Aeronautics and Space Report of the President

Fiscal Year 2010 Activities

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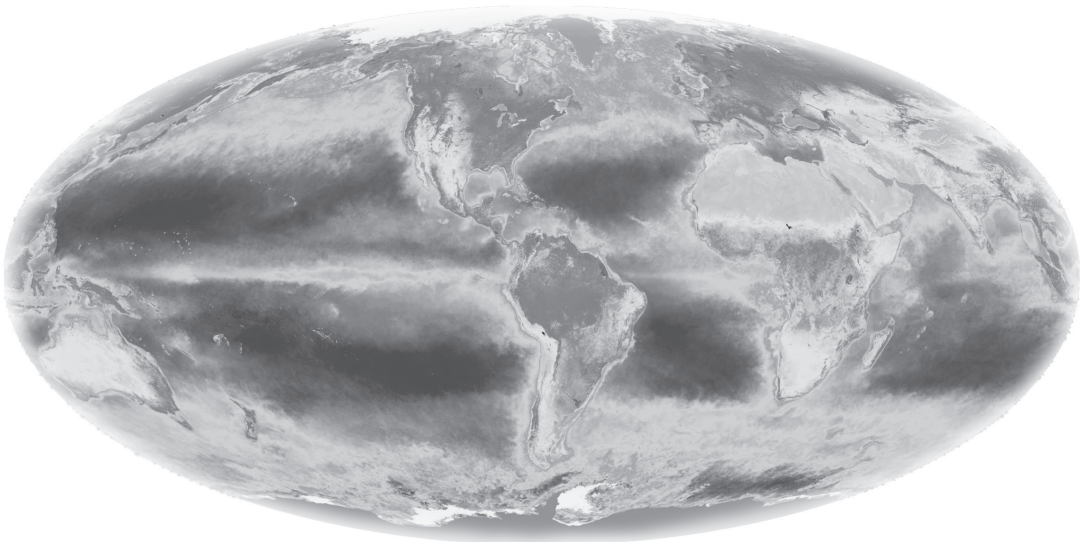

Fiscal Year 2010 Activities

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, 2009, through September 30, 2010.

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National Aeronautics and Space Administration

NASA

Exploration Systems Mission Directorate

Fiscal year 2010 (FY 10) was a year of transition for the National Aeronautics and Space Administration's (NASA) 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 (LEO). The FY 10 President's Budget articulated a transition from activities that focused on developing capabilities to explore the moon. As a result, during 2010 NASA pursued options to leverage ESMD's achievements for new exploration programs as directed by Congress and the President.

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 Robotic 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. HRP's goal is to develop the knowledge and technologies to enable safe and productive human space exploration, as well as to support compliance with NASA's medical, environmental, and human factors standards.

In FY 10, the IntraVenous Fluid GENeration (IVGEN) project tested a system for producing United States Pharmacopeia (USP)–grade IV fluid using in-orbit resources. This is important for future exploration missions because IV fluid has a finite shelf life and International Space Station (ISS) missions require roughly 12 liters of IV fluid, with missions beyond LEO potentially requiring more. After IVGEN hardware was launched to the ISS in April 2010, ISS astronauts successfully produced two 1.5-liter bags of 0.9 percent normal saline solution, both of which were returned to Earth for testing at a USP-certified laboratory. The IVGEN-produced IV fluid passed all USP requirements, except for the saline concentration, which was slightly outside of the expected range but within the limits tolerated by the body.

After returning to Earth in December 2009, U.S. and Japanese astronauts of the Soyuz 21 mission were transported directly from Kazakhstan to the United States, reaching NASA facilities in Houston within 24 hours of their descent from space. This differed from standard procedures, which delay crew return for several days, thereby complicating post-flight data collection. This first-ever instance of Direct Crew Return was successful in several respects: it enabled a full schedule of post-flight medical and science testing, reduced the need to transport NASA scientists and hardware to Russia, and allowed the crew more rest time. Direct Crew Return was used for the Soyuz 22 mission and is planned for subsequent landings.

The Mission Medical Information Systems (MMIS) is a ground-based system for managing medical data from ISS missions. In FY 10, the system was expanded to facilitate the electronic dissemination of, and access to, ISS medical data; MMIS now allows laboratories directly receiving and analyzing ISS medical data to submit their reports to end users, namely, crew flight surgeons and epidemiologists, in a secure and rapid manner. The completion of MMIS was a significant milestone for more efficient and effective management and application of crew health and performance data for human spaceflight.

Also in FY 10, NASA completed the largest systematic, subjective assessment to date of Shuttle astronauts' sleep behavior and quality. Results indicated a large variability in the overall quality of sleep during flight but also showed that most crewmembers have difficulty sleeping in orbit, with a significant relationship between difficulty of falling asleep on Earth and sleep disruptions in flight. These findings will inform strategies for astronauts, medical personnel, and habitat designers for future ISS and space exploration missions.

Exploration Technology Development Program

The Exploration Technology Development Program (ETDP) was responsible for developing new technologies to enable NASA to conduct future exploration missions in a safe and cost-effective manner. ETDP accomplished this by maturing new technologies in the early stages of their associated programs, in time to support Preliminary Design Reviews, thereby reducing both cost and risk in NASA's exploration initiatives.

The Vehicle Cabin Atmosphere Monitor (VCAM) is an instrument used on the ISS for identifying the presence of minute quantities of harmful gases in the air. Because the closed environment on the ISS magnifies the impact of pollutants on crew health, instruments like VCAM are critical to crew safety on the station. To date, VCAM has operated successfully. Future long-duration exploration missions could utilize instruments like VCAM to help protect astronaut health aboard transport systems such as the Crew Exploration Vehicle (CEV).

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 System's efforts. The goal of these robotic missions is to gather data essential for reducing risks to astronauts, identify resources and landing sites, and refine the requirements for lunar surface hardware.

LPRP's first mission was the Lunar Reconnaissance Orbiter (LRO). Launched in June 2009, LRO operated flawlessly throughout FY 10, 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 pole to investigate the possible presence of water and other volatiles. LRO imagery has 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. After completing a one-year exploration phase, LRO was handed over to NASA's Science Mission Directorate at the end of FY 10.

Another key component of LPRP was the Lunar Mapping and Modeling Project (LMMP), an initiative to ensure that the results of precursor robotic missions are accessible to lunar exploration planners. LMMP data are accessed through a single, common NASA portal designed for the convenient dissemination of lunar mapping and modeling data, products, and tools. A beta version of LMMP software was released for limited distribution in December 2009, with public release scheduled for FY 11.

Constellation Systems Division[1]

Within the ESMD, the Constellation Systems Division consists of two components: the Constellation Program and the Commercial Crew and Cargo Program Office. Together, these initiatives focus on developing the capabilities for safe, sustainable, and affordable crew and cargo transportation to LEO and beyond.

Constellation Program (CxP)

The Constellation Program (CxP) focused on developing the next generation of NASA launch vehicles and spacecraft for human space exploration beyond LEO. Its key systems included the Orion crew exploration vehicle, Ares I crew launch vehicle, and Ares V heavy lift launch vehicle. Additionally, CxP's

1. President Barack Obama's FY 11 budget request, announced in February 2010, cancelled the Constellation Program. However, the FY 10 Consolidated Appropriations Act prohibited the cancellation of Constellation while the 2010 NASA Authorization Act directed NASA to develop a new approach to human spaceflight. Constellation program elements continued into the development of the new program, but please note that this report reflects a historical approach to the data available at the time.

Program Integration and Operations covered the necessary systems to support ground and mission operations, extravehicular activity, and lunar lander and surface systems.

In FY 10, ESMD continued to move forward on existing CxP initiatives, focusing primarily on Orion and Ares I. While uncertainty surrounded CxP work for most of the year due to the program's proposed transition following the release of the FY 11 President's budget submission in early 2010, CxP developments during FY 10 provided valuable insights and capabilities to support new human spaceflight initiatives.

Orion is the crew exploration vehicle designed to ferry astronauts to and from the ISS, serve as a crew rescue vehicle while docked at the ISS, or to link up with another spacecraft in orbit to explore beyond LEO. Work continued on the Orion capsule throughout FY 10. Most notably, the two halves of the Orion crew capsule—the bulkhead and nosecone—were fused together using a new technology, friction stir welding. The activities culminated in a successful Pad Abort-1 test in May 2010. NASA will explore options for using versions of the Orion capsule, as well as associated work carried out in areas such as autonomous landing and advanced robotics, in new exploration initiatives directed by Congress and the President.

During FY 10, the development of the launch vehicle, Ares I, designed to transport the crew vehicle (Orion) into LEO to enable missions beyond Earth orbit, achieved several major milestones. Ares I was designed to provide transportation for crew and cargo to and from the ISS after the retirement of the Space Shuttle. Project achievements during FY 10 included a successful Ares I-X test flight from the Kennedy Space Center in October 2009, which produced a number of lessons learned that can be applied to future American space launch vehicles. Other notable accomplishments from the Ares I project in FY 10 included the second Ares I First Stage Development Motor (DM-2) test firing, as well as the completion of the first stage avionics and upper stage roll control systems.

Commercial Crew and Cargo Program Office

The Commercial Crew and Cargo Program Office (C3PO) encourages domestic, private-sector development of safe, reliable, and cost-effective space transportation

capabilities that could serve the ISS after Space Shuttle retirement. In FY 10, the Commercial Orbital Transportation Services (COTS) and the newer Commercial Crew Development (CCDev) activities achieved substantial progress.

The goal of COTS is to facilitate the development of commercial vehicles for providing cargo to low-Earth orbit, encouraging the successful growth of a competitive market that could potentially provide ISS resupply services. CCDev activities focused on stimulating efforts within the private sector for the development and demonstration of safe, reliable, and cost-effective human space transportation capabilities.

The COTS program featured two funded Space Act Agreements (SAA), one with the Space Exploration Technologies Corporation (SpaceX) and one with the Orbital Sciences Corporation (Orbital). Both SpaceX and Orbital have experienced delays common to aerospace development programs. However, both companies continued to make good progress with their COTS agreements in FY 10 by completing several agreed-upon milestones.

In June 2010, SpaceX performed the successful maiden test flight of the Falcon 9 launch vehicle, which lifted off from Kennedy Space Center. This test was in anticipation of SpaceX's first COTS demonstration flight, which took place in early FY 11 and included a Dragon spacecraft aboard the Falcon 9, which successfully entered low-Earth orbit, performed several orbits of Earth, safely re-entered the atmosphere, and splashed down in the Pacific Ocean.

In November 2009, Orbital passed the ISS phase-2 safety review in accordance with the Space Station safety review process. Achievement of the COTS Critical Design Review, demonstrating completion of the design phase, followed in March 2010. In August 2010, Orbital completed the assembly of its Service Module structure in preparation for structure testing. Orbital has selected the Wallops Flight Facility for launching its COTS demonstration flight, which is planned for late 2011 or early 2012.

The CCDev activities were funded by $50 million of American Recovery and Reinvestment Act (ARRA) funds. Through a competitive process, these funds were awarded to five corporations that focused on developing a range of technologies to ensure safe and affordable human exploration. These five companies (Paragon, Blue Origin, Boeing, Sierra Nevada, and United Launch Alliance) successfully met all their milestones, and those agreements were concluded in April 2011.

Space Operations Mission Directorate

Space Shuttle/International Space Station

For the past 12 years, NASA has applied the full capabilities of the Space Shuttle to the mission for which this unique vehicle was originally conceived—the assembly of a large, advanced research station in low-Earth orbit, one that can serve as a critical international way station for further missions beyond low-Earth orbit. In FY 10 alone, the Space Shuttle deployed nearly 120,000 pounds of hardware, equipment, and supplies to the ISS and hosted 12 spacewalks over four highly successful missions at the ISS.

FY 10 began aggressively with the first of six Russian Progress spacecraft flights to the ISS launched on October 14, 2009. Launched on October 18, 2009, from the Baikonur Cosmodrome in Kazakhstan and carrying 2,600 kilograms of food, spare parts, propellant, and scientific experiments, the Progress 35P resupply mission successfully docked with the ISS. This mission readied the ISS for the final surge in U.S. and Russian assembly missions needed to complete the basic ISS configuration on cost and schedule as planned for FY 10.

The Progress 5R assembly mission launched on schedule on November 20, 2009. This flight delivered the Russian assembly element "Poisk," or "Search," which is a mini-research module providing further capability for extravehicular activity (EVA) using Russian Orlan spacesuits. Additionally, Poisk provided systems for servicing and refurbishing the Orlan spacesuits and a zenith port needed for docking additional Soyuz and Progress spacecraft as the pace of visiting vehicle traffic continued to increase.

The crew of Space Shuttle Atlantis flew the first Shuttle mission of the fiscal year with the launch of STS-129 to the ISS on November 16, 2009. STS-129, the 31st Space Shuttle flight to the ISS, was a logistics mission. Atlantis carried nearly 30,000 pounds of spare hardware packed into two ExPRESS Logistics Carriers (ELC). (ExPRESS stands for Expedite the PRocessing of Experiments to the Space Station.) The ELCs carried two Control Moment Gyroscopes; tanks for ammonia, nitrogen, and oxygen; pump modules; a Latching End Effector for the ISS; a reel assembly for the ISS mobile transporter; and spare equipment for the ISS electrical

power system. Whereas many missions include spacewalks that are focused on the installation and checkout of a single large piece of hardware, the three extravehicular activities for STS-129 included over a dozen different primary tasks, each of which was essential to ensuring the full operability of all ISS systems. The STS-129 crew enjoyed a full Thanksgiving dinner, courtesy of the ISS Expedition 21 crew, before landing at the Kennedy Space Center on November 27, 2009.

Three of the Expedition 21–22 crew, O. Kotov, T.J. Creamer, and S. Noguchi, were launched December 20, 2009, on the Soyuz 21S mission. This mission was followed quickly by Progress 36P, which sustained ISS operations through resupply of another 2,600 kilograms of mission-critical cargo when it docked on February 5, 2010. The heads of the ISS agencies from Canada, Europe, Japan, Russia, and the United States then met in Tokyo, Japan, on March 11, 2010, to review ISS cooperation. They agreed that there were no identified technical constraints to continuing ISS operations beyond the current planning horizon of 2015 to at least 2020 and that the partnership should continue working to certify on-orbit elements through 2028. They recognized that the U.S. fiscal year 2011 President's budget request would allow the U.S. to support the continuation of ISS operations and utilization activities to at least 2020 and emphasized their common intent to undertake the necessary procedures within their respective governments to reach consensus on continuation of the ISS through the next decade.

The STS-130 astronauts delivered the two new ISS pieces, the final components of the U.S. segment of the ISS, aboard Space Shuttle Endeavour during the second mission of the fiscal year on February 8, 2010. The 27,000-pound Node 3 module provides additional room for crewmembers as well as important new life support and environmental control hardware to augment the ISS crew support capabilities. Node 3 was renamed Tranquility prior to launch, the result of an online NASA naming event that attracted over 190,000 submissions. The Cupola, built for the European Space Agency by Alenia Spazio in Turin, Italy, provided full, panoramic views for supporting EVAs and robotic and docking operations at the ISS. Three EVAs during STS-130 were dedicated to installing and outfitting Tranquility and the Cupola. Environmental control and life support racks were also installed, including the Urine Processor Assembly's replacement distillation assembly, the Advanced Resistive Exercise Device, racks 1 and 2 of the Water Recovery System, a

Waste and Hygiene Compartment, and the Oxygen Generation System. Endeavour touched down for a nighttime landing at Kennedy Space Center on February 21, 2010, after completing all primary mission objectives.

On April 2, 2010, the Soyuz 22S crew rotation mission launched Expedition 23–24 crewmembers A. Skvortsov, M. Kornienko, and T. Caldwell-Dyson to the ISS in time for President Obama's April 15, 2010, conference at Kennedy Space Center. The conference focused on charting a bold new course for NASA and the future of U.S. leadership in human spaceflight. A diverse group of senior officials, space leaders, academic experts, industry leaders, and others who have specific expertise or interests related to spaceflight attended the conference and participated in four concurrent sessions on different aspects of the President's new direction for NASA.

The predawn launch of Space Shuttle Discovery and its crew for STS-131 on April 5, 2010, proceeded without incident. Like STS-129, the mission was a logistics and outfitting run, with Discovery carrying over 17,000 pounds of cargo in the Multi-Purpose Logistics Module Leonardo and with three scheduled EVAs to continue maintenance and experiment activities outside the ISS. There were several technical issues that the on-orbit crews and ground teams had to work around, including issues with Discovery's high-data-rate Ku-band system, stuck bolts on external hardware, and a malfunctioning nitrogen tank assembly valve. Despite these issues, the crews completed all primary mission objectives, including transfer of 16 experimental and operations racks from Leonardo to the ISS. Leonardo's next and final journey to the ISS was scheduled to be a one-way trip, when it will be attached and left on the ISS during the STS-133 mission. Weather forced a wave-off and one-day delay to landing at the Kennedy Space Center, but both Discovery and its crew touched down safely at Shuttle Landing Facility Runway 33 on April 20, 2010. Another Progress cargo resupply flight, designated mission 37P, was then launched on April 28, 2010, and docked with 2,600 kilograms of supplies on May 1, 2010.

For STS-132, the crew of Space Shuttle Atlantis focused on the delivery and installation of the Russian-built Mini Research Module, or "Rassvet," meaning "dawn." Nearly 20 feet long and weighing more than 17,700 pounds, including its cargo, the module features eight workstations designed for a variety of science

experiments and educational research. Launch from the Kennedy Space Center was at 2:20 p.m. on May 14, 2010. After overcoming a snagged cable on the Orbiter Boom Sensor System (OBSS), which impacted the survey of Atlantis's thermal protection system on flight day 2, the Shuttle docked with the ISS and began preparations for outfitting Rassvet, transferring external cargo on the Integrated Cargo Carrier–Vertical Light Deployable 2 (ICC-VLD2), and conducting a series of three EVAs. Over the course of 18 hours spent outside the ISS, Shuttle crewmembers Steve Bowen, Garrett Reisman, and Michael Good configured the Rassvet, installed a new antenna on the ISS Z1 truss segment, removed and replaced six batteries on the ISS P6 truss, and dislodged the snagged cable from the sensor package on the OBSS. After completing all primary mission objectives, Atlantis and its crew landed safely at the Kennedy Space Center on May 26, 2010.

Expedition 24–25 crew F. Yurchikhin, D. Wheelock, and S. Walker were launched to the ISS on the Soyuz 23S mission on June 15, 2010. In the subsequent months, two Progress resupply missions were conducted to sustain ISS operations through the end of FY 10. Progress 38P arrived at the ISS on July 2, 2010, delivering 2,230 kilograms of needed supplies; Progress 39P arrived on September 12, 2010, delivering another 2,290 kilograms.

FY 10 was also an important year for Space Shuttle transition and retirement activities. NASA's first priority continued to be a focus on maintaining the capabilities needed to safely complete the Space Shuttle manifest. The last set of major flight hardware was shipped to the Kennedy Space Center, including the last set of Space Shuttle Reusable Solid Rocket Motor segments (RSRM-114), the last two External Tanks (ET-138 and ET-122), and the last Space Shuttle Main Engine (SSME-2062). The former Space Shuttle and Apollo launch pad at LC-39B was the stage for the launch of the Ares I-X test flight, which utilized not only Space Shuttle hardware but also personnel and processing facilities. In addition, NASA continued to focus on the critical role played by the Agency's highly skilled contractor and civil service workforce. Efforts included sharing a skilled workforce among the Space Shuttle, Constellation, and ISS programs; working with the Space Shuttle prime contractors on retention issues; and performing regular surveys of the Space Shuttle civil servant workforce and line management to identify and address emerging workforce issues. Over 2,200 members of the Space Shuttle prime contractor workforce were affected by reductions in FY 10.

During the course of FY 10, a total of four Space Shuttle missions, three Soyuz crew rotation missions, and six Progress cargo delivery missions were successfully conducted. These 13 spaceflight missions allowed the ISS to maintain the full complement of six crewmembers on board and complete the assembly of the basic ISS configuration on plan within cost and schedule. Thus, by the closure of FY 10, the ISS was positioned to enter into the era of full utilization with Canadian, European, Japanese, and Russian partners all working in concert to ensure a highly productive decade of research and development.

Space Communications and Navigation

In FY 10, 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, 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.

A major accomplishment in FY 10 was the contract award for the Space Network Ground Segment Sustainment (SGSS) project to General Dynamics C4 Systems. Its mission is to implement a flexible and extensible ground segment that will allow the SN to maintain the high level of service and accommodate new users and capabilities while reducing the effort required to operate and maintain the system. The TDRSS hardware and software at these stations, first implemented in 1983, are becoming increasingly difficult to sustain and maintain. This poses substantial risks to maintaining the highly reliable service that has been provided for over two decades. SGSS will update this national resource with a new architecture and system, providing even more reliable service to its valued customers, while continuing to attract new high-class, high-data-rate customers. SGSS will also ensure uninterrupted service to current customers during the transition to the new architecture.

In December 2010, NASA took the next step toward a new generation of Deep Space Network antennas by awarding General Dynamics SATCOM

Technologies, of San Jose, California, a contract for the implementation of additional 34-meter (112-foot) antennas in Canberra, Australia. This was part of the Phase-I implementation to eventually retire the network's aging 70-meter-wide (230-foot-wide) antennas.

The Deep Space Network consists of three communications complexes: Goldstone, California; Madrid, Spain; and Canberra, Australia. The 70-meter antennas are more than 40 years old and are showing signs of surface deterioration from constant use. Additional 34-meter antennas are being installed in Canberra in the first phase; subsequent phases will install additional 34-meter antennas in Goldstone and Madrid.

These 34-meter beam wave-guide antennas are essential to keeping communications flowing smoothly as NASA's fleet of spacecraft continues to expand. In addition, the 34-meter antennas provide easier access for maintenance and future upgrades because their sensitive electronics are housed in a below-ground pedestal equipment room instead of in the center of the dish.

NASA expects to complete the building of the first two 34-meter antennas in Canberra by 2016. They will be named Deep Space Stations 35 and 36. Deep Space Station 35 is scheduled to be online in 2014, and Deep Space Station 36 is expected to follow in 2016.

SCaN continued its technology development program in FY 10, including its pursuit of a Software-Defined Radio demonstration on board the ISS and a Lunar Laser Communications Demonstration (LLCD) on board the Lunar Atmosphere and Dust Environment Explorer (LADEE) mission. The LLCD will demonstrate a data rate from the moon that is higher by a factor of six than the current Lunar Reconnaissance Orbiter (LRO), which has transmitted more data than all prior planetary missions combined.

SCAN has also worked closely with NASA's international partners on developing a demonstration of the Disruption Tolerant Network (DTN) technology, which is aimed towards automating current space mission operations and beginning the transition to "Internet-like" communication across the solar system.

As NASA's representative in the Interagency Operations Advisory Group (IOAG), SCaN proactively sought cooperation with our international partners in a variety of new areas related to space communications interoperability, including

mission support and optical communication. The reinvigorated IOAG is actively pursuing international cooperation on these key issues in order to ensure better international cooperation and cross support among space agencies and better usage of national assets.

Launch Services

The Launch Services Program (LSP) successfully managed the launch of two missions on expendable launch vehicles (ELVs) during FY 10. The first was the Wide-field Infrared Survey Explorer (WISE), which launched from the West Coast's Vandenberg Air Force Base, California, on December 14, 2009, aboard a Delta II. The second was the Solar Dynamics Observatory (SDO), which launched from the East Coast's Cape Canaveral Air Force Station (CCAFS), Florida, on February 11, 2010, aboard an Atlas V. Additionally, LSP provided advisory services to the National Oceanic and Atmospheric Administration's (NOAA) Geostationary Operational Environmental Satellite (GOES)-P, which launched from CCAFS on March 4, 2010, aboard a Delta IV. To find out more about these and other NASA science missions, see the Science Mission Directorate section in this report.

Also in FY 10, the NASA Launch Services (NLS) II contracts were awarded to Lockheed Martin Space Systems Company, Orbital Sciences Corporation (OSC), Space Exploration Technologies, and United Launch Services, LLC. Under these contracts, the program will acquire services associated with launches of Athena, Pegasus, Taurus, Falcon, and Atlas launch vehicles. Services are provided on a multiple-award, indefinite delivery/indefinite quantity basis, spanning a ten-year period. Missions not presently under contract are competed among existing NLS II contractors through the use of a launch service task order mechanism. In addition to NLS II, 13 remaining missions will fly out under the terms of NLS I between FY 11 and FY 15.

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, the 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.

Science Mission Directorate

NASA's Science Mission Directorate (SMD) has five program divisions: Astrophysics, Planetary Science, Heliophysics, Earth Science, and Joint Agency Satellite. In FY 10, SMD successfully launched three new space and Earth science missions designed to improve our understanding of solar processes, Earth system change, the nature of the universe, and the history of the solar system.

On December 14, 2009, NASA launched the Wide-field Infrared Survey Explorer (WISE) spacecraft. From a vantage point 500 kilometers above Earth's surface, WISE surveyed the entire sky at infrared wavelengths, creating a cosmic clearinghouse of hundreds of millions of objects that will be catalogued. This will provide a vast storehouse of knowledge about the solar system, the Milky Way, and the universe. By the end of its six-month mission, WISE acquired nearly 1,500,000 images covering the entire sky. The mission uncovered objects never seen before, including the coolest stars, near-Earth asteroids, and comets. Its vast catalogs will be studied for years to come to help answer fundamental questions about the origins of planets, stars, and galaxies. WISE data will also reveal new information about the composition of near-Earth objects and asteroids—are they fluffy like snow or hard like rocks, or both? WISE is an Astrophysics Division mission.

On January 5, 2010, NASA's Hubble Space Telescope's new infrared camera, the Wide Field Camera 3 (WFC3), broke the distance limit for galaxies and uncovered a primordial population of compact and ultra-blue galaxies never seen before. The deeper Hubble looks into space, the farther back in time it looks, because light takes billions of years to cross the observable universe. This makes Hubble a powerful "time machine" that allows astronomers to see the most distant galaxies as they were 13 billion years ago, just 600 million to 800 million years after the Big Bang. The existence of these newly found galaxies pushes back the time when

galaxies began to form. The deep observations also demonstrate the progressive buildup of galaxies and provide further support for the hierarchical model of galaxy assembly in which small objects accrete mass, or merge, to form bigger objects over a smooth and steady but dramatic process of collision and agglomeration. This is analogous to streams merging into tributaries and then into a bay. The Hubble Space Telescope is an Astrophysics Division mission.

On January 28, 2010, the Cassini spacecraft made its 67th flyby of Titan, Saturn's largest moon. Titan's peculiar surface includes lakes of liquid hydrocarbons and other features that puzzle planetary scientists. In this flyby, Cassini spacecraft passed over the surface at an altitude of about 7,490 kilometers (4,654 miles); by contrast, other flights brought it as close as a few hundred miles. The relatively long-distance flyby between the Cassini spacecraft and Titan gave Cassini's instruments the ability to observe the context of specific features seen on closer passes. The Cassini spacecraft was launched in 1997 and entered Saturn's orbit in 2004. Since then, the spacecraft has been providing scientists with groundbreaking discoveries about the gas giant and its many moons. The spacecraft has helped shape our understanding of the various influences that the entire Saturnian system exerts within itself. Hence, the correlations between the planet, its moons, and the rings also became clearer. The Planetary Science Division manages the Cassini spacecraft.

On February 11, 2010, NASA launched the Solar Dynamics Observatory (SDO) spacecraft. SDO is revealing the processes inside the sun, on the sun's surface, and in its corona that result in solar variability. This variability, when experienced on Earth, is called space weather. Space weather affects not only our lives on Earth, but also Earth itself and everything outside its atmosphere—astronauts and satellites out in space and even the other planets. By better understanding the sun and how it works, scientists are better able to predict and forecast the "weather out in space," providing earlier warnings to protect our astronauts and satellites in their journeys through space. SDO is designed to operate for five years. It collects huge amounts of data every day and produces enough data to fill a single CD every 36 seconds. Because SDO has no recording system and collects so much information, the SDO mission uses a dedicated ground station. SDO is in a geosynchronous orbit so that the SDO spacecraft revolves around Earth at the same rate as Earth

rotates and is thus always directly above and in constant communication with its ground station in New Mexico. SDO is a Heliophysics Division mission.

On March 3, 2010, the Cassini spacecraft did a targeted flyby and made its closest approach of the mission to Helene (a moon) at about 1,800 kilometers (1,131 miles). (A "targeted flyby" refers to the times when the navigation team is anchoring the trajectory design to the flyby—tweaking the spacecraft's path to take full advantage of the opportunity. Usually targeted flybys are closer and, therefore, reveal greater surface detail.) Helene, a small moon, is referred to as a Trojan moon because it is gravitationally tied to the much larger moon, Dione. On approach to the small moon, the Cassini's Visible and Infrared Mapping Spectrometer (VIMS) took measurements that may help scientists analyze Helene's surface composition and understand if it is coated with particles from the E ring. Then, using a "skeet shoot"-style observation due to quickly changing geometries, the Cassini's Imaging Science Subsystem captured close-ups of the moon. Scientists anticipate that these new views may reveal clues about Helene's past, including how it was gravitationally captured by the larger moon, Dione, and whether a collision was part of its past. The Planetary Science Division manages the Cassini spacecraft.

On March 4, 2010, NASA launched the GOES-P satellite. Once the GOES-P reached geostationary orbit, it joined the fleet of satellites necessary to predict weather in North America. GOES-P will provide more accurate prediction and tracking of severe storms and other weather phenomena, resulting in earlier and more precise warnings to the public. The GOES program, started in 1974, is a program of NOAA, which is part of the U.S. Department of Commerce. NOAA funds and manages the program and determines the need for satellite replacement. NASA acts as NOAA's acquisition agent to design, develop, and launch GOES satellites. After a satellite is launched and checked out by NASA, the spacecraft is turned over to NOAA for its operation. GOES-P stands ready as the most advanced multi-mission weather and Earth-observation satellite ever built for NOAA geosynchronous operations. It supports NOAA and NASA scientists' collection and analysis of real-time environmental data, as well as the U.S. Coast Guard's searches of the open seas. In addition, GOES-P will provide enhanced weather monitoring and prediction capability, communications subsystems to rebroadcast data, and space environmental monitoring instruments and sensors

from an operational orbital slot of 75° or 135° west. Within NASA, the Joint Agency Satellite Division manages the GOES program.

In April 2010, the Global Hawk Pacific (GloPac) 2010 mission was the first environmental science mission of NASA's Global Hawk unmanned aircraft system. The flights in April 2010 ranged over the Pacific Ocean south to the equator, west past Hawaii, and north into the Arctic. Ten instruments on the aircraft collected a wide range of atmospheric data.

On April 28, 2010, the Cassini spacecraft's Radio Science Subsystem (RSS) tracked Enceladus, another Saturn moon, through a close pass to determine the nature of the interior beneath its south polar hot spot. Traveling at 6.5 kilometers per second (14,540 miles per hour), Cassini flew past Enceladus for a targeted flyby; the spacecraft's closest approach occurred at an altitude of 100 kilometers (60 miles). This spacecraft flyby featured a high-priority RSS gravity experiment to look for mass anomalies associated with the Enceladus plume. The flyby segment began with an RSS observation of a Saturn-solar occultation, both ingress and egress, which was followed by gravity observations that continued as Cassini traveled under the South Pole through the plume. These back-to-back observations required almost 30 hours of continuous Deep Space Network (DSN) support provided sequentially by all three of DSN's facilities. These observations will be used to look for anomalies indicating the presence or absence of mass concentrations at the south polar region of Enceladus, which may in turn provide insight into the source material for the plume. After passing Enceladus, RSS continued to monitor the spacecraft trajectory as a baseline for comparison with the flyby results. The Planetary Science Division manages the Cassini spacecraft.

In late April 2010, NASA aided the United States' response to the Deepwater Horizon oil spill. Advanced remote-sensing instruments on NASA Earth-observing satellites and aircraft collected observations of the spill and its impact on ecosystems in the Gulf of Mexico. Several NASA satellites took regular observations primarily to detect the locations, extent, and varying concentrations of the oil spill. NASA data were distributed to the many Federal and state agencies and organizations working to contain the spill and develop recovery efforts. NASA also sent several research aircraft to make targeted observations that will assist Federal and state agencies in documenting changes in the marshes, swamps, bayous, and beaches along the Gulf coast.

On May 25, 2010, the Stratospheric Observatory for Infrared Astronomy (SOFIA), a joint project of NASA and the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt—DLR), completed an important milestone by achieving "first flight" when it performed its first observations during the night. SOFIA is the only airborne observatory in the world. The observatory carried out observations of astronomical objects at infrared wavelengths in flight. During an eight-hour first flight that reached 11,000 meters in altitude, the 18-person crew of scientists, engineers, and technicians tested the telescope's performance to its limits and took the first infrared images of test objects in the night sky. The crowning achievement of the night: scientists recorded images of the Messier 82 galaxy and of Jupiter at wavelengths unobservable by ground- or space-based telescopes. The composite image of Jupiter showed heat pouring out of the planet's interior through holes in its clouds. In the infrared image of Messier 82, it is possible to look through the galaxy's interstellar dust clouds to see several "starburst" knots in which stars are forming by the tens of thousands. SOFIA is an Astrophysics Division mission.

On May 26, 2010, data from NASA's Swift satellite helped astronomers solve a decade-long mystery about why a small percentage of black holes emit vast amounts of energy. Only about one percent of super-massive black holes exhibit this behavior. The new findings confirm that black holes "light up" when galaxies collide. The data may offer insight into the future behavior of the black hole in our own Milky Way galaxy. The intense emission from galaxy centers, or nuclei, arises near a super-massive black hole containing between a million and a billion times the sun's mass. Giving off as much as 10 billion times the sun's energy, some of these active galactic nuclei (AGN) are the most luminous objects in the universe. They include quasars and blazars. Until Swift's hard x-ray survey, astronomers were never sure they had counted the majority of the AGN. Thick clouds of dust and gas surround the black hole in an active galaxy, which can block ultraviolet, optical, and low-energy (soft x-ray) light. Infrared radiation from warm dust near the black hole can pass through the material, but it can be confused with emissions from the galaxy's star-forming regions. Hard x-rays can help scientists directly detect the energetic black hole. Since 2004, the Burst Alert Telescope (BAT) aboard the Swift spacecraft has mapped the sky using hard x-rays. The survey, sensitive to

AGN as far as 650 million light-years away, uncovered dozens of previously unrecognized systems. Swift is an Astrophysics Division mission.

On June 3, 2010, rocks examined by NASA's Mars Exploration Rover Spirit indicated evidence of a wet, non-acidic ancient environment that may have been favorable for life. Confirming this mineral clue took four years of analysis by several scientists. An outcrop that Spirit examined in late 2005 revealed high concentrations of carbonate, which originates in wet, near-neutral conditions but dissolves in acid. The ancient water indicated by this finding was not acidic. Laboratory tests helped confirm the carbonate justification. Massive carbonate deposits on Mars have been sought for years without much success. Numerous channels apparently carved by flows of liquid water on ancient Mars suggest that the planet was formerly warmer, thanks to greenhouse warming from a thicker atmosphere than exists now. The ancient, dense Martian atmosphere was probably rich in carbon dioxide because that gas makes up nearly all the modern, very thin atmosphere. Spirit is a Planetary Science Division mission.

On August 15, 2010, the Global Hawk took part in NASA's Genesis and Rapid Intensification Processes (GRIP) airborne campaign to study how hurricanes and tropical cyclones form and strengthen. For the first time (and for up to 20 hours straight), the campaign used several NASA research aircraft to study these storms and the conditions that produce them. One of the major challenges in tropical cyclone forecasting is knowing when a tropical cyclone is going to form. Scientists analyzed the data from the field mission to better understand how tropical storms form and develop into major hurricanes. Three NASA satellites played an important role in supplying data about tropical cyclones during the field mission. The Tropical Rainfall Measuring Mission (TRMM) provided rainfall estimates and helped pinpoint the locations of "hot towers" or powerhouse thunderstorms in tropical cyclones. The CloudSat spacecraft provided cloud profiles of storms; the profiles included altitude, temperatures, and rainfall intensity. Several instruments on board NASA's Aqua satellite provided infrared, visible, and microwave data that revealed such factors as temperature, air pressure, precipitation, cloud ice content, convection, and sea surface temperatures. The Earth Sciences Division manages all three NASA satellites. The GRIP campaign is an Earth Sciences Division mission.

On August 26, 2010, NASA's Kepler team announced the discovery of the first confirmed planetary system with more than one planet crossing in front of, or transiting, the same star. The transit signatures of two distinct planets were seen in the data for the sun-like star designated Kepler-9. The planets were named Kepler-9b and -9c. The discovery incorporates seven months of observations. By observing several transits by each planet over the seven months of data, the team analyzed successive transits to confirm the presence, number, size, and orbit period of the planets in this distant solar system. The observations show that Kepler-9b is the larger of the two planets and both have masses similar to, but less than, that of Saturn. Kepler-9b lies closest to the star, with an orbit of about 19 days, while Kepler-9c has an orbit of about 38 days. Kepler is making multi-year observations of more than 156,000 stars as part of an ongoing search for Earth-sized planets outside our solar system. Kepler is an Astrophysics Division mission.

On September 9, 2010, data from NASA's Phoenix Mars Polar Lander suggested that liquid water has interacted with the Martian surface throughout the planet's history and into modern times. The research also provided new evidence that volcanic activity persisted on the Red Planet into geologically recent times, several million years ago. Although the Lander, which arrived on Mars on May 25, 2008, is no longer operating, NASA scientists continue to analyze data gathered from that mission. These recent findings are based on data about the planet's carbon dioxide, which makes up about 95 percent of the Martian atmosphere. Phoenix precisely measured isotopes of carbon and oxygen in the carbon dioxide of the Martian atmosphere. Isotopes are variants of the same element with different atomic weights. This chemical signature suggests that liquid water primarily existed at temperatures near freezing and that hydrothermal systems similar to Yellowstone's hot springs have been rare throughout the planet's past. Measurements concerning carbon dioxide showed that Mars is a much more active planet than previously thought. The results imply that Mars has replenished its atmospheric carbon dioxide relatively recently and that the carbon dioxide has reacted with liquid water present on the surface. The Phoenix Mars Lander is a Planetary Science Division mission.

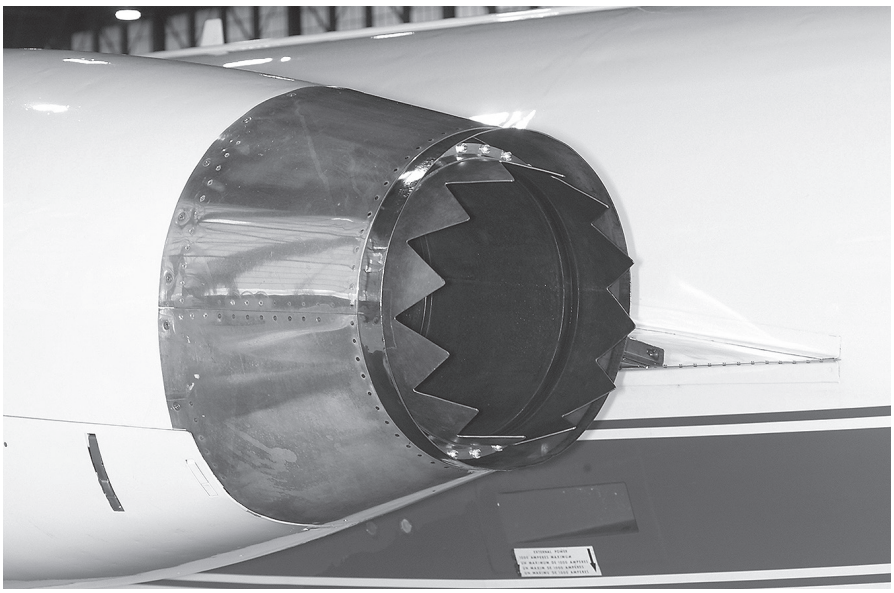
On September 29, 2010, NASA and the National Science Foundation sponsored a team of planet hunters from the University of California Santa Cruz and the Carnegie Institution of Washington to find a very Earth-like exoplanet. The team

announced the discovery of a planet with three times the mass of Earth orbiting a nearby star at a distance that places it squarely in the middle of the star's "habitable zone." The discovery was the result of more than a decade of observations using the W.M. Keck Observatory in Hawaii, one of the world's largest optical telescopes. The research placed the planet in an area where liquid water could exist on the planet's surface. If confirmed, this would be the most Earth-like exoplanet yet discovered and the first strong case for a potentially habitable one. To astronomers, a "potentially habitable" planet is one that could sustain life, not necessarily one where humans would thrive. Habitability depends on many factors, but having liquid water and an atmosphere is among the most important.

Aeronautics Research Mission Directorate

As an industry, aviation contributes $1.3 trillion to the Nation's economy and employs over one million people. Airlines in the U.S. transport over one million people daily, but during peak travel times, the air traffic and airport systems in the U.S. are stretched to capacity. Environmental concerns, such as aircraft noise and emissions, limit increased operations and the expansion of airports and runways. NASA's Aeronautics Research Mission Directorate (ARMD) works to solve these critical challenges while maximizing aviation safety. As an example of the realization of a technology addressing these challenges, NASA ARMD shepherded the development of chevron nozzles that are now making a difference in the noise impact from commercial jet engines. Chevrons are the serrated edges on the jet engine nozzles. They promote noise reduction for the high-speed jet of air that exits an aircraft engine. Chevron research started at NASA in the mid-1990s as basic research on jet mixing and has proceeded with the help of industry partners to become an operational reality. Chevrons are now featured on Boeing's latest two wide-body aircraft—the Boeing 787 and the Boeing 747-8.

In FY 10, ARMD's programs continued to address specific aeronautical research needs while taking an integrated systems approach to the above-mentioned challenges. ARMD also conducted research on technology approaches for advanced aircraft that could one day change the face of air transportation. By focusing on these challenges and future technologies, ARMD ensures that its fundamental



This early design of chevron nozzles—with the sawtooth edges—was installed on a NASA Learjet in 2001 to test how far the chevron edges could penetrate the airflow to reduce the most noise without reducing engine thrust beyond an acceptable level. A later design of the nozzles, which reduced engine noise up to three decibels, has since been included on engines for the Boeing 747-8 and 787 aircraft. Image credit: NASA

research portfolio not only supports NASA's strategic goals but is also well aligned with the principles, goals, and objectives of the National Aeronautics Research and Development (R&D) Policy and Plan and directly supports the development of the Next Generation Air Transportation System (NextGen).

Fundamental Aeronautics Program

The goal of the Fundamental Aeronautics Program is to enable a future in which a variety of advanced aircraft exist that improve the flexibility, efficiency, and environmental impact of air travel. As the Nation transitions to the NextGen, the Program helps develop the tools, advanced technologies, and scientific knowledge necessary for the design of new types of vehicles. The Fundamental Aeronautics Program conducts research on topics such as advanced configurations and concepts, lighter and stronger materials and structures, improved propulsion systems, advanced concepts for increasing lift and reducing drag, and advanced computational tools and models for design.

The Subsonic Fixed Wing (SFW) Project is developing technologies for quieter and cleaner aircraft that will meet the stringent noise and emissions requirements

of the future and reduce fuel burn. In FY 10, the SFW Project completed an 18-month study to develop advanced, high-payoff technology concepts for commercial subsonic transports that may enter service in the 2030–35 timeframe. The results of the study, conducted with four different industry and university teams, revealed a range of promising technologies and advanced vehicle architectures capable of meeting the stringent performance requirements in fuel burn, noise, and emissions reductions of this timeframe. There emerged unique configurations and concepts that offer potential solutions to a variety of future aviation challenges. Two examples are the "SUGAR Volt," a Boeing truss-braced wing concept with very long, slender wings and a hybrid electric propulsion system, and the Massachusetts Institute of Technology (MIT) "double bubble," with a double-wide fuselage that provides significant lift and is powered by a boundary layer ingesting propulsion system. Vehicle performance trends that emerged from the study included significant use of laminar flow technologies, advanced lightweight materials, use of alternative fuels to significantly reduce emissions, and lower cruise speeds at higher altitude. These studies, and the resulting advanced concepts and technologies, serve as guidance for future NASA research investment and inspire both industry and academia to continue to think innovatively and long-term.

The Subsonic Rotary Wing (SRW) Project addressed the technical challenges that limit rotorcraft from becoming more effective contributors to the national civil aviation system. The unique ability of rotorcraft, such as a future large civil tiltrotors, to operate independent of a runway could contribute to the NextGen vision by enhancing airspace capacity and efficiency and expanding access to air travel. This project invested in technologies that benefit a variety of rotary wing vehicles, as well as the development of large rotorcraft. Large civil rotorcraft could have the potential to increase passenger "block speed" (reducing the time it takes the passenger to get from one place to another) to something comparable to or better than current turboprops and regional jets for trips of up to 600 nautical miles. Research and technology investments in this project will help enable future higher speed rotorcraft, which can cruise at about 350 knots and which will also be efficient and lower in noise, vibration, and emissions.

The SRW Project completed a full-scale wind tunnel test of the UH-60A rotor in May 2010. The dataset resulting from this test is expected to set the international

standard for rotor validation data for at least the next decade. The full-scale rotor used was the most fully instrumented rotor configuration ever tested in the National Full-Scale Aerodynamics Complex (NFAC) wind tunnel. The test included the first-ever simultaneous use of several different laser-based experimental data measurement techniques. The results were detailed, high-quality, integrated data (including rotor performance, aeromechanical loads, wake characteristics, and rotating blade shape and deflection) that will be used to identify physical phenomena necessary for advanced rotor behavior prediction and design. The UH-60A rotor test research team received the American Helicopter Society's Howard Hughes Award for outstanding improvement to fundamental helicopter technology.

The Supersonics Project conducts research to address the efficiency, environmental, and performance barriers that prevent practical supersonic cruising over land. In FY 10, the Project completed a number of activities that contributed to the development of new capabilities to design and analyze supersonic vehicles with low sonic boom and high fuel efficiency. Among those activities was a set of advanced concepts and technology studies conducted in partnership with industry and academia to better define advanced airframe and propulsion concepts and enabling technologies. These address the many challenges for commercial supersonic aircraft that could enter service in 2025 or beyond. Two teams assessed the technology needs and sonic boom mitigation concepts for future supersonic transports. The studies revealed slender, highly integrated configurations with unique shapes can practically eliminate sonic boom. The configurations and associated advanced technologies will enable overland supersonic flight, a potential breakthrough for a number of different classes of future supersonic commercial aircraft. These detailed studies helped identify critical technology needs such as slender, flexible, highly integrated airframes and low-emissions engines with the capability to operate efficiently at cruise and operate quietly for landing and take-off. These results continued to provide guidance for NASA research investments.

The Hypersonics Project focuses on the development of high-fidelity tools, advanced technologies, and capabilities through foundational research and technology development to advance the state of the art in air-breathing access to space. In FY 10, the Hypersonics Project, in partnership with the Air Force Research Laboratory, completed a rigorous assessment and comparison of two different air-breathing, two-stage-to-orbit (TSTO) concepts—a NASA turbine-based combined cycle and the

Air Force's rocket-based combined cycle vehicle engine. This partnership established a national understanding of the state of the art of hypersonic vehicle and propulsion system design and performance prediction. It also identified challenges associated with designing space vehicles that could inform strategic investment decisions for eventually developing an air-breathing TSTO hypersonic vehicle.

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. But even with very low accident rates, the desire for continuous improvement is a given. Innovation is required to meet the remaining safety challenges. The Aviation Safety Program addresses key aviation safety challenges by developing 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 10, the Aviation Safety Program consisted of four projects that were each configured to provide solutions to these challenges. The Aircraft Aging and Durability (AAD) Project addressed the need for ensuring long-term vehicle health and airworthiness by improving the operational resiliency of future aircraft materials and structures throughout their projected lifetimes. The Integrated Intelligent Flight Deck (IIFD) Project conducted research to support sound decision making and situational awareness in all operating conditions by ensuring the proper integration of the human operator in a highly automated and complex operational environment. The Integrated Resilient Aircraft Control (IRAC) Project sought to prevent loss-of-control incidents through adaptive control methods and better modeling of upset flight conditions from a variety of causes, including icing and structural degradation. The Integrated Vehicle Health Management (IVHM) Project used a prognostic approach to vehicle health management and effectively discovered incident precursors within the large amounts of data contained in highly integrated and complex flight-critical systems.

All four projects helped address these challenges in FY 10. Recognizing the increased role of composite materials in new aircraft designs, the AAD Project developed an innovative, atomistically based methodology for modeling the effects of long-term water ingression on the surface of epoxy resin–based structural materials. Our greater understanding of how moisture ingression affects the adhesion characteristics of a bonded joint can aid in the development of new epoxy chemistries and surface treatments that resist the negative effects of moisture ingression. These moisture-tolerant materials will lead to more durable and reliable bonded aircraft structural assemblies. Since most aircraft stay in service for more than 20 years, the benefits of the new materials and associated repair practices will benefit the community for many years to come.

Future NextGen operational concepts will likely require more complex flight deck automation. The IIFD Project used flight deck simulators for human-in-the-loop studies to replicate the complex, advanced automation technology expected in the future. Maintenance of safety margins and improved performance were observed and documented. In addition to publishing flight deck guidelines and display requirements that meet projected NextGen operational concept needs, project personnel participated in aviation industry-wide and Federal Aviation Administration (FAA)–sponsored technical committees to disseminate their results. The studies contributed to operational and certification standards for NextGen technologies and procedures.

One potential means of preventing loss-of-control incidents is through modifications to the aircraft flight control systems. Such modified systems must themselves be proven safe and reliable. Therefore, the IRAC Project developed a unique software tool suite that can determine the flight envelope failure points of an adaptive control system responding to an adverse event. The new suite is an integrated package designed to efficiently analyze any dynamic system, such as aircraft controls, that is subject to uncertainty. Results demonstrated confidence levels as good as those achieved with conventional analysis techniques, but with 10 times less computing time. Since this software suite is also ideally suited for effectively evaluating the robustness of any nonlinear control systems, it can be widely applied to a variety of applications.

Detection of failures and prediction of the future state of a system are essential elements of health management systems. To address a portion of this challenge,

the IVHM Project developed an advanced hybrid diagnostic system for electromechanical actuators (EMA) that covers a wide variety of typical faults. The system combines both model-based and data-driven diagnostic approaches to achieve low false positive/false negative detection rates and thus a high diagnostic accuracy output. Validation experiments were conducted with 320 nominal and fault scenarios; the results showed over 95 percent diagnostic accuracy. As EMAs become increasingly applied to critical aircraft roles such as control surface actuation, having a reliable diagnostic system for EMA health management systems is essential.

In addition to these specific achievements, researchers throughout the Aviation Safety Program were very active in the aviation safety research community. During FY 10, they presented over 325 conference papers and published over 75 peer-reviewed journal papers and books. Program researchers also filed six invention disclosures and were awarded one patent. Work done under the Program resulted in the Agency's signing of 14 software licenses and usage agreements.

Airspace Systems Program

The Airspace Systems Program, in collaboration with its partners in the FAA, industry, and academia, addresses the fundamental air traffic management research needs of increasing capacity and efficiency of NextGen. The Program directly benefits the flying public by moving key concepts and technologies from the laboratory into the field. Its goal is to make air travel as efficient as possible by reducing aircraft fuel consumption, noise, and emissions. Concept simulations and field trials in real flight environments of NASA-developed technologies have demonstrated tens of millions of dollars in annual savings through reductions in flight delays and fuel usage. Its two projects—NextGen Concepts and Technology Development (CTD) and NextGen Systems Analysis, Integration, and Evaluation (SAIE)—made major contributions to future air traffic needs by developing advanced technologies and solutions for increased fuel efficiency with reduced noise and emissions. Because CTD focuses on foundational research, and SAIE on maturing and integrating these concepts, both projects are highly integrated, much like the airspace system itself.

During FY 10, the CTD Project developed concepts in priority technical challenge areas, such as surface operations, dynamic airspace configuration, traffic flow

management, and super-density operations, and then refined models to evaluate those concepts and performed initial benefits assessments. Evaluation continued in the area of traffic flow management of a capability developed under a NASA Research Announcement award, in conjunction with the FAA, to reduce fog-related delays in arrivals at San Francisco International Airport. This technology improved scheduling by using fog dissipation probabilities and predictions as well as advanced optimization algorithms. Engineering trials were completed in the summer of 2010 in partnership with the National Weather Service (NWS), the FAA, MIT's Lincoln Laboratory, and industry. Benefit assessments indicated a potential 19 percent reduction in delayed flights worth an annual savings to the aviation industry of over $10 million. The safety assessment has been completed, and, following a shadow evaluation, the capability will undergo operational evaluation during the summer fog season of 2011.

The SAIE Project meets program technological challenges by utilizing its system-wide analysis expertise to evaluate the benefits achievable through the integration of selected CTD concepts. It then further develops these integrated concepts through high-fidelity simulation and demonstration in relevant flight environments. The SAIE Project evaluates the impact of technologies within the Airspace Systems Program portfolio and identifies areas that benefit from new concepts developed by the project.

The Efficient Descent Advisor (EDA) continued its development under the SAIE Project as an integration of concepts for fuel-efficient descents, arrival scheduling, and the merging and spacing of arrival traffic. EDA is the core technology in a joint effort between the FAA, NASA, and Boeing to develop a ground-based automation capability that will generate fuel-efficient, conflict-free trajectories. It represents an initial implementation of trajectory-based operations, a key component of NextGen. Flight trials in San Francisco have indicated fuel savings of up to 3,000 pounds (a 10,000-pound reduction in carbon dioxide) per flight for large aircraft employing EDA capabilities during peak traffic conditions. In addition, United Parcel Service (UPS) claims that merging and spacing operations with continuous descent arrivals will enable savings of 1 million gallons of fuel per year. In FY 10, the EDA team conducted two human-in-the-loop (HITL) simulations of the decision support tool to verify the algorithm's core performance and to ensure

that enhancements to the algorithm issue a secondary clearance should a potential conflict emerge.

The Future Air Traffic Management (ATM) Concepts Evaluation Tool (FACET) was named the 2010 Government Invention of the Year. FACET is a flexible software tool capable of quickly generating and analyzing thousands of aircraft trajectories. It provides researchers with a simulation environment for preliminary testing of advanced ATM concepts. FACET is also used by the FAA for real-time operational planning. Its graphical displays have been showcased by the National Air and Space Museum to educate students and the public. This software made a significant contribution to making our airspace safer, increasing fuel efficiency, and minimizing airplane emissions.

Integrated Systems Research Program

In FY 10, ARMD initiated the Integrated Systems Research Program (ISRP) to conduct research in integrated system-level approaches to reduce the environmental impact of aviation (in terms of local and global emissions, local air quality, and noise) in the area of air-vehicle technologies. The ISRP goal is to accelerate the transition of aeronautics research and development results, including NextGen technologies, to industry and Government. Research is coordinated with ARMD's fundamental research programs and with relevant efforts by other Federal agencies and industry.

The first project within ISRP is the Environmentally Responsible Aviation (ERA) Project, a "green aircraft initiative," to conduct system research and experiments of promising vehicle concepts and technologies that will simultaneously reduce fuel burn, noise, and emissions. Progress was made toward this goal in FY 10 with the completion of the first phase of the X-48B Blended Wing Body (BWB) Low Speed Flight Test Program. Hybrid wing body aircraft configurations, such as the BWB, are promising candidates to reduce the environmental impact associated with aviation. Wind tunnel testing and a series of 80 free-flight demonstrations of an 8.5 percent scale aircraft confirmed its stability and control. The first phase began on July 20, 2007, and ended with the 80th flight on March 19, 2010. NASA system studies have shown that the BWB configuration has the potential to reduce

the amount of fuel burned by 20 to 30 percent compared to an equivalent tube-and-wing vehicle design.

In addition, the ERA Project, in collaboration with General Electric, completed a low-speed, open-rotor jet engine test campaign in the 8- by 6-Foot and 9- by 15-Foot wind tunnels at NASA's Glenn Research Center. The Project investigated open-rotor propulsion systems to improve fuel efficiency over that of current jet engines. The tests explored the design space for achieving lower noise while maintaining high propulsive efficiency from a counter-rotating rotor system. Additionally, these tests utilized new acoustic measurement techniques that provide an unprecedented ability to define noise sources. Diagnostic testing was completed in September 2010 and provided a comprehensive dataset for open-rotor propulsion systems that are of particular interest to our industry partners.

During FY 10, the ERA Project utilized $30 million in American Recovery and Reinvestment Act (ARRA) funding to kick-start some investigative areas of the ERA Project portfolio. Propulsion system injector technology and hardware were designed and fabricated to lower the landing and take-off emissions of current aircraft. In addition, the design and preliminary fabrication of a damage-tolerant light-weight composite material test article were completed. The specific concept explored is the Pultruded Rod Stitched Efficient Unitized Structure (PRSEUS), a stitched resin-infused composite material structure that can be used for non-circular fuselage sections required for a non-tube-and-wing-configuration aircraft such as a hybrid/blended wing body.

As air quality around airports continues to be an increasing concern, the ERA Project is maturing promising technologies to reduce nitrogen oxides emissions to 75 percent below existing standards. The engine technologies investigated in FY 10 included those with innovative fuel/air mixtures, active combustion control, and engines with higher pressure and bypass ratios.

Aeronautics Test Program

The Aeronautics Test Program (ATP) ensures the continuous availability of a portfolio of NASA-owned ground and flight test capabilities important to meeting national aerospace program goals and requirements. The Aeronautics Ground Test

Facilities Project provides facility operations support to ensure facility and staff availability, complete maintenance and upgrades, and test technology development for both ground and flight test capabilities.

The Program continued to support ground and flight test operations with the successful development of five test capability investment projects across three Centers totaling $46.9 million. These projects, funded through the ARRA, help to ensure maximum value to customers using NASA test facilities. Together, they represent the largest single NASA aeronautics test capabilities investment in many years. The five projects will enable the Aeronautics Test Program to create a return on investment in three strategic areas: enabling new research, enhancing existing asset performance, and improving the portfolio's overall reliability and availability.

At the Ames Research Center, ATP executed a project to reactivate a large, high-speed air compressor that can supply or evacuate air for the Unitary Plan Wind Tunnel circuit, one of the busiest wind tunnels in the Nation. Improvements in compressor reliability will help ensure continued facility availability and reduce the risk of test article damage during high-speed operations. Gains in facility operational efficiency will result in savings in wind tunnel drive power costs of up to 10 percent for test customers.

Modifications at Glenn Research Center's Propulsion Systems Laboratory will result in a new high-altitude, jet engine icing research capability. This will enable NASA and industry to address high-altitude ice crystal ingestion by commercial aircraft. Also, at the Glenn Research Center, ATP executed a project for a new refrigeration system for the Icing Research Tunnel, replacing a 60-year-old system that had been operating at significantly diminished capability and efficiency. The new high-performance, energy-efficient refrigeration system will position the tunnel for current and future icing research for NASA and the Department of Defense (DOD) and will support FAA certification testing for industry.

Projects at the Langley Research Center include modifications to the National Transonic Facility (NTF) and the 14- by 22-Foot Subsonic Tunnel (14 × 22). Facility enhancements at the NTF focused on modernizing the facility's data and control systems, wind tunnel flow measurement evaluation, wind tunnel modeling and simulation tools, and wind tunnel performance validation testing. The NTF project will address long-standing facility performance and reliability

issues and provide improved flexibility for individual customer needs and access. Modifications at the 14 × 22 will directly support critical research testing by the ARMD Integrated Systems Research Program by providing a unique test bed with an advanced acoustic measurement capability to address the technical challenge associated with community noise or aircraft noise in areas surrounding airports.

Partnerships with Government and Industry

ARMD's commitment to technical excellence and strong partnerships is critical to our ability to expand the boundaries of aeronautical knowledge. These partnerships with industry, academia, and other Federal agencies foster a collaborative research environment in which ideas and knowledge are exchanged across all communities to ensure the future competitiveness of the Nation's aviation industry. For example, in spring 2010, the X-48B flight test campaign, described in the ISRP paragraphs of this section, was the product of a multi-government agency and industry collaboration between NASA, the Air Force Research Laboratory, Boeing, and Cranfield Airspace. Similarly, several of the other highlights in the report were enabled through strong public-private partnerships.

NASA engages partners through many mechanisms, including industry working groups and technical interchange meetings at the program and project levels, SAAs for cooperative partnerships with industry, and the NASA Research Announcement (NRA) process, which provides full and open competition for the best and most promising research ideas. During FY 10, ARMD had 276 active NRA research efforts funded at over $105 million and 86 SAAs in place across all programs with different members of the aerospace industry and, in some situations, with consortia of industrial participants. These collaborative opportunities and partnerships provide the ability to leverage resources across stakeholders. This has produced very significant research results at the system level, where the expertise of industry and ARMD come together to integrate technologies that can eventually be incorporated into the Nation's aircraft fleet.

ARMD recognizes the importance of close coordination with its partners in other Government agencies as well. For example, ARMD utilizes NASA/FAA/Joint Program Development Office (JPDO) Research Transition Teams (RTT) to

conduct joint research and field trials to speed the acceptance of new air traffic management procedures. In FY 10, NASA conducted the final of three Multi-Sector Planner (MSP) simulations. ARMD managed these investigations under the Flow-Based Trajectory Management RTT. The MSP concept was developed as a practical way to reroute in-flight aircraft to maintain efficient operations across multiple airspace sectors in the face of changing air traffic conditions. Results of the simulations have shown that integrated tools, such as MSP, can manage traffic levels 30 percent greater than today's, helping to increase the capacity needed to support NextGen. Final delivery of these results will be completed in FY 11.

The Agency is also coordinating the management and operation of the Federal Government's large aeronautics ground test infrastructure through the National Partnership for Aeronautics Testing (NPAT). In FY 10, through NPAT, ARMD's Aeronautics Test Program initiated a collaborative assessment of national hypersonic wind tunnel capabilities to identify facilities that are critical to the Nation and that will require continued sustainment and capability investment by NASA and/or DOD. The study is scheduled for completion in FY 11.

Aeronautics Research Relevance and Benefits to the Public

Throughout FY 10, ARMD used innovative communication and outreach activities to engage the public through events, informational materials, and education. Its goals were to 1) utilize media and general interest in "green" issues to promote environmental benefits of NASA's aeronautics research; 2) take advantage of new technologies and social media to expand reach, leverage products, and invite interaction; and 3) engage, in particular, youth of high school age and higher to communicate opportunities in aeronautics engineering. Following are a few examples of these activities.

ARMD produced a live NASA TV broadcast of *The Leading Edge* on the topic of green aviation. Panelists from the FAA and NASA talked about new approaches to flight operations and aircraft design that can improve performance. NASA expanded the reach of the program by conducting a live, post-program NASA Web chat. The one-hour program had more than 3,500 views through post-broadcast downloads and video streaming from www.nasa.gov.

Later in FY 10, ARMD hosted the Green Aviation Summit at NASA's Ames Research Center. The Summit, which included a keynote speech by NASA Administrator Charlie Bolden, addressed the technical challenges of achieving green aviation and presented some of the groundbreaking solutions NASA is developing. The audience included participants from Government, industry, and academia interested in specific research and development activities for mitigating the environmental impact of aviation.

ARMD pioneered the availability of NASA publications as e-Books with the release of the Agency's first e-Book: *X-15: Extending the Frontiers of Flight*. The innovative e-reader format has proven to be an effective way to reach much higher numbers of users than traditional methods. To date, aeronautics e-Books have been downloaded hundreds of thousands of times. ARMD researchers in FY 10 also updated the unique public Web site called DASH*link* (DASH stands for Discovery in Aeronautics Systems Health). DASH*link* allows researchers, whether inside or outside NASA, who are working on improving aircraft systems health to share software applications they have written, test each other's work, and openly discuss the results.

In addition to public outreach, fostering new generations of highly skilled scientists and engineers is critically important to the aeronautics community. In FY 10, ARMD used various activities to advance science, technology, engineering, and math (STEM) education. ARMD helped develop the interactive Smart Skies program, which teaches students how air traffic controllers use distance, rate, and time calculations to safely merge and separate approaching aircraft to ensure safe landings. ARMD advanced STEM education resources by developing the new Museum in a Box activity, a comprehensive curriculum product designed for elementary, middle, and high school students in the classroom or in informal settings such as museums and science centers. Finally, in FY 10, ARMD completed its third year of motivating and inspiring the next-generation workforce through the Aeronautics Scholarship Program. The program funded 20 new two-year undergraduate and five three-year graduate scholarships and provided opportunities for university students to work at research centers as interns to gain real-world experience while contributing directly to the advancement of NASA research objectives.

Department of Defense

DOD

In FY 10, the Department of Defense's (DOD) space systems performed numerous critical missions for the Nation. As a result of the successful string of launches of Evolved Expendable Launch Vehicles (EELV), the Department continued to upgrade and modernize space capabilities in order to support our Nation's military operations in Iraq, in Afghanistan, and around the world.

DOD continued its close relationship with NASA to further our Nation's civil space program. In FY 10, DOD supported four Space Shuttle launches and four NASA unmanned spacecraft launches, including the Falcon 9 launch of the Dragon spacecraft test unit. All of these missions were successfully launched from Air Force–operated space launch ranges. DOD also supported NASA's launch of the Ares 1-X test flight from the Kennedy Space Center.

The EELV program continued its successful record of placing satellites in orbit. In addition to two NASA launches and the commercial launch of the Intelsat 14 communications satellite, the United Launch Alliance (ULA) conducted six successful EELV launches, including the Defense Meteorological Satellite Program's F18 on October 18, 2009; the third Wideband Global Satellite Communications (SATCOM) spacecraft on December 6, 2009; X-37B Orbital Test Vehicle 1 (OTV-1) on April 22, 2010; and NROL-41 for the National Reconnaissance Office (NRO) on September 21, 2010. The remaining two EELV launches were first-of-a-kind spacecraft for the Position, Navigation and Timing (PNT) and protected military satellite communications missions and are discussed below.

The Intelsat 14 spacecraft carries the Internet Routing in Space (IRIS) hosted payload, which extends the same Internet protocol (IP)–based technology used to build the World Wide Web into space. DOD is evaluating the reduced latency,

improved throughput, and increased flexibility provided by IRIS via a Joint Capabilities Technology Demonstration (JCTD). The long-term goal is to route voice, data, and video traffic between satellites over a single IP network in ways that are more efficient, flexible, and cost effective than is possible over today's fragmented satellite communications networks.

In addition to the EELV launches, ULA launched two Delta II rockets in FY 10. These included the civil launch of NASA's WISE mission and the commercial launch of DigitalGlobe's Worldview-2 remote sensing satellite.

The Air Force's first X-37B, Orbital Test Vehicle 1, demonstrated technologies for a reliable, reusable, unmanned space test platform to operate experiments that can be returned to Earth. It is designed for vertical launch to low-Earth orbit altitudes, where it can perform long-duration space technology experimentation and testing and then autonomously re-enter the atmosphere, descend, and land horizontally on a runway.

Significant upgrades and modernization of DOD space capabilities occurred in several mission areas in FY 10. The first Block IIF satellite of the Global Positioning System (GPS) constellation was launched on May 27, 2010, by a Delta-IV from Cape Canaveral. GPS IIF satellites will provide improved signals that will enhance the precise global PNT services supporting both the warfighter and the growing civilian needs of the global economy. The GPS constellation remains the most robust and capable system in the history of space.

In February 2010, a contract was awarded for the Next Generation Operational Control System (OCX). OCX will replace the current GPS Operational Control System, maintaining backwards compatibility with the Block IIR and IIR-M constellation; providing command and control of the new GPS IIF and GPS III families of satellites; and enabling new, modernized signal capabilities. OCX will allow Air Force Space Command to effectively and efficiently plan and control full-spectrum precision PNT information for all GPS user communities. OCX will achieve this vision by implementing an incremental development approach that supports the evolving military operational environment while enabling civil and international users who are employing GPS in innovative applications.

The first Advanced Extremely High Frequency (AEHF) communications satellite was launched on August 14, 2010, by an Atlas-V from Cape Canaveral. Shortly

after the launch, the orbit raising plan was modified as a result of an anomaly with the bi-propellant propulsion system, which was intended to place the spacecraft near its operational orbit. The modified plan entailed two phases: the first phase used hydrazine thrusters, and the other used the Hall Current Thruster (HCT) electrical propulsion system. The satellite, which operated as planned, reached its final orbit in October 2011. AEHF-1 will provide a significant enhancement to our Nation's survivable communications infrastructure by extending the capabilities of the operational Milstar satellite constellation with an order of magnitude increase in protected communications capability.

Another improvement in communications came about on November 22, 2009, with the implementation of the first phase of a system modification to increase Global Broadcast Service (GBS) full-motion video feeds to the U.S. Central Command's area of responsibility. The GBS is an extension of the Global Information Grid that provides high-capacity, one-way satellite transmission of video, high-quality imagery, data, and other information to warfighting forces. GBS supports the Nation's command centers and joint combat forces while in garrison, while in transit, and while deployed within global combat zones.

Modernization is also continuing for the environmental monitoring mission. On August 13, 2010, a plan for the new Defense Weather Satellite System (DWSS) was approved. The DWSS satellites will feature two instrument packages originally planned for the National Polar-orbiting Operational Environmental Satellite System (NPOESS): the Visible Infrared Imager Radiometer Suite and the Space Environmental Monitoring sensor. The system may also carry a to-be-determined microwave sensor.

For the space control mission, an important new capability will be provided by the first Space Based Space Surveillance (SBSS) satellite, which was launched by a Minotaur 4 from Vandenberg Air Force Base on September 26, 2010. This was the first orbital launch of the Minotaur 4, which uses refurbished U.S. strategic missile hardware for its first three stages with a commercial fourth-stage motor. The SBSS spacecraft will provide timely detection, collection, identification, and tracking of man-made space objects from deep space to low-Earth orbit without being constrained by weather, the atmosphere, or time of day. It is essential to the DOD space situational awareness architecture for the near future and beyond. By

making our space assets safer and more secure, it will help keep America at the forefront of space.

The Space Based Infrared System (SBIRS) achieved a milestone on May 11, 2010, when the National System for Geospatial Intelligence (NSG) announced the operational acceptance of the second SBIRS Highly Elliptical Orbit (HEO-2) payload and associated ground system for the Technical Intelligence (TI) mission. The National Geospatial-Intelligence Agency (NGA), on behalf of the NSG, validated that SBIRS met the TI community's need for accurate, timely, reliable, and unambiguous TI data for use in intelligence production.

A further effort to develop new capabilities in the Overhead Persistent Infrared (OPIR) arena is the innovative Commercially Hosted Infrared Payload (CHIRP) program. The CHIRP flight development program is intended to reduce risks in the development of wide field-of-view staring infrared sensors to meet future DOD needs. The sensor was delivered to the satellite manufacturer for integration onto a commercial communications satellite on August 4, 2010, and launched in the fall of 2011.

The transition of Tactical Satellite-3 (TacSat-3), launched in May 2009, from an experimental demonstration to an operational asset on June 12, 2010, was a groundbreaking milestone for the Operationally Responsive Space (ORS) concept, which seeks to address the military's requirements for rapid, flexible, and cost-effective systems. The small satellite, built using plug-and-play technology, and its primary payload, the Advanced Responsive Tactically Effective Military Imaging Spectrometer (ARTEMIS), demonstrated the utility of hyperspectral information for the warfighter. The high-quality, information-rich data from this satellite continue to be exploited for a wide range of applications.

On June 28, 2010, the White House announced a new national space policy. The policy states that the United States remains committed to the use of space systems in support of its national and homeland security. It calls for the United States to invest in space situational awareness capabilities and launch vehicle technologies; develop the means to ensure mission-essential functions enabled by space; enhance our ability to identify and characterize threats; and deter, defend, and, if necessary, defeat efforts to interfere with or attack U.S. or allied space systems. In addition,

the policy emphasizes cooperation in space, including commercial and international partnerships.

The Department's FY 10 activities discussed above indicate that DOD made significant investments in activities that will help implement the Nation's space policy. DOD looks forward to furthering this commitment and keeping the United States the world's premier spacefaring nation.

Federal Aviation Administration

FAA

In 2010, the Federal Aviation Administration (FAA) furthered its NextGen goals. NextGen is a comprehensive overhaul of the entire National Airspace System (NAS) to make air travel more convenient and dependable while ensuring that flights remain as safe, secure, and hassle-free as possible. In a continuous roll-out of improvements and upgrades, the FAA is building the capability to guide and track air traffic more precisely and efficiently, to save fuel, and to reduce noise and pollution.

An important step forward in 2010 was the FAA's decision to approve the nationwide use of a new satellite-based aircraft tracking system, Automatic Dependent Surveillance-Broadcast (ADS-B). The agency successfully integrated ADS-B into all four air traffic control automation platforms at key sites across the country, clearing the way to begin integrating ADS-B into FAA air traffic control facilities nationwide and to train its workforce.

Equally significant was the release of a final rule requiring that by January 1, 2020, aircraft operating in most controlled airspace be equipped to broadcast their position to the ADS-B network. This rule allows manufacturers to start mass-producing certified ADS-B avionics, which the FAA believes will drive prices down, thus addressing a key concern of operators.

The FAA has also been working to reduce airport delays and improve the environment with NextGen initiatives that help curb fuel burn and emissions by improving surface efficiencies. Airspace improvements including Performance Based Navigation are already reducing fuel burn and emissions. A new,

cleaner-burning biofuel is expected to be approved for use by commercial aircraft in FY 11.

With input from domestic and international stakeholders, the FAA continued developing a systematic Aviation Noise Research Framework to add to the scientific knowledge base of the extent of impact of aviation noise and to develop appropriate mitigation below historically defined significant noise levels. To develop the noise research framework, the FAA convened an international forum in Ottawa, Canada, in 2009, as well as two public workshops in Washington, DC, in 2009 and in San Diego, California, in 2010, to focus on the effects of aircraft noise on sleep disturbance and annoyance to the public. These discussions identified research activities to address aviation's global capability and knowledge gaps; some of these activities have since started. Together with noise-related studies conducted by the Partnership for AiR Transportation Noise and Emissions Reduction (PARTNER) through the Airport Cooperative Research Program (ACRP) and the U.S. Department of Transportation (DOT) Volpe Center, under the FAA Air Tour Management Plan, the FAA's more recently initiated research activities form a complement of work that seeks to advance scientific knowledge to better address the impacts of aviation noise on society.

The NextGen goal to increase NAS mobility and efficiency is dependent upon the ability to adequately address and mitigate aviation environmental impacts and to deal with related energy issues. The FAA is leading the development of a strategic NextGen Environmental Management Systems (EMS) approach for integrating environmental and energy objectives into the planning, decision making, and operation of NextGen. EMS is a management framework by which an organization identifies environmental aspects and impacts of its operations, assesses current performance, and formulates targets and plans to achieve improvements. The NextGen EMS framework is based on industry-standard EMS principles. At a high level, there are four phases—plan, implement/manage, monitor/review, and improve/adapt. In the plan phase, significant environmental issues are identified and evaluated, and goals and plans to manage these issues are developed. In the implement/manage phase, plans are implemented to manage significant environmental issues (i.e., reduce or avoid negative impacts or maximize positive impacts). During the monitor/review phase, the effectiveness of these implementation

activities is monitored and key performance metrics are tracked. These data are then used during the improve/adapt phase to make improvements and course corrections. NextGen EMS focuses on addressing the environmental constraints to sustainable aviation growth and efficiency, recognizing that these constraints might change over time. The strategic nature of the NextGen EMS will drive the air transportation system toward the achievement of long-term goals through the establishment of management system elements at both the enterprise and organizational levels. It will also provide improved data and information flow that will allow better decision making in a timelier manner. In turn, this will enable technology, operational procedures, and policy to be refined and adapted to meet real operating conditions in a cost-effective manner.

In 2010, to advance Four-Dimensional Flight Management System Trajectory-Based Operations (4D FMS TBO), FAA researchers leveraged existing technology and FMS capabilities as a starting point for informing standards and requirements for trajectory exchange, time of arrival controls, and other building blocks needed to meet both the desired mid-term operations described in the NAS Enterprise Architecture (EA) and far-term operations described in the JPDO NextGen Concept of Operations (CONOPS). Various activities were completed, including analysis of operational data, human-in-the-loop (HITL) simulations, and flight trials. During these activities, researchers provided the tools for conducting the HITL simulations, scenarios, and parametric studies of FMS Required Time of Arrival (RTA) behavior and Air Traffic Control (ATC) operational analysis to ensure the viability of the flight trials. Results from these activities were analyzed as they related to validating current standards and developing future RTA standards.

The FAA has a critical need for improving efficiency and throughput in high-density terminal operations. Task Force 5 recommendations called for an increase in capacity and throughput for converging and intersecting runway operations. Additionally, the NextGen Segment Implementation Plan contained an operational improvement (OI) for increased capacity and efficiency using Area Navigation (RNAV) and Required Navigation Performance (RNP). In response to these recommendations, the FAA is developing terminal ATC capabilities for efficient high-density operations. In 2010, to support future NextGen capabilities, the agency demonstrated Relative Position Indicator (RPI), a future automation

designed to aid air traffic controllers in merging and spacing terminal RNAV and RNP routes at two terminal sites. Researchers conducted Terminal Radar Approach Control (TRACON) field evaluations of the RPI capability at Southern California TRACON for operations at San Diego International Airport, and at Phoenix TRACON for operations at Phoenix/Sky Harbor International Airport. The field evaluations consisted of a demonstrator system of the RPI prototype on the operational floor connected to a live data feed as well as HITL simulations based on historic traffic. The purpose of the field evaluations was to expose controllers to the RPI prototype to demonstrate how RPI can assist their efforts in merging arrival flows. Operational insight and feedback were recorded from facilities regarding the functionality, computer-human interface, acceptability, and benefits of RPI use to manage merging arrivals. Controller questionnaires at both facilities indicated an increase in situational awareness, an increase in the predictability of traffic, and a reduction in workload. The full quantitative analysis of the field evaluations will be provided in FY 11.

The FAA is developing a concept for surface operations in the NextGen called Surface Trajectory-Based Operations (STBO). STBO introduces new automation and procedures to improve decision making, efficiency, and safety regarding airport configuration changes, scheduling and sequencing aircraft for departure, assigning runways and taxi routes, and monitoring conformance on the surface. In FY 10, researchers developed concepts of use for STBO decision support tools and began validating and refining the concepts through HITL simulations. One of the mid-term features of STBO, monitoring conformance to taxi routes, is a key research area for the FAA and its research partners. For example, researchers evaluated aspects of the surface conformance monitoring concept using prototype decision support tools. In FY 10, two HITL simulations were designed and conducted to assess the feasibility and benefits of the surface conformance monitoring concept. In the concept of operations for this monitoring capability, automation provides the tower controller with suggested taxi routes for departing flights and then monitors conformance to the assigned taxi routes—alerting the controller when problems arise. Additional research areas, such as concept and prototype refinement, were identified and will be investigated through HITL simulation in FY 11 and FY 12.

In-flight icing, turbulence, convective weather, and low ceilings and visibility affect both the capacity and the safety of the NAS on a daily basis. Timely and precise forecasts of these aviation-specific weather hazards require forecast models that not only are accurate and updated frequently but can be easily enhanced as research advancements become available. The Weather Research and Forecasting (WRF) Model, completed in FY 10, is an operational next-generation numerical weather prediction system designed to serve both operational aviation forecasting and atmospheric research needs. WRF Model outputs are key to reducing weather delays and, thus, achieving the FAA Flight Plan's greater capacity goal as well as NextGen weather operational improvements. Development of the WRF Model was done in collaboration with the FAA, NOAA, the Air Force Weather Agency, the U.S. Naval Research Laboratory, the University of Oklahoma, and the National Center for Atmospheric Research. The WRF model, with a one-hour update rate, was transitioned to NOAA's National Centers for Environmental Prediction for operational implementation. Also known as the WRF–Rapid Refresh (RR), this version of the WRF Model provides 13-km resolution, short-range weather model forecasts out to 18 hours, and one-hour background forecasts for a high-frequency 3-D objective analysis across North America. The WRF–RR data will be used as input for FAA-developed aviation weather applications that produce weather hazard forecasts.

National Transportation Safety Board (NTSB) data indicate that in-flight icing causes more than 25 accidents annually, with more than half resulting in fatalities and destroyed aircraft. This equates to $100 million in injuries, fatalities, and aircraft damage each year. To address this problem, FAA researchers developed the Current Icing Product (CIP) and Forecast Icing Product (FIP), which provide more accurate and timely diagnoses and forecast atmospheric conditions leading to ice accretion on aircraft during flight. CIP and FIP (depicted graphically via the Aviation Digital Data Service—a Web-based dissemination system operated by the Aviation Weather Center) provide the probability that icing will occur along the planned route of flight as well as its expected severity.

As in-flight icing is a major aviation hazard in Alaska, researchers are developing CIP and FIP products for Alaska. In FY 10, the Alaskan version of CIP was approved to begin the test phase.

In-flight icing is a potential hazard to all classes of aircraft, including those with ice protection. The formation of even a thin coat of ice on an aircraft surface can seriously impact its ability to fly by increasing drag, decreasing lift, and adversely affecting controllability. At greatest risk are aircraft without ice protection and those that fly at relatively low altitudes, where they are more likely to encounter atmospheric conditions conducive to icing. FAA researchers have already developed CIP and FIP for the continental U.S.

In 2010, the FAA's Office of Commercial Space Transportation (AST) continued to promote U.S. commercial space transportation, licensing four orbital commercial space launches: a Delta II launch from Vandenberg Air Force Base (VAFB) in California; an Atlas V launch from Cape Canaveral Air Force Station (CCAFS) in Florida; a Delta IV launch from CCAFS; and a Falcon 9 launch, which carried the Dragon capsule, by SpaceX, from CCAFS. There were no suborbital flights conducted under the authority of FAA experimental permits or licenses in FY 10.

Launch license renewals were granted by AST for Boeing Launch Services' Delta II launch vehicle, operating from VAFB, and Orbital Sciences Corporation's Taurus and Pegasus launch vehicles, both operating from VAFB. A new Launch Site Operator License was issued to the Jacksonville Aviation Authority to operate a launch site at Cecil Field Spaceport in Florida. During FY 10, AST also continued its evaluation of the first commercial reentry vehicle license application for the SpaceX Dragon.

AST conducted 55 safety inspections on over 22 different types of FAA-regulated activities. The goal of every AST safety inspection is to ensure public safety by verifying FAA licensee and permittee compliance with FAA regulations and license/permit terms and conditions. Inspectors traveled to various locations, including Cape Canaveral, Florida; Vandenberg Air Force Base, California; Mojave, California; Kodiak, Alaska; Wallops Flight Facility, Virginia; Upham and Las Cruces, New Mexico; Caddo Mills, Texas; Burns Flat, Oklahoma; and Jacksonville, Florida.

To support all new and renewed licenses in FY 10, AST carried out several environmental reviews including the Final Supplement Environmental Assessment to the September 2008 Environmental Assessment for Space Florida Launch Site Operator License. AST issued a Finding of No Significant Impact to support a

potential Launch Site Operator License to Space Florida to operate Launch Complex 36 at CCAFS. AST adopted NASA's 2009 Environmental Assessment for the Expansion of the Wallops Flight Facility Launch Range and issued a Finding of No Significant Impact and Record of Decision to support medium large class suborbital and orbital expendable launch vehicle activities at the Mid-Atlantic Regional Spaceport in Virginia. 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.

In 2010, the FAA researched the use of a black box for commercial transportation systems. A black box for space systems would provide key data to designers and operators after an anomaly and help prevent a recurrence. Researchers analyzed current FAA aviation black box data collection, operational, survivability, and retrieval requirements and reviewed current flight data recorders used on the NASA Shuttles. Based on their extensive experience with launch vehicles, they then developed a list of data parameters that would be critical in reconstructing damage or failures of space systems. Using these results, they mapped the derived space systems black box requirements to analogs currently used for commercial aviation. They found that it is possible that current aviation black boxes can be used for first-generation commercial space transport systems (specifically Reusable Launch Vehicles—RLVs—with low maximum velocities and brief times in space) with relatively little modification. Results were presented in the paper "Black Box for Reusable Launch Vehicles—Considerations and Potential Flight Test Opportunities" at the International Association for the Advancement of Space Safety Conference in May 2010.

In 2010, the FAA selected nine universities to compose the new FAA Center of Excellence for Commercial Space Transportation, with New Mexico State University designated as the Administrative Lead University. The center is a partnership of academia, industry, and Government, developed to address current and future challenges for commercial space transportation. The research and development efforts will include four areas: space launch operations and traffic management; launch vehicle systems, payloads, technologies, and operations; commercial human spaceflight; and space transportation industry viability.

The FAA also announced the Space Transportation Infrastructure Matching Grants program and awarded grants to the New Mexico Spaceport Authority, the Alaska Aerospace Corporation, the East Kern Airport District (Mojave, California), and the Jacksonville Airport Authority (Florida). These grants are solely discretionary and are designed to fund projects that develop and expand commercial space transportation infrastructure. AST will administer the new grants program on behalf of the FAA.

Several research and development projects were completed in FY 10, principally in the areas of vehicle safety analyses and safety systems and technologies. Representative tasks included the investigation of operational risks and probability-of-failure analysis, the consideration of risk from expendable launch vehicle overflight explosive impacts, and the definition of space vehicle black box requirements.

AST continued to provide real-time support to NASA during Shuttle reentries, using its Shuttle Hazard Area to Aircraft Calculator (SHAAC) tool. This tool predicts and identifies airspace that could contain falling debris hazardous to aircraft in the event of a Space Shuttle orbiter failure during reentry. AST has supported 20 reentries since the Space Shuttle Columbia failure in 2003.

Several reports of interest to the public, the space industry, and the Federal Government were released by AST, including *New Commercial Space Transportation Report: Point-to-Point Commercial Space Transportation in National Aviation System—Final Report*; *Triggered Lightning Risk Assessment for Reusable Launch Vehicles at Four Regional Spaceports*; *Aircraft Protection Standards and Implementation Guidelines for Range Safety*; *Lessons Learned in Operational Space and Air Traffic Management*; *FAA's Approach to Ground and NAS Separation Distances for Commercial Rocket Launches*; and *Risk Considerations for the Random Reentry of Space Debris*. Guidance was issued for the design and development of environmental control and life support systems (ECLSS) in *ECLSS for Flight Crew and Space Flight Participants in Suborbital Space Flight, Version 1.0*.

AST continued to issue annual updates of several reports, including *U.S. Commercial Space Transportation Developments and Concepts: Vehicles, Technologies, and Spaceports*; *The Economic Impact of Commercial Space Transportation on the U.S. Economy in 2009*; *Commercial Space Transportation: 2009 Year in Review*; and *the 2010 Commercial Space Transportation Forecasts, as well as the Semi-Annual*

Launch Report. The forecasts, prepared by the industry-led Commercial Space Transportation Advisory Committee and the FAA, projected an average worldwide demand of about 16 launches per year to geosynchronous orbit and about 12 launches per year to non-geosynchronous orbits between 2010 and 2019.

Information about the FAA Office of Commercial Space Transportation, regulations, reports, and other documents can be found at *http://ast.faa.gov*.

Department of Commerce

DOC

In FY 10, the Department of Commerce (DOC) engaged in a wide variety of activities related to aeronautics and space, including national policy development, satellite operations, technology developments, measurement and calibration, international cooperation, trade promotion, and spectrum management.

Office of Space Commercialization

The Office of Space Commercialization (OSC) played an important role in the development of the U.S. National Space Policy, released June 28, 2010. OSC provided input on the development of new goals and guidelines related to commercial space, space-based environmental observations, and international cooperation. OSC led or participated in several interagency activities intended to further the new policy's implementation.

The Deputy Secretary of Commerce continued to participate in the national management of the Global Positioning System (GPS) as a member of the National Executive Committee for Space-Based PNT. The Department hosted the meetings of the committee and its Executive Steering Group, engaging in discussions of GPS interference and other key topics. OSC provided office space, personnel, and other resources to support the committee's secretariat, the National Coordination Office for Space-Based PNT. The DOC representatives in the National Coordination Office led various outreach efforts to educate the public about GPS, including media interviews, speaking engagements, display booths at international conferences, and updates to the *http://www.gps.gov* Web site.

OSC participated in government-to-government consultations with Japan to support continued cooperation in the area of satellite navigation. OSC also continued to serve as co-chair of a bilateral working group with the European Commission to cooperate on satellite navigation trade issues.

National Oceanic and Atmospheric Administration

FY 10 was a year of challenging extremes—including temperature fluctuations, severe weather, natural disasters, and the oil spill in the Gulf of Mexico region. Space-related activities were integral to NOAA's response to these events as well as to many of its programs.

As in years past, NOAA's Satellite and Information Service (officially the National Environmental Satellite, Data, and Information Service, or NESDIS) continues to operate both the GOES and the Polar-orbiting Operational Environmental Satellite (POES) systems, which provide an uninterrupted flow of global environmental information to support weather, ocean, and space environmental modeling, as well as tropical storm analysis and forecasting, local weather forecasting, and ecosystem and climate monitoring. NOAA's weather and climate prediction numerical models used the global data from these satellites extensively. NOAA provided forecast support for NASA Space Shuttle missions before launching, during flight, and during landing. During the Atlantic hurricane season, NOAA's GOES system provided a continuous flow of imagery that contributed significantly to the development of storm forecasts. These forecasts helped minimize the loss of life in the United States.

NOAA launched GOES-P from Cape Canaveral, Florida, on a Delta IV Rocket on March 4, 2010. GOES-P, renamed GOES-15 once it reached final orbit, was then placed into orbital storage mode. GOES-15, the final spacecraft in the NOAA geostationary-N series of satellites, took its first infrared image of Earth on April 26, 2010. Once placed into operations, GOES-15 will capture high-resolution images of weather patterns and atmospheric measurements that will help NOAA forecasters track life-threatening weather—from tornadoes, floods, and hurricanes to solar activity that can impact satellite-based electronics and the communications industry. High-resolution imagery allows forecasters to pinpoint the location of severe weather with great accuracy. GOES-15 will provide data for space and solar weather thanks

to its Solar X-Ray Imager. GOES-15 will improve forecasts and warnings for solar disturbances, protecting billions of dollars of commercial and Government assets in space and on the ground. This vital information will also reduce the effects of power surges for satellite electronics and the communications industry.

A collaborative development and acquisition effort between NOAA and NASA, the Geostationary Operational Environmental Satellite Series R (GOES-R) Program is developing the Nation's next generation of geostationary environmental satellites, which will provide faster, higher resolution imagery and new lightning mapping capabilities. This new series of spacecraft is expected to double the clarity of today's satellite imagery and provide at least 20 times more atmospheric observations. GOES-R continues to make steady progress in its instrument development and ground system programs as it approaches the scheduled launch of its first satellite in 2015. GOES-R will improve support for the detection and observation of meteorological phenomena that affect public safety, protection of property, and the economy. The new weather products from GOES-R will significantly improve the ability of forecasters to more accurately predict dangerous weather and, in turn, warn the public to seek shelter faster.

In July 2010, NOAA selected Harris Corporation of Melbourne, Florida, to develop the antenna system that will support GOES-R. The GOES-R antenna system will be developed and operated at NOAA's Wallops Command and Data Acquisition Station in Wallops, Virginia, and at NOAA's GOES-R Remote Backup facility in Fairmont, West Virginia. The antenna system will be designed to ensure continuity of operations during severe weather and other threat scenarios, including storms as severe as a Category 2 hurricane with winds ranging from 96 to 110 miles per hour. Four existing receive-only antennas located at the NOAA Satellite Operations Facility in Suitland, Maryland, will also have their feed systems upgraded. The antenna system will include six new, large aperture antennas capable of receiving and transmitting radio signals in multiple frequencies. Harris Corporation will upgrade four existing antennas and integrate the entire antenna system into the overall GOES-R Ground System. NOAA will fund, manage, and operate the GOES-R satellites.

In May 2010, NESDIS repositioned the GOES-12 to a longitude of 60° west over South America, thus continuing critical coverage for the region. GOES-12 replaced

GOES-10, which was launched in 1997 and decommissioned on December 1, 2009, because it had exhausted its fuel and surpassed its original planned five-year mission. Continuing cooperation in the region, NESDIS determined that once GOES-13 replaced GOES-12 as the operational GOES East satellite, GOES-12 could be moved to support South America. To ensure a smooth transition, NESDIS analyzed the implications, developed the transition schedules so that GOES East operations would not be impacted, and developed and implemented plans for informing users, both domestically and internationally, of the satellite changes. NESDIS also developed the GOES-12 South America imaging schedules for the instruments.

The design of the Geostationary Operational Environmental Satellite Series N (which includes GOES-13, GOES-14, and GOES-15) does not allow hemispheric imaging while GOES East is in rapid scan mode monitoring an extreme weather event within the United States. Therefore, without GOES-12 at 60° west, during extreme weather events in the United States, the GOES East coverage of South America was reduced from every 30 minutes to every three hours. Consequently, South Americans could not track severe weather activity in the Southern Hemisphere. The repositioning of GOES satellites over South America supplies forecasters in South America with more imagery and data to track dangerous storms, including the storms that can trigger potentially deadly mudslides. In addition, the sounders on GOES East are not used over South America, depriving the region of vital datasets. The reassigning of GOES-12 gives South Americans uninterrupted imager data every 15 minutes and sounder data that greatly improve the ability of South Americans to predict and track severe weather events. In addition, this information improves their normal forecasting capabilities and supports U.S. civil aviation and military interests in South America.

Turning from geostationary to polar-orbiting satellites, the transition from the NPOESS to the Joint Polar Satellite System (JPSS), a collaborative development and acquisition effort between NOAA and NASA, was initiated in FY 10. On February 1, 2010, the Executive Office of the President (EOP) announced that it was restructuring the NPOESS program to ensure that the United States could continue to meet its civil and military weather forecasting, storm-tracking, and climate-monitoring requirements. The NOAA portion of the restructured NPOESS program is called JPSS.

The restructured program will retain the observational requirements of the NPOESS program; however, NOAA, NASA, and DOD will be responsible for meeting these requirements through their respective assigned orbits, as follows:

- NOAA, with NASA acting as its acquisition agent, will be responsible for JPSS, which will fly in the afternoon orbit.
- DOD will be responsible for the early morning orbit, called the Defense Weather Satellite System (DWSS).
- The European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) will continue to provide NOAA with observations in the mid-morning orbit through the MetOp satellite program.
- The agencies will continue to partner in those areas that have been successful in the past, such as sharing a common ground system.

NOAA's JPSS afternoon orbit will maintain the observations that were planned for NPOESS in the afternoon orbit. The JPSS Program will fly the Visible Infrared Imager Radiometer Suite (VIIRS), Cross-track Infrared Sounder, Advanced Technology Microwave Sounder (ATMS), and Ozone Mapping and Profiler Suite (OMPS). The JPSS Program will also fly instruments that are being procured with funds from the NOAA Climate Sensor Program: Clouds and the Earth's Radiant Energy System (CERES), Earth Radiation Budget Suite (ERBS), and Total and Spectral Irradiance Sensor (TSIS) instruments. NOAA has initiated discussions with the Japan Aerospace Exploration Agency (JAXA) to collaborate on the opportunity of using the Global Change Observation missions' planned Advanced Microwave Scanning Radiometer instrument to meet the requirements that would have been fulfilled through the Microwave Imager Sounder instrument. As is the case today, NOAA and DOD will share data with each other.

NOAA will maintain overall responsibility for developing, funding, and implementing the JPSS program. NOAA will provide the strategic guidance to NASA as it administers the JPSS program and its requirements, budget and planning, constellation architecture, and launch dates. Strategic direction will be conveyed to NASA through formal Guidance Letters. NOAA will lead the discussions with international partners such as EUMETSAT, JAXA, and Centre National d'Études Spatiales (CNES) on JPSS-related activities.

GOES satellites continued to provide space weather data that NOAA's Space Weather Prediction Center (SWPC) and DOD tactical operational units used to issue forecasts and warnings that protected spacecraft and power grids, as well as air travelers. As the number of airline passengers traveling on cross-polar routes from the United States to Asia increases, so, too, does the overall concern regarding the risks of radiation exposure to travelers and flight crew. Forecasting the location and severity of the aurora is required by airline flight planners responsible for passenger and crew safety.

This year, NOAA's National Geophysical Data Center Space Weather Team successfully collaborated with partners from SWPC and the Johns Hopkins University Applied Physics Laboratory to test a new predictive model of the aurora based on upstream solar wind measurements. The Ovation Prime Real-Time model will be transitioned to operations and used in conjunction with NOAA's future solar-wind sentinel to forecast space weather impacts on commercial air transportation.

On April 20, 2010, an explosion on the Deepwater Horizon drilling rig led to a massive oil spill in the Gulf of Mexico. Approximately 180 million gallons of oil leaked out before the sea-floor well at Deepwater Horizon was capped on July 15, 2010, according to the Flow Rate Technical Group, a team of scientists and engineers formed to estimate the extent of the spill. The disaster not only caused damage to the Gulf Coast's marine and wildlife habitats and its fishing and tourism industries, but also created a need for quality controlled ocean data. While directing recovery efforts for the spill, government officials and emergency responders needed detailed, up-to-date information to make important decisions.

NOAA's quick response to the spill was in part due to placing a pre-operational project into operations. In late 2008, in response to a request from the National Ocean Service (NOS), the Office of Satellite Data Processing and Distribution's Satellite Analysis Branch (SAB) developed the capability to observe and report the location and extent of oil on ocean surfaces using many sources of satellite data but primarily synthetic aperture radar (SAR) data. In January 2010, SAB began issuing oil spill analysis products to the United States Coast Guard (USCG) and NOS on a limited, experimental basis. Minutes after the Deepwater Horizon rig began sinking, SAB began converting its pre-operational pilot project in oil detection into a major disaster response effort. Within five hours of the rig sinking, SAB organized

staffing for a 20-hour-per-day oil spill response desk, issued its first Deepwater Horizon oil spill analysis, and accepted the role of International Disaster Charter Project Manager. SAB issued regular near-real-time satellite-based analyses of surface oil location multiple times per day and a daily summary to NOS, USCG, and other Federal, state, and local government personnel. This information supported more efficient resource allocation by the responders, such as where to deploy oil containment booms, skimmers, and reconnaissance overflights. NOS personnel also used the analyses as input to their trajectory forecasts, further enabling the public and government sectors to plan more effective actions to mitigate the spill damage.

After several weeks, NOAA's Center for Satellite Applications and Research (STAR) and NOAA's CoastWatch program, collaborating with scientists at NOAA's Atlantic Oceanography and Meteorology Laboratory, prepared and acquired specialized satellite data such as sea surface temperature, ocean color, and sea surface height, as well as ocean model products such as current fields, salinity, and subsurface trajectories. They began routine briefings for SAB personnel on the oceanographic conditions and forecasts for the eastern Gulf of Mexico.

STAR and CoastWatch obtained or facilitated the acquisition and distribution of a broad array of data from commercial, U.S. Government, and foreign environmental satellites for the broad NOAA and responder communities and the general public. STAR and CoastWatch officials also supported SAB's satellite-derived analyses with satellite products, scientific guidance, and oceanographic analyses. In addition, STAR and CoastWatch provided weekly tailored science briefings of the oceanographic conditions in the Gulf Coast and implemented or acquired specialized satellite and model products for the Gulf of Mexico to aid oil analysis. CoastWatch provided personnel with advanced satellite analytical experience to assist the National Marine Fisheries Service in the location, recovery, and rehabilitation of sea turtles. CoastWatch also made satellite imagery and products available to a broad audience through its Web site.

During the Deepwater Horizon oil spill, NOAA provided services and products based on its satellite information and databases to support government officials and emergency responders, as well as commercial and recreational fisheries, businesses, tourism, research, and the general public who live and work in the Gulf

area. NOAA continues to operate support Web sites that include coastal ecosystem maps and an online database that describes oil spill–related research, monitoring, and restoration activities.

NOAA provided critical information during yet another major natural disaster—the eruption of the Eyjafjallajökull volcano in Iceland in April 2010. Volcanic ash poses a major threat to jet aircraft and must be avoided. This Icelandic volcano's eruption led to the unprecedented closure of North Atlantic and European airspace, disrupting commerce and travel in the area. Therefore, in response to the Eyjafjallajökull eruption, NESDIS, through the Washington, DC, Volcanic Ash Advisory Center (VAAC), began providing near-real-time information about the resulting ash cloud to the London VAAC. Using an algorithm developed for the next-generation geostationary satellite series, GOES-R, and data from the European Organisation for the Exploitation of Meteorological Satellites' Spinning Enhanced Infrared and Visible Imager, NESDIS provided estimates of volcanic ash cloud height, mass loading, and particle size to the London VAAC in order to inform aviation interests flying through European airspace that could be adversely affected by the volcanic ash clouds.

A major infrastructure milestone was reached in FY 10 with the construction of the Fairbanks Satellite Operations Facility (FSOF), a new operations center for satellite command and control in Alaska. FSOF, which was completed on September 30, 2010, will support a broad range of U.S. and international environmental monitoring satellites, thus providing critical datasets, products, and services to users worldwide. FSOF replaces the current Fairbanks Command and Data Acquisition Station, parts of which date to the early 1960s. Modernizing this facility ensures reliable and robust satellite tracking for NOAA far into the future. On a global scale, public safety and economic interests will continue to benefit from the comprehensive and accurate information derived from the site's work. The new 20,000-square-foot FSOF was a shovel-ready project, using approximately $9 million of ARRA funds and $2.7 million from NESDIS to complete the project. NESDIS provided invaluable technical and management expertise for the complex project. The U.S. Army Corps of Engineers oversaw the construction, which took place between July 2009 and September 2010.

Also this year, NOAA took a significant step in improving coastal precipitation forecasts using geostationary satellite data. Heavy precipitation associated with severe storms can cause flooding and damage to life and property. Accurate predictions of precipitation amounts near coastal areas are often very difficult due to our limited understanding of storm development and a lack of applicable computer forecast models. To address this issue, scientists in NOAA's Center for Satellite Applications and Research (STAR), Florida State University, and the National Centers for Environmental Prediction (NCEP) assimilated infrared radiances from GOES-11 and GOES-12 using the grid point statistical interpolation (GSI) analysis system. GSI is an analysis system developed at NCEP that allows for uses of new observational data and produces an optimal initial condition so computer models can generate better forecasts. The team's studies demonstrated that the precipitation amount, especially for severe storm conditions, can be better predicted using GOES-11 and GOES-12 imager radiance data in computer models. GOES data assimilation requires a fast, radiative transfer model for ingesting GOES imager data in the computer forecast model and an adequate quality control algorithm for removing bad-quality data. To meet these needs, STAR scientists developed the community radiative transfer model and a better quality control procedure to detect and remove the measurements affected by clouds and precipitation. This work highlights the importance of geostationary satellite observations for improved cloud and precipitation forecasts. The GOES observations in regions of little or no clouds provide especially beneficial information to the computer forecast models for improved coastal precipitation forecasts. The developed data assimilation technique will also prepare weather data users, including the National Weather Service, for using advanced satellite data from the next-generation GOES Series R—GOES-R.
In July 2010, NESDIS negotiated and signed a four-party agreement with NASA, the European Organisation for the Exploitation of Meteorological Satellites, and CNES to cooperatively develop, launch, and operate the Jason-3 satellite. The Jason-3 ocean altimetry satellite will provide extraordinarily precise sea level height measurements that reveal upper level ocean heat content and patterns and indicate changes in water volume. Ocean altimetry data are essential to understanding our climate because ocean changes influence the weather.

NOAA's fleet of satellites played a vital role in the rescues of 281 people in life-threatening situations throughout the United States and its surrounding waters during FY 10. In each incident, NOAA satellites pinpointed these downed pilots, shipwrecked mariners, or stranded hikers by detecting a distress signal from an emergency beacon, called an Emergency Position-Indicating Radio Beacon, and relaying the information to first responders on the ground. NOAA's polar-orbiting and geostationary satellites, along with Russia's COSPAS spacecraft, are part of the international Search and Rescue Satellite Aided Tracking system (COSPAS-SARSAT). When a NOAA satellite locates a distress signal, the information is relayed to the COSPAS-SARSAT Mission Control Center based at NOAA's Satellite Operations Facility in Suitland, Maryland. From there, it is sent to a Rescue Coordination Center operated by the U.S. Air Force for land rescues or the U.S. Coast Guard for water rescues. Now in its 28th year, COSPAS-SARSAT is credited with supporting more than 27,000 rescues worldwide, including 6,232 in the United States and its surrounding waters.

NESDIS organized a critically important aircraft flight close to the North Pole and directly under the path of the European Space Agency's CryoSat-2 satellite on April 20, 2010, just 12 days after the satellite launched. This flight was an early opportunity to validate CryoSat-2's new radar technique for measuring the thinning of Arctic sea ice, a trend believed to be an early indicator of global warming.

National Institute of Standards and Technology

In FY 10, 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 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

2010, aerospace companies purchased 61 SRMs, including ferrous and nonferrous metals certified for chemical composition and for hardness, and artifacts certified for nanoscale dimensional properties. In addition, these companies submitted over 300 instruments or artifacts to NIST for calibration. NIST performed over 1,500 separate tests on these items, spanning dimensional, force, vibration, and electrical measurements, thus providing the 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 has been 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 (MN) (800 kilofootpounds [klbf]) of capacity. (MN and klbf are units of force.) 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 kN (50 klbf) force 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; weighing airplanes; and torque, pressure, and force measurements.

NIST participated in a workshop co-organized by the World Meteorological Organization (WMO) and the International Bureau of Weights and Measures (BIPM) on "Measurement Challenges for Global Observation Systems for Climate Change Monitoring: Traceability, Stability and Uncertainty," held at WMO

headquarters from March 30 to April 1, 2010. The workshop brought together scientists from the world's national metrology laboratories and national meteorological organizations to collaborate on improving the accuracy and comparability of environmental measurements, including satellite sensor measurements, through robust traceability to the SI.

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 developing calibration methodologies and facilities for laser scanner systems and national and international standardization of their measurement accuracy.

In preparation for possible launch, NIST, in collaboration with NASA, initiated the recalibration of the NIST Advanced Radiometer (NISTAR). This instrument is designed to measure the absolute spectrally integrated irradiance that is reflected and emitted from the sunlit face of Earth, as viewed from an orbit around the Earth-sun L-1 point. NISTAR was designed and built between 1999 and 2001 by Ball Aerospace and Technology Corporation and the NIST Optical Technology Division, in conjunction with the Scripps Institute of Oceanography and NASA, as part of the Deep Space Climate Observatory (DSCOVR) mission. The instrument consists of four detectors: three electrical-substitution active cavity radiometers and a photodiode, plus several band-defining optical filters that can be used with any of the detectors. NISTAR was calibrated in a thermal vacuum chamber in a clean-room environment at NIST, using a portable version of the NIST Spectral Irradiance and Radiance Responsivity Calibrations using Uniform Sources (SIRCUS) facility. The calibration includes system-level measurements of the relative spectral response of the NISTAR bands, using a wavelength-tunable laser and absolute responsivity measurements of each of the four NISTAR detectors at a wavelength of 532 nanometers (nm).

NIST and the NASA Langley Research Center signed a Memorandum of Understanding (MOU) to facilitate NIST support of the Climate Absolute Radiance and Refractivity Observatory (CLARREO) Mission. The mission will provide accurate benchmark measurements of Earth's climate system. NIST commenced several projects to improve optical radiation standards and the ability to

establish on-orbit traceability to the SI for measurements of the reflected solar and emitted infrared radiation from Earth.

NIST performed the first full system-level calibration of an operational satellite sensor, the NPP VIIRS, in collaboration with scientists and engineers from Ball Aerospace, NASA, NOAA, Raytheon, and Northrop Grumman. VIIRS operates from the infrared to the visible and will produce many key environmental data products when it is flown initially on the NPP satellite and later as part of the JPSS, formerly known as NPOESS. Previous testing of VIIRS at the component level in 2008 raised concerns about the sensor's ability to meet the stringent accuracy requirements for the 20-year climate data record for ocean color, which is used to assess ocean health and carbon storage. The system-level calibration performed with a transportable version of NIST SIRCUS confirmed that the radiometer's filters cause small leaks of radiometric flux between sensor bands, a phenomenon known as crosstalk. However, the amount of crosstalk is small enough that VIIRS scientists should be able to use the calibration results to make corrections in measurements made by VIIRS on orbit. Traveling SIRCUS was also employed to study the internal on-orbit calibration system used by VIIRS for the visible through shortwave infrared (IR) bands. The data analysis will provide critical information about the performance of the on-orbit calibration system.

NIST scientists completed a series of measurement comparisons with NASA Goddard Space Flight Center, Ball Aerospace, and the University of Arizona to help ensure the proper calibration and traceability of the measurements provided by the Operational Land Imager (OLI) sensor for the Landsat Data Continuity Mission (LDCM). The OLI is a mid-resolution, multispectral imaging radiometer designed and built by Ball Aerospace in Boulder, Colorado. This series of intercomparison activities will ensure the successful calibration of the OLI with respect to the SI through the NIST radiance scale. SI traceability will be accomplished using an integrating sphere from Ball Aerospace that has been calibrated at the NIST Facility for Automated Spectroradiometric Calibrations (FASCAL). To ensure proper calibration and traceability of the OLI, the sphere was characterized, following its calibration, in a weeklong comparison campaign in February 2010. A set of calibrated transfer radiometers and spectrometers from NIST, NASA's Goddard Space Flight Center, Ball Aerospace, and the University of Arizona measured the

radiance from the sphere, and these measurements were compared to measurements made from two NIST reference spheres.

NIST extended its present bidirectional reflectance distribution function (BRDF) capabilities to enable unbroken measurements across the solar reflected region, from 250 nm to 2,500 nm, permitting more accurate calibrations and radiance measurement in support of environmental satellite measurements conducted in support of climate-change research.

NIST upgraded its Aperture Area Measurement Facility to ensure the availability of accurate aperture area measurements that provide the traceability to the meter for satellite sensor measurements of the total solar irradiance (watts per square meter). Aperture area measurements were provided for the Total Irradiance Monitor on the Glory satellite.

NIST successfully characterized the marine optical system for the next-generation Marine Optical BuoY (MOBY) cited in the vicarious calibration plan for NOAA polar-orbiting satellites launched after NPP.

NIST provided calibration support to several operational environmental satellite programs, including GOES-13, GOES-R, and LDCM.

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) sensor that flew in June 2009 and June 2010. CIBER is designed to search for anisotropies in the cosmic infrared background by measuring fluctuations at wavelengths and spatial scales where first-light galaxy signals are expected to be detectable and discriminated from foregrounds. The calibrations were performed using a transportable version of NIST's Spectral Irradiance and Radiance Responsivity Calibrations using Uniform Sources Facility (Traveling SIRCUS). The SIRCUS calibration provided the most accurate available measurements of the CIBER sensor's absolute spectral response. This is critical because the CIBER experiment's success is strongly dependent

on the instruments' quantitative calibration to enable the subtraction of unwanted stellar (zodiacal) and solar background radiation.

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 towards 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.

The NIST Thermal-infrared Transfer Radiometer (TXR) was deployed to Space Dynamics Laboratory (SDL) in Logan, Utah, to calibrate a blackbody in a thermal vacuum chamber located there. There were several purposes for the deployment. The blackbody, called the Long-Wavelength Infrared Calibration Source (LWIRCS), had been previously calibrated at the NIST Low Background Infrared (LBIR) facility, so this provided a check of "at-NIST" calibration to "in-situ" calibration at SDL. LWIRCS had been developed at SDL with new calibration technology, particularly phase transition temperature sensors that are relevant for future NASA missions such as CLARREO. A third purpose of the deployment was

to prepare the TXR for an FY 11 deployment to ITT Corporation for the GOES-R Advanced Baseline Imager (ABI) mission.

NIST performed the initial calibration and field-testing of the Missile Defense Transfer Radiometer (MDXR), a new portable cryogenic radiometer designed to measure the collimated output infrared beam from space simulation chambers used in the calibration of infrared remote sensing systems. The MDXR 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 application to 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 is developing and characterizing 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 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 method that will improve 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; those requirements 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.

Using instruments developed to help improve semiconductor electronics, NIST has worked with NASA to measure the composition of meteorites. Different meteorite samples were cut and polished, then measured with a spectroscopic ellipsometer—a device that measures optical properties of materials. The data obtainable with the ellipsometer help to determine the alloy, crystal structure, and grain structure of the meteorites. Many meteorites are made up primarily of iron and nickel, and NIST also made thin films of iron and iron/nickel alloys for calibration and comparison.

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 2010, NIST provided results for atomic argon, hydrogen, lithium, beryllium, boron, nitrogen, sodium, iron, barium, strontium, 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 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. The data provided by NIST for iron atoms are important for determining whether the fundamental constants have changed over the lifetime of the universe. NIST also measured data for chromium atoms. This work was partially funded by NASA.

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 emissions 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 Goddard Space Flight Center 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 10, this collaboration tested GaN nanowires for the first time and determined that the quantum efficiency was greater than 14 percent at 254 nm.

NIST is collaborating with the Jet Propulsion Laboratory on the development of superconducting nanowire single photon detectors (SNSPD). 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. NIST also packaged some JPL devices with our self-aligned single mode optical fiber packaging scheme.

NIST worked with the NASA Glenn Research Center to add reverberation chamber functionality to the Plum Brook Station vacuum chamber (a cylinder approximately 30 meters in diameter and 60 meters in height). The feasibility tests (FY 10) and data processing (FY 11) have been completed and show that the vacuum chamber works well as a reverberation chamber over the 100 megahertz

(MHz) to 40 gigahertz (GHz) frequency range evaluated. It is important that the chamber have well-stirred uniform fields with no significant hot spots (high fields well above the nominal average level). Hot spots could lead to over testing and unintentionally damage expensive electronics. The final report was to be delivered to the sponsor (FY 11).

NIST extended its ability to test antenna parameters (gain, polarization, and pattern) above 110 GHz with the acquisition (FY 10) of new equipment under ARRA. The initial test object for the new capability is an antenna used in a water vapor detection radiometer near 180 GHz. Both the antenna parameter and radiometer calibration capability in development by NIST will serve the general aerospace community. In particular, NIST continued working (starting in FY 09) with NASA Goddard (Microwave Sensors and Hydrological Sciences Branch) to develop blackbody microwave brightness temperature measurement methods and SI traceable microwave radiometer calibrations.

In a collaboration with the University of Colorado (CU) Center for Astrophysics and Space Science, 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 ultra-precise, ultra-stable wavelength references in the infrared spectrum around 1,600 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. But for the radial velocity changes to be detectable, the exoplanets must usually be quite close to the parent star. The great majority of exoplanets so far detected with the radial velocity technique are orbiting hot stars emitting strong visible light, and the detectable exoplanets are much too hot to support Earth-like conditions. Cooler stars emitting mostly infrared light are very common (comprising about two-thirds of the stars nearest to our solar system) and could support Earth-like exoplanet orbits 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 was very successful, resulting in the first stellar spectra calibrated with a frequency comb. The NIST/CU team continues to perfect the infrared frequency comb calibration system and plans further tests at NASA's Infrared Telescope Facility (IRTF) in Hawaii before the system is deployed for long-term calibrations needed for detection of Earth-like exoplanets.

With NASA funding, NIST developed a prototype circuit for critical signal processing applications on future space-based observatories. The demanding specifications for these circuits were met by using superconducting electronics operated at ultra-low temperature.

NASA's next-generation satellite observatories require new detectors with improved sensitivity and scalability. With NASA funding, NIST developed new detectors based on the voltage-biased superconducting transition-edge sensor (TES). The TES offers new capabilities for the detection of electromagnetic signals, from millimeter waves through x-rays. Following on their successful development at NIST, the TES has become the reference technology or a leading candidate for future NASA satellite missions at x-ray, millimeter, and submillimeter wavelengths, as well as for many NASA-funded suborbital instruments (including balloon-borne instruments and instruments intended for SOFIA). More recently, NIST developed integrated TES polarimeters for measuring polarization of the cosmic microwave background (CMB). These devices incorporate multiple TESs per pixel to measure the power in the different polarizations of the CMB. This integrated detector utilizes fully micromachined silicon feedhorns for beam formation. This integrated detector technology will be incorporated in two ground-based instruments (ACTPol and SPTPol).

With NASA funding, NIST is also developing Superconducting Quantum Interference Devices (SQUID) 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 at NASA centers (Goddard Space Flight Center and JPL) and in academia working on NASA-funded projects (including the California Institute of Technology; Stanford University; the

Massachusetts Institute of Technology; the University of California, Berkeley; Princeton University; Cornell University; and others). 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 sub-frame 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 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 NASA Goddard Space Flight Center (GSFC) 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 observations 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.

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 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 onboard embedded controller.

The NIST Fluid Metrology Group makes air speed and hydrocarbon liquid flow measurements to support the aerospace sector. The air speed 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 usage 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 NIST-administered 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 Minimum (RVSM). This potentially exciting application would help to alleviate air traffic congestion around the Nation's airports (see *http://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/enroute/rvsm/*).

NIST's SURF III Synchrotron Ultraviolet Radiation Facility was used as a source of soft x-rays and vacuum ultraviolet light to calibrate mirrors, detectors, and spectrometers used in NASA spacecraft. These include calibrations of rocket-borne instruments to maintain the accuracy of the instrumentation for the EUV Variability Experiment (EVE) aboard the SDO and the Thermosphere Ionosphere

Mesosphere Energetics and Dynamics (TIMED) satellite. Both of these satellites are designed to study extreme ultraviolet (EUV) solar irradiance and its variability over minutes (flares) to years (11-year solar cycle). These measurements are important to the National Space Weather Program (NSWP), which tracks solar storms that impact space-based communications and navigation technologies. We continue to work on the calibration of UV (ultraviolet) instrumentation for satellites in the NOAA GOES program.

With NASA support, NIST developed a new measurement method and a proof-of-concept system for measuring the volume of liquid in spacecraft tanks in zero-gravity conditions. Measuring the level of a liquid in zero-gravity conditions is difficult because fluids (such as water or fuel) tend to break into clumps and float inside the container. This tendency makes it difficult to know, with certainty, how much liquid is left in the container. For organizations like NASA, this problem can lead to life-or-death consequences for astronauts or catastrophic results for satellites and other unmanned spacecraft. Multi-billion-dollar space missions are jeopardized because of uncertain knowledge about the amounts and distribution of remaining liquid hydrogen or liquid oxygen fuel within the tanks. In collaboration with NASA engineers, the NIST team advanced the measurement science for measuring the fluid contents of a tank in (near) zero-gravity by designing, building, and testing an innovative, macro-scale, low-noise capacitor array that gives accurate results regardless of the fluid's distribution within the tank. Prior to this development, NASA had no alternatives to using insufficient, low-accuracy sensors that approximated the amount of material within the container and gave no specifics about the distribution of that material within the volume.

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 two-fold challenge to meet the growing needs of domestic and world-wide 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 10, MEP centers engaged in 290 business improvement projects with 160 individual manufacturing companies designated with an aerospace North American Industry Classification System (NAICS) code.

In 2010, MEP and the Bureau of Veterans Affairs, via a formal interagency agreement, began a supplier scouting pilot. The purpose of the pilot is to increase and enhance the effectiveness and efficiency of the supply of critically needed parts by Veteran-Owned Small Businesses (VOSB) and Service-Disabled Veteran–Owned Small Businesses (SDVOSB) for the Naval Air Systems Command (NAVAIR). Specific emphasis is being placed upon items that NAVAIR has difficulty procuring for different reasons, such as the unavailability of technical data; sole source supply scenarios; or other difficult supply issues that may include lead-time, quality, or reliability problems. The pilot is creating new business opportunities for companies to supply needed parts to the Navy's aerospace programs.

NASA and MEP are collaborating to assist NASA suppliers affected by the pending retirement of the Space Shuttle Program. MEP is working with companies on market diversification and technology adoption projects.

NIST is working with industry to test and advance interoperability standards that can be used to communicate information about parts and processes. NIST is working with industry to test and advance MTConnect, a low-cost, open machine tool integration standard sponsored by the Association for Manufacturing Technology, General Electric, TechSolve, and other partners. U.S. manufacturers in the aerospace industry are highly interested in this standard and the productivity benefits that it provides. MTConnect fosters greater interoperability between controls, devices, and software applications by publishing data over networks using the Internet Protocol. NIST researchers are part of MTConnect's Technical Advisory Group, and they lead the performance evaluation tests. In 2010, NIST and Boeing partnered to explore on-machine process monitoring and continuous improvements following the Kaizen method. The integration of MTConnect and on-machine process analytics was implemented in real time to calculated Key Performance Indicators (KPI) that were incorporated into analytical tools such as Discrete Event Simulation systems to assess what-if scenarios and optimize production. NIST and members of the STandard for Exchange of Product (STEP) Manufacturing Team (including aerospace industry companies such as The Boeing

Company) met in June 2010 at the NIST Gaithersburg facility to demonstrate and discuss advanced uses of the STEP-NC AP238 (also known as ISO 10303-238) standard. STEP-NC is an enhancement of the international standard—STEP model data (a comprehensive ISO standard that describes how to represent and exchange digital product information)—that extends the STEP standard to parts created by computer numerical control. STEP-NC aims to enable manufacturers to design a three-dimensional part electronically and then send the part geometry, along with tolerance, feature, and high-level process information, directly to a machine tool without taking the extra step of defining all of the machine-specific motion codes needed to make the part. The June 2010 demonstration showed that a steel part machined by NIST was able to demonstrate predicted tool wear for machining operations and featured the integration of Boeing's metal cutting optimization techniques with STEP-NC data. Live force measurements from a machining dynamometer were made and showed to correlate with the predicted tool wear. The demonstration also highlighted the need for STEP-NC data to describe information needed by machinists when setting up a job and selecting tooling. These features were added to software used by the testing group and reduced the time needed to set up the machining operations and the cost to purchase tooling.

A mathematical construct involving Brownian motion in randomized time has been successfully applied at NIST to sharpen galaxy images obtained with the Hubble Space Telescope's Advanced Camera for Surveys (ACS). Two ingredients are required for the effective deblurring of imagery: (a) knowledge of the optical transfer function (OTF) that caused the blur and (b) a stable process for undoing the effect of the OTF. The new NIST procedure does not require explicit knowledge of the OTF; instead, it estimates it from an analysis of the image itself. This process is known as blind image deconvolution. In particular, the new NIST procedure considers generalized Linnik characteristic functions as candidate OTFs, whose parameters are estimated by least squares curve fitting of the absolute value of the blurred image's Fourier transform. The deblurring is then accomplished by solving an ill-posed logarithmic diffusion equation backwards in time using a "slow motion" integration procedure also developed at NIST. In many cases, Linnik blind deconvolution can extend the range of telescopes by making faint background objects more visible, while the structure of foreground objects becomes more clearly

defined. The research report describing the new technique presents a variety of stunning examples of image sharpening from the Hubble ACS.

In collaboration with NASA's Langley Research Center, NIST has developed statistical methods for data smoothing that can be applied to the estimation of aerosol extinction in the atmosphere, using measurements made from NASA aircraft. The same methods will be put to use in Differential Absorption Light Detection and Ranging (DIAL) for the measurement of greenhouse gas plumes.

NIST is currently working with NASA's Glenn Research Center (GRC) on spacecraft fire-detection research. The designs of the current ISS and Shuttle smoke detectors were based upon terrestrial test data and experience due to the lack of experimental data for spacecraft fires. The absence of or reduction in gravity has a significant impact on the smoke properties from a spacecraft fire. NASA and NIST first developed the Smoke Aerosol Measurement Experiment (SAME) to characterize smoke properties from overheated spacecraft materials using a suite of aerosol measurement instruments and smoke-collection devices. SAME was conducted aboard the ISS. The success of SAME subsequently led to the reflight of SAME (SAME-R) with additional smoke and aerosol diagnostic instruments. NIST is assisting the GRC science team in analyzing smoke and aerosol data obtained from SAME-R that will be used to provide technical guidance for the design of the next-generation smoke detectors for future manned spaceflights.

NIST is working with The Boeing Company to understand the suppression of fires in aircraft cargo bays. In order to replace existing cargo-bay fire suppressants (which have high ozone depletion potential), various alternative fire suppressants are being considered. Unfortunately, many of the otherwise desirable replacement compounds fail one required FAA qualification test. NIST researchers are helping to understand why these compounds fail the test and actually promote, rather than suppress, the combustion.

Industry and Trade Policy

The Office of Transportation and Machinery (OTM) within the Department of Commerce's International Trade Administration (ITA) 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, 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. In FY 11, the ASTS plans to update the associated Technical Appendix to the R&D Plan. The appendix identifies research investments by Federal departments and agencies related to the national goals and objectives and includes a preliminary assessment of current Federal R&D activities to identify areas of opportunity for potential increased emphasis.

OTM participated in the planning and implementation process for NextGen through the interagency 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 co-chaired 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 Avionics Roadmap, the Net-Centric Operations ConOps, and the Safety Culture Improvement Guide.

OTM continued its participation in aviation security activities, including work on the JPDO Aviation Security Working Group. 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). OTM also assisted the Commercial Service in recruiting for aviation-security-related trade missions to Brazil (September 2010) and to the Netherlands and Sweden (March 2011).

OTM helped support the Commercial Aviation Alternative Fuels Initiative (CAAFI) at the Farnborough Air Show in June 2010. CAAFI is a public/private group sponsored by the Federal Aviation Administration, the Air Transport Association of America, the Aerospace Industries Association, and Airports Council International-North America. Following the successful appearance of several alternative-fuel companies at Farnborough, OTM began working with Kallman Worldwide, CAAFI, and ITA's Invest in America to promote foreign direct investment in U.S.-based bio–jet fuel producers. The group began to plan a series of Webinars leading up to a live event to take place at the 2011 Paris Air Show.

OTM updated market and policy assessments for civil-use unmanned aircraft systems (UAS). OTM continued public outreach on UAS issues through meetings with major UAS manufacturers at the 2010 Farnborough International Air Show.

In September 2010, ITA signed a Memorandum of Understanding with Embry-Riddle Aeronautical University's Worldwide Center for Aviation and Aerospace Leadership to promote U.S. aerospace industry competitiveness through joint outreach, research, and other activities.

In July 2010, OTM participated in the first plenary meeting on commercial cooperation between the Department of Commerce and South Korea's Ministry of Knowledge Economy. OTM gave a presentation on ways to encourage U.S.-Korea aerospace collaboration and held policy discussions with Korean officials.

Throughout the year, OTM organized and led four 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 continued to support the Office of the U.S. Trade Representative on issues relating to enforcement of U.S. rights under the World Trade Organization and in free-trade agreement negotiations. In particular, OTM provided support for the ongoing U.S./EU trade dispute over subsidies to manufacturers of large civil aircraft, providing industry expertise in areas relating to changes in the market and 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 2010, a new round of negotiations was launched to address 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 Export-Import Bank programs affect the aerospace industry.

ITA continued its active participation in the implementation of the current National Space Policies, which include industrial base and competitiveness issues. ITA's OTM was very active in the drafting and release of 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 worked to ensure that all of the policies' implementation actions, as well as the new 2010 policy, will improve U.S. industry's competitiveness, stimulate the American economy, increase exports, and create U.S. jobs.

OTM continued to represent the interests of the commercial remote-sensing satellite industry 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 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 February 2010, OTM attended the 2010 Singapore Air Show to hold policy discussions with U.S. and foreign government officials and aerospace industry representatives. While at the show, OTM also supported the attendance of the

Deputy Director General of the U.S. and Foreign Commercial Service and the Commercial Service's Executive-Led Trade Mission that happened in conjunction with the Singapore Air Show.

In July 2010, ITA organized and supported the Commerce Department's participation in the Farnborough International Air Show and arranged senior-level meetings for 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.

In March 2010, OTM established the Civil Aviation Subcommittee of the U.S.-India High Technology Cooperation Group (HTCG) to discuss industry-specific trade issues previously covered in the Defense and Strategic Trade Subcommittee. One of the most important outcomes of the inaugural meeting of the HTCG Civil Aviation Subcommittee was the creation of the U.S.-India Airport Infrastructure Working Group (AIWG), which addresses ways to encourage greater U.S. private-sector participation in India's $20 billion airport infrastructure development market. The AIWG held its inaugural meeting in New Delhi in September 2010. The AIWG members agreed to select "focus" airports that will serve as models for future collaboration and redevelopment.

OTM continued to monitor the progress of the Indian Air Force's Medium Multi-Role Combat Aircraft (MMRCA) acquisition program for 126 aircraft worth over $10 billion. OTM staff updated policy assessments for the MMRCA as the competition progressed through technical and field evaluations as well as policy assessments on the Indian FY 07 rollback of tariff exemptions for the importation of general aviation aircraft into India.

Industry and Trade Promotion

ITA's U.S. and Foreign Commercial Service Aerospace Team recorded 157 export successes in FY 10 valued at over $2 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, Northrop Grumman, and others.

The CS Aerospace Team held over 500 counseling sessions with U.S. aerospace companies, helping them 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 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 also sponsored Aerospace Products Literature Centers at several air shows, which offered low-cost, efficient venues for U.S. small to medium-sized aerospace companies to explore international and niche aerospace markets. 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 Farnborough and Singapore Air Shows and an Aerospace Supplier Development Trade Mission to India, among others.

DOC's Bureau of Industry and Security (BIS) participates in seminars specific to the civil aircraft industry to address ongoing export control issues. For example, BIS participated in the Berlin Air Show in June 2010 and the Farnborough International Air Show in July 2010, in each case providing a one-day seminar on export controls and conducting one-on-one meetings with industry representatives.

Department of the Interior

DOI

Bureau of Land Management

Remote sensing is one of many tools that the Bureau of Land Management (BLM) utilizes to support its many resource management needs. While field-based measurements provide the foundational data for many of the decisions BLM makes on the ground, managers across BLM realize remote sensing plays a vital role. Remote sensing and field data used in tandem produce invaluable mapping and monitoring information. Additionally, remote sensing is essential because field-based collection alone does not address all BLM needs in relation to describing resource conditions and trends, especially across vast expanses of land. To fill in the gaps and meet the full spectrum of monitoring needs, both spatially and temporally, BLM is developing a core set of integrated, scalable, remote-sensing tools that are compatible with the field data collection methods already employed. Using these tools as a component of an integrated, quantitative monitoring approach, amongst others applications, BLM can begin to document the cumulative impacts from authorized and unauthorized disturbance and land treatment activities at local and potentially regional scales. By integrating remote sensing into the overall Assessment, Inventory, and Monitoring (AIM) strategy, scientists can better leverage the proposed field-based monitoring plans to produce additional mapping products that would otherwise be too expensive to generate independently.

FY 10 was the fourth year of collecting monitoring data through remote-sensing sources, with three primary focus areas to monitor the impacts of coal-bed methane discharge water on aquatic and riparian habitat in the Powder River: 1) aquatic habitat sample collection using very large-scale aerial (VLSA)

photography; 2) upland, riparian, and aquatic habitat mapping using AEROCam and QuickBird imagery; and 3) photogrammetric processing of VLSA to accurately register imagery for monitoring purposes, as well as provide detailed terrain data to examine bank stability.

BLM continues to be a leader in the field of aerial photography and photogrammetry, having pioneered the use of close-range photogrammetry for a host of applications, such as cultural resource preservation and quantifying erosion impacts due to off-highway vehicle activity, as well as applying traditional techniques for hazardous waste management, engineering projects, and boundary dispute litigation.

In FY 10, BLM continued its partnership with the Farm Service Agency (FSA) for access to the National Agricultural Imagery Program (NAIP) orthoimagery. Arizona, California, and Nevada acquired statewide, 4-band orthoimagery. Through the Department of the Interior (DOI) agreement with FSA, BLM and the other DOI bureaus were considered full partners with FSA and had access to these data at no additional cost. Due to the extensive landscapes that are covered by the NAIP product, the imagery is still the de facto base imagery dataset for BLM. NAIP uses are varied, including change-detection studies and surface-disturbance delineation; road development updates and routine inventory creation crucial to planning efforts; characterization of land exchanges; mining reclamation planning for recreation facilities; monitoring the health of rangelands and the impact of oil and gas development; vegetation treatments; fire planning; and trespass studies. Without this product, the cost to perform all of these activities would be significantly higher. It is also helpful at the state office and the field offices for vegetative studies, riparian analysis, range monitoring, wildlife inventory, forest inventory, and other specialized applications.

Traditionally, and for 2010, the widest use of remote-sensing data was for fire-related activities. Most of the activities center on the interpretation of aerial infrared photography to identify active fires, post-fire perimeter delineation, and vegetation classification for fire/fuel risk modeling and disturbance mapping. However, the utility of remote-sensing data goes far beyond the fire world. BLM, with its partners, conducted a large range of natural resource management projects that leveraged remote-sensing data and analyses to support our mission. Projects included vegetation mapping of 1.2 million acres in the west, range monitoring in the Upper Colorado River Basin, and wildlife habitat monitoring.

Due to the unique challenges that are presented in Alaska, from the sheer size of the state to the remoteness of its beautiful landscapes, remote sensing is a vital tool to assist in BLM's resource management goals of the state. Several projects highlight current activities and emphasize the need and value of partnerships. Land cover mapping, base mapping using digital elevation models, and wildland fire suppression studies were done in cooperation with regional Alaskan agencies.

Bureau of Reclamation

In 2010, the Bureau of Reclamation (BOR) used a wide variety of remote sensing methods in support of its water resource management mission. BOR staff continued to use remotely sensed imagery to monitor consumptive water use throughout the western United States. This was accomplished primarily through the mapping of irrigated crops and other vegetation at a variety of spatial scales.

BOR image analysts used Landsat Thematic Mapper imagery to map irrigated crop types and open water areas in the Central and Imperial Valleys of California and along the Lower Colorado River dividing California and Arizona. Because this area produces agricultural crops year-round, multi-date imagery was required to map up to four different crops on a single field each year.

Along the Lower Colorado River, phreatophytic vegetation within the river's floodplain consumes significant quantities of water from the river system, which is of concern to water managers. In order to obtain reliable estimates of their consumptive use, Landsat and NAIP imagery was used to map Salt Cedar and other phreatophytes along the Lower Colorado River. Because consumptive water use in phreatophyte areas is closely tied to tree density, BOR used high-resolution imagery to estimate tree canopy closure in these riparian areas.

High-resolution image mosaics were used for many purposes, including mapping invasive tree species in the riparian zone; performing counts of endangered fish in protected backwaters; and mapping in-stream habitat features, such as pools, riffles, and backwaters for fish habitat studies. Video imagery was particularly useful for in-stream habitat mapping because the wide range of illumination and view angles offered by the video allow for the detection of subtle roughness features on the surface of the water that provide information related to water depth, flow velocity, and channel substrate.

Office of Surface Mining

The Office of Surface Mining (OSM) continues to acquire and use high-resolution remotely sensed imagery and GPS information to support on-the-ground Surface Mining Control and Reclamation Act (SMCRA) activities. Particular focus in FY 10 was placed on interagency and interdepartmental partnerships as a way to reduce image acquisition costs and enhance effectiveness.

Remote-sensing projects included the continuation of a two-year pilot project working with the U.S. Geological Survey (USGS) and the National Geospatial-Intelligence Agency (NGA). The goals of the project were to determine the best methods for acquisition and delivery of image data, products, and services for OSM responsibilities under SMCRA and to determine which remote image data products and services support virtual inspection. The project focused on three surface coal mines—Centralia Mine in Washington, Valley Creek Mine in Tennessee, and McKinley Mine in New Mexico. Quarterly satellite image collects are required for all three sites in order to meet the inspection cycle required by Title V of SMCRA. The processed satellite imagery and derived products are intended to enhance the current OSM inspection/permitting processes to integrate image data and solutions into a virtual inspection process that will meet the needs of some routinely required inspections.

National Park Service

The National Park Service (NPS) has a long history and standing investment in remote sensing and GPS technologies. A wide range of projects and programs have business requirements that utilize aerial and spaceborne platforms for activities ranging from data acquisition to applications and the use of imagery in reports and related products.

The Northeast Coastal and Barrier Network (NCBN) of the NPS Inventory and Monitoring (I&M) Program collaborated with the USGS Florida Integrated Science Center to collect LIght Detection and Ranging (LIDAR) data and aerial photography at Fire Island National Seashore and Gateway National Recreation Area in support of the coastal geomorphologic monitoring program. These data are

used to generate highly accurate elevation models of beach, dune, and other coastal features and are used by park natural resource managers to assess rates of erosion and deposition. Ongoing monitoring of the NCBN coastal parks using LIDAR will also assist managers in assessing the effects of climate change, such as sea-level rise, on these coastal systems.

The I&M Program conducts 12 baseline inventories of over 270 parks spanning over 30 million acres of public lands. Geology, soils, vegetation, and base cartography are only 4 of the 12 inventories that provide important baselines for the support of land management decisions. Every level of resolution of space-based remote sensing is used for these efforts. In 2009 the NPScapes project packaged Landsat Thematic Mapper, National Land Cover Database, Gap Analysis Program (GAP) land cover, Landscape Fire and Resource Management Planning Tools (LANDFIRE), and various metrics from these data for all of the NPS units in order to allow parks to start monitoring landscape dynamics in and around their units. This will be expanded in the future to include land cover data for all of North America derived from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) imagery and NOAA Coastal Change Analysis Program (C-CAP) data.

Many park vegetation maps incorporate remote sensing, with 9 million acres mapped, 8.2 million acres underway, and 12 million remaining. NAIP imagery, sometimes coupled with Landsat Thematic Mapper, and a variety of Satellite Pour l'Observation de la Terre (SPOT), QuickBird, and IKONOS products, is used to support these inventories. GPS is also a critical tool in checking field data, accuracy assessments, and project mapping. The use of Continuously Operating Referenced Station (CORS) data and the National Differential GPS system maintained by the U.S. Coast Guard are critical tools in resource assessments.

NPS's I&M Program, Southwest Alaska Network, used a combination of high-resolution commercial satellite image data (IKONOS), Landsat data, and historical aerial photographs to quantify decadal changes in glacier ice cover (1973–2002) and to document land cover change (1955–2005) in three national park units. In addition, MODIS data were useful in documenting seasonal variation in lake ice and in calculating growing season metrics across the study region.

A University of Colorado research team, in coordination with the Alaska Arctic I&M Network, continued to assess rates of coastal erosion and accretion along the

shores of Bering Land Bridge National Preserve and Cape Krusenstern National Monument. The team used aerial photographs from the 1950s, the 1980s, and 2003, as well as IKONOS satellite imagery to determine coastline changes. The project will assist NPS in developing protocols to continue acquiring aerial photographs and satellite imagery for long-term monitoring of the coastline. Significant changes to the 450 kilometers of coastline along the park shorelines became evident by comparing the imagery. These changes affect animal habitat, water, soil, permafrost, and other aspects of coastal ecosystems, cultural resources, and local communities.

NPS Yellowstone National Park staff used a temporal series of high-resolution (1-meter resolution or less) commercial imagery and Landsat-derived Normalized Burn Ratio products to delineate stand-replacing fire effects from 1988 to the present in Yellowstone National Park. The park purchased 1,600 square kilometers of QuickBird commercial 2-foot-resolution satellite imagery along road corridors and developed areas. This imagery will be used for multiple park projects, including updating buildings, roads, utilities, vegetation, and trails in Geographic Information System (GIS) data layers. Since high-resolution imagery became the de facto background base map for park operations maps, the QuickBird imagery will also be used as background imagery for cartographic products.

Wildland fire burn severity products derived from Landsat imagery continued to be generated for fires occurring within the Alaska NPS region. In FY 09, the Denali land cover map was updated with fire perimeter information generated from burn scars found within Landsat imagery. This produced a map that reflects post-fire vegetation changes for fires dating back to 1986. This map provides vegetation and fuel information for use in spatially explicit fire behavior modeling tools and fire suppression activities. Additionally, Landsat and IKONOS satellite imagery of Denali National Park was provided to the Alaska Natural Heritage program at the University of Alaska Anchorage to verify land cover (vegetation) classes and field plot data for a LANDFIRE dataset accuracy assessment.

Alaska's national parks are perhaps the most remote park units within the NPS. As such, the use of remote-sensing technologies in the Alaska region has proved extremely valuable in supporting the NPS mission and its operations. Satellite imagery, aerial photography, and GPS technologies have been used during various

mapping efforts, to track wildlife, to conduct search and rescue missions, and to map and monitor trails, as well as to assess environmental and landscape changes related to lakes, streams, shorelines, vegetation, glaciers, and permafrost. Park managers, scientists, and planners relied on information derived from remotely sensed data during FY 10 in their stewardship of Alaska's national park resources.

U.S. Fish and Wildlife Service

The U.S. Fish and Wildlife Service (FWS) used a diverse set of remotely sensed data, from traditional aerial images to satellite radar imagery, to support a wide variety of conservation and land management activities. Just a few of those applications are habitat, wetland and vegetation mapping; monitoring fish and wildlife populations; refuge management; trend analysis; modeling; climate change forecasting; and strategic habitat conservation planning. These activities used a variety of remote-sensing data sources.

Without question, the leading remote-sensing event in 2010 was the Gulf oil spill. This and other oil spills around the country underscore the necessity for rapid remote-sensing response to disaster events. Access, analysis, and delivery of geospatial products underscore the importance of using real-time remote-sensing imagery to properly respond to emergency situations.

For 2010, the FWS Midwest Region's National Wetland Inventory (NWI) program continued to work with a variety of international, Federal, tribal, state, local, and nonprofit partners to strategically map and assess the Great Lakes Basin. These partnerships are critical to developing the current picture of our changing wetlands and habitats across the Basin, where the FWS and our partners address their natural resource management decisions. This unique opportunity, led by the President and Congress, is designed to help restore the Great Lakes Basin. Key to the restoration is the requirement to first understand the Basin's baseline conditions. Remote sensing plays a pivotal role in this effort.

One of the important needs for the Great Lakes Basin was the ability to map invasive species and forested wetlands. With additional funding provided by the USGS through the Great Lakes Restoration Initiative (GLRI), Michigan Tech Research Institute was able to field-verify and map all invasive Phragmites

for the entire coastline of Lake Huron in Michigan in 2010 using Phased Array type L-band Synthetic Aperture Radar (PALSAR) imagery. This unique kind of invasive species radar mapping had never been done before at this scale. In addition to mapping Phragmites, mapping wetland extents in forested regions was the other key objective to help improve the NWI delineations with the rest of the GLRI partnership.

DOI staff also used remote-sensing analytical approaches to identify flood-prone areas. The results of the analysis allowed refuge staff to identify areas of varying flood intensity. This helped in the planning of future habitat management. Regional office staff in the Division of Conservation Planning also mapped vegetation at three National Wildlife Refuges in 2010. This work helped the FWS create more visual analysis tools tailored to conservation planning and refuge management.

U.S. Geological Survey

The Landsat Project at the USGS manages two active satellites, Landsat 5 and Landsat 7, and the historical archive of data collected since 1972—more than 2.4 million images. In FY 09, a change in data policy (no-charge, Web-enabled data) transformed the distribution of Landsat data for scientists and operational users worldwide. As a result, more than three million Landsat images have been downloaded by customers. As of FY 10, Landsat 5 has reached 26 years in orbit and Landsat 7 has reached 11 years in orbit. Both of these satellites continue to provide essential data to scientists well beyond their designed lifespans of three years and five years respectively. The Landsat team continually worked to extend the longevity of the satellites in orbit; enhance Landsat data quality; and improve systems at the USGS Earth Resources Observation and Science (EROS) Center used to archive, process, and access Landsat data, while leading the design and development of the ground system for the LDCM.

Recent flood events in the Prairie Pothole Region of North America have stimulated interest in modeling water storage capacities of wetlands and surrounding catchments to facilitate flood mitigation efforts. Accurate measurements of basin storage capacities have been hampered by a lack of high-resolution elevation data.

A 0.5-meter bare Earth model was developed from LIDAR data in combination with NWI data. These data were used to delineate wetland catchments and spilling points within a 196-square-kilometer study area.

Many of the fundamental geophysical processes active at Earth's surface are controlled or strongly affected by topography, thus the critical need for high-quality terrain data. The USGS and the NGA collaborated on the development of a notably enhanced global elevation model, the Global Multi-resolution Terrain Elevation Data 2010 (GMTED2010), which replaces Global 30 Arc-Second Data Elevation Set (GTOPO30) as the elevation dataset of choice for global and continental scale applications.

The Famine Early Warning Systems Network (FEWS NET) uses a variety of remotely sensed data products and modeled outputs to support food aid decision making. One of the products that FEWS NET utilized throughout its 25-year history is the Normalized Difference Vegetation Index (NDVI), used primarily for monitoring cropland and pasture conditions, initially supporting FEWS NET efforts in Africa. In recent years, monitoring efforts were expanded to include Haiti, Central America, and Afghanistan and are now becoming more global.

Unmanned Aircraft Systems (UAS) are transforming Earth observation methods and techniques used by DOI and the USGS by providing reliable scientific information to more fully describe and understand Earth. Cost-effective UAS technology is currently available to support a wide variety of applications including managing Federal lands; monitoring environmental conditions and the use of natural resources; analyzing dynamic Earth processes to support global and climate change investigations; generating mapping, charting, and geodesy products; conducting environmental risk assessments; and preventing, preparing for, responding to, and recovering from natural and human-induced disasters. The USGS supported the FWS by successfully operating a UAS to inventory Sand Hill Cranes. The USGS supported the U.S. Forest Service and several DOI bureaus by operating UAS missions over prescribed burns. These demonstrations help pave the way for an expanded use of UAS technology to monitor wildfires.

Since July 2009, USGS staff utilized NASA's Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR), an aircraft-mounted polarimetric and differential interferometric L-band synthetic aperture radar system, to collect monthly

images of the Sacramento–San Joaquin Delta and much of the adjacent Suisun Marsh. The images help characterize levee stability, spatially image subsidence, and assess how well the UAVSAR performs in an area with widespread agriculture production. The UAVSAR allows scientists to identify small-scale motion (1 to 2 meters) on the levees and to characterize soil moisture change, biomass change, and inundation. Once areas of instability are identified, scientists collect ultra-high-resolution T-LIDAR imagery to document and measure surface deformations.

During the years 2000–09, the USGS developed a database of fire perimeters for Colorado based on Federal fire records, MODIS fire information, and Landsat imagery to assist the BLM with wildfire management, weed and insect outbreaks, energy development, and climate change impacts. Staff examined all reported fire locations on the appropriate Landsat imagery and manually digitized burned areas of ten acres and greater. For the year 2008, staff systematically searched the Landsat imagery for unreported fires. The database laid the foundation for generating, calibrating, and refining an automated method for burned area identification. The long-term goal for this project is to develop a Landsat-based Thematic Climate Data Record for burned areas.

Colorado has experienced widespread conifer mortality during the past several years, much of which has been attributed to the mountain pine beetle (Dendroctonus ponderosae) epidemic. This vegetation mortality poses ongoing concerns for forest health and potentially heightened wildfire risk, both threats to human safety and environmental quality. The threat of wildfires continues to put pressure on planning and mitigation efforts at Federal, state, and local levels—especially in the wildland-urban interface.

To characterize conifer forest distribution, health, and structure within three study areas in Grand County, Colorado, the USGS is integrating the Civil Air Patrol's Airborne Real-time Cueing Hyperspectral Enhanced Reconnaissance (ARCHER) electro-optical imagery and discrete return LIDAR data. The ARCHER system provides both high spatial resolution and hyperspectral capabilities not currently available from commercial satellites. The ARCHER system has 1-meter spatial resolution across 52 discrete bands spanning the visible green to near-infrared electromagnetic spectrum (500 to 1,000 nanometers). The sensor also offers a panchromatic imager with a spatial resolution of less than 1 foot.

Following the 7.0 magnitude earthquake near the capital city of Port au Prince, Haiti, on January 12, 2010, the USGS produced 1:24,000-scale post-earthquake image base maps incorporating high- and medium-resolution remotely sensed imagery. On January 15, 2010, following the initial earthquake, DigitalGlobe acquired commercial 2.4-meter multispectral satellite imagery. JAXA collected 10-meter multispectral Advanced Land Observing Satellite (ALOS) Advanced Visible and Near Infrared Radiometer Type-2 (AVNIR-2) imagery on January 12, 2010. The USGS obtained these data under the International Charter for Space and Major Disasters, a global team of space and satellite agencies that provide timely imagery in support of emergency response efforts worldwide. The base maps provided a temporally current representation of post-earthquake ground conditions, which may be of use to decision makers, scientists, and the general public.

During the 1990s, the Medea program brought Government and academic scientists together to review imagery acquired by classified intelligence satellites, known as National Technical Means, and to recommend declassifying certain datasets that could further the understanding of environmental change. Although the group disbanded in 2000, it reassembled in 2008. In 2009, the USGS, in cooperation with Medea, released to the public numerous images acquired since 1999 as Literal Image Derived Products (LIDP). These 1-meter-resolution images are from six locations in the Arctic Basin (Beaufort Sea, Canadian Arctic, Fram Strait, East Siberian Sea, Chukchi Sea, and Point Barrow). Each LIDP is a geocoded panchromatic image covering an area of approximately 15 by 15 km of Arctic sea ice.

In addition to these static sea ice sites, Medea scientists requested image collections to track assemblies of ice floes that drift in various directions on the Arctic Ocean. The locations of data buoys that were deployed in the vicinity of the floes guided the repeat imaging of the ice cover. A buoy will transmit GPS locations at regular intervals to track where it is and coordinate the climatologic and meteorological data with its location. Using the latest GPS locations to project travel direction and speed, the same piece of ice can be imaged as it moves throughout the Arctic region. This imagery can then be used as a reference for studying ice fracture patterns, melt pond activity, snow cover, ice thickness and age, ice and snow ridges, ocean currents, and many other variables that are important as input for refining more accurate climate models.

Scientists from the USGS have completed the initial data collection for the first ever multi-decadal national assessment of contemporary land use and land cover change in the U.S. Geographers across the country completed the manual interpretation of 2,688 100-km² sample blocks using Landsat Multispectral Scanner, Thematic Mapper, and Enhanced Thematic Mapper Plus satellite imagery spanning five years (1973, 1980, 1986, 1992, and 2000). The land use and land cover mapping effort yielded five individual dates and four discrete periods for analysis. Sample blocks were selected by using a stratified random sample allocated across 84 U.S. Environmental Protection Agency Level III ecoregions. Results from all 84 conterminous U.S. ecoregions show that the responses to various economic, policy, technological, and social driving forces differ significantly based on the unique environmental and socioeconomic factors shaping each ecoregion. Analysis and national synthesis of the data will be conducted in FY 11.

As groundwater basins in California are increasingly being used as local reservoirs to enhance water supply reliability, water managers are seeking more information on the relationship between land subsidence and water extraction. The USGS conducted studies in southern California with this focus. One involved the region around Palm Desert and other desert resort cities in the Coachella Valley east of Los Angeles. It used conventional and persistent scatter InSAR (also known as PS InSAR or IPTA InSAR) remote-sensing data to measure changes in land surface elevation between 2005 and 2010 and compared those data to information on groundwater levels. The study used conventional InSAR to characterize land subsidence associated with groundwater-level declines in areas of the Mojave Desert. InSAR data were developed to determine the location, extent, and magnitude of land-surface changes in the Mojave River and Morongo groundwater basins.

Developing water budgets, particularly estimating perennial yield, is a major issue in Nevada. The Nevada State Engineer uses perennial yield estimates to allocate groundwater in many basins. Perennial yield estimates are typically determined from basin-wide groundwater evapotranspiration (ET) studies. The Nevada Water Science Center is working cooperatively with Nevada state agencies, DOI bureaus, and other Federal agencies to refine groundwater discharge estimates associated with ET in select hydrographic basins and regional studies in the Great Basin. Landsat Thematic Mapper and Enhanced Thematic Mapper Plus data, along with imagery from the

NAIP and MODIS, are used to quantify ET from groundwater discharge. To fine-tune imagery-derived vegetation indices with on-ground observations, imagery is used in conjunction with ET micrometeorological stations set up on the ground within potential areas of groundwater recharge and in focus areas of vegetation of interest.

Florida scrub-jays (Aphelocoma coerulescens) are listed as threatened under the Endangered Species Act due to loss and degradation of oak-scrub habitat. A USGS study investigated the development of an optimal strategy for the restoration and management of scrub habitat at Merritt Island National Wildlife Refuge (MINWR), which is colocated with the Kennedy Space Center in east-central Florida. The USGS and NASA collaborated to use color imagery to classify the condition of scrub habitat. Using annual sequences of imagery, researchers were able to determine how scrub responds to three different management actions: scrub restoration (mechanical cutting followed by burning), prescribed burning, or no intervention. The analyses suggested that prescribed burning as practiced by MINWR was relatively ineffective at setting back scrub succession, which is important for providing good habitat for scrub-jays. NASA also developed a remote-sensing protocol for mapping fire scars from Landsat satellite imagery; researchers used the resulting fire-scar maps to better understand how fire spreads as a function of various environmental conditions. In response, MINWR has taken a much more aggressive approach to the problem of managing scrub-jay habitat.

Landscape structure and function in flowing aquatic environments are strongly linked to the feedbacks between flow and vegetation. In low-gradient wetlands and floodplains, vegetation is the primary physical resisting force to flow. USGS scientists developed empirical predictive relationships based on biomass samples harvested at 80 locations in the Florida Everglades. They also found that spatial and temporal variations in flow resistance are impacted by vegetation architecture and human-induced effects, such as water management and water quality. In order to scale up flow resistance parameters, scientists correlated meter-scale biomass measurements to the NDVI derived from digital multispectral video. This enabled scientists to estimate spatiotemporal variations in flow resistance to improve hydrologic modeling and to guide restoration efforts in the Everglades and elsewhere.

A common measure of cover crop success (wintertime biomass) can be easily quantified from space using vegetation indices applied to moderate resolution

multispectral imagery. The USGS used commercial SPOT data and Landsat data to select pixels that fall within specific agricultural field boundaries, converted vegetation index statistics to calculated estimates of cover crop biomass and nitrogen content, and matched these results with agronomic management information derived from conservation program farm records. Over five years of collaborative research, the project developed a set of geospatial toolkits and methodologies that support a remote sensing analysis of winter cover crops. USGS staff programmed a prototype geospatial toolkit to assist Soil Conservation Districts with the recording of geospatial field boundaries and agronomic information during the cover-crop farmer enrollment process. Then USGS programmed a second prototype toolkit to link the field-specific enrollment data with satellite imagery analysis to produce vegetation index statistics associated with each field.

The erosion of riverbanks along the Missouri River has been a concern of many of the Native American tribes within South Dakota. Changing reservoir levels combined with precipitation, wind, and ice create conditions that can cause substantial shoreline erosion within a single season. The Lower Brule Sioux Tribe is concerned about water pollution caused by this shoreline erosion. The Reservation has experienced the massive shoreline erosion of an estimated 8 feet per year along the entire length of the reservation border along the Missouri River. The USGS is using various technologies to obtain accurate measurements of shoreline erosion, with the current study area consisting of a 7-mile stretch near the community of Lower Brule. The Lower Brule Sioux Tribe's Environmental Protection Office, in cooperation with the USGS South Dakota Water Science Center, is using ground-based LIDAR to obtain precise land-surface elevation data for areas of interest. During 2011 and 2012, changes in the shoreline also will be monitored with a small UAS that will be used as a reconnaissance and surveillance tool with flights at equal time intervals.

The application of Landsat imagery to estimates of inland lake water quality provides resource managers with information for unsampled lakes, the capability to identify potential areas of concern, and the ability to evaluate trends in lake water quality. Landsat imagery was used to determine the water quality for over 3,000 of Michigan's inland lakes larger than 20 acres. High-quality lakes are a vital economic and environmental resource, but physical measurement of the quality of

each lake is not economically viable. The USGS used Landsat imagery to predict water quality based on Secchi-disk transparency (SDT) physical measurements provided by USGS, the Michigan Department of Environmental Quality (MDEQ), and the Cooperative Lakes Monitoring Program, a network of volunteer monitors trained by MDEQ. The trophic state of unsampled inland lakes greater than 20 acres is estimated by regression equations relating SDT to Landsat imagery. SDT is a measure of water clarity and can be used to estimate Trophic State Index (TSI). TSI is a measure of a lake's primary biological productivity. TSI estimates are available for three time periods: 3,121 lakes from 2003–05; 3,024 lakes from 2007–08; and 2,591 lakes from 2009–10. Similar approaches were implemented in Wisconsin and Minnesota.

The USGS routinely applies and uses remote-sensing methodologies and data to mineral resource assessments in the United States and around the world. The Global Mineral Resource Assessment Project uses Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data for mapping hydrothermally altered rocks to identify porphyry copper mineralization. This technique assisted USGS scientists with the estimation of undiscovered deposits and copper resources in Kazakhstan, Iran, Afghanistan, and Mexico. Similar studies were carried out in Alaska using ASTER data in conjunction with rock sample surveys and spectral processing methods to identify hydrothermal alteration anomalies associated with polymetallic massive sulfide mineralization. In the Basin and Range of the southwestern United States, maps compiled from ASTER data were developed for mineral-environmental and concealed-deposits mineral resource assessments.

In combination with GIS spatial analysis and modeling, remotely sensed data are increasingly becoming essential components of larger, interdisciplinary, natural resource assessments that consider mineral, water, environmental, and socioeconomic factors.

Federal Communications Commission

FCC

The Federal Communications Commission (FCC) formulates rules 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 accomplishments for FY 10 related primarily to commercial communications satellites.

The FCC took one significant action in a rule-making proceeding in FY 10. Specifically, the FCC established a "Ka-Band Permitted List." This list identifies non-U.S.-licensed satellites that the FCC has approved for the provision of service to the United States. Once a satellite is placed on the Ka-Band Permitted List, all earth stations with standard technical characteristics may communicate with that satellite without further regulatory approval.

The FCC also took several notable actions concerning the use by terrestrial communications systems of radio-frequency spectrum assigned to the mobile satellite service (MSS). Under rules adopted in FY 03, MSS operators can deploy an ancillary terrestrial component (ATC), which is a terrestrial network that enhances the capabilities of an MSS system. In one action, on March 26, 2010, the FCC modified the technical specifications of an ATC authorization held by SkyTerra Communications. SkyTerra plans to deploy an ATC that will enhance consumer broadband connections for Internet and other uses. In another action, on September 14, 2010, the FCC suspended the regular authority for ATC operations held by Globalstar because Globalstar was unable to meet the conditions of

the authorization. The FCC permitted short-term operations to continue, however, in order to avoid disruption to consumers.

The FCC authorized a number of commercial communication satellite launches and operations as follows:

- November 25, 2009: to Intelsat for a geostationary satellite planned for the longitude 85.15° east orbit location.
- December 15, 2009: to DirecTV for a geostationary satellite planned for the longitude 102.765° west orbit location.
- April 2, 2010: to Intelsat for a geostationary satellite to operate at the longitude 31.5° west orbit location. Intelsat acquired the on-orbit satellite, formerly known as Protostar 1, in a bankruptcy proceeding.
- April 20, 2010: to SES Americom for a geostationary satellite to operate at the longitude 101° west orbit location.
- June 4, 2010: to Intelsat for a geostationary satellite to operate at the longitude 19.95° west orbit location. The authorization covered Ku-band operations of the NSS-5 satellite as part of a cooperative arrangement with another operator, SES New Skies.

The FCC added two non-U.S.-licensed space stations to the Commission's permitted space station list in order to allow the space stations to provide domestic and international satellite service to U.S. earth stations that have routine technical parameters. Specifically, on October 15, 2010, the FCC added Brazil's Amazonas 2 space station to its permitted list for Ku-band frequencies; on June 4, 2010, the FCC added the Netherlands' NSS-5 satellite to the permitted list for C-band frequencies.

The FCC also granted a number of requests for non-U.S.-licensed space stations to provide service in the United States on a non-routine basis as listed below:

- May 5, 2010: The FCC reserved Ka-band spectrum for Hughes to use with a satellite to be licensed by the United Kingdom. The satellite will operate at the longitude 107.1° west orbit location.
- June 24, 2010: ViaSat received authorization to deploy terminals to communicate with the AMC-21 satellite, licensed by the United Kingdom to operate at the longitude 125° west orbit location.

- June 25, 2010: Hawaii Teleport received authorization to communicate with the Apstar VI satellite, licensed by China to operate at the longitude 134° east orbit location.
- July 2, 2010: Inmarsat Hawaii received authorization for earth stations to operate with the Wide Area Augmentation System payload of the Inmarsat 4F3 satellite, licensed by the United Kingdom to operate at the longitude 97.65° west orbit location. The Wide Area Augmentation System provides enhanced radionavigation capabilities for certain users of Global Positioning System receivers, particularly for aeronautical radionavigation.

The FCC also remained active in international satellite coordination. In the second quarter of FY 10, the FCC reached a total of 145 Administration-to-Administration Coordination Agreements for U.S. networks with Japan and Canada. In the third quarter of FY 10, the FCC reached a total of 51 Administration-to-Administration Coordination Agreements for U.S. networks with Malaysia, the United Kingdom, Mexico, and Canada.

U.S. Department of Agriculture

USDA

According to the Food and Agriculture Organization (FAO) of the United Nations, an estimated 45 percent of the United States and an estimated 38 percent of the global land surface is agricultural land. The FAO estimates that approximately 33 percent of the United States and about 31 percent of the global land surface is covered by forests. Proportionally, agriculture and forestry combined are the single most intensive human activity on the planet, accounting for impacts on an estimated 78 percent of the United States landscape and 69 percent globally.

The U.S. Department of Agriculture (USDA) continues a tradition of leadership in food, farm, natural resource, science, market, and related agricultural issues. Specific departmental objectives in FY 10 included enhancing economic opportunities for U.S. farmers and ranchers; ensuring a safe, affordable, nutritious, and accessible food supply; fostering responsible land management practices on both public and private lands; supporting the sound, sustainable development of rural communities; expanding global markets for agricultural and forest products and services; and working to reduce hunger and improve America's health through good nutrition.

Multiple USDA agencies employed aspects of remote-sensing data, technologies, and expertise to support the departmental contribution to public value, governance, and innovation. The wide aerial coverage and geographic detail of satellite images and aerial photography supplied tangible benefits to the Department and its customers by providing a comprehensive view of the landscape not attainable through ground-based observations or sensors alone. Many USDA agencies shared

remote-sensing resources, ensuring the efficient and cost-effective use of these data and technologies within the Department. USDA agency contributions for FY 10 are described individually in the following sections.

Agricultural Research Service

The Agricultural Research Service (ARS) conducted research on issues related to global food security, agricultural air quality, ecosystem health, biofuels, and climate change. ARS collaborated with NASA and other USDA agencies to further develop remote-sensing instruments, decision-support systems, and data management technologies to help USDA agencies accomplish their missions. Partnerships with other Federal agencies, universities, industry, and state governments remained a key component of ARS research.

Water quality and quantity management are critically important capabilities for agriculture and were thus a focus for ARS remote-sensing activities. Soil moisture remote-sensing research continued with the development of algorithms for soil moisture estimation from aircraft and satellite sensors. Researchers further developed guidance systems for remotely sensing crop nitrogen status, enabling farmers to reduce the application of excess fertilizer while helping to maintain water quality and improve economic returns. ARS scientists contributed to the development of the next generation of satellite remote-sensing systems through the Soil Moisture Active-Passive mission, with three scientists serving on the Science Definition Team. ARS scientists also continued to develop algorithms using thermal infrared and multispectral visible, near-infrared, and shortwave infrared data for spatially and temporally variable irrigation scheduling, mapping evapotranspiration and drought, and estimating soil moisture and vegetation canopy water content. An ARS scientist served on the Landsat Science Team, and several ARS scientists contributed to research supporting the Hyperspectral Infrared Imager concept as part of this effort.

ARS scientists continued to develop data assimilation techniques 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. These techniques were designed to enhance the value of

remote-sensing retrievals for monitoring key environmental variables and precipitation estimates from numerical weather prediction models.

ARS scientists investigated the use of remotely sensed information for 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 sustaining soil, water, and air and for sequestering carbon. Research on monitoring reductions of nitrogen runoff to sensitive ecosystems used remote sensing to map and quantify winter cover crops. LIDAR remote sensing was developed as a tool to better understand and manage the fate of agrochemicals and sediment in coastal watersheds.

ARS also developed spectral and spatial procedures to monitor invasive species with remote sensing to manage rangeland and understand the impacts of changing climate on managed and natural ecosystems. ARS researchers continued to develop a rangeland decision support tool for public land management that accesses remote-sensing data via the Internet. 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 Institute of Food and Agriculture

The National Institute of Food and Agriculture (NIFA) is the extramural research arm of the USDA. The NIFA primarily provides financial assistance in the form of grants to partner organizations, such as land grant institutions, to conduct high-priority agricultural research and education. The NIFA awarded many grants that used 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 NIFA-supported research and education are

- developing new courses related to geographic information systems (GIS) and remote-sensing applications and enhancement of teaching and research capabilities of faculty and staff from Delaware State University, a historically black land-grant university;
- using remote sensing for biological assessment of headwater streams in ravine ecosystems of northwest Florida;

- enhancing the capacity of the Ohio plant diagnostic network by providing a remote-sensing diagnostic station;
- evaluating improved methods for surveillance and control of the tropical bont tick (Amblyomma variegatum) in the Caribbean using modeling and remote-sensing techniques; and
- assessing the influence of mid-continent land-use trends on floral diversity and pollen availability to sustain bee health, diversity, and ecosystem services using satellite data products.

The NIFA had a special focus on funding GIS and remote-sensing curriculum development at minority-serving institutions in 2010. The NIFA funded a number of projects that will help train students in using these technologies and also developed new courses that will service many departmental programs at land grant universities. The NIFA also funded long-term studies in Mississippi, Kentucky, Alabama, and Wisconsin that utilized remote sensing and geospatial technologies to develop precision management techniques for various agricultural production strategies and to evaluate land use practices. The NIFA and the Science Mission Directorate of NASA jointly funded several geospatial extension programs at land-grant, sea-grant, and space-grant institutions. After NIFA/NASA funding had terminated, these geospatial outreach programs continued to 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 geospatial technologies (e.g., interoperability, standards, metadata, architecture), the geospatial extension specialists helped ensure that the vast quantity of information being collected by NASA and other Federal agencies was utilized effectively and shared more broadly with the public.

U.S. Forest Service

The U.S. Forest Service (USFS), in collaboration with the NASA Goddard Space Flight Center Direct Readout Laboratory, the MODIS Rapid Response Project, and the University of Maryland (UMD), continued to process MODIS data from the NASA Terra and Aqua satellites as part of the USFS Active Fire Mapping Program. The USFS Remote Sensing Applications Center antenna at its

facility in Salt Lake City, Utah, collected real-time MODIS imagery for the western U.S. Additionally, the Active Fire Mapping Program integrated real-time MODIS imagery for Alaska, Canada, and the eastern U.S. Collectively, the USFS processed these data to generate comprehensive active fire detection data and a dozen other land, atmosphere, and ocean products. Derived active fire detection data and reflectance imagery formed the basis for a suite of daily wildfire mapping, visualization, and data products that were produced operationally for the Continental U.S. (CONUS), Alaska, and Canada. In addition to MODIS, the Active Fire Mapping Program coordinated with the NOAA National Environmental Satellite, Data, and Information Service to acquire near-real-time active fire detection data using NOAA GOES and the Advanced Very High Resolution Radiometer (AVHRR) on board NOAA polar-orbiting satellites. These satellite fire detection data were also integrated into the daily geospatial product suite provided by the program.

The USFS disseminated MODIS, AVHRR, and GOES fire products to national fire managers and the general public via the Internet (*http://activefiremaps.fs.fed.us*). The program Web site received approximately 4.2 million visits in 2010. The products provided the interagency fire community with a synoptic view of the wildland fire situation, aiding in the strategic allocation of firefighting resources and assets throughout the country. In addition, the Active Fire Mapping Program data and products were integrated into several interagency fire support programs and applications. Major media entities routinely used the maps and fire detection data as well.

The USFS also continued to work with the NASA Ames Research Center (ARC) on a number of fire-related remote-sensing technologies. ARC work included advanced sensor design and image processing from airborne platforms, utility of satellite communication data links, mission profiling for tactical wildland fire mapping, and unmanned aerial system (UAS) development. More specifically, the USFS and ARC continued to collaborate on the use of UAS for fire mapping and forest health missions. Because of the light fire season, efforts in 2010 focused primarily on further development of the ARC-sponsored Wide Area Imager and testing and integration of the Autonomous Modular Scanner sensor on a USFS aircraft. Due to the success of the Wildfire Research Applications Partnership, the USFS actively incorporated many of

the technologies demonstrated through the partnership. Other NASA/USFS activities included

- determining the utility of MODIS sensors for the characterization of changing forest health conditions in our Nation's forests;
- estimating the amount, spatial distribution, and statistical uncertainty of aboveground carbon stocks of North American boreal forests;
- investigating the utility of a Ground Penetrating Synthetic Aperture Radar to measure soil moisture, fuel moisture, and biomass;
- implementing and testing of direct readout technologies and algorithms for Earth Observing System (EOS), NPP, and JPSS sensors;
- integrating historic patterns of wildfire, emissions, and climate for Siberia as a basis for estimating the impacts of fire on carbon cycling, quantifying past fire/climate interactions, and projecting future fire/climate change impacts; and
- studying the influence of changing forestry practices on the effects of wildfire and on interactions between fire and changing climate in central Siberia.

Farm Service Agency

The Farm Service Agency (FSA) administered and managed farm commodity, credit, conservation, disaster, and loan programs as laid out by Congress through a network of Federal, state, and county offices. Geospatial systems and data played a fundamental role in the management of FSA's programs. The agency's core dataset was a Common Land Units (CLU) layer, a nationally consistent digital dataset representing farm and field boundaries. FSA used CLUs, digital soil surveys, 1-meter imagery, satellite imagery, and other datasets for program implementation, management, and monitoring of its many and varied agriculture programs.

Throughout 2010, FSA used remotely sensed data to respond to and help mitigate the impacts of flooding, fires, hail, tornadoes, and hurricanes in agricultural areas. MODIS, Advanced Wide Field Sensor (AWiFS), and locally collected high-resolution aerial imagery were used in conjunction with National Weather Service and other USDA and FSA geospatial datasets to immediately respond to

and coordinate efforts with other Federal, state, and local agencies. These data were also used during the recovery period to assist impacted producers and support FSA administration of the Emergency Loan, Emergency Conservation, and Livestock Indemnity Programs.

As the primary source of aerial imagery for the USDA, FSA administered NAIP, leveraging partnership funds from other Federal, state, and local entities to acquire imagery during the growing season over the CONUS. In 2010, FSA collected 4-band imagery over 2 million square miles in 30 states. NAIP, as well as a large imagery archive, was accessible to the public through the USDA Geospatial Data Gateway.

National Agricultural Statistics Service

The National Agricultural Statistics Service (NASS) used remote-sensing data to construct and sample area frames for statistical surveys, estimate crop area and yield, and create crop-specific land cover data layers as inputs for GIS. NASS used remote-sensing data and techniques to improve the accuracy of its statistics. For example, NASS used Landsat imagery, digital National Agriculture Imagery Program orthophoto quadrangles, and other remotely sensed inputs for the CONUS and Puerto Rico to select the yearly area-based samples for the June Agricultural Survey. In addition, NASS constructed a new area-based sampling frame for North Dakota and California.

The remote-sensing acreage estimation project used Resourcesat-1's AWiFS and USGS Landsat data to produce crop acreage estimates for crops at the state and county levels for 36 states for the 2010 crop year, up from 27 states for the previous year. Acreage estimates were created for 16 different crops, up from 15 for the previous year, now covering all the market-sensitive crops and states. With the expanded coverage and timeliness, the NASS Agricultural Statistics Board fully utilized the remote-sensing acreage estimates to set the official estimates for the speculative regions for the creation of its Monthly Crop Production Reports. The FAS Satellite Imagery Archive (SIA) provided 1,194 AWiFS images through a cooperative partnership. Researchers derived remote-sensing-based acreage estimates from a crop-specific land cover categorization called the Cropland Data Layer (CDL). The ground truth for building the CDL came from the FSA CLU program over the

agricultural domain, while the USGS National Land Cover Dataset circa 2001 provided the nonagricultural ground truth. In addition, NASS distributed the CDL for 48 states to users for the previous 2009 crop season on DVD and via the USDA Geospatial Data Gateway Web site.

NASS also continued its partnership with ARS to conduct research and implement the use of MODIS sensor vegetative index and surface temperature data for setting state and county corn and soybean yield estimates. Three states—North Dakota, Missouri, and Arkansas—were added to the remote-sensing yield program for the 2010 crop year, bringing the total number of states from seven to ten. The Agricultural Statistics Board utilized estimates from this algorithm when setting the official September and October yield estimates for these states. State and district level yield indications were provided monthly to the states in September and October. County-level indications were provided for all 10 states in October.

Foreign Agricultural Service

The Foreign Agricultural Service (FAS) administered and managed the primary international missions for the USDA. The FAS managed market development, trade agreements and negotiations, market intelligence, and congressionally mandated global crop statistics. The FAS Office of Global Analysis assessed and produced the global agricultural crop production outlook and conditions that affect world food security. Satellite and additional advanced remote-sensing information provided an objective and repeatable source of information for early warnings of unusual crop conditions and potential disruptions in the global food supply. This information, when used in the context of the FAS convergence of evidence methodology, enabled rapid and precise determinations of global food supply conditions by the FAS global crop analysts and GIS specialists. The FAS geospatial program remained a key element in the USDA mission critical analysis of global agricultural production and crop conditions by providing timely, accurate, and unbiased estimates of global crop area, yield, and production. The pertinent intelligence was issued monthly in the FAS *World Agricultural Production Report* as part of the monthly commodity analysis procedure conducted by the World Agricultural Outlook Board (WAOB) and its World Agricultural Supply and Demand Estimates

Report. The FAS partnered with the Department of Defense in assessing food supply conditions for stabilization and reconstruction operations in Iraq, Pakistan, Afghanistan, and the surrounding Middle East region. The FAS also provided an early warning of drought- and flood-related food supply disruptions in several countries including Afghanistan, Pakistan, and Iraq, which enabled the U.S. Government to position emergency food supplies, ascertain crop conditions, and make critical crop planting decisions.

The FAS partnered with the Department of State U.S. Agency for International Development (USAID), the National Geo-Spatial Agency (NGA), NASA, USGS, and NOAA to share pertinent satellite-derived datasets and information (including weather data) that exploited space technologies for food security, special projects, foreign market intelligence, and agricultural cropland data that could affect specific commodities and be of concern to the U.S. Government, trade groups, and farm organizations. The FAS also maintained the USDA's SIA, which is the agency's primary source of satellite imagery, housing an archive of global imagery (including of the CONUS). The SIA saved the USDA millions of dollars by employing a centralized data acquisition, archival, and dissemination strategy to eliminate redundant satellite purchases. The FAS, UMD and NASA also cooperated on a key project to exploit space technologies, including near-real-time satellite data acquisition and global lake and reservoir monitoring. This ongoing USDA/UMD/NASA Global Agriculture Monitoring partnership continued to expand to multiple universities, commercial companies, and international organizations. Robust information on the FAS remote sensing program can be found online at *http://www.pecad.fas.usda.gov/cropexplorer.* This site features satellite imagery, global reservoir and lake monitors, a tropical cyclone monitor, vegetation indexes, soil moisture information, precipitation data, and more.

Natural Resources Conservation Service

The Natural Resources Conservation Service (NRCS) worked with private landowners through conservation planning and assistance to benefit the soil, water, air, plants, and animals for productive lands and healthy ecosystems. Seventy percent of the land in the U.S. is privately owned, making stewardship by private

landowners absolutely critical to the health of our Nation's environment. For over 50 years, NRCS has used remote-sensing products to carry out agency programs.

Digital orthoimagery, derived from aerial and satellite data, was the primary remote-sensing product used by NRCS to inventory, monitor, manage, and assess our natural resources in GIS nationwide. By partnering with other Federal and state agencies, NRCS acquired statewide 1-meter or better resolution orthoimagery for 32 states and parts of Alaska, Hawaii, the Pacific Basin, and Puerto Rico. NRCS was an active member of several geospatial coordination groups, including the National Digital Orthophoto Program, which assisted in orthoimagery coordination efforts. All orthoimagery purchased by NRCS was made available to internal users and the general public via the USDA Geospatial Data Gateway Web site. NRCS contracted for high-resolution aerial photography (4-inch ground resolving distance) over 70,901 confidential statistical sites to collect natural resources data for the annual National Resources Inventory (NRI) program. The NRI also acquired direct digital, 4-band, 15-centimeter-resolution orthoimagery over 2,000 sites to evaluate possible issues with a transition from film to digital imagery. NRCS contracted for high-resolution aerial photography over 10,306 Stewardship Land Easements covering about 1.9 million acres to be used to monitor compliance and ecological succession. The use of remote-sensing techniques has replaced making expensive on-site visits to collect the same data. High-resolution satellite imagery was acquired for conducting conservation, NRI, and Soil Survey data in Alaska, Hawaii, and the Pacific Basin.

NRCS also used commercial high-resolution satellite imagery from NGA's Web-based Access and Retrieval Portal to fill in gaps in aerial film coverage. NRCS continued using Landsat and AWiFS scenes from the USDA SIA and ASTER data from the Land Processes Distributed Active Archive Center for statewide natural resource analysis, change detection, and Soil Survey pre-mapping. NRCS upgraded most satellite orthoimagery licenses in Hawaii and the Pacific Basin to allow more open distribution of orthoimagery data to Government, universities, not-for-profit organizations, and the general public. NRCS cooperated on the acquisition of high-resolution orthoimagery with the U.S. Army Corps of Engineers for Puerto Rico and the U.S. Virgin Islands.

NRCS also funded high-resolution digital elevation data in selective areas of many states. The data were used in a variety of NRCS agency programs such as Soil Survey, Engineering, Watershed Assessments, Water Resources, and Conservation Planning. NRCS was a member agency of the National Digital Elevation Program (NDEP), a multi-agency Federal partnership chaired by the USGS to expedite the collection and availability of digital elevation data. NRCS funded Interferometric Synthetic Aperture Radar (IfSAR)–based digital elevation data in North Dakota and South Dakota. NRCS funded LIDAR-based digital elevation data in coordination with USGS/NDEP in Alabama, Arkansas, Illinois, Kansas, Oregon, Tennessee, and Kentucky.

Risk Management Agency

The Risk Management Agency (RMA) administered an area-based insurance policy for livestock grazing and forage lands to help agricultural producers better manage risk. First piloted in 2006, a satellite-derived Rainfall Index (RI) and Vegetation Index (VI) served as the triggers for Pasture, Rangeland, and Forage (PRF) Insurance Program indemnity payments. The RI, which was based on data obtained from the NOAA Climate Prediction Center, required producers to select at least two two-month time periods when precipitation was important for the growth and production of a forage crop. Insurance payments were calculated based upon the deviation from normal rainfall during the selected time periods. Alternatively, the VI, which is based on USGS EROS Normalized Difference Vegetation Index (NDVI) data derived from AVHRR and MODIS, required producers to select one or more three-month time periods when NDVI data can be used to assess the growth and production of a forage crop. The NDVI measures vegetation greenness and can serve as an indicator of vegetation conditions and productive capacity. The VI-related insurance payments were determined based on NDVI deviations from normal. Given the success of these satellite-based indices in administering the PRF Insurance Program, the RMA began using the RI and VI as triggers in the Apiculture Pilot Insurance Program for beekeepers.

Office of Chief Information Officer

The Office of Chief Information Officer (OCIO) developed a geospatial information tool using remote-sensing data to help visually identify and analyze renewable energy opportunities for multiple stakeholders. Opportunities in renewable energy are viewed broadly to include the entire supply chain from feedstock production to end use (delivery) of renewable energy.

The geospatial tool is used to identify transportation biofuels (ethanol, biodiesel) for renewable energy opportunities. It is considered static and based upon existing data and information that would enable (1) a potential producer of feedstock to identify whether it makes sense to produce a biofuel feedstock such as miscanthus or switchgrass vis-à-vis alternatives such as grain or to have land in the Conservation Reserve Program; (2) a potential owner of a biorefinery, such as an organization or local community, to assess whether it may be economical to build a facility or retrofit an existing one; and (3) owners of refueling stations to consider adding blender pumps.

At all three of these levels, there may be Federal, state, and local programs or incentives that could affect the economic viability of growing a particular biomass, building a biorefinery, or adding blender pumps. The idea is to have as much needed information as possible within the tool so that one could assess whether an opportunity exists. An important outcome is to provide Federal-, state-, and county-level logistics, environmental linkages, and economic linkages across feedstock production, renewable energy production, and renewable energy demand using the latest technologies to create an interactive tool to help users identify agricultural linkages that will help better the environment and economy.

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. 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, and 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 National Astronomy and Ionosphere Center (NAIC), 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.

In partnership with Europe, Canada, Japan, and Taiwan, the United States continued construction on the Atacama Large Millimeter/submillimeter Array (ALMA), an interferometer located near San Pedro de Atacama, Chile. FY 10 saw continued delivery of North American antennas at a rate of about one every two months and transport of the first eight accepted North American and Japanese antennas to the 16,500-foot, high-altitude site. Commissioning of the antenna array was started. The number of antennas at various stages of commissioning, integration, and testing in Chile now totals 41–19 from the United States, 13 from Japan, and 9 from Europe.

AST continued support for the development 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. In FY 10, 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. Contracts for the detailed design and construction of the major subsystems have been issued, and the primary mirror blank has been cast. Construction will begin after final permits authorizing access to the site on Haleakala peak on Maui, Hawaii, have been granted.

In FY 10, AST continued to fund a four-year technology development and design effort for the Large Synoptic Survey Telescope (LSST). The LSST will be a 6.7-meter effective aperture telescope with a field of view exceeding 3 degrees, using a 3.3-gigapixel camera to image the entire accessible sky repeatedly, producing approximately 20 terabytes of data nightly. The science goals of the LSST project are extremely broad, spanning the fields of cosmology, galactic structure, and solar system astronomy and especially opening up the transient time domain. The LSST will undertake both a census of distant (trans-Neptunian) solar system objects and surveys of near-Earth and potentially hazardous asteroids. Over a 10-year lifetime, the LSST should provide a 90-percent-complete sample of potentially hazardous

objects with diameters greater than 250 meters and an 80-percent-complete sample of those with diameters down to 140 meters. The University of Arizona's Steward Observatory Mirror Lab is fabricating the 8.4-meter-diameter primary/tertiary mirror using funds from private donors. The camera is being designed at the Stanford Linear Accelerator Center (SLAC) National Accelerator Laboratory with the expectation that it will be funded by the Department of Energy. The LSST project was rated as the highest priority ground-based facility by the 2010 Astronomy and Astrophysics decadal survey, *New Worlds, New Horizons*. As a consequence, the National Science Foundation and the Department of Energy formed a Joint Oversight Group and are moving aggressively to enable the construction of LSST and its operation for a 10-year prime mission.

The Atacama Cosmology Telescope (ACT) is a new 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 (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 10, the telescope continued to operate successfully in its second 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. Also in FY 10, funding was approved to continue the project for another five years and to upgrade and expand the bolometer cameras and add polarization measurement capability.

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 (FFRDC) of the NSF. HIAPER is FAA-certified to operate at 51,000 feet. 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 10, the DLR's 550 staff and the GV's staff continued collaboration on instrument pod development and shared instrumentation. In FY 10, 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 10 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 10. 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 the NSF's heavy-lift C-130Q research aircraft. In FY 10, the C-130Q completed a major inspection and, with ARRA funding, was given an avionics upgrade to meet new requirements and to make it compatible with HIAPER's avionics. The C-130Q also participated in international airborne exhibition and instrument calibration flights in Toulouse, France, in October 2010, organized by the European Facility for Airborne Research.

The AGS Geospace Section (GS) supported a wide variety of research programs in space science in FY 10. 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 10 included the Upper Atmospheric Facilities (UAF) 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.

NSWP is a multi-agency 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 10, GS contributed to the further development of NSWP's Strategic Plan and Implementation Plan. These plans are available online at the Web site of the Office of the Federal Coordinator for Meteorology (OFCM).

In addition, during FY 10, 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 10, the Community Coordinated Modeling Center (CCMC) for space weather research, co-sponsored 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 the key component of GS efforts. In FY 10, 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 10, 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 mid-latitude 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 10, GS continued to support its new program for CubeSat-based small satellite science missions for atmospheric and space weather research. The first project started as a result of the NSF's 2008 CubeSat competition; a small satellite, known as RAX, completed its mission in 2010. The RAX CubeSat was launched successfully as part of an Air Force Space Test Program launch from Kodiak in Alaska in November 2010. Initially all subsystems, as well as the science payload, operated better than expected, but the RAX satellite subsequently suffered from a premature degradation of the solar cells and has now ceased operations. Another three missions selected from the first NSF CubeSat competition in 2008 have progressed very well, and all three have been manifested on launches with NASA's Educational Launch of Nanosatellites (ELaNa) program. From the NSF's second CubeSat solicitation in May 2009, two more excellent science projects were started in FY 10, adding exceptional capabilities and breadth to the overall CubeSat program. 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.

GS continued support for the satellite-based Active Magnetosphere and Planetary Electrodynamics Response Experiment (AMPERE) through FY 10. 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 10, with funding dedicated to Major Research Instrumentation from the American Recovery and Reinvestment Act of 2009, GS was able to support much-needed upgrades at the Owens Valley Solar Array in California.

In FY 10, 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 Ionosphere Photometers; and the Tri-Band Beacons. These data have been provided freely to the world scientific community.

COSMIC RO 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, the Taiwan 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 the response of the global ionosphere to the impact of solar storms.

During FY 10, 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 three 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 has received funding from U.S. agencies and Taiwan to continue its operation through April 2011.

Office of Polar Programs

For FY 10, the primary activities of the 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 to survey deep space galaxy clusters, as well as preparing for the completion of the construction of the IceCube Neutrino Observatory.

The South Pole Telescope successfully completed its fourth winter survey-observing period (northern summer 2010), adding a few hundred new massive galaxy clusters via the Sunyaev-Zeldovich Effect (SZE) independent of redshift. (SZE is a decrement in the strength of the Cosmic Microwave Background Radiation as it is scattered by electrons in galaxy clusters.) This survey of SZE galaxy clusters is mostly complete—one more austral winter season is needed to cover all 4,000 square degrees of the southern skies. This mapping allows the reconstruction of the universe's evolution through the power of this new method of distant galaxy cluster mass detection.

During the austral summer 2009–10, the South Pole IceCube Neutrino Observatory deployed 21 new strings of optical photodetectors in deep ice under the South Pole Station in Antarctica, making the majority of the detector volume (79 strings) available for science observations. The observatory expects the completion of all 86 strings (six constitute the additional Deep Core Array for low-energy-neutrino detection) in the beginning of FY 11. 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/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.

The DOS continued to represent the U.S. 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, the DOS considers promoting the safe and responsible use of space by all current and future spacefaring nations as a vital goal. At UNCOPUOS, the DOS led U.S. efforts on 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, the DOS continued to promote space weather as an important foreign policy topic worldwide.

The DOS continued strong international efforts to implement the National Space Based Positioning, Navigation, and Timing (PNT) Policy in FY 10. Building on the successful fourth plenary meeting of the International Committee on Global Navigation Satellite Systems (ICG-4) held in Russia in September 2009, State pursued work plans throughout the year 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. Throughout the year, State also led interagency preparations for ICG-5, which was held in Turin, Italy, in October 2010.

The U.S. and EU conducted satellite navigation working group meetings on compatibility and interoperability as well as security issues in May 2010 in Brussels, Belgium, that allowed a frank exchange on future plans for each system. A U.S.-EU follow-up meeting in July 2010 in Washington opened the way for closer cooperation and resolution of outstanding signal and security issues. The U.S.-EU working group on next-generation systems completed work on two papers showing the advantages of combined GPS-Galileo receivers in various impeded environments. A joint press announcement lauded the accomplishment. The technical papers were released to the international community in the summer of 2010.

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

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 IIIB and new GLONASS satellites.

State supported a strong public outreach and diplomatic campaign to underscore the reliability and accuracy of GPS. State speakers gave presentations at many international conferences, including the Moscow International GNSS Conference, the Korean International GNSS symposium, the European Position Determination System (EUPOS) meeting, meetings of the international section of the Civil GPS Service Interface Committee, and the annual Institute of Navigation conference. State also attended the Cairo International Conference and Exhibition on GNSS issues, sponsored by the Arab Institute of Navigation.

Talks with the president of the Arab Institute of Navigation, Dr. Refaat Rashad, led to his nomination for a position as an international member and maritime GPS expert on the U.S. National PNT Advisory Board.

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 one intergovernmental organization (the International Committee on the Global Navigation Satellite System), one participant from the European Commission, and one non-governmental 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 U.S. 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, the DOS initiated a new dialogue with the EU and European Space Agency (ESA) on space weather as part of ESA's space situational awareness program. The 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.

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 Nonproliferation and Verification Research and Development, the Office of Science, and the Office of Nuclear Energy.

Office of Nonproliferation and Verification 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 Office of Defense Nuclear Nonproliferation Research and Development (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 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 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. Analysis, insights, and computer codes based on this research are routinely provided to the user/operations communities as the basis for 24/7/365 global monitoring. These capabilities represent an important non-commercial 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 NuDet 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 AMS02, is a particle physics experiment. Launched on the Space Shuttle in May 2011, AMS02 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. The Large Area Telescope (LAT), the primary instrument on FGST, studies the 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 and NASA, under an interagency Memorandum of Understanding, jointly supported the mission concept development for a Joint Dark Energy Mission (JDEM) until the end of FY 10. The primary scientific objective for JDEM was to determine the nature of dark energy in the universe by measuring the expansion history and the growth rate of large-scale structure. However, the August 2010 report of the National Academy of Sciences' (NAS) Astronomy and Astrophysics Decadal Survey (Astro2010) did not recommend the development of a dedicated space-based dark energy mission. The NAS Survey Committee recommended instead a multi-purpose space-based mission, the Wide-Field Infrared Space Telescope (WFIRST), whose science goals include exoplanet detection, an infrared astronomical survey, and dark energy. SC is not currently participating in the design of WFIRST, although it may consider participation in the future.

The Office of Science also supports research in plasma science, which contributes to SC-NASA mutual interests in 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 will complete a joint experiment in 2011, the Midlatitude Continental Convective Clouds Experiment (MC3E), at the Atmospheric Radiation Measurement (ARM) Climate Research Facility's Southern Great Plains site in central Oklahoma. This experiment supports the development of model improvements and critical algorithms for the NASA Global Precipitation Mission satellite. ARM also provides support at three sites (Southern Great Plains; Barrow, Alaska; and Manus Island, Papua New Guinea) for validation of the Cross-track Infrared Sounder and the Advanced Microwave Sounder that will fly on the Joint Polar Satellite System satellite and will provide profiles of temperature and moisture. 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 system radiation studies. The NASA Space Radiation Laboratory (NSRL) was established at DOE's Brookhaven National Laboratory (BNL) to study the radiobiological effects 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 U.S.

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 (RPS) 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 rover, named Curiosity, launched in November 2011. Voyagers 1 and 2 left Earth in 1977 and began their grand tour of the outer planets; they are expected to continue functioning until 2025. The Cassini mission launched in 1997, entered orbit around Saturn in 2004, and should continue to operate until at least 2017. The New Horizons mission, launched in 2006, is on its way to a planned Pluto encounter in 2015.

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 assure 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 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.

FY 10 marked the seventh year of operations for NASA's Spitzer Space Telescope, whose Infrared Array Camera (IRAC) was developed at SAO and constructed at the NASA Goddard Space Flight Center. Spitzer is operated by the Jet Propulsion Laboratory. Spitzer studies the universe at infrared wavelengths of light, enabling the telescope 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 2009, more than five and a half years after launch, Spitzer ended its cryogenic mission phase when it ran out of liquid helium coolant. However, Spitzer is still cold enough (–406 degrees Fahrenheit) that two of IRAC's four detectors can continue to operate. The Spitzer Warm Mission has an anticipated lifetime of five years.

IRAC team members at SAO are leading or participating in six Spitzer Warm Mission Exploration Science Programs and were awarded the largest observing times in the Exploration Science Programs. To date, IRAC has logged a total of over 16,300 hours of operation in the Warm Mission.

A major program of the Spitzer/IRAC team at SAO is the study of birth and evolution of galaxies in the very early universe, just a few hundred million years

after the Big Bang. These early galaxies serve as beacons of the first sites of star formation, as a constraint on galaxy formation models, and as probes of the era of reionization in the early universe.

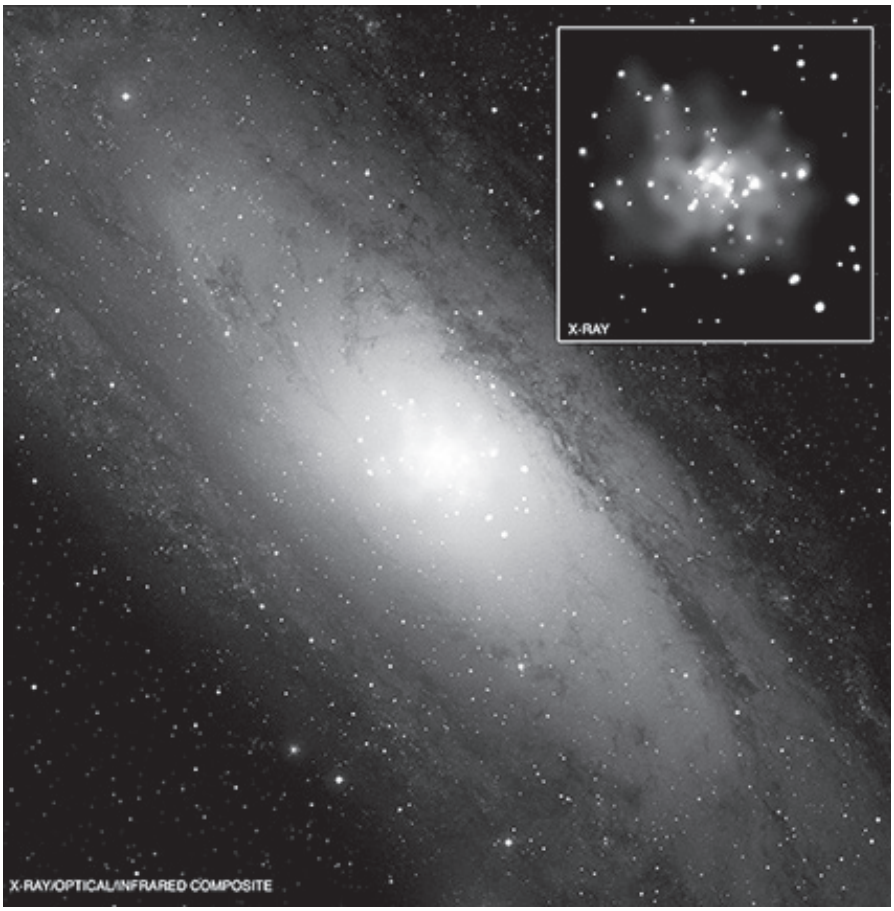
The IRAC team is currently carrying out the largest observing program (2,100 hours) on the Warm Spitzer Mission (Spitzer Extended Deep Survey—SEDS) to search in five different fields (approximately 1 square degree of the sky) to identify and characterize the spectrum of the very early galaxy population. The IRAC team members are also co-investigators on the Cosmic Assembly Near-infrared Deep Extragalactic Legacy Survey (CANDELS), which is a recently approved Hubble Space Telescope (HST) Cosmology Survey Multi-Cycle Treasury Program. During 901 HST orbits, CANDELS will image more than 250,000 galaxies within the same fields as the SEDS program. IRAC team members were also recently awarded 1,182 hours of Warm Spitzer Mission observing time to significantly increase the depth of the IRAC observations in the CANDELS Wide Fields (approximately 0.2 square degrees of the sky). These probes of the early universe, over a relatively large area and to such a depth by HST and Spitzer/IRAC, will have a major impact on our knowledge of galaxy evolution and leave an important legacy for years to come.

A sample of other FY 10 findings made by the Spitzer Space Telescope in which SAO IRAC team members participated include

- physical characterization of 65 near-Earth objects (asteroids) to determine their potential as targets to land spacecraft, including determining their size, albedo (reflectivity), and thermal history;
- discovery of the most massive known galaxy cluster at a distance of 7 billion light-years;
- an ultra-deep survey of the HST Early Release Science field to detect the most distant galaxies; and
- observations of the most massive galaxy clusters in the 2,500-square-degree South Pole Telescope survey.

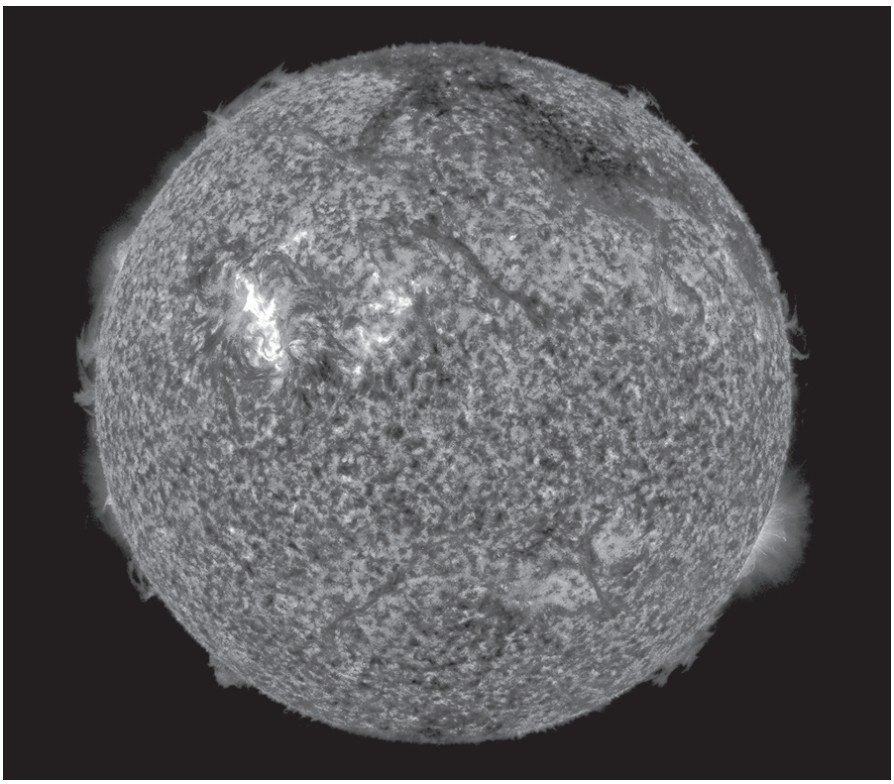
As one of NASA's Great Observatories, the Chandra X-ray Observatory studies the high-energy universe with unparalleled vision in X-ray light. In January 2010, NASA announced that it had extended the contract with SAO to provide science and operational support for Chandra.

In FY 10, astronomers using Chandra made several important and intriguing discoveries. These included providing a major advance in understanding a type of supernova critical for studying the dark energy that astronomers think pervades the universe. The results show that mergers of two dense stellar remnants are the likely cause of many of the supernovae that have been used to measure the accelerated expansion of the universe.



Scientists also reported evidence for a thin veil of carbon found on the neutron star in the Cassiopeia A supernova remnant. By analyzing Chandra's X-ray spectrum—akin to a fingerprint of energy—and applying it to theoretical models, a team of researchers determined that the neutron star in Cassiopeia A has an ultrathin coating of carbon. This is the first time the composition of an atmosphere of an isolated neutron star has been confirmed.

Chandra continued to increase our understanding of black holes. One result provided evidence for powerful winds blowing away from the vicinity of a supermassive black hole in a nearby galaxy. This discovery indicated that "average" supermassive black holes may play an important role in the evolution of the galaxies in which they reside. Another result supported the premise that two mid-sized black holes exist close to the center of a nearby starburst galaxy. These "survivor" black holes avoided falling into the center of the galaxy and could be examples of the seeds required for the growth of supermassive black holes in galaxies, including the one at the center of the Milky Way.



The Solar Dynamics Observatory (SDO) launched in February 2010. SDO provides better-than-HD-quality images of the sun's surface and outer atmosphere. SAO is a major partner in the Atmospheric Imaging Assembly—a group of four telescopes that photograph the sun in 10 different wavelength bands, or colors, once every 10 seconds. In August 2010, SAO issued an aurora alert after detecting a solar eruption heading our way. The announcement garnered major media

coverage. Sky watchers from Minnesota to Norway enjoyed spectacular views of the Northern Lights. Such alerts will become more common as the sun's activity increases toward a 2013 maximum.

In the future, SAO will play a major role in a mission to "touch" the sun. When NASA's Solar Probe Plus launches before the end of the decade, it will carry a suite of cutting-edge scientific instruments. Only one—the Solar Wind Electrons Alphas and Protons (SWEAP) Investigation—will directly sample the sun's outer atmosphere. Designed by Smithsonian scientists, part of SWEAP will extend beyond the probe's heat shield to scoop up some of the sun's tenuous gases. In September 2010, the SWEAP proposal received $67 million from NASA for instrument design and development.

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

SAO is playing a leading role in working toward the scientific success of NASA's Kepler mission. Launched in 2009, Kepler is tasked with hunting for exoplanets orbiting select stars in the Lyra and Cygnus constellations. SAO has been involved in the development of the Kepler mission for more than a decade. SAO has seven members of the Kepler Science Team, supported by a much larger number of staff members, postdocs, and students.

SAO scientists are making major contributions to the confirmation and characterization of planet candidates identified by Kepler. The highlights in FY 10 included follow-up observations and preparation of publications for the first five confirmed Kepler planets, announced in January 2010, and the announcement of five systems with multiple transiting planets in June 2010.

The most spectacular success of Kepler in FY 10 was the detection of transit timing variations in the multiple transiting system Kepler 9. SAO scientists led the effort to determine the masses of the two Saturn-sized planets, the first time this technique had been applied to exoplanets. This discovery was published in *Science Express* in August 2010 and was featured on the cover of the printed version in *Science* magazine. This technique may prove to be critical for the success of the primary goal of the Kepler mission—to confirm and characterize the population of planets like Earth, especially those that might be the right temperature for liquid water on their surfaces.

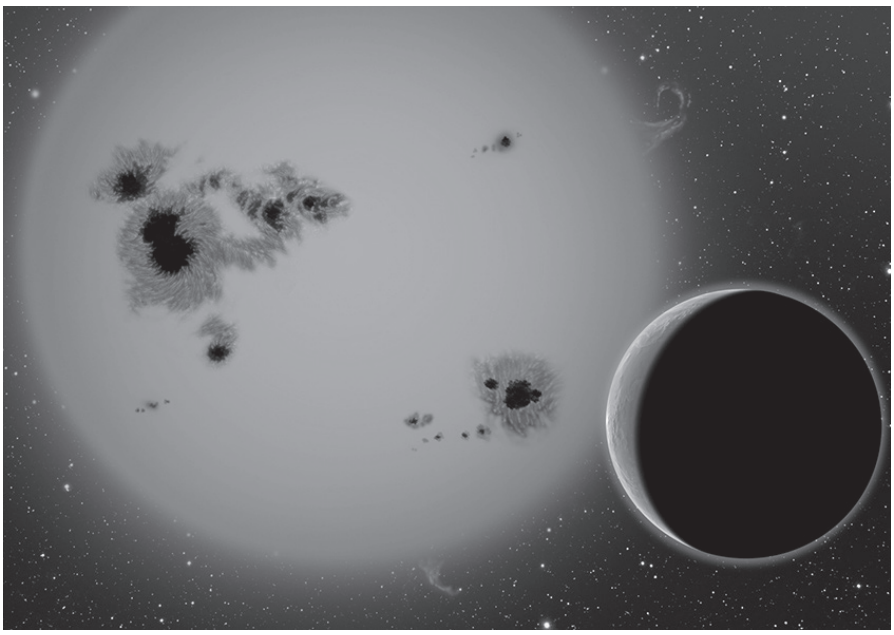
Less spectacular, but equally important for Kepler to achieve a large yield of planets, was the work led at SAO to validate planets with too little mass to be confirmed by the traditional radial-velocity technique. This approach was used to validate a third, small, inner planet in the Kepler-9 system. This approach is now a major element in plans for confirming and validating planets.

SAO's largest field installation is the Fred Lawrence Whipple Observatory (FLWO) on Mount Hopkins, near Amado, Arizona. FLWO is the site for a number of instruments ranging from arrays of small robotic telescopes searching for variable stars and exoplanets to the 6.5-meter (256-inch) Multiple Mirror Telescope (MMT), a joint facility operated with the University of Arizona for solar system, galactic, and extragalactic astronomy.

In FY 10, the smallest research telescopes at FLWO, the Hungarian-made Automated Telescope Network (HATNet), added seven more planet discoveries, bringing the total to 30 confirmed exoplanet systems since 2007. In this completely robotic system working with related sites in Hawaii, Israel, and Chile, the HAT planet candidates are followed up with observations on other FLWO telescopes. Such follow-up observations contributed to the discovery of exoplanet HAT-14b's unusual retrograde, or "backwards," orbit.

FLWO also hosts the MEarth (pronounced "mirth") Project—an array of eight identical, 16-inch-diameter RC Optical Systems telescopes that monitor a preselected list of 2,000 red dwarf stars to hunt for exoplanets. Soon after startup in early FY 10, MEarth scientists announced the discovery of the most Earth-like planet to that date, a "super-Earth" orbiting a red dwarf star 40 light-years from Earth. They found the planet with a set of ground-based telescopes no larger than those many amateur astronomers have in their backyards. (A super-Earth is a planet up to 3 times the size of Earth and weighing 2 to 10 times as much.)

In FY 10, the workhorse MMT continued its wide-ranging research into projects from stars in our own Milky Way Galaxy to mapping the large-scale structure of the universe. The wide-field configuration of the MMT is being put to use in the HectoMAP galaxy survey. HectoMAP, the largest of the redshift surveys, will cover 50 to 75 square degrees of the northern sky, examining light from galaxies up to 3.75 billion light-years distant. This large, dense survey offers rich opportunities for the study of galaxy and galaxy-cluster evolution as well as the large-scale structure



of the universe. This project will make use of the Hectospec multi-object spectrograph, which is fed by 300 optical fibers. Dual robots, dubbed Fred and Ginger, reconfigure all 300 optical fibers in just 300 seconds.

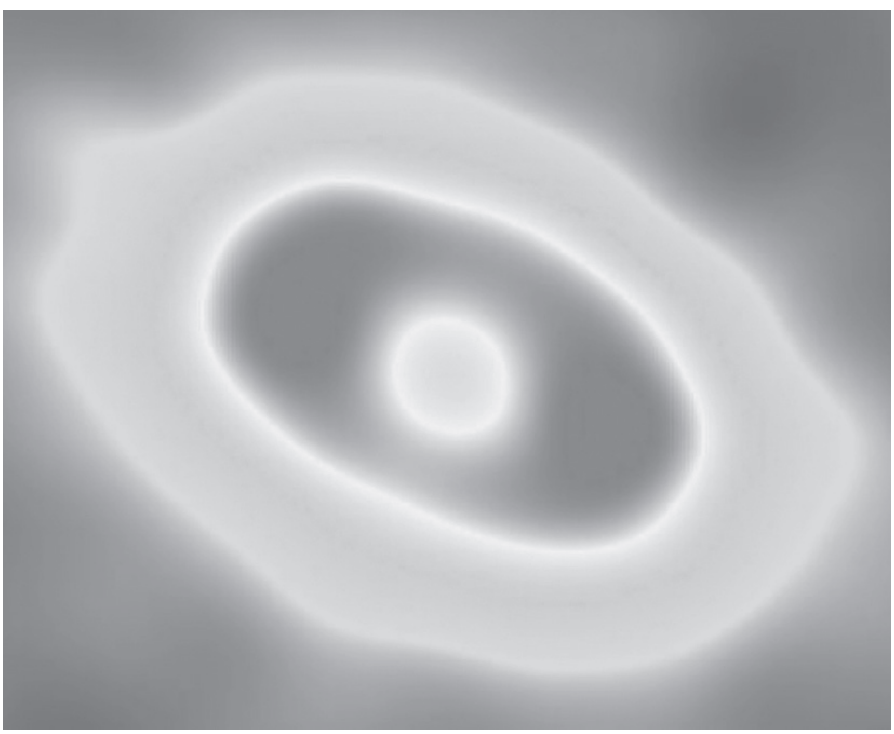
The Very Energetic Radiation Imaging Telescope Array System (VERITAS) at FLWO observes cosmic gamma rays. Each of the four 12-meter optical reflectors composing the VERITAS array is equipped with an extremely sensitive, extraordinarily fast camera. Unlike conventional telescopes, VERITAS does not directly observe the radiation from astronomical sources. Rather, it detects the fleeting burst of light (Cherenkov radiation) produced by the interaction of gamma rays with Earth's atmosphere.

In FY 10, VERITAS helped solve a 100-year-old mystery concerning the origin of cosmic rays. Cosmic rays are atomic particles—mostly protons—that zip through space at nearly the speed of light. The mystery was, where and how are these particles accelerated? VERITAS detected an over-abundance of cosmic rays in Messier 82, a nearby starburst galaxy in which the rates of massive star formation and of supernovae are much higher than in our own galaxy. Astrophysicists had long predicted that the winds associated with massive stars and the shocks created by supernovae would produce cosmic rays. By observing gamma rays resulting from the collision of cosmic rays with gas and dust in Messier 82, VERITAS was able

to confirm this hypothesis. Not until the advent of VERITAS was any instrument sensitive enough to provide this important observation.

The Smithsonian Astrophysical Observatory's Submillimeter Array (SMA), a pioneering observatory for radio astronomy, continued to engage in a wide variety of astronomical observations in FY 10. Three key areas of investigation were distant galaxies, planet-forming disks around other stars, and magnetic fields within star-forming molecular clouds.

Submillimeter telescopes such as the SMA are ideal for studying star and galaxy formation in the distant universe because light from those galaxies is shifted into the submillimeter part of the spectrum by the universe's expansion. In FY 10, the SMA studied a rich collection of galaxies, discovered by the Herschel infrared satellite, that are unusually bright at submillimeter wavelengths. The high-resolution SMA images confirmed that in each case, the high brightness is due to gravitational lensing—focusing of the submillimeter emission by another galaxy intervening along the line of sight. Because all the brightest submillimeter galaxies are gravitationally lensed, astronomers can study the properties of these distant galaxies, which would be near the detection limit of the SMA without the lensing effect.



Recent discoveries of several hundred planets orbiting distant stars have motivated great interest in the evolution of solar systems similar to our own. The submillimeter is an ideal wavelength to study nascent solar systems. In FY 10, the SMA examined truncated disks of material orbiting newborn stars, disks whose sharp boundaries may be created by a newly formed but unseen planet. This continuing research will help determine whether solar systems such as ours with Earth-like planets are common.

Magnetic fields are themselves invisible, but their structure in the interstellar medium is often evident in the pattern of polarized radio emission, which is emitted by dust grains aligned with the field. In FY 10, the SMA used polarized emission to map the magnetic field direction in large-scale molecular clouds and in the accretion flows around just-forming stars. These observations will test theories asserting that the process of star formation is controlled entirely by magnetic forces.

In public outreach, SAO celebrated the 80th anniversary of 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 and view the Moon, stars, and planets through a variety of telescopes. Attendees routinely fill the observatory auditorium and a nearby overflow room to capacity. The lectures are Webcast live and archived online to reach a broader audience.

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."

The From Earth to the Universe (FETTU) project, which started as a major initiative of the International Year of Astronomy 2009, continued to be on display in locations around the world. FETTU seeks to inspire and help contextualize planetary and space science by exhibiting large-scale images of astronomical objects in non-traditional and mostly public locations such as parks, metro stations, art centers, and others. By the close of FY 10, FETTU had been displayed in over 1,000 separate locations in over 70 countries, and the captions had been translated into some 40 languages. FETTU was developed and led by a team at SAO's Chandra X-ray Center.

A museum exhibit developed by SAO educators and scientists also continued to tour the country. Titled *Black Holes: Space Warps & Time Twists*, the

2,500-square-foot traveling exhibition pulled visitors into the modern search for real black holes—the most mysterious and powerful objects in the universe.

In FY 10, NASM continued to educate and inspire the public through exhibits and education programs, including discovery stations, lecture series, family educational events, and intern programs. The Museum commemorated the 40th anniversary of the Apollo 13 mission with a panel discussion with the surviving Apollo 13 astronauts and other NASA figures involved in the mission. Three major exhibitions were opened this fiscal year: *Moving Beyond Earth* on the topic of human spaceflight; *Beyond: Visions of Our Solar System*, an exhibit of striking planetary images collected by unpiloted spacecraft missions; and the *Barron Hilton Pioneers of Flight Gallery*, on aviation and early rocketry in the 1920s and 1930s. The *Pioneers of Flight* gallery featured public programs and a space emphasizing early childhood education.

Construction was completed at the Museum's Steven F. Udvar-Hazy Center. The newly completed areas include a large restoration hangar, a conservation lab, and storage for the artifact and archival collections.

Staff members in NASM's Center for Earth and Planetary Studies (CEPS) continued to participate on the science teams of several spacecraft missions. Dr. John Grant served as a participating scientist for the Mars Exploration Rover (MER) mission, as a chair of the MER Science Operations Working Group. In that capacity he directed the science team to consensus on targets and operations for the long-lived rovers. He conducted real-time mission planning from a control station installed on site at CEPS. Dr. Grant also co-chaired the Mars Science Laboratory (MSL) Landing Site Steering Committee, which worked to identify landing sites for the new Mars rover, scheduled for launch in late 2011.

CEPS staff served on the science teams for the Mars Advanced Radar for Subsurface and Ionosphere Sounding (MARSIS) instrument on Mars Express, both the High Resolution Imaging Science Experiment (HiRISE) and Shallow Subsurface Radar (SHARAD) instruments on the Mars Reconnaissance Orbiter (MRO), the Lunar Reconnaissance Orbiter (LRO), and the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) mission to Mercury.

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, and Mercury, resulting in 40 peer-reviewed publications. Research topics included lunar radar studies; Mars rover results; Mercury tectonics and volcanism; terrestrial fluvial studies; and Martian aeolian, fluvial, and polar features. In addition, CEPS scientists used newly acquired LRO data to identify previously undetected fault scarps distributed across the lunar surface that indicate that the moon has contracted in recent geologic time.

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, serving the mid-Atlantic and southeastern U.S. The CEPS RPIF holds the most complete collection of 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 (through September 30, 2010)	11	0	0	0
TOTAL	**1,663**	**156**	**106**	**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*	11	20			3	9			4	1	1	
*(through September 30, 2010)												
TOTAL	**1,413**	**2,879**	**10**	**8**	**77**	**128**	**1**	**1**	**195**	**29**	**6**	**1**

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, 2009–September 30, 2010

Launch Date Spacecraft Name COSPAR* Designation Launch Vehicle	Mission Objectives	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
October 8, 2009 2009-057A Worldview 2 Delta 2	Commercial/imaging	768 km 765 km 100.2 min 98.5°	Commercial satellite providing Earth imagery in eight color bands
October 18, 2009 2009-057A DMSP 5D-3 F18 (USA 210) Atlas 5	Military/weather	858 km 843 km 101.9 min 98.9°	Department of Defense satellite, one of several in the Defense Meteorological Satellite Program
November 16, 2009 2009-062A STS-129 Shuttle	International Space Station	348 km 336 km 91.4 min 51.7°	Delivered parts to the International Space Station, including a spare gyroscope Final Space Shuttle crew rotation flight to or from the International Space Station
November 23, 2009 2009-064A Intelsat 14 Atlas	Commercial/communications	35,795 km 35,778 km 1,436.1 min 0°	Commercial satellite providing television and data
December 6, 2010 2009-068A WGS F3 (USA 211) Delta 4	Military/geostationary communications	35,789 km 35,784 km 1,436.1 min 0.1°	Wideband Global SATCOM geostationary communications satellite
December 14, 2009 2009-071A WISE Delta 2	Science	525 km 520 km 95.1 min 97.5°	NASA's Wide Field Infrared Survey Explorer will perform a sky survey in four infrared wavelengths
February 8, 2010 2010-004A STS-130 Shuttle	International Space Station	348 km 334 km 91.4 min 51.7°	Installation of the Tranquility module
February 11, 2010 2010-005A SDO Atlas 5	Heliophysics	35,795 km 35,777 km 1,436.1 min 27.9°	Solar Dynamics Observatory will study the sun at high time and spatial resolution
March 4, 2010 2010-008A GOES-15 Delta 4	Geostationary weather	35,884 km 35,802 km 1,438.99 min 0.16°	NOAA's Geostationary Operational Environmental Satellites
April 5, 2010 2010-012A STS-131 Shuttle	International Space Station	346 km 322 km 91.2 min 51.6°	Delivered a multi-purpose logistics module
April 22, 2010 2010-015A OTV 1 (USA 212) Atlas 5	Military	Unknown	United States Air Force X-37B Orbital Test Vehicle, reusable mini-spaceplane capable of autonomous re-entry and landing

Appendix B

(Continued)

Successful Launches to Orbit on U.S. Vehicles

October 1, 2009–September 30, 2010

Launch Date Spacecraft Name COSPAR* Designation Launch Vehicle	Mission Objectives	Apogee and Perigee (km), period (min), Inclination to Equator (°)	Remarks
May 14, 2010 2010-019A STS-132 Shuttle	International Space Station	359 km 336 km 91.5 min 51.7°	Delivered an Integrated Cargo Carrier and a Russian-built Mini Research Module
May 28, 2010 2010-022A Navstar 65/GPS 2F-1 Delta 4	Military/navigation	20,201 km 20,161 km 717.9 min 55.3°	U.S. Air Force satellite, first in a new breed of GPS satellites in the Block 2F series
June 4, 2010 2010-026A Dragon Falcon 9	Commercial	140 km 138 km 87.3 min 34.5°	SpaceX spacecraft flight test, module remained mounted to the upper stage of the rocket
August 14, 2010 2010-039A AEHF 1 (USA 214) Atlas	Military/communications	35,799 km 35,775 km 1,436.1 min 4.3°	First of four Advanced Extremely High Frequency (AEHF) U.S. Air Force satellites that will replace the earlier Milstar system Placed in an initial 221 × 50,179 km × 22.2 degree geosynchronous transfer orbit until the satellite's main engines failed
September 21, 2010 2010-046A USA 215 Atlas 5	Military	Unknown	Classified satellite for the U.S. National Reconnaissance Office
September 26, 2010 2010-048A SBSS (USA 216) Minotaur 4	Military	632 km 631 km 97.4 min 98°	U.S. Air Force Space Based Space Surveillance satellite, part of the United States Strategic Command's Space Surveillance Network

*U.N. Committee on Space Research

Appendix C
HUMAN SPACEFLIGHTS

October 1, 2009–September 30, 2010

Spacecraft	Launch Date	Crew	Flight Time (d:h:min)	Highlights
Space Shuttle Atlantis (STS-129)	November 16, 2009	Charles O. Hobaugh Barry E. "Butch" Wilmore Leland D. Melvin Michael J. Foreman Randolph J. Bresnik Robert L. Satcher, Jr. Nicole P. Stott	10:19:16	Delivered parts to the International Space Station, including a spare gyroscope Final Space Shuttle crew rotation flight to or from the International Space Station Returned Nicole Stott to Earth from ISS Expedition 21
Soyuz-TMA 17 (Expedition 22)	December 20, 2009	Oleg Kotov T.J. Creamer Soichi Noguchi	163:06:33	Carried one Russian crewmember, one U.S. crewmember, and one Japanese crewmember
Space Shuttle Endeavour (STS-130)	February 8, 2010	George D. Zamka Terry W. Virts, Jr. Nicholas J. M. Patrick Robert L. Behnken Stephen K. Robinson Kathryn P. Hire	13:18:06	Delivered the Tranquility Node and a cupola to be used as a control room for robotics
Soyuz-TMA 18 (Expedition 23)	April 2, 2010	Alexander Skvortsov Mikhail Kornienko Tracy Caldwell Dyson	176:01:19	Carried two Russian crewmembers and one U.S. crewmember
Space Shuttle Discovery (STS-131)	April 5, 2010	Alan G. Poindexter James P. Dutton, Jr. Clayton C. Anderson Rick Mastracchio Dorothy M. Metcalf-Lindenburger Stephanie D. Wilson Naoko Yamazaki	15:02:47	Delivered the Leonardo Multi-Purpose Logistics Module (MPLM) Returned with a Japanese experiment retrieved from the International Space Station's exterior
Space Shuttle Atlantis (STS-132)	May 14, 2010	Kenneth T. Ham Dominic A. Antonelli Michael T. Good Garrett E. Reisman Piers J. Sellers Stephen G. Bowen	11:18:29	Delivered an Integrated Cargo Carrier and a Russian-built Mini Research Module (Rassvet)
Soyuz-TMA 19 (Expedition 24)	June 15, 2010	Fyodor Yurchikhin Shannon Walker Doug Wheelock	163:06:11	Carried one Russian crewmember and two U.S. crewmembers

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

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-1B

SPACE ACTIVITIES OF THE U.S. GOVERNMENT

HISTORICAL TABLE OF BUDGET AUTHORITY

(in millions of inflation-adjusted FY 10 dollars)

FY	Inflation Factors	NASA Total	NASA Space	DOD	Other[a]	DOE[b]	DOC	DOI	USDA	NSF[c]	DOT	Total Space
1959	6.091	2,016	1,590	2,985	207	207						4,781
1960	6.002	3,145	2,773	3,367	258	258						6,398
1961	5.928	5,714	5,489	4,825	403	403						10,717
1962	5.846	10,669	10,505	7,588	1,163	865	298					19,257
1963	5.782	21,236	20,964	8,962	1,486	1,237	249					31,412
1964	5.710	29,121	28,641	9,130	1,216	1,199	17					38,987
1965	5.643	29,625	28,993	8,882	1,360	1,292	68					39,235
1966	5.544	28,689	28,079	9,363	1,186	1,037	150					38,628
1967	5.429	26,961	26,223	9,034	1,156	999	157					36,414
1968	5.261	24,133	23,307	10,112	916	763	147	1	5			34,335
1969	5.082	20,282	19,423	10,230	866	600	102	1	5	158		30,519
1970	4.858	18,199	17,233	8,152	685	500	39	5	5	136		26,070
1971	4.611	15,267	14,298	6,972	747	438	124	9	5	170		22,017
1972	4.391	14,521	13,484	6,178	586	241	136	26	9	173		20,248
1973	4.192	14,280	12,967	6,804	618	226	168	42	8	173		20,390
1974	4.017	12,200	11,083	7,094	635	169	241	36	12	177		18,812
1975	3.748	12,104	10,927	7,092	591	112	240	30	7	202		18,610
1976	3.393	12,044	10,941	6,728	571	78	244	34	14	201		18,240
TQ*	3.165	2,950	2,687	1,456	136	16	70	9	3	38		4,279
1977	3.068	11,715	10,555	7,401	594	68	279	31	18	198		18,550
1978	2.945	11,956	10,669	8,063	665	100	303	29	24	209		19,397
1979	2.759	12,679	11,117	8,375	684	163	270	28	22	201		20,177
1980	2.553	13,379	11,949	9,825	590	102	237	31	36	184		22,365
1981	2.346	12,946	11,712	11,327	550	96	204	28	38	184		23,588
1982	2.136	12,907	11,805	14,263	668	130	310	26	32	170		26,737
1983	1.999	13,741	12,648	18,027	654	78	356	10	40	170		31,328
1984	1.915	14,279	13,130	19,519	756	65	452	6	36	197		33,404
1985	1.846	13,982	12,786	23,574	1,078	63	781	4	28	203		37,438
1986	1.788	13,962	12,813	25,262	853	63	553	4	41	193		38,928
1987	1.748	19,092	17,145	28,467	814	84	486	14	33	195	2	46,426
1988	1.703	15,429	14,169	30,100	1,262	410	599	24	31	196	2	45,531
1989	1.650	18,095	16,657	29,539	924	160	497	28	35	200	5	47,120
1990	1.588	19,571	18,199	24,798	803	125	386	49	40	196	6	43,800
1991	1.532	21,467	19,982	21,720	1,183	384	384	44	40	323	6	42,884
1992	1.476	21,128	19,478	22,170	1,177	329	483	50	43	267	6	42,826
1993	1.438	20,582	18,789	20,288	1,051	237	466	47	36	259	6	40,129
1994	1.407	20,502	18,323	18,526	890	104	439	44	44	252	7	37,739
1995	1.378	19,090	17,284	14,667	1,045	82	485	43	44	383	8	32,996
1996	1.349	18,734	16,960	15,536	1,117	62	637	49	50	311	8	33,613
1997	1.324	18,148	16,490	15,524	1,045	46	593	56	52	291	8	33,059
1998	1.300	17,742	16,017	16,066	1,091	134	565	56	51	278	8	33,174
1999	1.284	17,525	15,993	16,948	1,261	135	738	76	47	257	8	34,201
2000	1.267	17,230	15,862	16,394	1,337	208	728	76	56	262	8	33,594
2001	1.242	17,678	16,528	17,798	1,319	180	717	75	45	288	15	35,645
2002	1.214	18,045	16,835	19,103	1,432	201	782	78	34	323	15	37,369
2003	1.194	18,344	17,145	23,149	1,558	228	775	88	50	402	14	41,852
2004	1.170	17,987	16,750	22,356	1,712	244	871	83	71	428	14	40,819
2005	1.140	18,471	17,372	22,453	1,769	261	920	80	83	411	14	41,594
2006	1.104	18,357	17,409	24,420	1,819	271	950	91	93	402	13	43,649
2007	1.068	17,389	16,623	23,938	1,794	214	974	93	69	431	13	42,355
2008	1.037	17,742	17,105	25,700	1,760	202	893	93	61	496	13	44,565
2009	1.013	18,011	17,505	26,881	1,893	203	1,092	65	27	491	14	46,278
2010	1.000	18,725	18,228	26,463	2,057	203	1,261	67	27	484	15	46,748

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)

	Budget Authority						Budget Outlays		
Federal Agencies	**2008 actual**	**2009 actual**	**Recovery enacted**	**2010 actual**	**2010 ARRA**	**2011 est.**	**2008 actual**	**2009 actual**	**2010 actual**
NASA[1, 2]	16,502	17,275	852	18,228			17,231	18,389	18,362
DOD	25,949	26,528		26,463			24,080	24,273	24,142
DOE[3]	195	200	1	203		217	192	193	204
DOC	862	1,078	75	1,261			603	991	1,221
DOI	64	64	0	67			64	64	67
USDA	26.8	26.3		26.6			22.6	21.6	21.6
DOT	13	14	0	15		15	12	14	15
NSF[4, 5]	464	485	142	484	146		361	310	515

(1) The 2008 Consolidated Appropriations Act rescinded $192.5 million in NASA prior-year unobligated balances, effectively reducing NASA's total FY 08 budget authority by this amount.

(2) Beginning in 2009, 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) Beginning in 2007, 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.

(4) The 2008 Actuals that NSF reported in June 2009 were $479 million in authority and $361 million in outlays.

(5) $146 million in FY 10 American Recovery and Reinvestment Act (ARRA) authority is carried over from FY 09 ARRA authority.

Appendix D-3

FEDERAL AERONAUTICS ACTIVITIES BUDGET

(in millions of dollars by fiscal year)

	Budget Authority					Budget Outlays		
Federal Agencies	2008 actual	2009 actual	Recovery enacted	2010 actual	2011 est.	2008 actual	2009 actual	2010 actual
NASA[1, 2]	615	500	150	497		603	778	542
USDA	33.2	48.9		55.4		30.1	47.5	52.6
DOD	10,873	13,248	49	14,166		10,994	12,252	13,573
DOI	26	22	15	30		26	22	30
DOT	2,646	2,897	200	3,104	2,886	2,562	2,587	2,742

(1) The 2008 Consolidated Appropriations Act rescinded $192.5 million in NASA prior-year unobligated balances, effectively reducing NASA's total FY 08 budget authority by this amount.

(2) Beginning in 2009, 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).

Acronyms

4D FMS TBO	Four-Dimensional Flight Management System Trajectory-Based Operations

A

AAD	Aircraft Aging and Durability
ABI	Advanced Baseline Imager
ACD	Advanced Capabilities Division
ACRP	Airport Cooperative Research Program
ACS	Advanced Camera for Surveys
ACT	Atacama Cosmology Telescope
ADS-B	Automatic Dependent Surveillance-Broadcast
AEHF	Advanced Extremely High Frequency
AGN	active galactic nuclei
AGS	Division of Atmospheric and Geospace Sciences
AIM	Assessment, Inventory, and Monitoring
AIWG	Airport Infrastructure Working Group
ALMA	Atacama Large Millimeter/submillimeter Array
ALOS	Advanced Land Observing Satellite
AMISR	Advanced Modular Incoherent-Scatter Radar
AMPERE	Active Magnetosphere and Planetary Electrodynamics Response Experiment
AMS	Alpha Magnetic Spectrometer
APEC	Asia-Pacific Economic Cooperation
ARC	Ames Research Center
ARCHER	Airborne Real-time Cueing Hyperspectral Enhanced Reconnaissance
ARMD	Aeronautics Research Mission Directorate
ARRA	American Recovery and Reinvestment Act
ARS	Agricultural Research Service
ARTEMIS	Advanced Responsive Tactically Effective Military Imaging Spectrometer
AS	Atmosphere Section
AST	Office of Commercial Space Transportation; Division of Astronomical Sciences
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ASTM	American Society for Testing and Materials
Astro2010	Astronomy and Astrophysics Decadal Survey
ASTS	Aeronautics Science and Technology Subcommittee
ASU	Aircraft Sector Understanding
ATC	Air Traffic Control
ATC	ancillary terrestrial component
ATM	Air Traffic Management
ATMS	Advanced Technology Microwave Sounder
ATP	Aeronautics Test Program
ATST	Advanced Technology Solar Telescope
AVHRR	Advanced Very High Resolution Radiometer
AVNIR-2	Advanced Visible and Near Infrared Radiometer Type-2
AWiFS	Advanced Wide Field Sensor

B

BAT	Burst Alert Telescope
BIPM	Bureau of Weights and Measures
BLM	Bureau of Land Management
BNL	Brookhaven National Laboratory

BOR	Bureau of Reclamation
BRDF	bidirectional reflectance distribution function
BWB	Blended Wing Body

C

C3PO	Commercial Crew and Cargo Program Office
CAAFI	Commercial Aviation Alternative Fuels Initiative
CANDELS	Cosmic Assembly Near-infrared Deep Extragalactic Legacy Survey
CBS3	Controlled-Background System for Spectroradiometry and Spectrophotometry
CCAFS	Cape Canaveral Air Force Station
C-CAP	Coastal Change Analysis Program
CCDev	Commercial Crew Development
CCMC	Community Coordinated Modeling Center
CDL	Cropland Data Layer
CDR	Climate Data Records
CEDAR	Coupling, Energetics, and Dynamics of Atmospheric Regions
CEPS	Center for Earth and Planetary Studies
CERES	Clouds and the Earth's Radiant Energy System
CEV	Crew Exploration Vehicle
CfA	Center for Astrophysics
CHIRP	Commercially Hosted Infrared Payload
CIBER	Cosmic Infrared Background Experiment
CIP	Current Icing Products
CISM	Center for Integrated Space Weather Modeling
CLARREO	Climate Absolute Radiance and Refractivity Observatory
CLU	Common Land Unit
CMB	cosmic microwave background
CNES	Centre National d'Études Spatiales
CONOPS	Concept of Operations
CONUS	Contiguous United States
CORS	Continuously Operating Reference Station
COSMIC	Constellation Observing System for Meteorology, Ionosphere, and Climate
COTS	Commercial Orbital Transportation Services
CS	Commercial Service
CTD	Concepts and Technology Development
CU	University of Colorado
CxP	Constellation Program

D

DASH	Discovery in Aeronautics Systems Health
DEM	digital elevation model
DIAL	Differential Absorption Light Detection and Ranging
DLR	German Aerospace Center
DNN R&D	Office of Defense Nuclear Nonproliferation Research & Development
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DOI	Department of the Interior
DOS	Department of State
DOT	Department of Transportation
DSCOVR	Deep Space Climate Observatory
DSN	Deep Space Network

DTN	Disruption Tolerant Network
DWSS	Defense Weather Satellite System

E

EA	Enterprise Architecture
ECLSS	environmental control and life support systems
ECMWF	European Centre for Medium-Range Weather Forecasts
EDA	Efficient Descent Advisor
EELV	Evolved Expendable Launch Vehicle
ELaNa	Educational Launch of Nanosatellites
ELC	ExPRESS Logistics Carrier
ELV	expendable launch vehicle
EMA	electromechanical actuator
EMS	Environmental Management Systems
EOP	Executive Office of the President
EOS	Earth Observing System
ERA	Environmentally Responsible Aviation
ERBS	Earth Radiation Budget Suite
EROS	Earth Resources Observation and Science
ESA	European Space Agency
ESMD	Exploration Systems Mission Directorate
ET	external tank, evapotranspiration
ETDP	Exploration Technology Development Program
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EUPOS	European Position Determination System
EUV	extreme ultraviolet
EVA	Extravehicular Activity
EVE	EUV Variability Experiment
ExPRESS	Expedite the Processing of Experiments to the Space Station

F

FAA	Federal Aviation Administration
FACET	Future Air Traffic Management Concepts Evaluation Tool
FAO	Food and Agriculture Organization
FAS	Foreign Agricultural Service
FASCAL	Facility for Automated Spectroradiometric Calibrations
FCC	Federal Communications Commission
FETTU	From Earth to the Universe
FEWS NET	Famine Early Warning Systems Network
FFRDC	Federally Funded Research and Development Center
FGST	Fermi Gamma-ray Space Telescope
FIP	Forecast Icing Products
FLWO	Fred Lawrence Whipple Observatory
FMS	flight management system
FSA	Farm Service Agency
FSOF	Fairbanks Satellite Operations Facility
FWS	Fish and Wildlife Service
FY	fiscal year

G

GaN	gallium nitride
GAP	Gap Analysis Program

GBD	Global Burst Detector
GBS	Global Broadcast Service
GEM	Geospace Environment Modeling
GHWG	Global Harmonization Working Group
GHz	gigahertz
GIS	Geographic Information System
GLONASS	Global Navigation Satellite System
GloPac	Global Hawk Pacific
GLRI	Great Lakes Restoration Initiative
GMTED2010	Global Multi-resolution Terrain Elevation Data 2010
GNSS	Global Navigation Satellite System
GOES	Geostationary Operational Environmental Satellite
GPS	Global Positioning System
GRIP	Genesis and Rapid Intensification Processes
GS	Geospace Section
GSI	grid point statistical interpolation
GTOPO30	Global 30 Arc-Second Data Elevation Set
GV	Gulfstream V

H

HCT	Hall Current Thruster
HEO	Highly Elliptical Orbit
HIAPER	High-performance Instrumented Airborne Platform for Environmental Research
HIPPO	HIAPER Pole to Pole Observations
HiRISE	High Resolution Imaging Science Experiment
HITL	human-in-the-loop
HRP	Human Research Program
HST	Hubble Space Telescope
HTCG	High Technology Cooperation Group

I

I&M	Inventory and Monitoring Program
ICC-VLD2	Integrated Cargo Carrier–Vertical Light Deployable 2
ICG	International Committee on Global Navigation Satellite Systems
IfSAR	Interferometric Synthetic Aperture Radar
IIFD	Integrated Intelligent Flight Deck
IOAG	Interagency Operations Advisory Group
IP	Internet protocol-based
IR	infrared
IRAC	Integrated Resilient Aircraft Control; Infrared Array Camera
IRIS	Internet Routing in Space
IRTF	Infrared Telescope Facility
ISRP	Integrated Systems Research Program
ISS	International Space Station; Imaging Science Subsystem
ITAC 1	Industry Trade Advisory Committee for Aerospace Equipment
IVGEN	IntraVenous Fluid GENeration
IVHM	Integrated Vehicle Health Management

J

JAXA	Japan Aerospace Exploration Agency
JCTD	Joint Capabilities Technology Demonstration
JDEM	Joint Dark Energy Mission

JPDO	Joint Program Development Office
JPL	Jet Propulsion Laboratory
JPSS	Joint Polar Satellite System

K

K	kelvin
klbf	kilopound-force
km	kilometer
KPI	Key Performance Indicator

L

LADEE	Lunar Atmosphere and Dust Environment Explorer
LANDFIRE	Landscape Fire and Resource Management Planning Tools
LANL	Los Alamos National Laboratory
LAT	Large Area Telescope
LBIR	Low Background Infrared
LCROSS	Lunar CRater Observation and Sensing Satellite
LDCM	Landsat Data Continuity Mission
LEO	Low-Earth Orbit
LIDAR	LIght Detection and Ranging
LIDP	Literal Image Derived Products
LLCD	Lunar Laser Communications Demonstration
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
LWIRCS	Long-Wavelength Infrared Calibration Source

M

MARSIS	Mars Advanced Radar for Subsurface and Ionosphere Sounding
MC3E	Mid-latitude Continental Convective Clouds Experiment
MDEQ	Michigan Department of Environmental Quality
MDXR	Missile Defense Transfer Radiometer
MEP	Manufacturing Extension Partnership
MER	Mars Exploration Rover
MESSENGER	MErcury Surface, Space ENvironment, GEochemistry, and Ranging
MHz	megahertz
MINWR	Merritt Island National Wildlife Refuge
MIT	Massachusetts Institute of Technology
MKID	microwave kinetic inductance detector
MMIS	Mission Medical Information Systems
MMRCA	Medium Multi-Role Combat Aircraft
MOA	Memorandum of Agreement
MOBY	Marine Optical BuoY
MODIS	Moderate Resolution Imaging Spectroradiometer
MOU	Memorandum of Understanding
MRO	Mars Reconnaissance Orbiter
MSL	Mars Science Laboratory
MSP	Multi-Sector Planner
MSS	mobile satellite service

NAIC	National Astronomy and Ionosphere Center
NAICS	North American Industry Classification System
NAIP	National Agricultural Imagery Program
NAIS	North American Ice Service
NAS	National Airspace System; National Academy of Sciences
NASA	National Aeronautics and Space Administration
NASM	National Air and Space Museum
NASS	National Agricultural Statistics Service
NAVAIR	Naval Air Systems Command
NCAR	National Center for Atmospheric Research
NCBN	Northeast Coastal and Barrier Network
NCDC	National Climatic Data Center
NCEP	National Centers for Environmental Prediction
NDE	nondestructive evaluation
NDEP	National Digital Elevation Program
NDVI	Normalized Difference Vegetation Index
NE	Office of Nuclear Energy
NESDIS	National Environmental Satellite, Data, and Information Service
NextGen	Next Generation Air Transportation System
NFAC	National Full-Scale Aerodynamic Complex
NGA	National Geospatial-Intelligence Agency
NGDC	National Geophysical Data Center
NIC	National Ice Center
NIFA	National Institute of Food and Agriculture
NIST	National Institute of Standards and Technology
NISTAR	NIST Advanced Radiometer
NLS	NASA Launch Services
nm	nanometer
NNSA	National Nuclear Security Administration
NOAA	National Oceanic and Atmospheric Administration
NOAO	National Optical Astronomy Observatory
NOS	National Ocean Service
NPAT	National Partnership for Aeronautics Testing
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
NSG	National System for Geospatial Intelligence
NSO	National Solar Observatory
NSPO	National Space Organization
NSRL	NASA Space Radiation Laboratory
NSTC	National Science and Technology Council
NSWP	National Space Weather Program
NTF	National Transonic Facility
NTSB	National Transportation Safety Board
NuDet	Nuclear Detonation Detection
NVLAP	National Voluntary Laboratory Accreditation Program

NWI	National Wetland Inventory
NWS	National Weather Service

O

OBSS	Orbiter Boom Sensor System
OCIO	Office of Chief Information Officer
OCX	Next Generation GPS Operational Control Segment
OECD	Organization for Economic Cooperation and Development
OFCM	Office of the Federal Coordinator for Meteorology
OI	operational improvement
OLI	Operational Land Imager
OMPS	Ozone Mapping and Profiler Suite
OPIR	Overhead Persistent Infrared
OPP	Office of Polar Programs
ORCA	Ocean Radiometer for Carbon Assessment
ORS	Operationally Responsive Space
OSC	Orbital Sciences Corporation
OSC	Office of Space Commercialization
OSM	Office of Surface Mining
OTF	optical transfer function
OTM	Office of Transportation and Machinery
OTV-1	Orbital Test Vehicle 1

P

PALSAR	Phased Array type L-band Synthetic Aperture Radar
PARTNER	Partnership for AiR Transportation Noise and Emissions Reduction
PNT	Position, Navigation, and Timing
POES	Polar-orbiting Operational Environmental Satellite
PRF	Pasture, Rangeland, and Forage
PRSEUS	Pultruded Rod Stitched Efficient Unitized Structure

Q

QZS	Quasi-Zenith Satellite

R

R&D	Research and Development
RI	Rainfall Index
RLV	Reusable Launch Vehicle
RMA	Risk Management Agency
RNAV	Area Navigation
RNP	Required Navigation Performance
RO	radio occultation
RPI	Relative Position Indicator
RPIF	Regional Planetary Image Facility
RPS	radioisotope power system
RPT	Rocket Propulsion Test
RR	Rapid Refresh
RSIWG	Remote Sensing Interagency Working Group
RSRM	Reusable Solid Rocket Motor
RSS	Radio Science Subsystem
RTA	Required Time of Arrival

RTT	Research Transition Team
RVSM	Reduced Vertical Separation Minimum

S

SAA	Space Act Agreement
SAB	Satellite Analysis Branch
SABRS	Space and Atmospheric Burst Reporting System
SAIE	Systems Analysis, Integration and Evaluation
SAME	Smoke Aerosol Measurement Experiment
SAO	Smithsonian Astrophysical Observatory
SAR	synthetic aperture radar
SARSAT	Search and Rescue Satellite Aided Tracking
SATCOM	Satellite Communications
SBIRS	Space Based Infrared System
SBSS	Space Based Space Surveillance
SC	Office of Science
SCaN	Space Communications and Navigation
SCUBA	Submillimeter Common-User Bolometer Array
SDL	Space Dynamics Laboratory
SDO	Solar Dynamics Observatory
SDT	Secchi-disk transparency
SDVOSB	Service Disabled Veteran Owned Small Businesses
SEDS	Spitzer Extended Deep Survey
SFW	Subsonic Fixed Wing
SGSS	Space Network Ground Segment Sustainment
SHAAC	Shuttle Hazard Area to Aircraft Calculator
SHARAD	Shallow Subsurface Radar
SHINE	Solar, Heliosphere, and INterplanetary Environment
SI	International System of Units
SIA	Satellite Imagery Archive
SIRCUS	Spectral Irradiance and Radiance Responsivity Calibrations Using Uniform Sources
SLAC	Stanford Linear Accelerator Center
SMA	Submillimeter Array
SMCRA	Surface Mining Control and Reclamation Act
SMD	Science Mission Directorate
SN	Space Network
SNL	Sandia National Laboratory
SNSPD	superconducting nanowire single photon detectors
SOFIA	Stratospheric Observatory for Infrared Astronomy
SpaceX	Space Exploration Technologies Corporation
SPOT	Satellite Pour l'Observation de la Terre
SQUID	Superconducting Quantum Interference Devices
SRM	Standard Reference Materials
SRW	Subsonic Rotary Wing
SSME	Space Shuttle Main Engine
STAR	Center for Satellite Applications and Research
STBO	Surface Trajectory-Based Operations
STEM	science, technology, engineering, and mathematics
STP	Space Test Program
SuperDARN	Super Dual Auroral Radar Network
SWEAP	Solar Wind Electrons Alphas and Protons
SWPC	Space Weather Prediction Center

T

TACSAT	Tactical Satellite
TDRSS	Tracking and Data Relay Satellite System
TES	transition-edge sensor
TI	Technical Intelligence
TIMED	Thermosphere Ionosphere Mesosphere Energetics and Dynamics
TOC	Test Operations Contract
TRACON	Terminal Radar Approach Control
TRL	technology readiness level
TRMM	Tropical Rainfall Measuring Mission
TSI	Trophic State Index
TSIS	Total and Spectral Irradiance Sensor
TSTO	two-stage-to-orbit
TXR	Thermal-infrared Transfer Radiometer

U

UAF	Upper Atmospheric Facilities
UAS	unmanned aircraft system; unmanned aerial system
UAVSAR	Uninhabited Aerial Vehicle Synthetic Aperture Radar
UCAR	University Corporation for Atmospheric Research
ULA	United Launch Alliance
UMD	University of Maryland
UNCOPUOS	United Nations Committee on the Peaceful Uses of Outer Space
UPS	United Parcel Service
USAID	U.S. Agency for International Development
USCG	U.S. Coast Guard
USDA	U.S. Department of Agriculture
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
USNDS	U.S. Nuclear Detonation Detection System
USP	United States Pharmacopeia

V

VAAC	Volcanic Ash Advisory Center
VAFB	Vandenberg Air Force Base
VCAM	Vehicle Cabin Atmosphere Monitor
VERITAS	Very Energetic Radiation Imaging Telescope Array System
VI	Vegetation Index
VIIRS	Visible Infrared Imager Radiometer Suite
VIMS	Visible and Infrared Mapping Spectrometer
VLSA	very large-scale aerial
VOSB	Veteran-Owned Small Businesses

W

WFC3	Wide Field Camera 3
WFIRST	Wide Field Infrared Space Telescope
WISE	Wide-field Infrared Survey Explorer
WMM	World Magnetic Mode
WMO	World Meteorological Organization
WRF	Weather Research and Forecasting

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