumptive water use at a wide range of spatial scales, from individual agricultural fields to entire river basins.

BOR staff are involved with a number of river restoration efforts throughout the western United States, including the San Joaquin and Trinity in California, the Grande Rhonde in Oregon, the Lemhi and Yankee Fork in Idaho, the Elwah in Washington, and the Colorado along the California/Arizona border. Although the specific goals of the restoration activities vary from river to river, they usually include provisions to improve riverine habitat for native fish populations that have been adversely affected by human activity. Examples of adverse effects

include reduced flows due to agricultural development, as well as altered temperature and sediment load regimes and blocked migration routes resulting from dam construction. Remediation activities might include river channel modification; the addition or removal of floodplain vegetation; and, where possible, the modification of river flow regimes. Most of these projects make use of LIDAR and multispectral image data to characterize pre-treatment vegetation and terrain conditions, to aid in the development of site improvement plans, and to monitor restoration activities.

BOR staff have partnered with state and local organizations in the Salmon River Basin to restore salmon habitat in tributaries to the Salmon River. As a part of this effort, Reclamation acquired LIDAR and 6-inch-resolution aerial multispectral imagery of the Yankee Fork River in central Idaho. The LIDAR data are of sufficient quality to classify important floodplain features such as sand and gravel bars, as well as disconnected river channels, and to provide estimates of surface roughness useful in hydraulic modeling. These data were used to model inundated areas at estimated 10-year and 100-year flood flows. The LIDAR imagery and orthoimagery (generated from the LIDAR and multispectral image data) were also useful for identifying channelized portions of the river for potential remediation and quantifying volumes of placer mining waste.

United States Geological Survey

A primary objective of the Changing Arctic Ecosystems Initiative of the USGS Alaska Science Center is to measure and forecast the effect of changing terrestrial ecosystem processes on wildlife populations along Alaska's Arctic Coastal Plain. Part of the Changing Arctic Ecosystem Initiative seeks to understand the physical changes in the environment that are occurring as a result of warming during the 20th and 21st centuries and how these environmental changes are impacting molting and breeding bird populations, such as those of Pacific black brant geese (*Branta bernicla*) and white-fronted geese (*Anser albifrons*). The current work is applying time-series image analysis and field sampling to determine the timing and areal extent of permafrost-related subsidence occurring along and near the Arctic coast.

The Arctic Coastal Plain (ACP) in northern Alaska provides a denning habitat for polar bears (*Ursus maritimus*) and also has high potential for recoverable

hydrocarbons, with several oil and gas fields in the central plain currently in development or extraction phases. To ensure that wintertime oil and gas exploration and development activities do not disrupt denning and threaten the survival of cubs, managers require knowledge of the distribution of the landscape features in which pregnant polar bears are most likely to dig maternal dens. Maps of potential den habitat were developed for the central and eastern portions of the ACP using standard photogrammetric techniques.

Additionally, remotely sensed data have proven economically viable and scientifically useful for studying the following:

- The Atlantic sturgeon spawning habitat along the eastern seaboard.
- Coral reef habitat for sea turtles.
- Turbid water conditions and resources for Florida manatees.
- The effects of Burmese pythons as invasive exotic species in southern Florida.
- The effects of road and vehicle disturbances on rangelands.
- The accurate assessment of fuel loads and restoration in sagebrush habitat.
- The use of LIDAR to characterize oak trees, forests, and landscapes.
- The documentation of year-round movements of Swainson's hawks.

USGS scientists, in partnership with the U.S. Agency for International Development (USAID), developed forecasts of drought conditions that led to intense monitoring in support of the United Nations' famine declaration for southern Somalia. Parts of eastern Africa, including Somalia, experienced two consecutive seasons of very poor rainfall, resulting in the worst drought in 60 years. Crops failed; livestock deaths were widespread; and food prices were very high. While the depth of the crisis outstripped the capacity of the humanitarian response, USGS support of the Famine Early Warning Systems Network (FEWS NET) helped mitigate severe malnutrition and mortality.

The combination of USGS climate research and remote sensing applications provided a powerful tool for 1) advance warning of impending drought and 2) immediate and accurate assessments of a broad range of environmental and agricultural conditions. When considered within historical context, these tools leverage the capacity of remote sensing to help mitigate the effects of drought.

According to the United Nations' Food Security and Nutrition Analysis Unit (of Somalia), the crisis represents the most serious food insecurity situation in the world today, in terms of both scale and severity. Historically, it is Africa's worst food security crisis since Somalia's 1991–92 famine.

The USGS Eastern Geographic Science Center (EGSC) is conducting research that develops advanced data mining, fusion, and evaluation techniques to create biophysical remotely sensed data; demonstrate the utility of those data in particularly challenging or scientifically important regions of the eastern United States; and improve process-based hydrologic, biologic, and climate modeling. Current efforts focus on vegetation structure, fire disturbance, and surface water extent.

Fire disturbance and variations in vegetation dynamics following fire are primary factors in shaping the patchwork nature of wetland vegetation/surface water cover. Very little is known about wetland fire ecology. Remote sensing technologies have become an important data source for the study of fire disturbance and recovery, but method development has occurred almost exclusively in upland environments, not wetland ones. EGSC is conducting research to develop improved methods for fire detection, fire scar mapping, burn severity indexing, and post-fire vegetation monitoring in wetland environments. Since 2003, the USGS Earth Resources Observation and Science (EROS) Center fire science staff have worked jointly with the U.S. Forest Service (USFS) Remote Sensing Applications Center (RSAC) staff to map all significant wildfires on DOI- and Forest Service–managed lands primarily to satisfy the burn severity mapping requirements of Burn Area Emergency Response (BAER) Teams. EROS receives national-level funding from DOI fire management programs to support this ongoing activity.

EROS staff rapidly processes Landsat and other satellite imagery, enabling the timely generation of DOI and USFS map products, generally in less than two days after fire containment. Historically, seven to eight years ago, BAER soil burn severity mapping was done by sketch, mapping severity patterns on topographic maps, perhaps with the aid of a digitized fire perimeter. Today, burn severity mapping derived using satellite imagery has replaced the manual method for BAER teams, except in cases where timely imagery is not available due to clouds, smoke, and missed acquisitions.

As of 2011, USGS EROS and USFS RSAC have mapped over 1,000 wildfires representing over 35 million burned acres in support of BAER and other local DOI and USFS land managers. Recently, USGS EROS has been asked to support international emergency fire incidents. In 2009, USGS EROS supported U.S. BAER teams deployed to Australia and mapped over 700,000 acres over a period of two weeks. Also in 2009, USGS EROS staff assisted fire managers in Greece and the Republic of Georgia.

The USGS routinely uses remote sensing methodologies and data to address wildland fuels in the United States. USGS leads the Landscape Fire and Resource Management Planning Tools (LANDFIRE) program, which produces consistent and comprehensive maps and data describing vegetation, wildland fuel, and fire regimes across the United States. The LANDFIRE geospatial data are derived from Landsat satellite data and ecological models that provide layers of vegetation composition and structure, surface and canopy fuel characteristics, and historical fire regimes. The LANDFIRE program is now in the phase to update the geospatial information to incorporate major landscape changes such as wildfire, insect, and disease and other management activities that alter the vegetation and fuel characteristics. The USGS has also investigated the use of LIDAR to better characterize forest vegetation structure and change to improve fire behavior models.

Space-based remote sensing techniques are an invaluable tool for monitoring volcanic activity around the world. While especially useful at poorly accessible volcanoes with little or no in situ instrumentation, remote sensing datasets are also used extensively at well-monitored volcanoes to fill observational gaps in ground-based monitoring. For example, remote sensing forms a core monitoring dataset at Kīlauea Volcano in Hawaii—one of the best-monitored volcanoes in the world. High-resolution (10–30 meters per pixel size) multispectral data, such as EO-1 Advanced Land Imager, Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), and Landsat, have provided precise locations on active lava flows that augment the information collected during routine field observations. Combining the active flow locations with topographic data collected from other satellites, the USGS Hawaiian Volcano Observatory can forecast the descent path and potential hazard of the lava flows.

Coastal wetlands are essential to ocean productivity and critical as nursery areas for coastal and oceanic life. The robustness of these systems is intrinsically linked to the frequency and duration of inundation and the salinity of the flushing waters. In order to identify the thresholds of these inundation variables required for wetland viability, their spatial and temporal changes must be determined; however, rapid temporal changes and high spatial complexity often thwart the application of conventional contouring and hydraulic flow models.

Envisat Advanced Synthetic Aperture Radar data were used to provide accurate spatial mapping and consistent temporal patterns of storm surge flooding and its recession following Hurricane Rita's landfall in September 2005.

The results of a recently published study, conducted by the U.S. Geological Survey, reveal that faults west of Lake Tahoe, California, represent a substantial seismic hazard to the greater Lake Tahoe region of California and Nevada. The study utilized a high-resolution, three-dimensional (3D) imaging technology, known as bare-earth airborne LIDAR, which is capable of seeing through dense forest cover to reveal active earthquake faults that were not detectable with conventional aerial photography.

Terrestrial LIDAR, or T-LIDAR, was deployed by the USGS in the immediate aftermath of Hurricane Isaac to map urban flooding and quickly generate 3D maps of buildings, dams, levees, and other structures that were damaged in the storm.

Tens of millions of people felt the M5.8 earthquake that occurred in Louisa County, Virginia, on August 23, 2011. Damage to buildings and structures was widespread, with cost estimates in the millions. The earthquake impact was great not only because of high population densities, but also because regional geologic features transmit seismic energy very efficiently. The earthquake occurred on a fault that had not previously been mapped, and no corresponding surface rupture was observed. Within days following the event, the USGS and other organizations deployed a set of seismic monitoring stations in the earthquake area. Aftershocks recorded by these stations delineate the probable causative fault in the hypocentral region. In order to map the lateral extent of the fault and associated geologic structures, the USGS commissioned high-resolution airborne magnetic, gravity, and radiometric (gamma-ray spectroscopy) surveys, as well as LIDAR surveys, over the epicentral region.

Cold Regions Lake and Landscape Research at the Alaska Science Center focuses on the study of the Arctic and Subarctic landscape, with an emphasis on Alaska. The primary objective of this research program is to gain an understanding of landscape change in the recent (last 50 years) and distant (last 20,000 years) past. This is accomplished through a combination of techniques that include remote sensing, GIS, field surveys, laboratory analyses, and model development. Ultimately, these studies provide information that land and resource managers can use to better inform their decision-making process. During FY 11, remotely sensed imagery derived from a number of sources to better understand thermokarst lake dynamics in the continuous permafrost regions of northern Alaska were used. By combining historical aerial photography with more contemporary high-resolution commercial satellite imagery, scientists were able to document changes to the abundance and surface area of lakes in two regions that provide important fish and wildlife habitat as well as sources of water for winter oil and gas exploration.

The USGS is using remote sensing technology as part of a field-to-sky approach for integrated monitoring and assessment of wetland-upland landscapes across the United States and Canada. This approach was developed for the Terrestrial Wetland Global Change Research Network (TWGCRN), a U.S.–Canadian effort to assess key impacts of climate, interacting with other drivers of global change (e.g., land-cover and land-management change), on wetland-upland landscapes across environmental gradients in North America.

Astrogeology is an important activity for the USGS, and remote sensing techniques are used for further understanding of extraterrestrial bodies.

The innermost planet of our solar system (Mercury) is being investigated by the NASA MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) mission. The Integrated Software for Imagers and Spectrometers (ISIS) software is used for processing the data from the Mercury Dual Imaging System (MDIS). USGS is also tasked with leading the international effort to combine data from the laser altimeter and stereo imaging to produce the highest-quality global topographic map of Mercury. This is the first time altimetry and stereogrammetry are being combined to this degree on a global scale for any body.

Similarly, remote sensing techniques have been used for studies of the moon, Mars, Saturn, and asteroids.

The erosion of riverbanks along the Missouri River is a continuing concern of many of the Native American tribes within South Dakota. Changing reservoir levels combined with precipitation, wind, and ice result in conditions under which substantial shoreline erosion may occur within a single season. The Lower Brule Sioux Tribe is concerned about water pollution caused by this shoreline erosion. The Missouri River has experienced massive riverbank erosion, estimated up to 8 feet or more per year, along the entire length of the reservation border. The USGS is using various technologies to obtain accurate measurements of shoreline erosion along a 7-mile stretch of shoreline near the community of Lower Brule.

Since the launch of Landsat 1 in 1972, International Cooperators have formed a key strategic alliance with the USGS to facilitate direct downlinks of Landsat data and to build the foundation for scientific and technical collaboration. The International Cooperators provide critical emergency response support and contribute historical Landsat imagery for the Landsat Global Archive Consolidation. The USGS plays a leadership role in two international groups for satellite observations, the Committee on Earth Observation Satellites (CEOS) and the International Charter for Space and Major Disasters. CEOS (*http://www.ceos.org*) is a voluntary international partnership of 52 space agencies and related organizations, which strive to enhance the international coordination of satellite observations and data exchange for societal benefit. Through its participation in CEOS, the USGS is uniquely positioned to advance space-based land remote sensing technologies and applications with foreign partners, to obtain new datasets, and to serve the science and technology needs of its user community.

The International Charter (*http://www.disasterscharter.org*) provides a unified system of satellite observations and data delivery to those affected by natural or anthropogenic disasters, through a network of Authorized Users. The USGS participates in the Charter in order to receive foreign remote sensing data support for U.S. disaster response and recovery efforts and to ensure the provision of U.S. land imaging data to support foreign disaster response and recovery efforts. In 2011, the Charter was activated 32 times in response to U.S. and foreign disasters.

The National Elevation Dataset (NED) is the primary elevation data product provided by the USGS in partnership with the National Geospatial Program. The

NED provides seamless raster elevation data of the conterminous United States, Alaska, Hawaii, and the island territories, and it is derived from diverse source data that are processed to a specification with consistent resolution, coordinate system, elevation units, and horizontal and vertical datums. The NED is the logical result of the maturation of the long-standing USGS elevation program and serves as the elevation layer of the National Map. The NED provides elevation information for Earth science studies and mapping applications in the United States, and it is available nationally at grid spacings of 1 and 1/3 arcsecond (~30 meters and 10 meters respectively) for the conterminous United States and 1/9 arcsecond (~3 meters) for parts of the United States.

Midcontinent carbonate aquifers are some of the most productive in the Nation, yielding water for agriculture, industry, and public drinking supplies. Caverns and springs provide unique habitats for many rare and unique animal and plant species. Managing these water resources in a sustainable way requires an understanding of groundwater storage, flow, and recharge, which depend on aquifer geology and structure. The Crustal Geophysics and Geochemistry Science Center (CGGSC) in Denver, Colorado, uses remote sensing geophysics to assist geologists and hydrologists in creating and updating two-dimensional maps and three-dimensional digital models of the complex geology associated with fractured, faulted, weathered, deformed, and altered carbonate rock formations.

Using Landsat imagery with the Mapping EvapoTranspiration at high Resolution and Internalized Calibration (METRIC) procedure, scientists estimated consumptive water use of irrigated and non-irrigated lands at 30-meter resolution in the Klamath Basin, Oregon. Because ground surfaces with large ET rates are left cooler than ground surfaces that have less ET, irrigated fields appear on images as being cooler than nonirrigated fields. Both the rate and spatial distribution of ET can be efficiently and accurately quantified independent of the crop development stages or the specific crop type.

The USGS Upper Midwest Environmental Sciences Center (UMESC, *http://www.umesc.usgs.gov*) remained an active user and developer of remote sensing data and products. UMESC has used remote sensing data for over 20 years to develop vegetation maps/spatial databases, elevation products, and orthophoto mosaics for the U.S. Army Corps of Engineers (USACE), U.S. Fish and Wildlife

Service (FWS), National Park Service (NPS), and Upper Mississippi River System (UMRS, the Mississippi River from Minneapolis, Minnesota, to Cairo, Illinois, and the full length of the Illinois River). UMESC also uses remote sensing technology to track the movements of wildlife, study wildlife diseases, and assess the potential impacts of wind energy developments and other high-tower projects (e.g., electrical lines or radio towers). FY 11–12 remote sensing activities include the following:

- Evaluating the impacts of wind energy developments on wildlife by observing water bird use of the Great Lakes.
- Using weather radar to track waterfowl disturbances.
- Mapping vegetation for the National Park Service.
- Mapping land cover for the Upper Mississippi River System Floodplain.

In the late summer of 2010 and 2011, UMESC collected high-resolution color infrared aerial photography of the 2.75-million-acre UMRS. This photography is being used to create a systemic land-cover/land-use dataset. Systemic datasets were created previously using 1989 and 2000 aerial photos. These data are being developed for the Long Term Resource Monitoring Program, an element of the USACE's Upper Mississippi River Restoration-Environmental Management Program. This multi-agency Federal and state cooperative program is designed to monitor, restore, and enhance the multi-use functionality of the UMRS.

Bureau of Land Management

The Bureau of Land Management (BLM) utilizes remote sensing to support many multi-use resource management needs. High-resolution imagery depicts current and past conditions required by managers and specialists to make timely and scientifically sound decisions. Many projects reflect a few of the ways that remote sensing supports the daily on-the-ground needs of our resource managers.

Cadastral Surveys

LIDAR data and aerial photography are valuable tools for preliminary investigations by cadastral surveyors. Boundary disputes are often decided using survey information. Remote sensing data provide a visual presentation of the ground

conditions to help interpret the situation. Historical aerial photography, satellite imagery, and LIDAR data combined with ground survey data provide clues to surveyors investigating trespass, boundary issues, and other situations dealing with monument lands. Remote sensing investigations may drive the need for field surveys or provide enough information to resolve issues without field data collection.

Mapping Stream Networks

The Pacific Northwest Hydrography Framework sponsors a working group tasked to evaluate the use of LIDAR-derived Digital Elevation Models (DEMs) as a principal data source for updating the National Hydrography Dataset (NHD). The working group has identified a workflow leading to the acceptance of revisions to the national stream network dataset.

Two 10-digit hydrographic unit watersheds located in Oregon's Coast Range and Cascade Range were chosen as study areas. For each watershed, a bare-earth DEM at 3-foot resolution was created from a LIDAR point cloud. The workgroup followed the standard sequence for modeling surface drainage patterns from DEMs: 1) resolving depressions, 2) routing flow, 3) calculating flow accumulation values at every cell, and 4) applying a flow-accumulation threshold to derive the stream network. The result can be combined with the flow-direction grid to determine stream order, generate a vector representation of the stream network, and delimit watershed boundaries.

Experiences show the quality of stream features modeled from LIDAR-derived DEMs exceeds that of the original sources used for the Oregon dataset. The LIDAR-based delineations represent a significant workload, however, and the effort should not be underestimated. Ultimately, programmatic use of LIDAR-derived DEMs to update NHD will be determined by the perceived benefits to the resource management programs relative to available budgets.

Juniper Vegetation Mapping

The Oregon BLM State Office developed a semiautomated technique to map juniper distribution for specific project areas. The technique uses 0.5-meter

color infrared NAIP imagery to identify juniper vegetation and map individual trees. The maps are used to plan for field activities such as fuel treatments and habitat restoration.

Cultural Resource Monitoring and Documentation

The famous Laetoli footprints were made by a human ancestor 3.56 million years ago in the Rift Valley of Tanzania and are the earliest fossil evidence of bipedalism in our ancestors. The trail of 70 tracks, found in 1976, is believed to correspond to an *Australopithecus afarensis*. The tracks were covered for protection after initial investigations. At the request of the Tanzanian government, a partial re-excavation of the site was conducted in February 2011 to evaluate the preservation of the buried footprint trail and to get samples for further scientific studies. The information gained from the re-excavation will be used to develop a state-of-the-art museum that will cover the site.

Photogrammetric specialists from the BLM were part of the interdisciplinary team of scientists that worked at the site during the re-excavation. Close-range digital photogrammetry is a no-contact procedure that produces a high-accuracy, 3D digital reconstruction of a subject using a sequence of overlapping photographs. This method is excellent for remote field locations because it requires only a digital camera of appropriate resolution. The photographs are processed in multi-view matching software that generates a very dense "cloud" of data.

Office of Surface Mining

The mission of the Office of Surface Mining (OSM) is to carry out the requirements of the Surface Mining Control and Reclamation Act (SMCRA) in cooperation with states and tribes. A primary objective of SMCRA is to ensure that coal mines are operated in a manner that protects citizens and the environment during mining and to ensure that the land is restored to beneficial use following mining activities. To support this mission, active and inactive surface coal-mining and reclamation operations are inspected on a routine basis to ensure compliance with approved permits.

In 2011, OSM investigated the use of high-resolution satellite imagery to determine if it could be used to support the SMCRA regulatory program. This two-year pilot project was an interagency and interdepartmental partnership working with the USGS and the National Geospatial Intelligence Agency (NGA). The scope of the project was limited to three mine sites: Centralia mine site within the state of Washington, the McKinley mine site located in New Mexico, and the Valley Creek mining sites in Tennessee.

Imagery used for the pilot project range from a single panchromatic (black-and-white) image to multispectral (natural-color and color-infrared) images. Land-imaging satellites used include the panchromatic-only WorldView-1 satellite, the panchromatic and 8-band multispectral WorldView-2, the panchromatic and 4-band multispectral QuickBird-2, the panchromatic and 4-band multispectral GeoEye-1, and the aging panchromatic and 4-band multispectral IKONOS satellite.

Most of the Virtual Inspection Priorities (VIP)s require orthorectified imagery to permit the measurement of distances directly on the image and precise alignment with other map data layers. DEMs can be extracted from stereo imagery and provide vertical elevations for features in the images.

A mining permit describes the lands that will be affected by coal-mining activities. The SMCRA inspector ensures that the mining and associated operations are within these approved boundaries.

Remote sensing imagery is ideal for this requirement. Using high-resolution satellite imagery and GIS techniques, the inspector can perform a virtual inspection and, without a field visit, determine if mining disturbance is contained within the approved boundaries.

Water diversions are constructed to prevent and control water runoff and erosion problems associated with the disturbed area. Water diversions constructed on mine sites must be the same in terms of placement and size as identified in the permit requirements.

Using orthorectified satellite imagery in a GIS, the inspector can determine if water diversions have the correct location, length, and (in rare cases) width as specified in the permit.

High-resolution WorldView-2 satellite imagery was analyzed using GIS to calculate the actual length of the water diversion. This technique allows the inspector

to measure actual distance on the satellite image without having to go to the mine site and walk the entire diversion to measure the distance.

Additional applications of remotely sensed data include the following:

- Identifying the location and extent of acid mine drainage.
- Backfilling and grading the spoil.
- Generating contours from a digital surface model.
- Performing post-mining topography—slope angle.
- Performing post-mining topography—slope shape (curvature).
- Performing post-mining topography—slope length.
- Performing post-mining topography—aspect (slope direction).
- Performing post-mining topography—viewshed analysis.
- Performing post-mining topography—volumetrics.
- Performing drainage reconstruction.
- Impounding structure identification.
- Performing distance prohibition validation.
- Performing revegetation—vegetation establishment.
- Performing revegetation—vegetation cover density.
- Performing revegetation—vegetation community types.
- Performing revegetation—vegetation change over time.

Bureau of Indian Affairs

Remote sensing offers the Bureau of Indian Affairs (BIA) a low-cost solution to field-based forest inventories. All reservations and tribes with forested land must develop and implement a forest-management plan by the end of 2015. A management plan requires a forest inventory to identify timber resources, estimate timber volume, calculate allowable cuts, and support other management decisions. Some reservation lands are remote, with limited access to the forested areas; others border Mexico and are dangerous places for field data collection. Also, some lands do not have high-value timber to justify the expense of field-based measurements. The BIA turned to remote sensing to gather data on general cover types and densities. This information was combined with biomass and Forest Inventory and Analysis Program data derived from adjacent lands to estimate timber volumes on BIA lands.

U.S. Fish and Wildlife Service

A variety of remote sensing tools are needed to support the breadth of conservation and land-management activities by the U.S. Fish and Wildlife Service (FWS). Aerial cameras, satellite radar and optical sensors, LIDAR systems, and other sensors reflect the diverse set of remote sensing tools employed to support the FWS's Endangered Species, Migratory Bird, Joint Venture, and Refuges programs.

The Migratory Bird Program in the FWS utilizes remotely sensed data to survey migratory birds, conduct research on bird migration and habitat use, evaluate habitat conditions, and manage migratory bird populations and habitat through Joint Ventures, a collaborative, regional partnership of government agencies, nonprofit organizations, corporations, tribes, and individuals; it conserves habitat for priority bird species, other wildlife, and people.

Migratory Bird Program biologists rely on remotely sensed data to plan bird surveys, delineate survey strata, place transects, and identify habitat boundaries. The western Gulf Coast mottled duck aerial survey, a joint effort of the FWS, Texas Parks and Wildlife Department, and Louisiana Department of Wildlife and Fisheries, utilizes the Chabreck-Linscombe coastal vegetation map derived from helicopter transect sampling using sampling sites along each transect to delineate salt and freshwater marsh habitat along the Gulf Coast. Aerial sea duck and seabird transect surveys along the U.S. Atlantic coast were designed using bathymetry data from the NOAA National Geophysical Data Center (NGDC) Coastal Relief Model to delineate substrates used by foraging diving ducks. In 2011, a research study investigating detection bias along road routes for mourning dove count surveys used aerial imagery to locate off-road survey points within a specified distance of houses and human disturbance.

Within the FWS Branch of Population and Habitat Assessment, Moderate Resolution Imaging Spectroradiometer (MODIS) satellite imagery is used to evaluate daily ice and snow cover and develop forecasts for goose production in remote portions of the high western Arctic breeding range.

To evaluate habitat conditions for Arctic geese populations, daily ice maps of the Canadian and Alaskan Arctic are generated by the National Ice Center analysts using imagery from Envisat, DMSP, Advanced Very High Resolution Radiometer (AVHRR), and RADARSAT sensors.

Satellite telemetry is an important tool for investigating migratory bird movements at continental scales. In 2011, the third year of a four-year study, 27 sandhill cranes with solar-powered GPS satellite transmitters were monitored traveling from their summer territories in Minnesota, Wisconsin, Michigan, and Ontario to their winter ranges in Indiana, Kentucky, Tennessee, Georgia, and Florida. Weekly crane movements are posted on the project's Facebook page: *http://www.facebook.com/pages/Eastern-Population-Sandhill-Crane-Monitoring-Project/279069252152006*.

Sea ducks are another group of birds that have been monitored using satellite telemetry. Due to concerns about declining populations in the Atlantic Flyway, the Sea Duck Joint Venture has been tracking sea ducks (black, surf, and white-winged scoters, as well as long-tailed ducks) since 2009 to identify key habitat regions used for staging, molting, and wintering areas. Telemetry data from black scoters have provided a completely new view of their breeding range. As a result of this study, a new area has been identified as an area of continental significance to North American ducks, geese, and swans in the North American Waterfowl Management Plan.

The FWS's Division of Bird Habitat Conservation (*http://www.fws.gov/midwest/hapet/*) staff uses a variety of remotely sensed data to survey habitat quality for breeding and wintering birds. In the Prairie Pothole region, this group conducts an annual Waterfowl Breeding Population and Production Estimates Survey to assess the contributions of National Wildlife Refuge System lands to continental waterfowl populations. Color infrared aerial photos of 186 4-square-mile sample plots in Minnesota and 60 plots in Iowa are acquired annually to assess habitat conditions. These plots are surveyed by ground and helicopter to estimate waterfowl abundance and productivity during the breeding season.

Refuges

Land-cover and vegetation maps are common products used by many refuges to portray current conditions. A variety of remote sensing and geospatial layers may be used to derive these products.

Over the past year, the Pacific Southwest Region of the U.S. Fish and Wildlife Service has undertaken several land-cover mapping efforts on National Wildlife Refuges (NWRs). The goal of these projects is to provide detailed, accurate

land-cover maps that will inform management decisions on the refuges. The projects utilize a combination of image sources including NAIP aerial imagery as well as Quickbird, WorldView, and ASTER satellite imagery, depending on image quality and availability. The refuges mapped in 2011 include Hopper Mountain NWR, Bitter Creek NWR, Blue Ridge NWR, Coachella Valley NWR, and portions of the Desert NWR.

Bureau of Land Management

The Bureau of Land Management (BLM) has issued a national sage-grouse policy to ensure environmentally responsible exploration, authorization, leasing, and development of energy resources within the range of the Gunnison sage-grouse. To support the Colorado State Office and the Gunnison Field Office, the BLM acquired LIDAR and airborne digital imagery for approximately 30,000 acres in the Gunnison basin. In 2011, LIDAR data were acquired at 8 to 10 points per square meter density and used to create highly accurate bare-earth elevation models and representations of sagebrush vegetation structure. Also, high-resolution, 4-band stereo airborne imagery at a 10-centimeter resolution was acquired to create very-high-resolution orthoimagery for the project area. The new imagery and elevation data will be added to the suite of data already available: 1993 to 1995 Landsat TM; 2004 Digital Globe QuickBird; 2004 E01 Advanced Multispectral Land Imager; 2005, 2009, and 2011 NAIP; and the National Elevation Dataset.

Federal Communications Commission

FCC

The Federal Communications Commission (FCC) formulates rules and administers proceedings to facilitate the provision of commercial satellite services in the United States. It also issues licenses for the launch and operation of all nongovernmental U.S. satellites. Internationally, the FCC coordinates satellite radio-frequency usage with other countries. The FCC's activities in FY 11 related primarily to commercial communications satellites.

The FCC took several significant actions in administrative and rule-making proceedings in FY 11. On January 26, 2011, the FCC issued an order concerning a proposal by LightSquared Subsidiary LLC, a Mobile Satellite Service (MSS) licensee, to use MSS radio-frequency spectrum for a terrestrial service that would provide mobile broadband service. The FCC waived some of its rules on the condition that LightSquared address concerns of potential interference with Global Positioning System (GPS) receivers. The order specified a process for resolving these interference concerns. This included a GPS interference technical working group to work with LightSquared to resolve potential GPS compatibility and interference concerns. LightSquared submitted a report on June 30, 2011, concerning testing interference to GPS receivers. After a period for public comment, on September 13, 2011, the FCC's International Bureau and Office of Engineering and Technology determined that additional testing was necessary.

In a rulemaking order released on April 6, 2011, the FCC adopted rules to enhance the use of MSS spectrum in the 2-gigahertz (GHz) frequency range.

First, the FCC added terrestrial Fixed and Mobile allocations to the MSS 2-GHz band. This action laid the groundwork for more flexible use of the band, including for terrestrial broadband services, in the future. The FCC took this action to make additional spectrum available for new investment in mobile broadband networks while also ensuring that the United States maintains robust MSS capabilities. Second, in order to create greater predictability and regulatory parity with bands licensed for terrestrial mobile broadband service, the FCC extended the Commission's secondary market "spectrum manager" spectrum-leasing policies, procedures, and rules to terrestrial systems operating in certain MSS frequency bands.

On June 14, 2011, the FCC released rules concerning 17/24-gigahertz Broadcasting-Satellite Service (BSS) space-to-Earth transmissions. The rules were adopted to mitigate so-called "space path" interference between such satellites. As part of the new rules, the FCC revised informational requirements to mandate that 17/24-gigahertz BSS space station applicants file information about antenna characteristics for such stations. These rules facilitate the introduction of 17/24-gigahertz BSS, which in turn is expected to provide new and innovative services (e.g., video, audio, data, and video-on-demand) as well as promote increased competition among satellite and terrestrial services.

The FCC authorized a number of commercial communications satellite launches and operations. The authorizations include the following:

- November 17, 2010: To Intelsat North America, LLC, to launch and operate a replacement C/Ku-band satellite at the longitude 66° east orbit location.
- February 4, 2011: To Satellite CD Radio, Inc., to launch and operate a satellite at the longitude 115.2° west orbit location.
- July 26, 2011: To Intelsat North America, LLC, to launch and operate a satellite at the longitude 180.0° east orbit location.
- August 30, 2011: To Pegasus Development DBS Corporation, to launch and operate a satellite at the longitude 95.15° west orbit location.

The FCC granted a number of licensee modifications and special temporary authorizations for satellite networks. Many involved the routine testing or

redeployment of satellites within a multi-satellite system. One action, however, warrants particular mention:

- November 4, 2010: The FCC granted SES Americom, Inc., authorization to relocate satellite AMC-4 to operate at longitude 67° west orbit location consistent with a Colombian filing at the International Telecommunication Union.

The FCC added three non-U.S.-licensed space stations to the Commission's permitted space station list in order to allow these space stations to provide domestic and international satellite service to U.S. earth stations. Specifically, on October 13, 2010, the FCC added the Brazilian Star One B1 space station using the C-band at the longitude 68° west orbit location to the permitted list on a conditional basis. On June 17, 2011, the FCC added the United Kingdom's Spaceway 6 space station to access the United States market using the Ka-band at the longitude 90.9° west orbit location. On June 24, 2011, the FCC allowed the United Kingdom's Spaceway 5 space station to access the United States market using the Ka-band at the 109.1° west orbit location.

U.S. Department of Agriculture

USDA

National Institute of Food and Agriculture

The National Institute of Food and Agriculture (NIFA) is the extramural research arm of the USDA. In partnership with land-grant universities, as well as other public and private organizations, NIFA provides the focus to advance a global system of extramural research, extension, and higher education in the food and agricultural sciences. NIFA primarily provides financial assistance, in the form of grants, to conduct high-priority agricultural research, extension, and education. In FY 11, NIFA awarded many grants that use NASA data products to solve complex, environmentally related problems on topics such as land use, water and nutrient management, resource conservation, and pest management in forest and crop lands. A few examples of the above topics supported by NIFA that use NASA data products include the following:

- Satellite imagery and geospatial databases have been used to manage carbon and nitrogen and to do greenhouse gas accounting in corn cropping systems in the Midwest and Northeast.
- Nutrient status of nut orchards in California have been mapped with hyperspectral imagery to develop management strategies.
- Thermal images in the Northern Great Plains have been used to validate water balance models for evapotranspiration.
- Geospatial toolkits have been developed and used by agricultural extension agents in a train-the-trainer program in Utah to access NASA imagery.

Along with the Science Mission Directorate of NASA, NIFA jointly funded several geospatial extension programs at land-grant, sea-grant, and space-grant institutions. These geospatial outreach programs continue to operate after the funding has terminated to help train local and regional technologists in the use of NASA data products and geospatial technologies. By leveraging the ongoing coordination in these state geospatial programs in the realm of geospatial technologies (interoperability, standards, metadata, architecture, etc.), the geospatial extension specialists will help ensure that the vast quantity of data being collected by NASA and other Federal agencies is utilized effectively and shared more broadly with the public.

Natural Resources Conservation Service

The Natural Resources Conservation Service (NRCS) is the primary Federal agency working with private landowners to help protect and conserve the Nation's natural resources. It provides leadership in partnership efforts to help people conserve, maintain, and improve our natural resources and environment. For more than 50 years, the NRCS use of remote sensing products has helped to carry out conservation programs. Aerial and satellite imagery processed in the form of digital orthoimagery remained the primary remote sensing product used by NRCS to inventory, monitor, manage, and assess our natural resources in GIS nationwide. By partnering with the USDA Farm Service Agency and other Federal and state agencies, NRCS acquired statewide 1-meter orthoimagery for 19 states and parts of Alaska, Hawaii, and the Pacific Basin. NRCS participates in many Federal Government interagency coordination committees such as the National Digital Orthophoto Program and the National Digital Elevation Program to avoid duplication of orthoimagery and digital elevation acquisitions. The USDA Geospatial Data Gateway Web site made available all orthoimagery purchased by the NRCS to internal users and the general public.

NRCS orthoimagery acquisitions for Hawaii and the Pacific Basin used predominately high-resolution commercial satellites from DigitalGlobe and GeoEye. All acquisitions were contracted at USGS's Mid-Continent Mapping Center. All orthoimagery acquisitions are at 1-meter or higher resolution and 4 to 8 multispectral bands, depending on the satellite sensor. In FY 11, NRCS acquired Hawaii

(Oahu, Maui, and Kahoolawe), Guam, and the Commonwealth of the Northern Mariana Islands (Saipan, Tinian, and Rota). Moreover, NRCS acquired orthoimagery for Alaska's Kodiak Island under the USDA Small Area Aerial Photography Contract. This acquisition was for color infrared film at 1-meter ground resolution. NRCS used the Aerial Contract at USGS's Mid-Continent Mapping Center to acquire an area northeast of Fairbanks called the Yukon Flats. This acquisition was for 1-meter, 4-band digital orthoimagery.

NRCS used the USDA Small Area Aerial Photography Contract to acquire high-resolution aerial photography (4" ground-resolving distance) and scans over 70,196 confidential statistical sites to collect natural resource data for the annual National Resources Inventory (NRI) program in the contiguous United States (CONUS). NRCS also contracted for aerial photography over 451 NRI sites in Puerto Rico and the U.S. Virgin Islands. NRCS used the USDA Small Area Aerial Photography Contract to acquire 20,287 photos over 12,021 Stewardship Land easements in CONUS and Hawaii. The easements cover approximately 2.18 million acres, and the imagery was used to monitor restoration efforts on each property enrolled.

NRCS continued to investigate direct digital imagery as a replacement for analog film. Acquisitions included 55 NRI sites acquired with 3-centimeter- and 15-centimeter-resolution, 4-band imagery for a joint rangeland investigation with the Agricultural Research Service (ARS). NRCS also evaluated 8-centimeter-resolution and 15-centimeter-resolution, stereo, 4-band imagery for a National Easement Assessment Project with the University of Tennessee. Although the digital imagery was excellent, the significant increase in cost over that of analog film limits more widespread use.

The NRCS also continued using satellite imagery from the USGS Hazard Data Distribution System and the USDA Satellite Imagery Archive to respond to natural disasters. In response to the 2011 flooding along the Mississippi and Missouri rivers, NRCS provided pre- and post-event imagery from satellite and aerial sources via Web services to state offices, supporting their ability to deliver Emergency Watershed Protection assistance.

NRCS Elevation Program

NRCS has a national strategy and requirements for high-quality elevation data. NRCS has a national strategy to acquire, integrate, and deliver high-quality elevation data that meet the USDA's geospatial requirements. High-quality digital elevation data will support the USDA's business activities by improving employee effectiveness and efficiency in providing assistance to our customers through the use of digital elevation models (DEMs), as well as hillshade, slope, and contour map and data products.

NRCS is a member agency of the National Digital Elevation Program (NDEP). NDEP is a multi-agency Federal partnership chaired by the U.S. Geological Survey (USGS) to expedite the collection and availability of elevation data. NDEP member agencies intend to leverage funds for the acquisition of elevation data in common areas of interest. NDEP supports data sharing, promotes using flexible and common standards, and encourages the leveraging of resources to minimize redundant data production. NRCS uses USGS's LIDAR Base Specifications Version 1.0 as the baseline for the acquisition of high-resolution elevation to meet agency requirements. NRCS tracks data investments using a file geodatabase and publishes a status map on a monthly basis.

National Enhanced Elevation Assessment

NRCS participated in and helped fund the National Enhanced Elevation Assessment (NEEA). The NEEA was performed to document national requirements for improved elevation data, estimate the benefits and costs of meeting these requirements, and evaluate multiple national enhanced program implementation scenarios. The study was sponsored by member agencies of the NDEP and was completed in December 2011. The 3D Elevation Program (3DEP) was recommended by NDEP and was endorsed by the National States Geographic Information Council (NSGIC) and the National Geospatial Advisory Committee (NGAC).

Elevation Data Sources and Provisioning

Types and sources of elevation data commonly used for NRCS applications are DEMs and the National Elevation Dataset (NED). These data have 10- , 30-, and 3-meter resolution and are available via the USGS and USDA Web sites. The USGS offers a central Web site for downloading or ordering digital elevation data in Geographic and NAD83 formats via the National Map. The Geospatial Data Gateway is a USDA data distribution Web site where DEM and NED data are downloadable in the Universal Transverse Mercator (UTM) projection, NAD83 datum.

Foreign Agricultural Service

The USDA's International Production Assessment Division (IPAD) of the Office of Global Analysis (OGA) within the Foreign Agricultural Service (FAS) serves as the USDA's primary focal point for assessing global agricultural production outlook and conditions that affected world food security. For approximately three decades, satellite imagery analysis by FAS has provided the USDA's World Agricultural Supply and Demand Estimates (WASDE) report and the FAS Production Supply and Distribution (PSD) online database with objective and reliable global crop production estimates for foreign countries. The USDA's monthly WASDE report is part of OMB's Principal Federal Economic Indicators, and it is a timely assessment of national crop statistics collected worldwide. Free Landsat and MODIS imagery supplied crucial data inputs in deriving the monthly crop area and crop production estimates in the WASDE report, which is widely used by commodity market traders, producers, and U.S. Government policy decision makers.

During the 2011 crop season, FAS crop analysts examined and assessed satellite imagery with global coverage to enhance the reliability and objectivity of foreign crop production estimates. Satellite imagery analysis was utilized in conjunction with meteorological data, trade reports, and other sources of information that provided great strategic intelligence in determining crop production estimates for foreign countries.

The FAS crop analysts utilized multiple-resolution satellite imagery during the 2011 crop season to provide early warning of potential food supply disruptions worldwide, with free Landsat and MODIS imagery being the two primary satellite

imagery sources utilized. Free daily MODIS imagery (with 250-meter spatial resolution) from NASA's Terra and Aqua satellites helped to provide "cloud-free" imagery for relative crop yield monitoring, while free 16-day Landsat imagery (with 30-meter spatial resolution) from the USGS helped to provide timely crop area assessments worldwide. In addition, the FAS worked in cooperation with NASA's Goddard Space Flight Center (GSFC) and established the Global Agricultural Monitoring (GLAM) system, which quickly compared near-real-time MODIS imagery with historical imagery and allowed rapid crop yield estimates to be determined by systematic crop yield regression procedures.

FAS also managed the USDA's Satellite Imagery Archive (SIA), which saved millions of dollars in purchased commercial imagery through bulk imagery discounts and shared agency-wide imagery licenses. Reduced price-per-image savings and shared license costs helped to leverage limited USDA imagery funds for the benefit of all USDA agencies with remote sensing programs. For example, the 2011 North America Data Buy (NADB) contract with SPOT/Astrium provided the greatest cost savings for USDA-SIA because it offered "ground-receiver" discount rates for SPOT4 and SPOT5 imagery (with 20-meter and 10-meter spatial resolution, respectively) at approximately $14 per image, or a USDA cost savings of approximately $3,000 per image. In addition, the USGS orthorectified all "cloud-free" SPOT4 and SPOT5 imagery, which provided additional cost savings to all USDA agencies.

For more information about the remote sensing program at FAS, please refer to the Crop Explorer Web site at *http://www.pecad.fas.usda.gov/cropexplorer.*

Forest Service

As the primary forestry agency of the United States and the largest agency in the USDA, the U.S. Forest Service (USFS) continues to sustain the health, diversity, and productivity of the Nation's forests and grasslands. This work is conducted via three specific agency mission areas: Research and Development (USFS R&D), the National Forest System (NFS), and State and Private Forestry (USFS S&P).

In FY 11, USFS R&D conducted research to address forestry and natural resource issues both internationally and domestically, including the development of relevant

science and technologies. Partnerships with states, tribes, and other Federal agencies, as well as with universities and private industry, are integral to accomplishing the USFS R&D mission. Additionally, the USFS administered and managed 155 national forests and 20 national grasslands, collectively known as NFS lands. These lands encompassed 193 million acres in 44 states and Puerto Rico and were managed to meet diverse needs through sustainable multipurpose use. Lastly, USFS S&P provided assistance to private landowners and state, tribal, and community forestry agencies in the stewardship of approximately 500 million acres of non-Federal forest lands throughout the United States. This assistance included the provision of information and support to partner agencies to protect forests from wildland fires, insects, disease, and invasive plants.

To address the information needs of these USFS mission areas in FY 11, the USFS collaborated with NASA, as well as NOAA, the USGS, and other agencies, to apply operational satellite and airborne imagery and the most advanced remote sensing and geospatial technologies. Specific FY 11 USFS accomplishments are summarized below:

- Collecting comprehensive Earth Observing System (EOS) MODIS direct broadcast data for the United States and Canada; performing operational processing and disseminating relevant fire mapping and geospatial data products to fire managers and the general public (*http://activefiremaps.fs.fed.us*).
- Continuing activities with NASA Goddard Space Flight Center's Direct Readout Laboratory to test and operationally implement direct readout technologies to support resource management including land, atmosphere, and ocean science processing algorithms for EOS sensors (*http://directreadout.fs.fed.us*).
- Utilizing MODIS imagery for the operational detection of damage and changing forest health conditions in our Nation's forests (*http://foresthealth.fs.usda.gov/portal/Flex/FDM?dL=0*).
- Using MODIS imagery and other geospatial predictor data to produce 250-meter forest attribute data surfaces using nearest neighbor imputation methods.
- Using MODIS imagery and other geospatial predictor data to produce 250-meter forest carbon estimates using nearest neighbor imputation methods.

- Conducting operational crewed wildfire mapping missions using the Autonomous Modular Sensor (AMS) via coordination between the USFS, NASA Ames Research Center, and NASA's Airborne Sciences Program.
- Using Landsat TM/Enhanced Thematic Mapper (ETM) imagery to map the location, extent, and severity of year 2011 wildfires to support post-fire emergency stabilization/hazard mitigation activities, and of over 1,000 historical wildfires to assess the effectiveness of national fire management policies (*http://www.fs.fed.us/eng/rsac/baer, http://www.fs.fed.us/postfirevegcondition, and http://www.mtbs.gov)*.
- Continuing the exchange of knowledge and technologies between the USFS and Ames on the use of unmanned aircraft systems (UASes) under the auspices of the NASA/USFS Wildfire Research Applications Partnership (*http://geo.arc.nasa.gov/sge/WRAP/index.html*).
- Coordinating with Ames on the development of the Wide Area Imager (WAI) (developed under the NASA Small Business Innovation Research [SBIR] Program) as part of the next generation of Forest Service airborne sensors for fire/resource mapping.
- Using Landsat 5 TM and National Agriculture Imagery Program (NAIP) imagery to initiate and complete mid-level vegetation mapping products for National Forest lands and adjacent land areas throughout the country.
- Using Landsat TM/ETM and NAIP imagery to model Tree Canopy Cover (TCC) for study areas in the southeast and intermountain west as a prototype to generate a comprehensive TCC layer for the United States as part of the Multi-Resolution Land Characteristics Consortium (MRLC) National Land Cover Database 2011 update.
- Using Landsat TM/ETM and MODIS imagery to map and assess damage to forests in the immediate aftermath of the severe tornado outbreak of spring 2011 in the southeastern United States.
- Coordinating with the USGS in using Landsat TM imagery to update the Nationwide LANDFIRE vegetation and fuel layers originally compiled in 2001 (*http://landfire.gov*).
- Supporting an Environmental Protection Agency (EPA) assessment of the effects of land-cover change on water quality using Landsat TM/ETM

time-series stacks to detect and monitor forest land-cover change in the Lake Superior and Lake Michigan watersheds from the mid-1980s to the present.

- Leveraging multi-season Landsat TM imagery and other predictor layers to model key forest parameter surfaces used as inputs for the 2010 update of the National Forest Insect and Disease Risk Map (*http://www.fs.fed.us/foresthealth/technology/nidrm.shtml*).
- Using Landsat TM/ETM and NAIP imagery in conjunction with other core geospatial datasets to conduct ecological and soil-type mapping on NFS lands that are used by the USFS, NRCS, and other agencies for resource management, planning, and decision making (*http://www.fs.fed.us/eng/rsac/programs/teui/about.html*).
- Using Landsat TM/ETM time-series stacks, NAIP imagery, and USFS Forest Inventory and Analysis plot data to support carbon and biomass monitoring for 55 selected forested sites across the United States in support of the North American Forest Dynamics (NAFD) Project (*http://daac.ornl.gov/NACP/guides/NAFD_Disturbance_guide.html*).

Agricultural Research Service

As the primary research agency for the USDA, the Agricultural Research Service (ARS) conducts research to solve problems affecting global food security, agricultural air quality, biofuels, ecosystem services such as watersheds, and humanity's ability to adapt to climate change. ARS collaborates with NASA in partnership with other USDA agencies (NRCS, the Risk Management Agency [RMA], the World Agricultural Outlook Board [WAOB], FAS, the National Agricultural Statistics Service [NASS], and the Animal and Plant Health Inspection Service [APHIS]) to develop technologies that will help the agencies carry out their missions. Partnerships with other Federal agencies, universities, industry, and state governments are integral to ARS research. ARS develops technologies for the management of water and soil resources, crop production, and rangeland resources. The sensor systems used by ARS include satellite systems, airborne systems such as unmanned aerial vehicles (UAVs), on-the-go sensors mounted on field equipment, and other ground-based systems.

In FY 11, water quality and quantity management continued to be the largest area of emphasis for ARS remote sensing activities. Soil moisture remote sensing research continued with the development of algorithms for soil moisture estimation from aircraft and satellites. ARS scientists also contributed to the development of the next generation of satellite remote sensing systems through the Soil Moisture Active-Passive (SMAP) mission, with three scientists serving on the Science Definition Team. Researchers developed an Evaporative Stress Index (ESI) that will be used to map evapotranspiration and plant moisture stress from scales ranging from within-field to continental. ARS scientists have also shown that thermal infrared (TIR) and multispectral visible, near-infrared, and shortwave infrared data could be used to schedule irrigation, perform spatially variable irrigation, map drought, and estimate soil moisture and vegetation canopy water content. Additional research into more efficient fertilizer application using remote sensing of crop nitrogen status reduced excess fertilizer losses to the environment, thus leading to improved water quality and better economic returns to farmers.

In FY 11, ARS delivered to the FAS a data-assimilation system for merging land-surface information from models and remote sensing into a single enhanced estimate of land-surface variables including root-zone soil moisture, stream flow, and evapotranspiration. The data-assimilation technique enhances the value of remote sensing retrievals for monitoring key environmental variables, as well as improved precipitation estimates from numerical weather prediction models.

Scientists used remotely sensed information in the management of soil and nutrient resources via projects to map crop tillage practices, crop residue cover, and soil carbon. These applications remain important for conserving soil and water, sustaining soil quality, and sequestering carbon. Specific research on how winter cover crops reduced nitrogen runoff to sensitive ecosystems, like the Chesapeake Bay, used remote sensing to map and quantify the contributing landscapes. Similarly, radar remote sensing was developed as a tool to better understand and manage the fate of agrochemicals and sediment in coastal watersheds. Development began between ARS and Goddard on the implementation of a hyperspectral instrument on the International Space Station that will aid in the monitoring of vegetation status and soil carbon.

ARS also developed procedures to monitor the proliferation of invasive species with remote sensing to manage rangeland and understand the impacts of changing

climate on managed and natural ecosystems. Additionally, pest management research was enhanced with airborne and satellite imagery. Both cattle fever tick and screwworm flies were the focus of eradication and containment research, in which remote sensing was used to map infestations and favorable habitats.

National Agricultural Statistics Service

The National Agricultural Statistics Service (NASS) serves the basic agricultural and rural data needs of the country by providing objective, important, and accurate statistical information and services to farmers, ranchers, agribusinesses, and public officials. These data are vital to monitoring the ever-changing agricultural sector and carrying out farm policy. In FY 11, NASS used remote sensing data to construct and sample area frames for agricultural statistical surveys, estimated crop area and yield, began investigations of a NASA science grant on crop progress/condition, and published crop-specific land-cover data for dissemination via the new CropScape Web portal.

Furthermore, NASS used remote sensing data and techniques to improve the quality and accuracy of its statistics. For example, NASS used Landsat imagery, digital NAIP orthophoto quadrangles, and other remotely sensed inputs for CONUS and Puerto Rico to select the yearly area-based samples for the June Agricultural Survey. In addition, NASS constructed or updated new area-based sampling frames for Arizona, New Mexico, and Oklahoma.

The remote sensing acreage estimation program used Disaster Monitoring Constellation (DMC) and USGS Landsat data to produce crop acreage estimates for crops at the state and county levels for 41 states during the FY 11 crop year, up from 36 states the previous year. Acreage estimates were created for 18 different crops, up from 16 the previous year, covering all market-sensitive crops and states. With the expanded coverage and timeliness, NASS's Agricultural Statistics Board (ASB) was able to utilize the remote sensing acreage indications as independent input for setting the official estimates for the board's monthly Crop Production Reports. Analysts derived remote sensing–based acreage indications from a crop-specific land-cover categorization called the Cropland Data Layer (CDL). For the primary satellite imagery inputs, the FAS Satellite Imagery Archive provided 1,262

DMC images through a cooperative partnership while utilizing 3,972 Landsat images from the USGS. In addition, NASS distributed the CDL for 48 states to stakeholders for the previous 2010 crop season via the USDA Geospatial Data Gateway and the new CropScape data visualization portal at *http://nassgeodata.gmu.edu/CropScape*. Developed in cooperation with George Mason University (GMU) and released January 10, 2011, CropScape provides an open and freely available data exploration and query method to interact with current and historical CDLs.

NASS utilized MODIS normalized difference vegetation index (NDVI) products for modeling corn and soybean yield indications over the 12 largest production states. Updated yield estimates were delivered operationally to the ASB as an independent indication for setting official August, September, and October yield estimates by state, district, and county.

Finally, NASS continued work with GMU in FY 11 on a NASA-funded science grant titled "A National Crop Progress Monitoring System Based on NASA Earth Science Results." Research focused on crop growth modeling, crop phenology stage detection algorithm development, system prototyping and implementation, and crop progress ground truth data collection for validation. Additionally, prototyping efforts began on a Web-based national vegetation condition geospatial monitoring application based on MODIS data products and incorporated several vegetation metric indices for vegetation greenness and drought anomaly assessment.

Animal and Plant Health Inspection Service

USDA's Animal and Plant Health Inspection Service (APHIS) Center for Plant Health and Science used the North Carolina State University APHIS Plant Pest Forecasting System to generate global predictive maps; climate data were obtained from NOAA to generate the maps.

National Science Foundation

NSF

The National Science Foundation (NSF) continued to serve as the lead Federal agency for the support of ground-based astronomy and space science in FY 11. Through the Divisions of Astronomical Sciences, Atmospheric and Geospace Sciences, and Physics, as well as through the Office of Polar Programs, the NSF sponsored a broad base of observational, theoretical, and laboratory research aimed at understanding the states of matter and physical processes in the universe. Areas of research ranged from the most distant reaches of the universe and the earliest moments of its existence to nearby stars and planets, including our own sun and planetary system, as well as Earth's atmosphere and space environment.

Division of Astronomical Sciences

The Division of Astronomical Sciences (AST) supported the development of advanced technologies and instrumentation for astronomical sciences, in addition to providing core support for the optical and radio observatories whose state-of-the-art instrumentation and observing capabilities are accessible to the community on the basis of scientific merit. The NSF's national astronomical facilities included the National Radio Astronomy Observatory (NRAO), the Arecibo Observatory (AO), the National Optical Astronomy Observatory (NOAO), and the National Solar Observatory (NSO). The NSF also served as the executive agency for the Gemini Observatory—an international partnership operating optical/infrared telescopes in

both the Northern and Southern hemispheres—providing the United States' share of support for the program.

AST, in partnership with Europe, Canada, Japan, and Taiwan, continued construction on the Atacama Large Millimeter/submillimeter Array (ALMA), an interferometer located near San Pedro de Atacama, Chile. FY 11 saw continued delivery of North American antennas at a rate of about 1 every two months and transport of a further 11 accepted antennas to the 16,500-foot high-altitude site. The number of antennas at various stages of commissioning, integration, and testing in Chile now totals 51. Science observations by the community commenced using a 16-element subset of the full array.

AST continued its oversight of the Advanced Technology Solar Telescope (ATST), the next-generation U.S. ground-based solar telescope. The ATST, a collaboration of scientists from 22 institutions representing a broad segment of the U.S. solar physics community, previously earned the strong recommendation of the National Research Council of the National Academy of Sciences. When completed in 2019, the ATST will be the world's flagship ground-based telescope designed specifically for the study of solar magnetic fields on scales as small as 30 kilometers. In FY 11, funding for the construction of the $298 million ATST began with funds from the American Recovery and Reinvestment Act and the NSF's Major Research and Facilities Construction account. Detailed design and fabrication of the major telescope subsystems and instruments are under way, and the primary mirror blank has been cast. Construction awaits final permits from the state of Hawaii authorizing construction to begin on the site on Haleakala peak on Maui.

In FY 11, AST was moving toward the next phase of funding for the design and development of the Large Synoptic Survey Telescope (LSST) and starting the process for presenting LSST for construction support. LSST is a joint project of the NSF and the Department of Energy (DOE), with private and international partners. An interagency joint oversight group met regularly, both internally and with representatives from the project, throughout FY 11. The LSST Project will produce a purpose-built wide-field survey telescope and use the attached 3.3-gigapixel camera to image the entire accessible sky repeatedly for at least 10 years, producing more than 20 terabytes of data nightly. The LSST Project will enable breakthrough

research not just in cosmology (notably studies of dark energy and dark matter), but also in galactic structure and solar system astronomy. In addition, LSST opens up the time domain and will revolutionize the study of transient events. Project design work continued in FY 11, mostly with Federal support, while private funding was used for long-lead-time items and to address items of higher risk. The University of Arizona's Steward Observatory Mirror Lab started preliminary figuring and rough polishing of the innovative combined primary/tertiary mirror. The camera is a deliverable from DOE being designed at the Stanford Linear Accelerator Center (SLAC) National Accelerator Laboratory, and development work on the required detectors proceeded satisfactorily with more than one possible supplier. Full environmental and cultural compliance was completed early in FY 11, and site preparation work was completed during the year at Cerro Pachon, Chile. The NSF and DOE moved forward in their review processes: DOE's CD-1 review for the camera the agency will be supplying, and NSF's Preliminary Design Review of the full project. Both were completed successfully during FY 11. Community interest and support remain high.

The Atacama Cosmology Telescope (ACT) is a 6-meter-diameter millimeter-wave telescope located at 5,200 meters (17,000 feet) on Cerro Toco in the Atacama Desert of northern Chile, near the ALMA site. It is designed to measure minute variations in intensity of the cosmic microwave background (CMB, the radiation at microwave wavelengths that is a remnant of the Big Bang) to study how the universe began, what it is made of, and how it evolved to its current state. ACT is a dedicated special-purpose telescope and is equipped with a state-of-the-art customized camera with over 2,500 detectors cooled to a third of a degree above absolute zero. During FY 11, the telescope continued to operate successfully in its third year of full science operations, obtaining measurements that span size scales on the sky two to three times finer than any previous experiment to measure the microwave background. Under renewed funding in FY 11, work was begun to upgrade and expand the bolometer cameras and add polarization measurement capability.

The POLARBEAR telescope, funded by AST, is a new addition to the suite of observatories on the Atacama plateau. The telescope will be used to measure polarization of the cosmic microwave background to search for so-called B-modes, which will open up a new window on the early universe and the physics of inflation

if detected. POLARBEAR is a 3.5-meter-diameter microwave telescope, custom designed and fabricated by General Dynamics SATCOM, and looks most like a radio telescope or satellite dish. Unlike previous radio telescopes, POLARBEAR was designed for a very large field of view to accommodate a large imaging camera. Following a full field test of the system in California, the telescope was disassembled and shipped to Chile during FY 11.

Division of Atmospheric and Geospace Sciences

The Division of Atmospheric and Geospace Sciences' (AGS) high-altitude aircraft, the High-performance Instrumented Airborne Platform for Environmental Research (HIAPER), is a highly modified and instrumented Gulfstream V (GV) midsize jet operated by the National Center for Atmospheric Research (NCAR), a Federally Funded Research and Development Center of the NSF. HIAPER is FAA-certified to operate at 51,000 feet, and its ability to fly for long durations (over 12 hours), its long range (over 6,000 kilometers), and its scientific payload capacity (6,000 pounds) have enabled scientific research previously not possible with existing platforms. HIAPER is the most advanced airborne research platform in the U.S. civilian fleet. The German Aerospace Center (DLR) recently completed modifications, including advanced instrumentation, to a Gulfstream 550 that can collaborate with the NSF's GV HIAPER aircraft in scientific campaigns. During FY 11, the DLR's 550 staff and the GV's staff continued collaboration on instrument pod development and shared instrumentation. Also in FY 11, the GV continued to conduct long-duration flights for the HIAPER Pole to Pole Observations (HIPPO) deployment to study the carbon cycle and greenhouse gases as part of a multi-year campaign. The HIAPER GV also participated in additional field projects during FY 11 and remained one of the world's most advanced airborne research platforms.

NCAR's Research Aircraft Facility continued to operate and maintain HIAPER through FY 11, and HIAPER's expected lifetime is 10 to 25 years, during which new instrumentation innovations will be continually integrated onto the airframe as appropriate. NCAR also operated and maintained NSF's heavy-lift C-130Q research aircraft. In FY 11, the C-130Q participated in the Ice in Clouds—Tropical

(ICE-T) experiment, flying 13 missions through cumulonimbus clouds in the vicinity of the Virgin Islands in the Caribbean. The primary goal of ICE-T was to understand how ice particles originate in these clouds and how they impact the subsequent spread of ice in clouds from this climatologically important region.

The AGS Geospace Section (GS) supported a wide variety of research programs in space science in FY 11. These included the funding of advanced radar systems to study the ionosphere and magnetosphere, ground-based optical equipment to study the aurora and airglow, partial support to ground-based solar telescopes and instruments, and a wide-ranging portfolio of basic research in space physics. Major GS-funded activities in FY 11 included the Geospace Facilities (GF) program; the National Space Weather Program (NSWP); the Coupling, Energetics, and Dynamics of Atmospheric Regions (CEDAR) program; the Geospace Environment Modeling (GEM) program; and the Solar, Heliosphere, and INterplanetary Environment (SHINE) program.

The NSWP is a multiagency Federal program aimed at mitigating the adverse effects of space weather on the Nation's technological infrastructure by providing timely, accurate, and reliable space environment observations, specifications, and forecasts. In FY 11, GS contributed to the further development of the NSWP's Strategic Plan and Implementation Plan. These plans are available at the Web site of the Office of the Federal Coordinator for Meteorology.

In addition, during FY 11, a formal NSF Science and Technology Center called the Center for Integrated Space Weather Modeling (CISM) continued to develop and test an end-to-end computer simulation for space physics research and applications. CISM's coupled models simulated the processes by which energy from the sun and solar wind propagates to Earth, as well as the resulting effects on Earth's magnetosphere, ionosphere, and thermosphere. CISM researchers integrated these results with education and outreach activities. An effective knowledge transfer program also ensured that CISM shared these models for use in operational space weather forecasting centers of the United States Air Force and NOAA.

Throughout FY 11, the Community Coordinated Modeling Center (CCMC) for space weather research, cosponsored by the NSF and NASA and located at NASA's Goddard Space Flight Center, continued to provide the research community with access to state-of-the-art space weather models and conducted important

model validation activities necessary for the transition of research models to operational use.

Research facilities remained as the key component of GS efforts. In FY 11, the Upper Atmospheric Facilities program continued to promote basic research on the structure and dynamics of Earth's upper atmosphere. In particular, the CEDAR and GEM programs conducted research efforts utilizing these facilities. Throughout FY 11, observations made by the Advanced Modular Incoherent-Scatter Radar (AMISR) at Poker Flat, Alaska, demonstrated the unique capabilities of this new instrument, including its ability to image the ionospheric effects of auroral particle precipitation in three dimensions. These observations provided a wealth of data particularly useful to modelers interested in validating space weather models. A second AMISR system has been operating at Resolute Bay in Arctic Canada since 2009. This radar is ideally situated to observe the properties of the ionosphere in the polar cap, a region that is characterized by high ionospheric variability that often causes disruption of important navigation and communication systems.

GS also continued to support the study of magnetospheric physics within the international Super Dual Auroral Radar Network (SuperDARN) consortium through the addition of a new radar installation in central Oregon in 2010. Along with two other midlatitude SuperDARN radars that had been constructed in southern Virginia and central Kansas in 2009, the new Oregon site in Christmas Valley extended the longitudinal coverage of this growing instrument chain.

In FY 11, GS continued to support its new program for CubeSat-based small satellite science missions for atmospheric and space weather research. During the third CubeSat competition in May 2010, GS received proposals for a total of 23 new missions. As was the case for the previous CubeSat solicitations, the quality of the proposals, in terms of both scientific creativity and technological innovation, was exceptional. From this competition, another two excellent CubeSat science projects were started in FY 11, adding new capabilities and breadth to the overall CubeSat program, which, with this addition, encompassed eight CubeSat projects. Two NSF-funded CubeSat missions were launched successfully in November 2011 as part of NASA's Educational Launch of Nanosatellites (ELaNa) program.

GS continued support for the satellite-based Active Magnetosphere and Planetary Electrodynamics Response Experiment (AMPERE) through FY 11.

AMPERE utilized the 66 networked satellites of the existing Iridium constellation to create a new facility for collecting geomagnetic field data. The AMPERE facility has provided the first-ever real-time observations of the electric currents that link Earth's magnetosphere and ionosphere and the first-ever continuous, global observations for tracking geomagnetic storm-time dynamics. Geomagnetic storms occur when charged particles emitted by solar flares interact with Earth's magnetosphere. Such storms can cause major disruptions of power and communications systems on the ground. The AMPERE data server facility has been established and placed online, and data for the full year of 2010 have been made freely available to researchers, with new data being added continually.

The GS solar physics community also continued to benefit from the Division of Astronomical Sciences' ongoing efforts to develop and manage the Advanced Technology Solar Telescope being constructed in Hawaii. Also in FY 11, GS continued to provide oversight for much-needed upgrades at the Owens Valley Solar Array in California.

During FY 11, the AGS Atmosphere Section (AS) continued to support the Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC). The University Corporation for Atmospheric Research (UCAR) and its collaborator, Taiwan's National Space Organization (NSPO), designed and built the COSMIC six-satellite constellation, which was launched on April 14, 2006, with the support and assistance of the U.S. Air Force's Space Test Program (STP). Shortly thereafter, data became available from the three payloads: the special space-based GPS radio occultation (RO) receivers, the so-called tiny ionospheric photometers, and the tri-band beacons. These data have been provided freely to the world scientific community.

COSMIC radio occultation data have been assimilated at many operational weather prediction centers, including the U.S. National Centers for Environmental Prediction (NCEP), the European Centre for Medium-Range Weather Forecasts (ECMWF), Météo France, the U.K. Met Office, the Meteorological Service of Canada, Taiwan's Central Weather Bureau, and others. All of these centers have reported that RO data are having a significant positive impact on numerical weather forecasts. In ionospheric studies, COSMIC RO data have accelerated the development of physical models for space weather prediction by providing dense,

accurate, and global electron-density measurements. These data are used for model testing and initialization, including for the response of the global ionosphere to the impact of solar storms.

During FY 11, all six COSMIC satellites were operating and providing data. On average, COSMIC produced from 1,500 to 2,000 GPS RO soundings per day. Ninety percent of these were processed and delivered to operational centers within 3 hours. COSMIC has supported more than 1,100 registered users from 52 countries. In collaboration with UCAR's Unidata, COSMIC soundings have been provided in real time to support the university community. COSMIC received funding from U.S. agencies and Taiwan in order to continue its operation through April 2011.

Office of Polar Programs

For FY 11, the primary activities of the NSF's Office of Polar Programs (OPP) in ground-based space science and astronomy included continued full-scale observations with the 10-meter off-axis radio telescope at the U.S. Amundsen-Scott South Pole Station that was surveying deep space galaxy clusters, as well as continued observations of high-energy neutrinos with the IceCube Neutrino Observatory (ICNO), fully completed and commissioned with a total of 86 strings in December 2010.

By December 2011, the South Pole Telescope successfully completed five-year-long austral winter (northern summer) observations of the redshift-independent Sunyaev-Zel'dovich Effect (SZE) in the cosmic microwave background radiation. (The SZE is a decrement in the strength of CMB radiation as it was scattered by electrons in galaxy clusters on its way toward Earth.) Covering a total of 2,500 square degrees of the southern skies, the SZE survey discovered over 500 massive galaxy clusters in the early universe. This mapping will allow reconstruction of the universe's evolution through the power of this new method of distant galaxy cluster mass detection.

By the end of 2011, the South Pole ICNO had collected data for the first full year of operating the complete array of 86 strings of optical photodetectors deployed, at the 1.4- to 2.4-kilometer depth, in the ice under the South Pole Station in Antarctica. This makes ICNO the largest (by volume—1 cubic kilometer) neutrino detector in the world available for science observations. Data collection continued

with the advanced filtering and reconstruction of neutrino events. Scientific topics under study included searches for weakly interacting massive particles, neutrino point sources, and magnetic monopoles. An additional scientific topic of interest is a study of the symmetry and asymmetry of the distribution of galactic cosmic rays between the Northern and Southern hemispheres.

Department of State

DOS

The Department of State (DOS) carries out diplomatic efforts to support U.S. space policies and programs internationally. State supports U.S. civil space activities through the negotiation of bilateral and multilateral agreements with partner countries and leads U.S. participation in numerous international space and technological venues and international organizations. State also maintains outreach programs to advance U.S. space and foreign policy objectives.

DOS continued to represent the United States on the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS) and its Legal and Scientific and Technical subcommittees. With so many countries now engaged in space activities, DOS considers promoting the safe and responsible use of space by all current and future spacefaring nations a vital goal. At UNCOPUOS, DOS led U.S. efforts on the long-term sustainability of space, including such issues as orbital space debris, meteorology, astronomy and astrophysics, space transportation, nuclear power sources in space, and legal issues related to international liability and responsibility of launching nations. Still building on the results of the International Heliophysical Year to improve international cooperation in understanding the impact of space weather on satellites and Earth's environment in general, DOS continued to promote space weather as an important foreign policy topic worldwide.

DOS continued strong international efforts to implement the National Space Based Positioning, Navigation, and Timing (PNT) Policy and the U.S. Space Policy in FY 11. The fifth plenary meeting of the International Committee on Global Navigation Satellite Systems (ICG-5) was held in Turin, Italy, in October 2010, and the sixth plenary meeting of the ICG (ICG-6) was held in Tokyo, Japan,

in September 2011. In both ICG meetings and throughout the year, State pursued work plans in the four ICG working groups to obtain better understanding of other Global Navigation Satellite System (GNSS) providers' systems and to promote common time and geodesy standards for interoperable civil systems. Templates describing geodetic and timing references for all systems were completed at ICG-6 and were made available on the ICG Web site.

An Interference Detection and Mitigation Workshop was approved by the ICG-6 plenary. A new ICG subgroup was also formed to focus on GNSS applications.

The United States and European Union continued close cooperation under the auspices of the 2004 GPS-Galileo Cooperation Agreement. In November 2010, the United States was informed that all EU member states had deposited entry-into-force notes, and the United States subsequently sent an entry-into-force diplomatic note to the EU Depository (Commission) on June 6, 2011. The United States and EU conducted a plenary-type digital videoconference in May 2011, and the EU proposed an updated joint strategy for closer GNSS cooperation.

Close U.S.-Japanese cooperation in satellite navigation issues continued with our annual plenary meeting in January 2011 in Washington, DC. In September 2010, Japan had launched its first Quasi-Zenith Satellite (QZS), called Michibiki, which is designed to be compatible and highly interoperable with GPS. Work designed to improve QZS performance continued on QZS monitoring sites in Guam and Hawaii.

Bilateral U.S.-Russia talks on compatibility and interoperability issues between GPS and Russia's Global Navigation Satellite System (GLONASS) continued on the margins of international conferences. Technical work continued on next-generation search-and-rescue capabilities that are planned for GPS III SVs9+ and new GLONASS satellites.

In July 2011, the U.S. and India convened the third U.S.-India Joint Working Group on Civil Space Cooperation in Bangalore. Among other agenda items, the Indian Space Research Organisation (ISRO) agreed to resume work with U.S. Government agencies to promote interoperability between GPS and two emerging Indian counterpart systems, the Indian Regional Navigational Satellite System (IRNSS) and the GPS Aided Geo Augmented Navigation (GAGAN) System.

State supported a strong public outreach and diplomatic campaign to underscore the reliability and accuracy of GPS. DOS speakers gave presentations at many

international conferences, including the Moscow International GNSS Conference, the Korean International GNSS Symposium, meetings of the international section of the Civil GPS Service Interface Committee, and the annual Institute of Navigation conference.

In June 2010, the United States hosted the Asia-Pacific Economic Cooperation (APEC) GNSS Implementation Team in Seattle, Washington. The meeting was attended by 80 experts from 12 APEC economies (Chile, People's Republic of China, Indonesia, Japan, Republic of Korea, Malaysia, Mexico, Chinese Taipei, Peru, Russia, Thailand, and the United States) and 1 intergovernmental organization (the International Committee on the Global Navigation Satellite System), 1 participant from the European Commission, and 1 nongovernmental organization (the International Federation of Surveyors). An industry forum was conducted as part of the program, and representatives from Boeing, Lockheed Martin, ITT, Raytheon, Trimble, OnStar, FedEx, United Airlines, Alaska Airlines, and others highlighted satellite navigation technology developments that would reduce congestion, enhance transport safety and security, and achieve effective sustainability, as called for by APEC transportation ministers. The United States demonstrated several GNSS applications in the transportation area, and the APEC GNSS Implementation Team endorsed a strategy for the adoption of measures to include GNSS technologies in the development of seamless intermodal transportation systems for 2010 through 2015.

In 2010, DOS initiated a new dialogue with the EU and the European Space Agency (ESA) on space weather as part of ESA's space situational awareness program. DOS also supported an international meeting called by the National Security Council staff on mitigating space weather events. State is supporting formal and informal interagency dialogue with a view to coordinating U.S. Government efforts in this area in terms of both research and operations.

Finally, DOS continued to promote the use of GPS in the African continent, working through the AfricaArray consortium and the United Nations Office of Outer Space Affairs. AfricaArray is a public-private partnership led by academic researchers at the Universities of Witwatersrand in South Africa and Pennsylvania State University in the United States; it is focused on supporting training and research in Earth, atmospheric, and space sciences in Africa. At the AfricaArray

annual meeting held November 14–22, 2011, in Johannesburg, DOS facilitated the travel of scientists from Botswana, Cameroon, the Democratic Republic of the Congo, Ethiopia, Ghana, Malawi, Nigeria, Tanzania, Uganda, and Zambia, as well as their participation in workshops on GPS applications taught by UNAVCO scientists.

Department of Energy

DOE

The Department of Energy (DOE) participates in the national effort to further U.S. interests in space. Three organizations within DOE provide this capability: the National Nuclear Security Administration's (NNSA) Office of Defense Nuclear Nonproliferation Research and Development (DNN R&D), the Office of Science (SC), and the Office of Nuclear Energy (NE).

Office of Defense Nuclear Nonproliferation Research and Development

The Nuclear Detonation Detection program builds the Nation's operational sensors to monitor the entire planet from space to detect and report surface, atmospheric, or space nuclear detonations (NuDets). The Space-Based Nuclear Detonation Detection subprogram provides much of the Nation's capability to detect, report, locate, and identify nuclear explosions using orbiting satellites. The DNN R&D develops, builds, and delivers these satellite payloads to meet interagency performance and schedule commitments and provides launch and on-orbit operational support for the current generation of the U.S. NuDet Detection System (USNDS).

Since the Vela satellite program in 1960, NNSA and its predecessors have provided the underlying science and technology capability for space-based detection of foreign nuclear weapon detonations to meet test-ban-treaty monitoring and missile warning needs. Today, these associations continue and have expanded to include military support missions and space control. These efforts span decades of overlapping generations of instruments deployed on multiple platforms in different orbital configurations. NNSA will continue full-scale production and deliveries of sensor

packages to ensure that payloads are ready, as needed, to meet national security requirements. To ensure that the technologies and capabilities developed for the program support stakeholder needs, DNN R&D actively engages in intergovernmental working groups that reduce duplication among agencies, bring new user requirements to the fore, and improve the quality of relevant technology across the funding agencies. Strong synergy exists between the work performed in the USNDS program and planetary science and astrophysics. The current gamma-ray spectrometers used for USNDS share their heritage with the NASA Swift mission, which evolved from earlier USNDS sensors. This mission exemplifies how collaboration between DOE's national laboratories and NASA for astrophysics has benefited USNDS capabilities and vice versa. Additionally, the NASA Living With a Star program contributes to, and is benefited by, the NNSA-developed payloads that monitor and operate in the near-Earth space environment.

The NNSA weapons laboratories, most notably Los Alamos National Laboratory (LANL) and Sandia National Laboratory (SNL), supply the science, technology, and engineering required for USNDS, with Lawrence Livermore National Laboratory (LLNL) contributing to the end-to-end testing of USNDS. These NNSA laboratories have unique and comprehensive capabilities in understanding nuclear weapons, as well as knowledge of the signatures and observables associated with a nuclear detonation and the propagation of signals from the weapon to the sensor. Moreover, these laboratories provide capabilities in the design, construction, calibration, deployment, and operation of satellite-based detection instruments, along with detailed modeling and analysis. As the basis for 24/7/365 global monitoring, the user/operations communities routinely receive analysis, insights, and computer codes based on this research. These capabilities represent an important noncommercial source of national space expertise and competency that NNSA is committed to sustaining and nourishing.

Two payloads built by NNSA at these laboratories accomplish the NuDets reporting mission—the Global Burst Detector (GBD) and the Space and Atmospheric Burst Reporting System (SABRS). The GBD payload is hosted on all GPS satellites. The SABRS payload is carried on satellite hosts in geosynchronous orbit. In order to maintain a vital capability to design and implement these systems, DNN R&D supports demonstration-validation payloads to explore new technologies and

new sensing modalities and to increase the technology readiness level (TRL) for parts that might be used in future payload designs.

Office of Science

The Office of Science (SC) supports many cooperative efforts with NASA covering a broad range of space interests. Projects funded by SC include the development of techniques to conduct fundamental physics in space to investigate high-priority national science objectives. Examples of these efforts include the Alpha Magnetic Spectrometer and the Fermi Gamma-ray Space Telescope (FGST). The Alpha Magnetic Spectrometer, also designated AMS-02, is a particle physics experiment. Launched on the Space Shuttle in May 2011, AMS-02 is now mounted on the International Space Station, where it searches for various forms of unusual matter by measuring cosmic rays. Among the experiment's science goals are the search for evidence of dark matter and for cosmic domains of antimatter. When it becomes available, the AMS-02 database of tens of billions of cosmic ray events can also benefit NASA's Human Space Exploration Program by its use in future NASA space-radiation dose models.

The Large Area Telescope (LAT), the primary instrument on FGST, is a satellite mission that studies the high-energy gamma-ray sky. SC managed the LAT fabrication and now operates the LAT Science Operations Center. Researchers use the data to learn about high-energy acceleration mechanisms generated by supermassive black holes and supernovae and to search for dark matter.

The Office of Science also supports research in plasma science, which contributes to SC-NASA mutual interests in the knowledge of astrophysical systems. A major area of research supported by SC's Office of Fusion Energy Sciences is centered on developing a comprehensive understanding of astrophysical magnetic processes, including particle acceleration in cosmic gamma-ray bursts, magnetic reconnection and turbulent processes in Earth's magnetosphere and solar corona, the formation and evolution of astrophysical jets, and dynamo processes creating planetary/galactic magnetic field structures. Other research sponsored by this office focused on probing the properties of warm dense matter as found in planetary cores.

The Office of Science and NASA completed a successful joint experiment in 2011, the Midlatitude Continental Convective Clouds Experiment (MC3E), at the Atmospheric Radiation Measurement (ARM) Climate Research Facility's Southern Great Plains (SGP) site in central Oklahoma. Findings from this experiment support the development of model improvements and critical algorithms for the NASA Global Precipitation Mission satellite. Several publications by teams of DOE and NASA scientists are nearing publication. NASA scientists are also co-investigators in a current experiment, MAGIC (the Marine ARM GPCI Investigation of Clouds; GPCI is a project comparing data from the major climate models), which is studying marine clouds by deploying the second ARM Mobile Facility (AMF2) on the Horizon Lines container ship Spirit, making regular transects between Los Angeles and Hawaii from October 2012 to September 2013. The Orbiting Carbon Observatory-2 (OCO-2) Science/Validation Team has deployed ground-based solar-viewing Fourier transform spectrometer (FTS) mobile laboratories at the SGP and Darwin Tropical West Pacific (TWP) ARM sites for several years. This work is scheduled to continue through 2016. These data have been utilized to validate space-based CO_2 retrievals from a variety of different satellite instruments. SC also engages in joint efforts to understand atmospheric and environmental phenomena.

Since astronauts are spending more time in space, NASA is working on ground-based studies with DOE and others to understand the possible risks to human beings exposed to space radiation. SC provides scientific user facilities for the scientific community, including particle accelerators and ion beams for biological and electronic systems radiation studies. The NASA Space Radiation Laboratory (NSRL) was established at DOE's Brookhaven National Laboratory (BNL) to study the radiobiological effects of using beams that simulate the cosmic rays found in space. Jointly managed during the four-year construction period by SC and NASA's Johnson Space Center, the facility employs beams of heavy ions extracted from BNL's Booster accelerator, providing a leading capability for radiobiology studies in the United States.

Since FY 01, under a joint Memorandum of Agreement, DOE and NASA have engaged in coordinated efforts to better understand and predict the health risks associated with exposure to low-dose radiation. SC's Low Dose Radiation Research

Program interacts with the Space Radiation Project within NASA's Human Research Program. The Low Dose program focuses on doses of radiation measured at or below current workplace exposure limits. NASA's Space Radiation Project seeks to understand the biological effects of space radiation so that radiation risks may be accurately assessed.

Office of Nuclear Energy

The Office of Nuclear Energy (NE) supports NASA's space science and exploration programs by maintaining the necessary nuclear facilities' infrastructure capabilities to produce and deliver power systems for Federal user agencies, such as NASA. These facilities support NE's production of space radioisotope and reactor power system technologies for current space mission applications.

DOE and its predecessors have provided radioisotope power systems that have safely enabled deep space exploration and national security missions for five decades. Radioisotope power systems (RPSs) convert the heat from the decay of the radioactive isotope plutonium-238 into electricity. RPSs are capable of producing either heat or electricity for decades under the harsh conditions encountered in deep space. They have proven to be safe, reliable, and maintenance-free in missions to study the moon and all of the planets in the solar system except Mercury. Systems that utilize RPS-powered systems are currently in many different stages of their mission lives. The Mars Science Laboratory Curiosity rover was launched in November 2011. Curiosity is powered by a Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) that was designed, built, and delivered by DOE. Curiosity is the largest and most capable rover ever sent to another planet. It is currently exploring a region on Mars known as Gale Crater. Voyagers 1 and 2 left Earth in 1977 to conduct a grand tour of the outer planets and are currently exploring the heliosheath on the edge of the solar system, seeking out the boundary of interstellar space. Currently, Voyager 1 is the farthest humanmade object from Earth; it is in interstellar space more than 11 billion miles away. Three Multi-Hundred Watt Radioisotope Thermoelectric Generators (MHW-RTGs) serve as the central power source for the Voyager spacecraft. Both spacecraft remain operational and are sending back useful scientific data after over 36 years of operation;

they are expected to continue functioning through 2025. The Cassini mission launched in 1997 and entered orbit around Saturn in 2004. The Cassini spacecraft uses three DOE-supplied General Purpose Heat Source Radioisotope Thermoelectric Generators (GPHS-RTGs) and is the largest spacecraft ever launched to explore the outer planets. It is successfully returning data and images of Saturn and its surrounding moons, using a broad range of scientific instruments, and is expected to continue to operate until at least 2017. The New Horizons spacecraft, launched in 2006, is the fastest spacecraft ever to leave Earth and also uses a GPHS-RTG. New Horizons has already returned images and scientific data from Jupiter and will continue its journey of 3 billion miles to study Pluto and its moon, Charon, in 2015. It may also go on to study one or more objects in the vast Kuiper Belt, the largest structure in our planetary system.

The stockpile of plutonium-238 used to power these missions to explore the solar system and for other Government applications is limited. NE is working with NASA to reestablish domestic plutonium-238 production in order to ensure continued availability of these power systems for future science missions.

Smithsonian Institution

The Smithsonian Institution continued to contribute to national aerospace goals through the activities of the Smithsonian Astrophysical Observatory (SAO), which, together with the Harvard College Observatory in Cambridge, Massachusetts, forms the Harvard-Smithsonian Center for Astrophysics (CfA). Through this organization, more than 300 scientists are engaged in a broad program of research in astronomy, astrophysics, Earth and space sciences, and science education. The Smithsonian National Air and Space Museum (NASM) in Washington, DC, also contributed to national aerospace goals through its research and education activities.

In FY 11, SAO astronomers announced the discovery of giant, previously unseen structures at the center of our galaxy. They found two gamma-ray-emitting bubbles that extend 25,000 light-years above and below the galactic plane. Those bubbles may be fossils from an earlier, more active period in our galaxy's history. The energy required to create them probably came from an eruption from the supersized black hole at the center of the Milky Way.

SAO continued to be at the forefront of a decades-long effort to map the local universe. In May 2011, researchers unveiled the most complete 3D map of nearby galaxies ever created. The 2MASS redshift survey took more than 10 years to accomplish. It cataloged more than 43,000 galaxies out to a distance of 380 million light-years.

FY 11 marked the eighth year of operations for NASA's Spitzer Space Telescope, whose Infrared Array Camera (IRAC) was developed at SAO and constructed at NASA's Goddard Space Flight Center. Spitzer is operated by the Jet Propulsion Laboratory. Spitzer studies the universe at infrared wavelengths of light, enabling it to peer into nearby dust-obscured regions to study the birth and evolution of stars,

observe planets around other stars (exoplanets), and detect distant galaxies in the early universe.

In FY 11, SAO scientists released a photo album of galactic "train wrecks." The new images combined observations from Spitzer, which observes infrared light, and NASA's Galaxy Evolution Explorer spacecraft, which observes ultraviolet light. By analyzing information from different parts of the light spectrum, scientists can learn much more than from a single wavelength alone because different components of a galaxy are highlighted. The combined data highlighted areas in colliding galaxies where stars are forming most rapidly, permitting astronomers to take a more complete census of the new stars.

Spitzer also has proved valuable in studying exoplanets. For example, in FY 11, it showed that a gas giant planet circling Upsilon Andromedae has a "hot spot" shifted 80° around the planet, rather than being hottest directly under the glare of its sun. This suggests that the planet has extremely fast winds. Spitzer also revealed the first carbon-rich planet, which contrasts with the silicon-rich worlds in our solar system.

As one of NASA's Great Observatories, the Chandra X-ray Observatory studies the high-energy universe with unparalleled vision in x-ray light; SAO has operated it on NASA's behalf since 1999.

There were many exciting and significant astronomical advances made by the Chandra X-ray Observatory in FY 11. For example, astronomers using Chandra announced the discovery of evidence for the youngest black hole known to exist in our cosmic neighborhood. This black hole could help scientists better understand how massive stars explode, which ones leave behind black holes or neutron stars, and the number of black holes in our galaxy and others.

Scientists also found a pattern of x-ray "stripes" in the remains of an exploded star in the data from a long Chandra observation of what is known as the Tycho supernova remnant. This result may provide the first direct evidence that a cosmic event can accelerate particles to energies a hundred times higher than that achieved by the most powerful particle accelerator on Earth. It could also explain how some of the extremely energetic particles bombarding Earth, called cosmic rays, are produced.

Astronomers also used Chandra in FY 11 to discover the first pair of supermassive black holes in a spiral galaxy similar to the Milky Way. At a distance of

160 million light-years, it is also the nearest known pair of supermassive black holes. The black holes are located near the center of the spiral galaxy NGC 3393. Separated by only 490 light-years, the black holes are likely the remnant of a merger of two galaxies of unequal mass a billion or more years ago.

The Solar Dynamics Observatory provides better-than-HD-quality images of the sun's surface and outer atmosphere. SAO is a major partner in the Atmospheric Imaging Assembly (AIA), a group of four telescopes that photograph the sun in 10 different wavelength bands, or colors, once every 10 seconds.

In FY 11, AIA offered stunning images of solar material dancing up into the sun's atmosphere, of intense bursts of light from powerful solar flares, and of "active regions" as they merge and grow. By looking at these pictures in different wavelengths—each wavelength corresponds to gases at a different temperature—scientists can better map how these events fit in to the sun-Earth system as a whole.

AIA spotted hypothesized, but never before detected, magnetic field ripples in the sun's atmosphere called Alfvén waves. Scientists found that the waves in the sun's atmosphere carry more energy than previously thought, and possibly enough to drive two solar phenomena whose causes remain points of debate: the intense heating of the corona to some 200 times hotter than the sun's surface, and solar winds that blast up to 1.5 million miles per hour.

AIA also had another first in FY 11: it observed a comet's last moments as it evaporated into nothing while flying too close to the sun. Comets often die this way, but humans had never before seen them do so against the backdrop of the sun. Watching the death throes offered scientists a chance to measure the mass of the comet, something that cannot usually be determined from afar. In its final moments, the comet was about 100 million pounds and had a glowing tail some 10,000 miles long, while traveling about 400 miles per second.

SAO maintained its partnership in two other sun-watching spacecraft: Hinode and the Solar and Heliospheric Observatory.

SAO continued to play a leading role in the work leading toward the scientific success of NASA's Kepler mission. Kepler is tasked with hunting for exoplanets orbiting select stars in the Lyra and Cygnus constellations. SAO scientists are making major contributions to the confirmation and characterization of planet candidates identified by Kepler. The highlights in FY 11 included the discoveries of

a gas-giant planet blacker than coal and a planet that resembles the fictional world of Tatooine, Luke Skywalker's home in the movie *Star Wars*. This real-life Tatooine circles a pair of stars, so it has two suns in its sky.

The Submillimeter Array (SMA), a pioneering observatory for radio astronomy, continued to engage in a wide variety of astronomical observations. Its top research highlight for FY 11 was the study of a dusty disk surrounding the star CQ Tauri, a roughly 10-million-year-old star located about 300 light-years away.

A dust grain emits most strongly at wavelengths of radiation that are approximately the same as its size; its efficiency radiating at other wavelengths similarly depends on its size. By measuring the spectral behavior of dust emission, therefore, it is possible to determine the ensemble properties of the dust grains in a disk. The dust in the interstellar medium (and by implication in the very early disk around a star) has sizes comparable to or smaller than a wavelength of optical light.

In contrast, SAO astronomers found that the dust in the disk of CQ Tauri was huge: consistent with sizes of a centimeter or perhaps even more—almost 10 thousand times larger than the typical dust grains in interstellar space. They also reported evidence that the dust grains in the inner portion of the disk were larger than those in the outer regions. These new results lend support to models of bottom-up grain growth and, in turn, help to explain how, where, and when new planets are made.

In public outreach, SAO continued its popular monthly Observatory Night lectures and observing sessions. Begun by observatory director Harlow Shapley in 1930, these public nights offer the local community an opportunity to learn about the latest advances in astronomy as well as view the moon, stars, and planets through a variety of telescopes. During FY 11, attendees routinely filled the observatory auditorium and a nearby overflow room to capacity. The lectures are Webcast live and archived online to reach a broader audience.

SAO participated in the fifth annual Cambridge Science Festival—a celebration showcasing the leading edge in science, technology, engineering, and math. This multifaceted, multicultural event takes place every spring in Cambridge, Massachusetts.

SAO also provided occasional Author's Night programs, as well as Sci-fi Movie Nights that explored the theme "Everything I learned about science, I learned at the movies."

In FY 11, NASM continued to educate and inspire the public through exhibits and education programs, including discovery stations, lecture series, family educational events, publications, and intern programs. A new, updated edition of the bestselling overview on aeronautical engineering, *Introduction to Flight*, by NASM curator for aerodynamics Dr. John Anderson, was published this year. In collaboration with the National Museum of American History, NASM began construction on a new major exhibition, "Time and Navigation," which will explore the relationship between timekeeping and finding our way in air, in space, on land, and on sea. Work also continued on updates to the "Moving Beyond Earth" exhibition on the topic of human spaceflight in the Space Shuttle/International Space Station era.

NASM's Archives Division began moving to the museum's Steven F. Udvar-Hazy Center, which houses a new restoration hangar, conservation lab, and storage areas for the national artifact and archival collections. The World War II–era Curtiss SB2C Helldiver was the first aircraft moved by the Collections Division to the new facility.

Staff members in NASM's Center for Earth and Planetary Studies (CEPS) continued to serve on the science teams of several spacecraft missions. Dr. John Grant is a participating scientist for the Mars Exploration Rover (MER) mission that is currently operating on Mars. He is a chair of the MER Science Operations Working Group; in that capacity, he directs the science team to consensus on targets and operations for the long-lived rovers. He conducts real-time mission planning from a control station installed on-site at CEPS. Dr. Grant is also on the Mars Science Laboratory (MSL) science team and was cochair of the MSL Landing Site Steering Committee, which worked to identify candidate landing sites for the rover Curiosity. NASA announced the selection of Gale Crater as the landing site at NASM during the museum's annual "Mars Day!" family educational event, which included a full-scale model of Curiosity on display.

CEPS staff are on the science teams for the Mars Advanced Radar for Subsurface and Ionosphere Sounding instrument on Mars Express, both the High Resolution Imaging Science Experiment and the Shallow Subsurface Radar instruments on the Mars Reconnaissance Orbiter, the Lunar Reconnaissance Orbiter, and the MESSENGER mission to Mercury. This year, the MESSENGER spacecraft was successfully inserted into Mercury orbit. Dr. Tom Watters, a participating scientist

on MESSENGER, helped plan and implement data collection for the orbital phase of the mission.

CEPS continued its active research program in planetary and terrestrial geology and geophysics using remote sensing data from Earth-orbiting satellites, as well as piloted and unpiloted space missions. The scope of research activities included work on the moon, Mars, Earth, Mercury, and Asteroid 433 Eros. Research topics included cratering and volcanism on Mercury; lunar geomorphic and tectonic studies; comparative planetology; terrestrial arid land studies; and Martian aeolian, depositional, fluvial, volcanic, and glacial features.

As a NASA Regional Planetary Image Facility (RPIF), CEPS continued to house a collection of over 300,000 images of the planets and their satellites that is a reference library for science researchers and the public. The CEPS RPIF holds the most complete collection of hard-copy lunar images of any RPIF in the world.

APPENDICES

Appendix A-1

U.S. Government Spacecraft Record

(Includes spacecraft from cooperating countries launched by U.S. launch vehicles.)

	Earth Orbit[a]		Earth Escape[b]	
Calendar Year	**Success**	**Failure**	**Success**	**Failure**
1957	0	1	0	0
1958	5	8	0	4
1959	9	9	1	2
1960	16	12	1	2
1961	35	12	0	2
1962	55	12	4	1
1963	62	11	0	0
1964	69	8	4	0
1965	93	7	4	1
1966	94	12	7	1[b]
1967	78	4	10	0
1968	61	15	3	0
1969	58	1	8	1
1970	36	1	3	0
1971	45	2	8	1
1972	33	2	8	0
1973	23	2	3	0
1974	27	2	1	0
1975	30	4	4	0
1976	33	0	1	0
1977	27	2	2	0
1978	34	2	7	0
1979	18	0	0	0
1980	16	4	0	0
1981	20	1	0	0
1982	21	0	0	0
1983	31	0	0	0
1984	35	3	0	0
1985	37	1	0	0
1986	11	4	0	0
1987	9	1	0	0
1988	16	1	0	0
1989	24	0	2	0
1990	40	0	1	0
1991	32[c]	0	0	0
1992	26[c]	0	1	0
1993	28[c]	1	1	0
1994	31[c]	1	1	0
1995	24[c, d]	2	1	0
1996	30	1	3	0
1997	22[e]	0	1	0
1998	23	0	2	0
1999	35	4	2	0
2000	31[f]	0	0	0
2001	23	0	3	0
2002	18	0	0	1[b]
2003	28[c, f]	0	2	0
2004	8[c]	0	1	0
2005	10	0	2	0
2006	20[d]	0	2	0
2007	16	2	2	0
2008	22[f]	0	0	0
2009	24[f]	1	0	0
2010	15	0	0	0
2011 (through September 30, 2011)	15	1	2	0
TOTAL	**1,682**	**157**	**108**	**16**

a. The criterion of success or failure used is attainment of Earth orbit or Earth escape rather than judgment of mission success. "Escape" flights include all that were intended to go to at least an altitude equal to lunar distance from Earth.
b. This Earth-escape failure did attain Earth orbit and, therefore, is included in the Earth-orbit success totals.
c. This excludes commercial satellites. It counts separately spacecraft launched by the same launch vehicle.
d. This counts various sets of microsatellites as a single payload.
e. This includes the Small Spacecraft Technology Initiative (SSTI) Lewis spacecraft that began spinning out of control shortly after it achieved Earth orbit.
f. This includes American spacecraft not launched in the U.S.

Appendix A-2

World Record of Space Launches Successful in Attaining Earth Orbit or Beyond

(Enumerates launches rather than spacecraft; some launches orbited multiple spacecraft.)[a]

Calendar Year	United States[b]	USSR/ CIS	France[c]	Italy[c]	Japan	People's Republic of China	Australia	United Kingdom[c]	European Space Agency	India	Israel	Iran
1957		2										
1958	5	1										
1959	10	3										
1960	16	3										
1961	29	6										
1962	52	20										
1963	38	17										
1964	57	30										
1965	63	48	1									
1966	73	44	1									
1967	57	66	2	1			1					
1968	45	74										
1969	40	70										
1970	28	81	2	1	1	1						
1971	30	83	1	2	2	1		1				
1972	30	74		1	1							
1973	23	86										
1974	22	81		2	1							
1975	27	89	3	1	2	3						
1976	26	99			1	2						
1977	24	98			2							
1978	32	88			3	1						
1979	16	87			2				1			
1980	13	89			2					1		
1981	18	98			3	1			2	1		
1982	18	101			1	1						
1983	22	98			3	1			2	1		
1984	22	97			3	3			4			
1985	17	98			2	1			3			
1986	6	91			2	2			2			
1987	8	95			3	2			2			
1988	12	90			2	4			7			
1989	17	74			2				7		1	
1990	27	75			3	5			5		1	
1991	20	62			2	1			9	1		
1992	31	55			2	3			7	2		
1993	24	45			1	1			7			
1994	26	49			2	5			6	2		
1995	27	33			1	2			12		1	
1996	32	25			1	3			10	1		
1997	37	28			2	6			12	1		
1998	34	24			2	6			11			
1999	32	26				4			10	1		
2000	30	34				5			12			
2001	23	23			1	1			8	2		
2002	18	23			3	4			11	1	1	
2003	26	21			2	6			4	2		
2004	19	22				8			3	1		
2005	16	26			2	5			5	1		
2006	15	16			5	3			5			
2007	25	33			3	13			8	3	1	
2008	19	26			1	11			7	3		
2009	25	29			3	4			9	4		1
2010	15	30			2	15			6	1	1	
2011*	15	20			2	10			5	2		1
*(through September 30, 2011)												
TOTAL	**1,432**	**2,906**	**10**	**8**	**78**	**144**	**1**	**1**	**202**	**31**	**6**	**2**

a. This includes commercial expendable launches and launches of the Space Shuttle as well as launches to useless orbit.
b. Launches from U.S.-Russia joint platform included in U.S. totals.
c. Since 1979, all launches for ESA member countries have been joint and are listed under ESA.

Appendix B

Successful Launches to Orbit on U.S. Vehicles

October 1, 2010–September 30, 2011

Launch Date Spacecraft Name COSPAR* Designation Launch Vehicle	Mission Objectives	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
November 6, 2010 COSMO-SkyMed 4 2010-060A Delta 2	Earth observation	623 km 622 km 97.2 min 97.9°	Constellation of Small Satellites for Mediterranean basin Observation (COSMO) Italian Space Agency, dual-use for civilian and military
November 20, 2010 USA 217-222, 228 (STP-S26) 2010-062A-J Minotaur IV	Military, technology, science	655 km 628 km 97.5 min 71.9°	U.S. Department of Defense Space Test Program (STP) for experiments and technology demonstration First use of a Multi-Payload Adaptor developed for the Minotaur IV
November 21, 2010 USA 223 (NROL-32) 2010-063A Delta IV Heavy	Military/classified	1,204 km 1,200 km 692.2 min 26.5°	U.S. National Reconnaissance Office
December 8, 2010 Dragon C1 2010-066A-H Falcon 9	Commercial	300 km 275 km 88.1 min 34.5°	SpaceX demonstration for NASA's Commercial Orbital Transportation Services
January 20, 2011 USA 224 (NROL-49) 2011-002A Delta IV Heavy	Military/classified	251 km 991 km 97.1 min 97.8°	U.S. National Reconnaissance Office
February 6, 2011 USA 225 (NROL-66) 2011-006A Minotaur 1	Military/classified	1,230 km 1,202 km 109.7 min 90°	U.S. National Reconnaissance Office's Rapid Pathfinder Program
February 24, 2011 STS-133/Discovery 2011-008A Space Shuttle	International Space Station	234 km 157 km 88.4 min 51.6°	
March 5, 2011 USA 226 (X-37B OTV-2) 2011-010A Atlas 5 501	Military	334 km 333 km 91.2 min 42.8°	U.S. Air Force robotic space plane
March 11, 2011 USA 227 (NROL-27) 2011-011A Delta 4 Medium+(4,2)	Military/classified	37,496 km 269 km 665.9 min 26.5°	U.S. National Reconnaissance Office
April 15, 2011 USA 229 (NROL-34) 2011-014A-B Atlas 5 411	Military/classified	1,209 km 1,013 km 107.5 min 63.4°	U.S. National Reconnaissance Office
May 7, 2011 USA 230 (SBIRS GEO1) 2011-019A Atlas 5-401	Military	36,919 km 252 km 654.2 min 21.7°	U.S. Air Force's Space Based Infrared System Geosynchronous Earth Orbit satellite

Appendix B

(Continued)

SUCCESSFUL LAUNCHES TO ORBIT ON U.S. VEHICLES

October 1, 2010–September 30, 2011

Launch Date Spacecraft Name COSPAR* Designation Launch Vehicle	Mission Objectives	Apogee and Perigee (km), period (min), Inclination to Equator (°)	Remarks
May 16, 2011 STS-134/Endeavour 2011-020A Space Shuttle	International Space Station	325 km 231 km 90.1 min 51.6°	
June 10, 2011 SAC-D/Aquarius 2011-024A Delta 2-7320	Military	410 km 400 km 92.6 min 40°	U.S. Air Force First launch in the Operationally Responsive Space Program (ORS)
June 30, 2011 USA 231 (ORS 1) 2011-029A Minotaur 1	Military	410 km 400 km 92.6 min 40°°	U.S. Air Force First launch in the Operationally Responsive Space Program (ORS)
July 8, 2011 STS-135/Atlantis 2011-031A Space Shuttle	International Space Station	232 km 157 km 88.4 min 51.6°	
July 16, 2011 USA 232 (GPS IIF-2, Navstar 66) 2011-036A Delta 4 Medium+(4,2)	Navigation	20,406 km 241 km 359.5 min 43.4°	U.S. Air Force Global Positioning System (GPS) satellite
August 5, 2011 Juno 2011-040A Atlas 5-551	Jupiter exploration	229 km 195 km 88.6 min 28.8°	NASA mission to understand the origin and evolution of Jupiter
September 10, 2011 GRAIL A/B 2011-046A-B Delta 2 7920H-10	Lunar exploration	172 km 171 km 87.8 min 28.5°	NASA's Gravity Recovery and Interior Laboratory (GRAIL) twin spacecraft (Ebb and Flow) mapped the moon's gravity field to study its subsurface structures and advance understanding of its thermal evolution
September 27, 2011 TacSat-4 2011-052A Minotaur IV+	Military	11,836 km 658 km 235.2 min 63.6°	U.S. Naval Research Laboratory communications technology demonstration

*U.N. Committee on Space Research

Appendix C
HUMAN SPACEFLIGHTS

October 1, 2010–September 30, 2011

Spacecraft	Launch Date	Crew	Flight Time (d:h:min)	Highlights
Soyuz TMA-01M (Expedition 25)	October 7, 2010	Aleksandr Kaleri Scott Kelly Oleg Skripochka	159:08:44	First flight of the TMA-M series spacecraft
Soyuz TMA-20 (Expedition 26)	December 15, 2010	Catherine Coleman Dmitry Kondratyev Paolo Nespoli	159:08:18	
Space Shuttle Discovery (STS-133)	February 24, 2011	Steven Lindsey Eric Boe Michael Barratt Stephen Bowen Benjamin Drew Nicole Stott	12:19:04	Delivery of the EXpedite the PRocessing of Experiments to the Space Station (EXPRESS) Logistics Carrier 4 (ELC 4) and Permanent Multipurpose Module (PMM) Leonardo Mission extended by two days so its crew could help outfit the PMM Leonardo, which included Robonaut 2 Bowen became the first astronaut on consecutive Space Shuttle flights, STS-132 and STS-133 Last flight of Discovery
Soyuz TMA-21 (Expedition 27)	April 4, 2011	Andrei Borisenko Ronald Garan Aleksandr Samokutyayev	164:05:41	Spacecraft named the Gagarin to celebrate the 50th anniversary of the first human spaceflight, made by Yuri Gagarin
Space Shuttle Endeavour (STS-134)	May 16, 2011	Mark Kelly Gregory Johnson Gregory Chamitoff Michael Fincke Andrew Feustel Roberto Vittori	15:17:38	Delivery of EXPRESS Logistics Carrier 3 (ELC 3) and Alpha Magnetic Spectrometer (AMS) Last flight of Endeavour
Soyuz TMA-02M (Expedition 28)	June 7, 2011	Michael Fossum Satoshi Furukawa Sergey Volkov	167:05:14	
Space Shuttle Atlantis (STS-135)	July 8, 2011	Christopher Ferguson Douglas Hurley Sandra Magnus Rex Walheim	12:18:28	Delivery of the Raffaello Multi-Purpose Logistics Module Last flight of Atlantis and last Space Shuttle flight

Appendix D-1A

SPACE ACTIVITIES OF THE U.S. GOVERNMENT

HISTORICAL TABLE OF BUDGET AUTHORITY

(in millions of real-year dollars)

FY	NASA Total	NASA Space	DOD	Other[a]	DOE[b]	DOC	DOI	USDA	NSF[c]	DOT	Total Space
1959	331	261	490	34	34						785
1960	524	462	561	43	43						1,066
1961	964	926	814	68	68						1,808
1962	1,825	1,797	1,298	199	148	51					3,294
1963	3,673	3,626	1,550	257	214	43					5,433
1964	5,100	5,016	1,599	213	210	3					6,828
1965	5,250	5,138	1,574	241	229	12					6,953
1966	5,175	5,065	1,689	214	187	27					6,968
1967	4,966	4,830	1,664	213	184	29					6,707
1968	4,587	4,430	1,922	174	145	28	0.2	1			6,526
1969	3,991	3,822	2,013	170	118	20	0.2	1	31		6,005
1970	3,746	3,547	1,678	141	103	8	1	1	28		5,366
1971	3,311	3,101	1,512	162	95	27	2	1	37		4,775
1972	3,307	3,071	1,407	133	55	31	6	2	39		4,611
1973	3,406	3,093	1,623	147	54	40	10	2	41		4,863
1974	3,037	2,759	1,766	158	42	60	9	3	44		4,683
1975	3,229	2,915	1,892	158	30	64	8	2	54		4,965
1976	3,550	3,225	1,983	168	23	72	10	4	59		5,376
TQ*	932	849	460	43	5	22	3	1	12		1,352
1977	3,818	3,440	2,412	194	22	91	10	6	65		6,046
1978	4,060	3,623	2,738	226	34	103	10	8	71		6,587
1979	4,596	4,030	3,036	248	59	98	10	8	73		7,314
1980	5,240	4,680	3,848	231	40	93	12	14	72		8,759
1981	5,518	4,992	4,828	234	41	87	12	16	78		10,054
1982	6,044	5,528	6,679	313	61	145	12	15	80		12,520
1983	6,875	6,328	9,019	327	39	178	5	20	85		15,674
1984	7,458	6,858	10,195	395	34	236	3	19	103		17,448
1985	7,573	6,925	12,768	584	34	423	2	15	110		20,277
1986	7,807	7,165	14,126	477	35	309	2	23	108		21,768
1987	10,923	9,809	16,287	466	48	278	8	19	112	1	26,562
1988	9,062	8,322	17,679	741	241	352	14	18	115	1	26,742
1989	10,969	10,097	17,906	560	97	301	17	21	121	3	28,563
1990	12,324	11,460	15,616	506	79	243	31	25	124	4	27,582
1991	14,016	13,046	14,181	772	251	251	29	26	211	4	27,999
1992	14,317	13,199	15,023	798	223	327	34	29	181	4	29,020
1993	14,310	13,064	14,106	731	165	324	33	25	180	4	27,901
1994	14,570	13,022	13,166	632	74	312	31	31	179	5	26,820
1995	13,854	12,543	10,644	759	60	352	31	32	278	6	23,946
1996	13,884	12,569	11,514	828	46	472	36	37	231	6	24,911
1997	13,709	12,457	11,727	789	35	448	42	39	219	6	24,973
1998	13,648	12,321	12,359	839	103	435	43	39	213	6	25,519
1999	13,653	12,459	13,203	982	105	575	59	37	200	6	26,644
2000	13,601	12,521	12,941	1,056	164	575	60	44	207	6	26,518
2001	14,230	13,304	14,326	1,062	145	577	60	36	232	12	28,692
2002	14,868	13,871	15,740	1,180	166	644	64	28	266	12	30,791
2003	15,364	14,360	19,388	1,305	191	649	74	42	337	12	35,053
2004	15,379	14,322	19,115	1,464	209	745	71	61	366	12	34,901
2005	16,198	15,234	19,690	1,551	229	807	70	73	360	12	36,475
2006	16,623	15,765	22,114	1,647	245	860	82	84	364	12	39,526
2007	16,285	15,568	22,418	1,680	200	912	87	65	404	12	39,666
2008	17,117	16,502	24,795	1,698	195	862	90	59	479	13	42,995
2009	17,775	17,275	26,528	1,868	200	1,078	64	27	485	14	45,671
2010	18,725	18,228	26,463	2,057	203	1,261	67	27	484	15	46,748
2011	18,432	17,898	27,234	2,186	229	1,444	66	20	412	15	47,318

a. The Other column is the total of the non-NASA and non-DOD budget authority figures that appear in the succeeding columns. The total is sometimes different from the sum of the individual figures because of rounding. The Total Space column does not include the NASA Total column because the latter includes budget authority for aeronautics as well as space. For the years 1989–1997, this Other column also includes small figures for the Environmental Protection Agency (EPA). Also includes $2.1 billion for the replacement of Space Shuttle Challenger in 1987.

b. The DOE has recalculated its space expenditures since 1998.

c. The NSF has recalculated its space expenditures since 1980, making them significantly higher than reported in previous years.

* Transition Quarter

Appendix D-1B

SPACE ACTIVITIES OF THE U.S. GOVERNMENT

HISTORICAL TABLE OF BUDGET AUTHORITY

(in millions of inflation-adjusted FY 11 dollars)

FY	Inflation Factors	NASA Total	NASA Space	DOD	Other[a]	DOE[b]	DOC	DOI	USDA	NSF[c]	DOT	Total Space
1959	6.144	2,034	1,604	3,011	209	209						4,823
1960	6.058	3,174	2,799	3,398	260	260						6,457
1961	5.983	5,767	5,540	4,870	407	407						10,817
1962	5.897	10,763	10,598	7,655	1,174	873	301					19,426
1963	5.833	21,423	21,149	9,041	1,499	1,248	251					31,689
1964	5.760	29,378	28,894	9,211	1,227	1,210	17					39,332
1965	5.693	29,887	29,249	8,960	1,372	1,304	68					39,581
1966	5.596	28,957	28,342	9,451	1,197	1,046	151					38,990
1967	5.477	27,201	26,456	9,114	1,167	1,008	159					36,737
1968	5.308	24,348	23,514	10,202	925	770	149	1	5			34,641
1969	5.127	20,463	19,597	10,321	874	605	103	1	5	160		30,792
1970	4.904	18,371	17,395	8,229	692	505	39	5	5	137		26,316
1971	4.652	15,404	14,427	7,035	753	442	126	9	5	172		22,215
1972	4.431	14,652	13,607	6,234	591	244	137	27	9	175		20,432
1973	4.231	14,410	13,085	6,866	623	228	169	42	8	175		20,575
1974	4.054	12,311	11,184	7,159	641	170	243	36	12	179		18,984
1975	3.782	12,211	11,023	7,155	597	113	242	30	8	203		18,775
1976	3.423	12,152	11,039	6,788	576	79	246	34	14	203		18,403
TQ*	3.194	2,976	2,711	1,469	137	16	70	10	3	38		4,318
1977	3.096	11,821	10,650	7,468	599	68	282	31	19	200		18,717
1978	2.971	12,064	10,766	8,136	671	101	306	30	24	211		19,573
1979	2.784	12,794	11,219	8,452	690	164	273	28	22	203		20,361
1980	2.576	13,499	12,056	9,913	595	103	240	31	36	186		22,564
1981	2.367	13,062	11,817	11,429	555	97	206	28	38	185		23,801
1982	2.155	13,025	11,913	14,393	674	131	312	26	32	172		26,980
1983	2.017	13,867	12,764	18,191	660	79	359	10	40	172		31,615
1984	1.932	14,409	13,250	19,698	763	66	456	6	37	199		33,711
1985	1.863	14,109	12,901	23,787	1,087	63	788	4	28	204		37,776
1986	1.805	14,088	12,929	25,491	860	63	558	4	42	194		39,281
1987	1.764	19,265	17,300	28,726	822	85	490	14	34	197	2	46,848
1988	1.718	15,567	14,296	30,369	1,273	414	605	24	31	198	2	45,938
1989	1.664	18,258	16,806	29,804	932	161	501	28	35	202	5	47,543
1990	1.602	19,747	18,362	25,021	810	127	389	50	40	198	6	44,194
1991	1.545	21,661	20,162	21,916	1,193	388	388	45	40	326	6	43,271
1992	1.489	21,317	19,652	22,368	1,188	332	487	51	43	269	6	43,208
1993	1.451	20,766	18,958	20,470	1,061	239	470	48	36	261	6	40,488
1994	1.420	20,688	18,490	18,695	898	105	443	44	44	255	7	38,083
1995	1.391	19,264	17,441	14,801	1,055	83	489	43	44	386	8	33,297
1996	1.362	18,905	17,115	15,678	1,127	63	643	49	50	314	8	33,920
1997	1.336	18,314	16,641	15,666	1,055	47	598	56	52	293	8	33,362
1998	1.312	17,902	16,161	16,211	1,101	135	571	56	51	280	8	33,474
1999	1.295	17,684	16,137	17,101	1,272	136	745	76	48	259	8	34,510
2000	1.278	17,386	16,006	16,543	1,349	210	735	77	56	264	8	33,898
2001	1.253	17,837	16,676	17,957	1,331	182	723	75	45	291	15	35,964
2002	1.225	18,209	16,988	19,277	1,445	203	789	78	34	326	15	37,709
2003	1.205	18,509	17,300	23,357	1,572	230	782	89	51	406	14	42,229
2004	1.181	18,157	16,909	22,567	1,728	247	880	84	72	432	14	41,204
2005	1.151	18,652	17,542	22,672	1,786	264	929	81	84	415	14	42,000
2006	1.115	18,538	17,581	24,662	1,837	273	959	91	94	406	13	44,079
2007	1.079	17,564	16,791	24,178	1,812	216	984	94	70	436	13	42,781
2008	1.048	17,931	17,286	25,973	1,779	204	903	94	62	502	14	45,039
2009	1.024	18,198	17,686	27,159	1,912	205	1,104	66	27	497	14	46,757
2010	1.009	18,898	18,396	26,707	2,076	205	1,273	68	27	488	15	47,179
2011	1.000	18,432	17,898	27,234	2,186	229	1,444	66	20	412	15	47,318

a. The Other column is the total of the non-NASA and non-DOD budget authority figures that appear in the succeeding columns. The total is sometimes different from the sum of the individual figures because of rounding. The Total Space column does not include the NASA Total column because the latter includes budget authority for aeronautics as well as in space. For the years 1989–1997, this Other column also includes small figures for the Environmental Protection Agency (EPA). Also includes $2.1 billion for replacement of Space Shuttle Challenger in 1987.

b. The DOE has recalculated its space expenditures since 1998.

c. The NSF has recalculated its space expenditures since 1980, making them significantly higher than reported in previous years.

* Transition Quarter

Appendix D-2

FEDERAL SPACE ACTIVITIES BUDGET

(in millions of dollars by fiscal year)

Federal Agencies	Budget Authority 2010 actual	2011 actual	2012 actual	2013 est[1]	Budget Outlays 2010 actual	2011 actual	2012 actual
NASA[2]	18,222	17,898	17,203	16,335	18,406	17,017	16,606
DOD[3]	26,463	27,234	26,677	25,555	24,142	25,924	26,457
DOE[4]	203	229	199	185	204	177	158
DOC [5]	1,398	1,444	1,876		567.1	803.2	1,074.3
DOI	67	66	76		67	66	76
USDA	26.6	19.5	6.7		21.6	18.1	17.3
DOT	15	15	16		15	15	16
NSF[6]	484	412	406	146	515	543	489

(1) FY 13 figures incorporate the effect of sequestration.

(2) NASA program budgets reflect only direct program costs. Indirect costs are budgeted within the Cross Agency Support Programs account (captured within the Federal Space Activities Budget table).

(3) DOD FY 11, 12, and 13 figures for Budget Authority and Outlays are estimated at the time of preparing this report.

(4) Department of Energy budget figures do not include any physics research and operations funding for ground-based experiments managed in the High Energy Physics program.

(5) Beginning in 2010, the Department of Commerce has defined the entire National Environmental Satellite, Data, and Information Service budget that is within the National Oceanic and Atmospheric Administration (NOAA) as a space activity. Prior years did not include some items, such as NOAA's National Climatic Data Center archives and Comprehensive Large Array-data Stewardship System (CLASS). The Budget Outlays columns reflect dollars "costed" in a fiscal year specific to that same fiscal year's appropriated dollars.

(6) Totals for NSF include Large Synoptic Survey Telescope (LSST) and all telescope activities. Outlay information includes American Recovery and Reinvestment Act (ARRA).

Appendix D-3

FEDERAL AERONAUTICS ACTIVITIES BUDGET

(in millions of dollars by fiscal year)

Federal Agencies	Budget Authority 2010 actual	2011 actual	2012 actual	2013 est.[1]	Budget Outlays 2010 actual	2011 actual	2012 actual
NASA[2]	497	534	570	530	500	601	584
USDA	55.4	37.1	36.9	34.5	52.6	35.3	36.8
DOD[3]	14,166	14,170	1,4221	1,4099	13,573	13,577	13,509
DOI	28	24	27	26	29	25	27
DOT	3,104	2,905	2,884	2,733	2,742	2,895	3,102

(1) FY 13 figures incorporate the effect of sequestration.

(2) NASA program budgets reflect only direct program costs. Indirect costs are budgeted within the Cross-Agency Support Programs account (captured within the Federal Space Activities Budget table).

(3) DOD FY 11, 12, and 13 figures for Budget Authority and Outlays are estimated at the time of preparing this report.

Acronyms

3D	three-dimensional
3DEP	3D Elevation Program

A

ABL	Airborne Laser
AC	alternating current
ACD	Advanced Capabilities Division
ACP	Arctic Coastal Plain
ACT	Atacama Cosmology Telescope
ADA	Antarctica Data Acquisition
ADS-B	Automatic Dependent Surveillance-Broadcast
ADVENT	ADaptive Versatile ENgine Technology
AEDC	Arnold Engineering Development Center
AEHF	Advanced Extremely High Frequency
AFB	Air Force Base
AFRL	Air Force Research Laboratory
AGS	Division of Atmospheric and Geospace Sciences (NSF)
AHAP	Alaska High-Altitude Photography
AIA	Atmospheric Imaging Assembly
AIAA	American Institute of Aeronautics and Astronautics
ALMA	Atacama Large Millimeter/submillimeter Array
AMC	Air Mobility Command
AMF2	ARM Mobile Facility
AMISR	Advanced Modular Incoherent-Scatter Radar
AMPERE	Active Magnetosphere and Planetary Electrodynamics Response Experiment
AMS	Autonomous Modular Sensor; Alpha Magnetic Spectrometer
AMS-02	Alpha Magnetic Spectrometer 2
AMSR2	Advanced Microwave Scanning Radiometer 2
AO	Arecibo Observatory
APEC	Asia-Pacific Economic Cooperation
APHIS	Animal and Plant Health Inspection Service
ARM	Atmospheric Radiation Measurement
ARMD	Aeronautics Research Mission Directorate
ARS	Agricultural Research Service
ARTEMIS	Acceleration, Reconnection, Turbulence and Electrodynamics of the Moon's Interaction with the Sun
AS	Atmosphere Section
ASB	Agricultural Statistics Board
ASDE-X	Airport Surface Detection Equipment-Model X
AST	Office of Commercial Space Transportation (FAA); Division of Astronomical Sciences (NSF)
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ASTM	American Society for Testing and Materials
ASTS	Aeronautics Science and Technology Subcommittee
ASU	Aircraft Sector Understanding, short for Group on the Sector Understanding on Export Credits for Civil Aircraft
ATST	Advanced Technology Solar Telescope
ATV-2	Automated Transfer Vehicle-2
Auto-GCAS	Automatic Ground Collision Avoidance System
AVHRR	Advanced Very High Resolution Radiometer

B

BAER	Burn Area Emergency Response
BIA	Bureau of Indian Affairs
BLM	Bureau of Land Management
BNL	Brookhaven National Laboratory
BOR	Bureau of Reclamation
BRDF	bidirectional reflectance distribution function
BSS	Broadcasting-Satellite Service
BXR	Ballistic Missile Defense Transfer Radiometer

C

CAP	Corrective Action Plan
CAVP	Cryptographic Algorithm Validation Program
CBS3	Controlled-Background System for Spectroradiometry and Spectrophotometry
CCAFS	Cape Canaveral Air Force Station
CCDev	Commercial Crew Development
CCMC	Community Coordinated Modeling Center
CDL	Cropland Data Layer
CEDAR	Coupling, Energetics, and Dynamics of Atmospheric Regions
CEOS	Committee on Earth Observation Satellites
CEPS	Center for Earth and Planetary Studies
CfA	Center for Astrophysics
CGGSC	Crustal Geophysics and Geochemistry Science Center
CHAMP	Counter-electronics High-powered Microwave Advanced Missile Project
CHCCP	National Center for Hypersonic Combined Cycle Propulsion
CHIRP	Commercially Hosted Infrared Payload
CIBER	Cosmic Infrared Background Experiment
CISM	Center for Integrated Space Weather Modeling
CLASS	Comprehensive Large Array-data Stewardship System
CLEEN	Continuous Lower Energy, Emissions and Noise
CMB	cosmic microwave background
CME	Coronal Mass Ejection
COBE	Cosmic Background Explorer
COE CST	Center of Excellence for Commercial Space Transportation
CONAE	Comisión Nacional de Actividades Espaciales
CoNNeCT	Communication, Navigation and Networking re-Configurable Testbed
CONNSTEP	Connecticut State Technical Extension Program
CONUS	contiguous United States
COSMIC	Constellation Observing System for Meteorology, Ionosphere, and Climate
CREATE	Computational Research and Engineering Acquisition Tools and Environments
CS	Commercial Service
CU	University of Colorado

D

DARPA	Defense Advanced Research Projects Agency
DEM	Digital Elevation Model
DISCOVER-AQ	Deriving Information on Surface conditions from COlumn and VERtically resolved observations relevant to Air Quality
DLR	German Aerospace Center
DMC	Disaster Monitoring Constellation
DMSP	Defense Meteorological Satellite Program
DNN R&D	Office of Defense Nuclear Nonproliferation Research and Development
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy

DOI	Department of the Interior
DOS	Department of State
DRG	digital raster graphics
DSC	Defense Space Council
DSN	Deep Space Network

E

ECMWF	European Centre for Medium-Range Weather Forecasts
EDA	Efficient Descent Advisor
EDT	electrodynamic-tether
EELV	Evolved Expendable Launch Vehicle
EFT-1	Exploration Flight Test
EGSC	Eastern Geographic Science Center
ELaNa	Educational Launch of Nanosatellites
ELC 4	Express Logistics Carrier 4
ELV	Expendable Launch Vehicle
EMS	Environmental Management System
EOS	Earth Observing System
ERAU	Embry-Riddle Aeronautical University
EROS	Earth Resources Observation and Science Center
ESA	European Space Agency
ESI	Evaporative Stress Index
ESMD	Exploration Systems Mission Directorate
ET	evapotranspiration
ETDP	Exploration Technology Development Program
ETM	Enhanced Thematic Mapper
EU	European Union
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EUV	extreme ultraviolet
EVA	extravehicular activity
EVE	EUV Variability Experiment
Ex-Im Bank	Export-Import Bank of the United States
EXIS	EUV and X-ray Irradiance Sensor
EXPRESS	EXpedite the PRocessing of Experiments to the Space Station

F

FAA	Federal Aviation Administration
FANS	Future Air Navigation System
FAS	Foreign Agricultural Service
FBTM	Flow-Based Trajectory Management
FCC	Federal Communications Commission
Fe_2O_3	oxidized iron
FEWS NET	Famine Early Warning Systems Network
FGST	Fermi Gamma-ray Space Telescope
FIPS	Federal Information Processing Standard
FTS	Fourier transform spectrometer
FWMAV	flapping wing micro air vehicle
FWS	Fish and Wildlife Service
FY	fiscal year

G

GAGAN	GPS Aided Geo Augmented Navigation
GaN	gallium nitride
GBD	Global Burst Detector
GCOM-W1	Global Change Observation Mission-Water 1

GDP	Ground Delay Program
GE	General Electric
GEM	Geospace Environment Modeling
GF	Geospace Facilities
GHWG	Global Harmonization Working Group
GHz	gigahertz
GIS	Geographic Information System
GLAM	Global Agricultural Monitoring
GLONASS	Global Navigation Satellite System (Russian)
GMU	George Mason University
GNSS	Global Navigation Satellite System
GOES	Geostationary Operational Environmental Satellites
GOES-R	Geostationary Operational Environmental Satellite Series R
GP-B	Gravity Probe B
GPHS-RTG	General Purpose Heat Source Radioisotope Thermoelectric Generator
GPS	Global Positioning System
GRAIL	Gravity Recovery and Interior Laboratory
GREAT	German REceiver for Astronomy at Terahertz Frequencies
GS	Geospace Section (NSF)
GSFC	Goddard Space Flight Center
GTF	Geared Turbofan
GV	Gulfstream V

H

HEETE	Highly Efficient Embedded Turbine Engine
HELLADS	high-energy liquid laser area defense system
HEO	Human Exploration and Operations
HIAPER	High-performance Instrumented Airborne Platform for Environmental Research
HIPPO	HIAPER Pole to Pole Observations
hPa	hectopascal
HRP	Human Research Program
HTV-2	H-II Transfer Vehicle-2; Hypersonic Technology Vehicle 2

I

I&M	Inventory and Monitoring
IC	Intelligence Community
ICAO	International Civil Aviation Organization
ICE-T	Ice in Clouds—Tropical
ICESat	Ice, Cloud, and land Elevation Satellite
ICESCAPE	Impacts of Climate on EcoSystems and Chemistry of the Arctic Pacific Environment
ICG	International Committee on Global Navigation Satellite Systems
ICNO	IceCube Neutrino Observatory
IPAD	International Production Assessment Division
IPM	Integrated Pest Management
IR	infrared
IRAC	Infrared Array Camera
IRNSS	Indian Regional Navigational Satellite System
ISIS	Integrated Software for Imagers and Spectrometers
ISRO	Indian Space Research Organisation
ISRP	Integrated Systems Research Program
ISS	International Space Station
ITA	Initial Tailored Arrival; International Trade Administration
ITAC 1	Industry Trade Advisory Committee for Aerospace Equipment

J

JAGM	joint air-to-ground missile
JAXA	Japan Aerospace Exploration Agency
JDTV	Jumbo Drop Test Vehicle
JPDO	Joint Planning and Development Office
JPL	Jet Propulsion Laboratory
JPSS	Joint Polar Satellite System
JSF	Joint Strike Fighter
JWST	James Webb Space Telescope

K

K	kelvin
klbf	kilopounds-force
KSC	Kennedy Space Center

L

LANDFIRE	Landscape Fire and Resource Management Planning Tools
LANL	Los Alamos National Laboratory
LAS	Launch Abort System
LAT	Large Area Telescope
LCROSS	Lunar CRater Observation and Sensing Satellite
LDCM	Landsat Data Continuity Mission
LEAP-X	leading edge aviation propulsion
LEMV	Long Endurance Multi-intelligence Vehicle
LEO	low-Earth orbit
LIDAR	Light Detection and Ranging
LLNL	Lawrence Livermore National Laboratory
LMMP	Lunar Mapping and Modeling Project
LPRP	Lunar Precursor Robotic Program
LRO	Lunar Reconnaissance Orbiter
LSP	Launch Services Program
LSST	Large Synoptic Survey Telescope

M

MAGIC	Marine ARM GPCI Investigation of Clouds
MANPADS	manportable air defense system
MAR	Mission Adaptive Rotor
MC3E	Midlatitude Continental Convective Clouds Experiment
MDIS	Mercury Dual Imaging System
MDXR	Missile Defense Transfer Radiometer
MEMS	microelectromechanical systems
MEP	Manufacturing Extension Partnership
MER	Mars Exploration Rover
MESSENGER	MErcury Surface, Space ENvironment, GEochemistry, and Ranging
METRIC	Mapping EvapoTranspiration at high Resolution and Internalized Calibration
Mg	magnesium
MHW-RTG	Multi-Hundred Watt Radioisotope Thermoelectric Generator
MIB	Mishap Investigation Board
mK	millikelvin
MKID	microwave kinetic inductance detectors
MMRTG	Multi-Mission Radioisotope Thermoelectric Generator
MOBY	Marine Optical BuoY
MODIS	Moderate Resolution Imaging Spectroradiometer
MOU	Memorandum of Understanding

MPCV	Multi-Purpose Crew Vehicle
mph	miles per hour
MPLM	Multi-Purpose Logistics Module
MRLC	Multi-Resolution Land Characteristics Consortium
MRO	Mars Reconnaissance Orbiter
MSL	Mars Science Laboratory
MSS	Mobile Satellite Service
MWAC	Midwest Archeological Center

N

NADB	North America Data Buy
NAFD	North American Forest Dynamics
NAICS	North American Industry Classification System
NAIP	National Agriculture Imagery Program
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NASM	National Air and Space Museum
NASS	National Agricultural Statistics Service
NCAR	National Center for Atmospheric Research
NCCN	North Coast and Cascade Network
NCEP	National Centers for Environmental Prediction
NCNR	National Center for Neutron Research
NDE	nondestructive evaluation
NDEP	National Digital Elevation Program
NDVI	normalized difference vegetation index
NE	Office of Nuclear Energy (DOE)
NED	National Elevation Dataset
NEEA	National Enhanced Elevation Assessment
NEEMO	NASA Extreme Environment Mission Operations
NEN	Near Earth Network
NEO	near-Earth objects
NEOWISE	Near-Earth Object Wide-field Infrared Survey Explorer
NExT	New Exploration of Tempel 1
NextGen	Next Generation Air Transportation System
NFAC	National Full-Scale Aerodynamics Complex
NFS	National Forest System
NGA	National Geospatial Intelligence Agency
NGAC	National Geospatial Advisory Committee
NGDC	National Geophysical Data Center
NHD	National Hydrography Dataset
NIFA	National Institute of Food and Agriculture
NIST	National Institute of Standards and Technology
NLS	NASA Launch Services
nm	nanometer
NNSA	National Nuclear Security Administration
NOAA	National Oceanic and Atmospheric Administration
NOAO	National Optical Astronomy Observatory
NOx	nitrogen oxides
npFe^0	nanophase iron
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NPP	NPOESS Preparatory Project
NPS	National Park Service
NRA	NASA Research Announcement
NRAO	National Radio Astronomy Observatory
NRCS	Natural Resources Conservation Service
NRI	National Resources Inventory
NRO	National Reconnaissance Office

NSF	National Science Foundation
NSGIC	National States Geographic Information Council
NSO	National Solar Observatory
NSPO	National Space Organization (Taiwan)
NSRL	NASA Space Radiation Laboratory
NSS	National Security Space
NSTC	National Science and Technology Council
NSWP	National Space Weather Program
NTF	National Transonic Facility
NuDets	nuclear detonations
NVLAP	National Voluntary Laboratory Accreditation Program
NWR	National Wildlife Refuge

O

OBSS	Orbiter Boom Sensor System
OCO	Orbiting Carbon Observatory
OECD	Organization for Economic Cooperation and Development
OGA	Office of Global Analysis
OPD	Optimized Profile Descent
OPP	Office of Polar Programs
ORCA	Ocean Radiometer for Carbon Assessment
ORS	Operationally Responsive Space
OSM	Office of Surface Mining
OSPO	Office of Satellite and Product Operations
OTM	Office of Transportation and Machinery
OTV	Orbital Test Vehicle

P

P&W	Pratt & Whitney
PA-1	Pad Abort 1
PDR	Preliminary Design Review
PIDDP	Planetary Instrument Definition and Development Program
PMM	Permanent Multipurpose Module
PNT	Positioning, Navigation, and Timing
POES	Polar-orbiting Operational Environmental Satellites
PPBE	Planning, Programming, Budgeting and Execution
PRSEUS	Pultruded Rod Stitched Efficient Unitized Structure
PSD	Production Supply and Distribution
PSU	Pennsylvania State University

Q

QZS	Quasi-Zenith Satellite

R

R&D	research and development
RANS	Reynolds-averaged Navier-Stokes
RCS	reaction control system
REBR	ReEntry Breakup Recorder
RMA	Risk Management Agency
RNP	Required Navigation Performance
RO	radio occultation
RPIF	Regional Planetary Image Facility
RPS	radioisotope power system
RPT	Rocket Propulsion Test

RSAC	Remote Sensing Applications Center
RSIWG	Remote Sensing Interagency Working Group
RTG	radioisotope thermoelectric generator
RTT	Research Transition Team
RVSM	Reduced Vertical Separation Minima

S

SAA	Sense-And-Avoid
SABRS	Space and Atmospheric Burst Reporting System
SAC-D	Satelite de Aplicaciones Cientificas-D
SANS	small-angle neutron scattering
SAO	Smithsonian Astrophysical Observatory
SARP	standard and recommended practices
SBIRS GEO	Space Based Infrared System Geosynchronous Earth Orbit
SBSS	Space-Based Space Surveillance
SC	Office of Science (DOE)
SCaN	Space Communications and Navigation
SDO	Solar Dynamics Observatory
SGP	Southern Great Plains
SHINE	Solar, Heliosphere, and INterplanetary Environment
SI	International System of Units
SIA	Satellite Imagery Archive
SIR	System Integration Review
SIRCUS	Spectral Irradiance and Radiance Responsivity Calibrations using Uniform Sources
SLAC	Stanford Linear Accelerator Center
SM-3	Standard Missile-3
SMA	Submillimeter Array
SMAP	Soil Moisture Active-Passive
SMCRA	Surface Mining Control and Reclamation Act
SMD	Science Mission Directorate
SN	Space Network
SNL	Sandia National Laboratory
SNSPD	superconducting nanowire single photon detector
SOFIA	Stratospheric Observatory for Infrared Astronomy
SpaceX	Space Exploration Technologies
SPDM	Special Purpose Dexterous Manipulator (also called Dextre)
SPOT	Satellite Pour l'Observation de la Terre
SQUID	Superconducting Quantum Interference Device
SRM	Standard Reference Material
SRR	System Requirements Review
SSA	Space Situation Awareness
SST	Space Surveillance Telescope
STAR	Center for Satellite Applications and Research
STEM	science, technology, engineering, and mathematics
STEREO	Solar TErrestrial RElations Observatory
STP	Space Test Program
SuperDARN	Super Dual Auroral Radar Network
SURF	Synchrotron Ultraviolet Radiation Facility
SUVI	Solar Ultraviolet Imager
SWA	Southwest Airlines
SZE	Sunyaev-Zel'dovich Effect

T

T-LIDAR	Terrestrial LIDAR
T-TSAFE	Terminal-Tactical Separation Assured Flight Environment
TacSat	Tactical Satellite

TCC	Tree Canopy Cover
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System
TEPCE	Tether Electrodynamic Propulsion CubeSat Experiment
TES	transition-edge sensor
THEMIS	Time History of Events and Macroscale Interactions during Substorms
TIR	thermal infrared
TM	Thematic Mapper
TOC	Test Operations Contract
TRL	technology readiness level
TWGCRN	Terrestrial Wetland Global Change Research Network
TWP	Tropical West Pacific

U

UAS	unmanned aircraft system; unmanned aerial system
UAV	unmanned aerial vehicle
UCAR	University Corporation for Atmospheric Research
UCAS	Unmanned Combat Air System
UHF	ultrahigh-frequency
ULA	United Launch Alliance
ULS	United Launch Services
UMESC	Upper Midwest Environmental Sciences Center
UMRS	Upper Mississippi River System
UNCOPUOS	United Nations Committee on the Peaceful Uses of Outer Space
USACE	U.S. Army Corps of Engineers
USAID	U.S. Agency for International Development
USDA	U.S. Department of Agriculture
USFS	U.S. Forest Service
USFS R&D	USFS Research and Development
USFS S&P	USFS State and Private Forestry
USGS	U.S. Geological Survey
USNDS	U.S. NuDet Detection System
UTM	Universal Transverse Mercator
UV	ultraviolet

V

VAFB	Vandenberg Air Force Base
VIP	Virtual Inspection Priority

W

WAI	Wide Area Imager
WAOB	World Agricultural Outlook Board
WASDE	World Agricultural Supply and Demand Estimates
WFF	Wallops Flight Facility
WISE	Wide-field Infrared Survey Explorer
WMAP	Wilkinson Microwave Anisotropy Probe

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