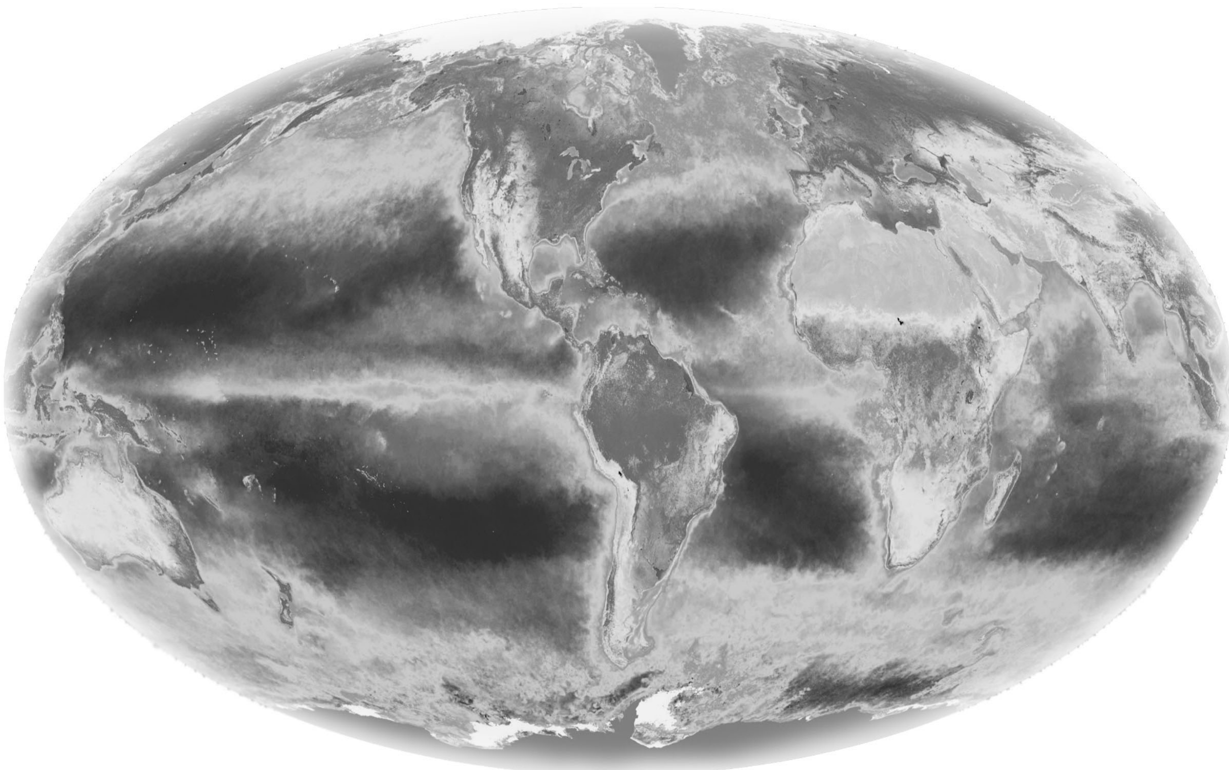
Aeronautics and Space Report of the President



Fiscal Year 2003 Activities

National Aeronautics and Space Administration

Washington, DC 20546

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, 2002, through September 30, 2003.

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Fiscal Year (FY) 2003 was a year of great accomplishments for the National Aeronautics and Space Administration's (NASA) Space Flight Enterprise. But no accomplishments, however extraordinary, could ever balance the terrible loss of the Space Shuttle Columbia and its crew of Rick Husband, William McCool, Michael Anderson, David Brown, Kalpana Chawla, Laurel Clark, and Ilan Ramon on February 1, 2003. The Columbia accident precipitated a wrenching investigation into the immediate, physical causes of the disaster, as well as the broader programmatic and cultural underpinnings of not only the Space Shuttle program but also the entire Agency. In 2003, the Nation honored our fallen comrades and friends by launching an intensive accident investigation with interagency assistance. Throughout the year, as the Columbia Accident Investigation Board (CAIB) carried out its service to our country with extraordinary skill and dedication, NASA began the long, arduous process of recovery and reform. With the release of the Board's final report on August 26, 2003, NASA solemnly pledged a return to the exploration goals to which the crew of Columbia, representatives of humanity's best from around the world, gave their lives.

Although the world grieved for Columbia and its crew, the danger of exploration does not permit a retreat from its passion and reward. This passion found expression through the success of critical NASA missions both before and after the accident. The Space Flight Enterprise continued to provide the foundation for NASA operations and missions, including space access and transportation, the maintenance and operation of in-space laboratories for world-class scientific research, and the means to return data from space to Earth. The Space Shuttle and International Space Station (ISS) programs continued to be two of NASA's most visible programs, and through that visibility, they supported important scientific research and inspired the next generation of explorers and leaders. The Space Flight Enterprise's Launch Services and Space Communications operations continued to be at the forefront of fostering innovative and effective partnerships between the Government and the private sector. Finally, the ever-expanding horizon of human knowledge and curiosity compelled the Space Flight Enterprise to continue investing in the next generation of space flight technology and capabilities through the Advanced Systems Office.

Prior to the loss of the Space Shuttle Columbia on STS-107, the Space Shuttle program successfully completed two assembly missions in support of the ISS. The Space Shuttle Atlantis carried out STS-112, launched on October 7, 2002, for Assembly Mission 9A. The six-person crew successfully delivered and installed the 31,000-pound Integrated Truss Assembly S1, part of the Station's structural, thermal, and electrical power backbone. STS-112 also delivered the Crew Equipment Translation Aid cart that, along with the Mobile Transporter system already installed, will provide future Station crews with important extravehicular activity support. STS-112 also flew hardware and samples for experiments conducted aboard the ISS.

The Space Shuttle Endeavour was successfully launched on November 23, 2002, en route to the ISS for STS-113, a mission to deliver major hardware components and to support an exchange of Station crewmembers. The primary payload was the Integrated Truss Assembly P1, the port complement to the starboard S1 segment launched on STS-112. In addition to the integration of truss segment P1, the crew of STS-113 deployed a small, two-satellite demonstration payload intended to validate new on-orbit inspection capabilities. STS-113 also ferried the Expedition 6 crew of Kenneth Bowersox, Nikolai Budarin, and Donald Petit to the Station and returned the Expedition 5 crew of Valeri Korzun, Peggy Whitson, and Sergei Treschev to Earth after a successful 6-month tour.

STS-107, the final flight of Space Shuttle Columbia, was launched on the morning of January 16, 2003, on an Earth-orbiting mission devoted to space, life, and physical science research. Once in space, the STS-107 crew worked tirelessly on research aimed at fighting cancer, improving crop yields, developing fire-suppression techniques, constructing earthquake-resistant buildings, and understanding the effects of dust storms on the weather. In all, STS-107 carried some 80 individual experiments, many of which relied upon the ingenuity of the astronauts assigned to them to record data, react to unexpected results, and quickly respond to the inevitable complications that are an integral part of laboratory science.

The overwhelming success of the mission was eclipsed during Columbia's reentry 16 days after launch. Mission controllers noted a growing number of instrumentation irregularities and failures during the reentry maneuver, and witnesses on the ground later reported debris coming off the red-hot orbiter as early as in the descent along the California coast. Breakup of the primary orbiter structure took place at approximately 9 a.m. eastern standard time on February 1, 15 minutes prior to Columbia's scheduled touchdown at Kennedy Space Center (KSC) in Florida.

The NASA Space Flight Contingency Action Plan for a major mishap guided NASA's actions in the initial minutes, hours, and days following the Columbia tragedy. This plan was inspired by lessons learned from the Challenger accident in 1986 and is updated regularly, based on crisis simulations. Among other things, the plan specifies notification or first-response procedures and defines the roles and responsibilities of mishap response and investigation teams. Within minutes of the loss of contact with Columbia, the Contingency Action Plan was activated. Immediate steps included impounding any potentially relevant information at Mission Control at Johnson Space Center (JSC) in Houston, TX, and notification of the President, the President's senior staff, members of Congress, and the Israeli Government. Ongoing mission preparations for the remaining Space Shuttle fleet (including the orbiters Discovery, Atlantis, and Endeavor) were immediately halted and all Shuttle flights grounded.

The Contingency Action Plan also called for the immediate selection of distinguished persons outside NASA to head an independent accident investigation team. The process of chartering the investigation team, later named the CAIB, began about 10:30 a.m. on February 1, 1 hour after the Contingency Action Plan was first activated. On February 1, NASA named retired Navy Admiral Harold W. Gehman, Jr., whose expertise included the investigation of the October 2000 attack on the USS *Cole*, to chair the CAIB. Over the next several weeks, 12 additional members of the

CAIB were chosen for their expertise in heading civil and military offices and for their knowledge of aviation accident investigations, aerospace safety, and NASA management and operations. Many hundreds more from Government, industry, academia, and NASA itself were to become involved in the ensuing 7-month, nationwide investigation. During its deliberations, the CAIB and its staff reviewed more than 30,000 documents and 84,000 pieces of debris recovered from Columbia, conducted more than 200 formal interviews, heard testimony from dozens of expert witnesses, and reviewed more than 3,000 comments from the public.

The interagency support and volunteerism for the recovery operations for STS-107 involved 20,000 men and women from the Department of Homeland Security (DHS), the Federal Emergency Management Agency, the Environmental Protection Agency, the Federal Bureau of Investigation (FBI), the Department of Defense (DOD), the Department of Transportation (DOT), the U.S. Forest Service (FS), the National Park Service (NPS), the Texas and Louisiana National Guard, State and local authorities, and private citizens. The Administrator testified on May 14, 2003, to the Senate Committee on Commerce, Science, and Transportation that "The morale and commitment of the recovery team was an inspiration to me and the entire NASA family. The outpouring of support from local businesses, community leaders, and the citizens of east Texas have especially humbled us." The recovery operations, which stretched from San Francisco, CA, to Lafayette, LA, recovered approximately 38 percent of Columbia's dry weight.

As a result of their investigation, the CAIB identified both proximate, physical causes of the accident and more long-term, systemic preconditions for the events that unfolded during STS-107. The examination of the physical evidence (including still and video footage taken during launch, analysis of radar data taken of Columbia by U.S. Air Force Space Command during the mission, telemetry downlinked from Columbia during its reentry, data gathered by Mission Control, recovered debris, and impact testing of existing Shuttle hardware) led the CAIB to conclude that a piece of insulating foam had dislodged from Columbia's External Tank during launch. This impact created a hole in the left wing leading edge, a hole large enough to let superheated air into the wing during reentry, resulting in irrecoverable loss of vehicle control.

In addition to examining the immediate physical causes of the accident, the CAIB conducted a broad investigation of the Space Shuttle program. The Board looked at the history of the program, budget and funding profiles, and the organizational and cultural contributors to the accident. The Board's deliberations on these issues were extensive, covering over 30 years of the Space Shuttle's history and delving deeply into the budget and management of the program during the past two decades. The CAIB identified issues such as lapses in the Mission Management Team that ran the final Columbia mission, declines in Space Shuttle program funding, perception of Space Shuttle launch schedule pressures related to ISS construction, and a flawed NASA safety culture as contributing factors to the loss of Columbia and its crew.

The heart of the CAIB final report is the 29 recommendations and 25 observations made by the CAIB over the course of its inquiry. In accepting the final report from Admiral Gehman, NASA Administrator O'Keefe thanked the Board for its thorough and comprehensive review of the STS-107 mission and the entire Space Shuttle program. The CAIB report will serve as the blueprint for a safe return to flight and will guide NASA's actions throughout all of its programs. NASA accepts the findings of the CAIB, embraces the final report, and will comply with all of the Board's recommendations.

With the CAIB Report in hand, providing an exhaustive summary of the events leading up to the loss of Columbia, NASA moved to develop the Implementation Plan for Space Shuttle Return to Flight and Beyond to return the Space Shuttle fleet to flight as safely and expeditiously as humanly possible. Starting almost immediately after the accident and for the next 7 months thereafter, NASA conducted its own internal review of the Shuttle program for possible technical and organizational improvements. This preliminary work allowed NASA to quickly prepare the first draft of a comprehensive plan for the Shuttle's return to flight following the release of the CAIB report. The first version of NASA's Implementation Plan for Return to Flight and Beyond was issued on September 8, 2003, and it has been periodically updated to reflect NASA's continuing progress toward a safe return to flight. The International Space Station program also drafted NASA's Implementation Plan for International Space Station Continuing Flight to demonstrate its commitment to applying the lessons contained in the CAIB report. In the meantime, NASA has postponed further consideration of additional competitive sourcing for the Space Shuttle program pending completion of the Agency's Return to Flight agenda. Finally, NASA named an independent task force chaired by veteran astronauts General Thomas Stafford and Richard Covey to verify NASA's compliance with the CAIB's Return to Flight recommendation.

The Space Shuttle Service Life Extension Program (SLEP) held its first summit in March of 2003, with the second summit planned for February 2004. The goal of the SLEP and the annual summit meeting is to produce a strategic investment plan for the Shuttle aimed at keeping the program safe, reliable, and able to perform the Agency's missions as prescribed in the Agency's Integrated Space Transportation Plan. The summit process organizes stakeholders from Government, industry, and academia into eight standing panels. The panels review proposals made from within NASA, as well as from industry partners and other stakeholders, concerning Shuttle safety, sustainability, infrastructure, technology, performance, and operations. An integration panel was also created to consolidate the results of the summit, while an industry panel provided perspectives from the NASA contractor community. A transition panel was established to oversee the incorporation of required return-to-flight recommendations from the CAIB. A strategy panel was added to the SLEP process so that scenarios regarding the Shuttle's future could be developed. The ongoing SLEP process contributed to the consideration of changes to the Space Shuttle made by the CAIB, including the following:

- hardening each orbiter's thermal protection system to reduce vulnerability to debris during both ascent and onorbit operations,
- updating the Space Shuttle Modular Auxiliary Data System to improve data collection during flights, and
- improving the inspection process that examines the dozens of miles of wiring that run through each orbiter.

With the grounding of the Space Shuttle fleet, the ISS program quickly adapted to the unplanned loss of access to the heavy-lift capabilities of the Shuttle system. The willingness of the International Partners of the ISS program (particularly Russia) to step forward was demonstrated by a Multilateral Coordination Board teleconference held in late February 2003. The ISS partners agreed to an interim operational plan that included a reduction in crew size to two, crew exchanges to be conducted on the scheduled semiannual Soyuz flights, and adjustments to the Progress resupply missions. Although the updated plan required readjustments to the manifests of flights to the ISS, the robustness of the onorbit ISS hardware and existing operation strategies proved capable of supporting continued crewed operations in an environment significantly different from that which was originally planned.

Since most of the major components of the ISS still awaiting launch required the unique cargo capacity of the Shuttle, no significant Station construction took place in 2003 following STS-113. However, NASA has maintained the original schedules for delivering all items of U.S.-provided ISS flight hardware to KSC and is continuing with the integration and testing of all ISS launch packages. Nevertheless, delays to the ISS assembly sequence resulting from the Columbia accident will require NASA to retain critical contractor expertise longer than anticipated. NASA's actions in response to CAIB recommendations may further impact the ISS assembly manifest, resulting in added assembly and/or logistics missions. In addition, the ISS program must recertify or replace launch package hardware with limited ground storage lives (for example, solar arrays and batteries), remanifest the logistics carrier scheduled for the first return mission to the ISS, compensate for components that no longer need to remain onorbit until the Shuttle's return to flight, address equitable adjustments submitted by support contractors, and replace flight hardware lost on Columbia.

By the end of FY 2003, the onorbit mass of the ISS reached 392,400 pounds (the total mass of the ISS at the time of International Partner completion will be approximately 1 million pounds). Eighty percent of U.S. components had been successfully delivered and installed on orbit, along with over half of the hardware committed to the program by the International Partners. Also by the end of the fiscal year, 183,534 pounds of U.S. and International Partner hardware had been delivered to KSC in Florida for final checkout and preparation for Space Shuttle integration. These components included the P3/P4, P5, S3/S4, S5, and S6 truss assemblies; Multipurpose Logistics Modules 1 and 2; the Japanese Experimental Module's pressurized segment; and the U.S. Node 2.

On April 26, 2003, ISS Flight 6S (Soyuz TMA-2), the first human space mission following the Columbia accident, was successfully launched from Kazakhstan to the ISS with the Expedition 7 crew of Commander Yuri Malenchenko and Flight Engineer Ed Lu (the NASA ISS Science Officer). Despite concerns that Station maintenance would monopolize or even overwhelm a two-person crew, Expedition 7 succeeded in developing new procedures that allowed them to conduct over 1,513 hours of scientific research in 74 different investigations during their 6-month tour. Research areas included biology, physics, chemistry, ecology, medicine, manufacturing, and the long-term effects of space flight on humans. Commercial experiments were also conducted on bone-loss treatments, plant growth, pharmaceutical production, and petroleum refining. A significant component of the research involved hundreds of primary and secondary school students who prepared experiments, assigned Earth photography targets, followed science activities via the Internet, and used the results in their classroom studies. Expedition 8, with Commander Michael Foale and Flight Engineer Alexander Kaleri, launched from the Baikonur Cosmodrome on a Soyuz rocket for ISS Flight 7S on October 18, 2003. Two days later, they arrived at the ISS. The Expedition 7 crew landed safely in Kazakhstan a week later. The Expedition 8 crew will be living and working on the Station through April 2004.

The Space and Flight Support activities within the Space Flight Enterprise also realized a number of important accomplishments during FY 2003. Space Communications completed the successful recovery of the Tracking and Data Relay Satellite-I (TDRS-I) geostationary space communication satellite, which had suffered a fuel tank failure shortly after launch on March 8, 2002. Along with the successful launch and checkout of TDRS-J in December 2002, TDRS-I allowed NASA to continue providing an assured and robust space-based communications network for civilian and national purposes for the remainder of the decade. Also in FY 2003, NASA began preliminary requirements definition for the follow-on TDRS Continuation Program in conjunction with the development of a Transformational Communications Architecture Program, an initiative led by the DOD and involving NASA, to provide an integrated national space communications infrastructure.

NASA was an active participant in the successful activities of the U.S. delegation to the World Radiocommunication Conference 2003 in Geneva, Switzerland, in June, in which several key spectrum allocations were reserved for space science and Earth science around the world. NASA also phased out the last of its old mainframe computers in the Mission Control Center (MCC) at JSC in Texas, completing a transition to a state-of-the-art workstation environment for all of MCC. Finally, due to a growing appreciation of the diversity of NASA's scientific and technology demonstration programs, the Agency decided not to exercise an additional 5-year option for its Consolidated Space Operations Contract. Instead, NASA established a new contractual framework for the provision of the Agency's communications requirements under seven separate competitive contracts, which were all awarded by the close of 2003.

The Space Flight Enterprise's Launch Services Program successfully managed all eight of its expendable launch vehicle flights in FY 2003. Launch highlights included the final flight of the Atlas 2A, three successful flights of Orbital Science Corporation's Pegasus XL small air-launched vehicle, the launch of the Mars Exploration Rovers (MER) Spirit and Opportunity, and the launch of the Spitzer Space Telescope. Opportunity used a high-energy version of the workhorse Delta 2 launch vehicle for the first time in order to send it through its narrow launch window and on to Mars. All launch services procured by NASA for its civilian missions are provided by private industry.

Office of Safety and Mission Assurance

Since the loss of the Space Shuttle Columbia and its seven-person crew, NASA has focused on understanding the causes of the accident and implementing the recommendations of the CAIB. More broadly, NASA's FY 2003 Federal Worker 2000 Presidential goal was 1.18 total workplace injury/illness cases per 100 workers. (The Federal Worker 2000 Presidential initiative challenges Federal agencies to reduce the overall occurrence of workplace injuries/illness by 3 percent per year, while improving agencies' timeliness in reporting by 5 percent each year. FY 1997 is the base year.) NASA's FY 2003 case rate was 0.80 total injury/illness cases per 100 workers. NASA continued to use the Occupational Safety and Health Administration's Voluntary Protection Program (VPP) to promote effective worksite-based safety and health. In FY 2003, the NASA JSC Sonny Carter Training Facility and one of JSC's contractor organizations were certified as VPP Star sites, and JSC was recertified as a VPP Star site. Two KSC contractor organizations were also recertified as Star sites. VPP Star, the highest level of achievement, is limited to companies that have implemented comprehensive, successful safety and health management systems that protect all employees.

Although NASA surpassed its goal at its ground-based work sites, the Columbia accident clearly indicates that improvements in approaches to mishap prevention in flight environments are necessary. Among the many changes underway that address the CAIB recommendations is the restructuring of Center-based engineering and safety organizations to give them more independence and authority in ensuring flight programs/projects. To further improve its capabilities in independent assessment of technical concerns, NASA created the NASA Engineering and Safety Center (NESC) at the Agency's Langley Research Center (LaRC) in Virginia. When fully operational, the NESC will become NASA's central location for independent engineering technical assessment and trend analysis of NASA programs.

As part of NASA's continual improvement activities in the area of safety, the NASA/Navy Benchmarking Exchange formalized and institutionalized relationships with Naval Sea Systems Command through three Memoranda of Agreement. The first addresses the sharing of information related to supplier quality; the second provides for reciprocal participation on technical assessment teams; and the third provides for reciprocal participation on functional (capability-verification) audits.

Space Science Enterprise

The year 2003 was a banner year for Space Science's exploration of the universe. The excitement of missions to Mars and all our other missions begins with a successful launch from Earth. NASA's expendable launch vehicle program has consistently delivered superb services and unprecedented success in launching our spacecraft.

The Space Science Enterprise started the year with a successful launch of the Cosmic Hot Interstellar Plasma Spectrometer (CHIPS) on January 12, 2003. This University-class Explorer mission is studying the gases and dust in space, which are believed to be the basic building blocks of stars and planets. The material between the stars is known as the Interstellar Medium (ISM) and contains important clues about the formation and evolution of galaxies. The ISM literally contains the seeds of future stars. Scientists using CHIPS are studying what is called the "local bubble," a region of space surrounding Earth's solar system that has a much lower concentration of gas and dust than average. CHIPS data will help scientists determine the electron temperature, ionization conditions, and cooling mechanisms of the million-degree plasma believed to fill the local interstellar bubble.

Next up was the Galaxy Evolution Explorer (GALEX) launched April 28, an orbiting space telescope that is observing galaxies in ultraviolet light across 10 billion years of cosmic history. The first light on GALEX detectors was received May 21–22, 2003. To honor the astronauts of the Space Shuttle Columbia, the first light field was chosen in an area of the heavens that was directly overhead Columbia as it made its last contact with NASA Mission Control. Observations such as these made by GALEX will tell scientists how galaxies, the basic structures of our universe, evolve and change. GALEX is also probing the causes of star formation during a period when most of the stars and elements we see today had their origins. GALEX was named "Best of what's new in 2003" by Popular Science magazine on November 7, 2003.

NASA's twin MERs, Spirit and Opportunity, were launched June 10, 2003, and July 7, 2003, respectively. As we began the second century of flight, Spirit and Opportunity landed safely on the surface of our neighboring planet in January 2004 and began their search for evidence of free-flowing water in Mars's ancient history. Spirit was the first of two golf-cart-sized rovers to land on Mars. These rovers have begun to explore two regions to discover whether the environment there might once have been capable of supporting life. NASA's robotic Mars geologist, Spirit, embodying America's enthusiasm for exploration, ran a grueling gantlet of challenges before it could start examining the red planet.

The last of NASA's "great observatories" was launched on August 25. The Spitzer Space Telescope, formerly named the Space InfraRed Telescope Facility (SIRTF), was renamed after Dr. Lyman Spitzer, Jr. This space-borne, cryogenically cooled infrared observatory is capable of studying objects ranging from our solar system to the distant reaches of the universe. Right away, images from Spitzer showed that celestial objects viewed by ground-based telescopes and even the Hubble Space Telescope (HST) look quite different when viewed in infrared light. Spitzer has a 5-year mission to reveal previously hidden dusty regions in the universe, as well as cold and distant objects.

NASA's Project Prometheus reached an important milestone with the first successful test of an engine that could lead to revolutionary propulsion capabilities for space exploration missions throughout the solar system and beyond. The test involved a High Power Electric Propulsion ion engine using commercial utility electrical power. The event marked the first in a series of performance tests to demonstrate the new high-velocity and high-power thrust needed for use in nuclear electric propulsion applications.

NASA's operating spacecraft continue to produce an abundance of science return throughout the year. NASA released the best "baby picture" of the universe ever taken, an image that contains stunning detail of the universe just after the Big Bang. During a sweeping 12-month observation of the entire sky, scientists using NASA's Wilkinson Microwave Anisotropy Probe (WMAP) captured this new cosmic portrait, including the afterglow of the Big Bang called the cosmic microwave background. For the first time, the Chandra X-Ray Observatory detected sound waves from a supermassive black hole. Evidence of the cosmic merger of two galaxies that collided violently, spewing out a long cloud of gas and generating a trail of black holes and neutron stars, has also been discovered in an image taken by the Chandra X-Ray Observatory. In just 1 year, Mars Odyssey has fundamentally changed our understanding of the nature of the materials on and below the surface of Mars. During its first year of surveying the martian surface, Odyssey's camera system provided detailed maps of minerals in rocks and soils. A wonderful surprise has been the discovery of a layer of olivine-rich rock exposed in the walls of Ganges Chasm. Additionally, new observations from our Voyager 1 spacecraft provided evidence that it was approaching formerly unexplored fringes of our solar system.

Stardust located and successfully photographed the comet Wild 2. The sighting took place 2 weeks earlier than expected, and NASA scientists were ecstatic. Finding Wild 2 this early drastically increased the likelihood of success in navigating the January encounter. The Stardust spacecraft will fly by comet Wild 2 on January 2, 2004, after almost 4 years in space. HST viewed one of the largest known cauldrons of star birth seen in a nearby galaxy. The Solar and Heliospheric Observatory (SOHO) spacecraft continues to capture the dynamics of a solar flare.

NASA's Space Science Enterprise Education and Public Outreach program continued to be one of the largest programs in astronomy and space science education. It is aligned with and strongly supports the new NASA mission to "inspire the next generation of explorers." NASA's commitment to education places a special emphasis on precollege education, diversity, and increasing the general public's understanding and appreciation of science, technology, engineering, and mathematics. NASA holds more than 3,500 education and public outreach events annually;

maintains an online directory of hundreds of space science educational resources, traveling museum exhibitions, and planetarium shows appearing in venues across the country; and has a presence in every State. The Space Science Enterprise effort has become a major national program in a very short period of time.

Earth Science Enterprise

NASA's Earth Science Enterprise (ESE) is dedicated to understanding Earth as a system. From the vantage point of space, NASA provides information about Earth's land, atmosphere, ice, oceans, and life that is obtainable in no other way, providing unique insight into the global environment and the effects of natural and human-induced changes on our home planet. ESE pursues answers to the fundamental question, "How is Earth changing, and what are the consequences for life on Earth?"

ESE works toward NASA's goal of understanding and protecting our home planet by producing scientific knowledge about the Earth system for decisionmakers and policymakers. NASA also develops innovative technologies and science-based applications of remote sensing for solving practical societal problems. ESE's applications program works in partnership with other Federal agencies, with industry, and with State and local governments to use NASA assets to improve agricultural efficiency, aviation safety, ecological forecasting, homeland security, disaster preparedness, renewable energy, public health, coastal management, invasive species management, water management, and air quality.

In FY 2003, ESE continued to break new ground with innovative science, technology, and applications. On January 25, 2003, NASA launched the Solar Radiation and Climate Experiment (SORCE) aboard a Pegasus XL rocket from the belly of an L-1011 carrier aircraft. A joint partnership between NASA and the University of Colorado's Laboratory for Atmospheric and Space Physics, SORCE will study the Sun's influence on our Earth and will measure from space how the Sun affects Earth's ozone layer, atmospheric circulation, clouds, and oceans. The Ice, Cloud and Land Elevation Satellite (ICESat), the latest in a series of Earth Observing System Spacecraft, was successfully launched into orbit from Vandenberg Air Force Base (AFB) on January 12, 2003. ICESat will quantify ice sheet growth or retreat and help answer questions concerning many related aspects of Earth's climate system, including global climate change and changes in sea level. The SeaWinds scatterometer was successfully launched into orbit aboard the Japanese Midori II spacecraft on December 13, 2002, from the Tanegashima Space Center. Because of SeaWinds's ability to "see" ocean level winds through clouds, its data will be an invaluable tool for hurricane tracking and high-seas marine forecasting.

In the past year, NASA also played a key role in the Earth Observation Summit. On July 31, 2003, senior Administration officials and representatives from 34 nations met in Washington, D.C., to plan a comprehensive, coordinated, and sustained international Earth-observation system. The Summit convened in order to raise awareness of the importance of cooperation and investment in Earth observations in providing key scientific data to support global economic, social, and scientific decisionmakers. Ministerial-level representatives of the G8 and other countries with a significant role in Earth observation attended, as did representatives from the World Bank, the World Meteorological Organization, and other multilateral organizations. The G8 countries rated Earth observations as one of the top three science and technology priorities. The presentation by the NASA Administrator of a video of a futuristic Earth-observation system and its practical benefits to society was one highlight of the Summit. Following the Summit, an international ad hoc Group on Earth Observations began work on a 10-year implementation plan for a comprehensive Earth-observation system.

In addition to launching and planning for present and future Earth-observing systems, ESE also used the vantage point of space to contribute to the scientific body of knowledge about our home planet.

Scientists operating the joint U.S.-German Gravity Recovery And Climate Experiment (GRACE) satellite released the most accurate map yet of Earth's gravity field. GRACE is oceanographers' newest tool to unlock the secrets of ocean circulation and its effects on climate. These early data, provided to eager oceanographers even before routine GRACE science operations, have already improved, by 10 to 100 times, the accuracy of our knowledge of Earth's gravity field. Ultimately, GRACE will help scientists to understand the distribution of mass under Earth's surface, including changes in the volume of large aquifers.

Scientists working with data from NASA's Aqua satellite have found ways to improve the accuracy of weather predictions using data from the satellite. The Atmospheric Infrared Sounder (AIRS) and Advanced Microwave Sounding Unit

(AMSU) instruments on the Aqua satellite are generating the most accurate, highest resolution measurements ever taken from space of the infrared brightness (radiance) of Earth's atmosphere and yielding a global, three-dimensional map of atmospheric temperature and humidity. U.S. and European research meteorologists are using these data to improve weather models and will employ them in an operational mode in the coming months.

NASA scientists have been conducting and learning from the Cold Land Processes Experiment. Scientists and students from six Federal agencies and many universities studied the snow packs of the Colorado Rockies from the ground, air, and space to improve forecasts of springtime water supply and snowmelt floods and to study how snow cover affects Earth's weather and climate. Measurements from four aircraft and NASA's Terra and Aqua satellites gathered snow data by remote sensing while scientists and students gathered data on the ground in order to make comparisons to determine the accuracy of the satellite data. These measurements have already proven useful in understanding how to update water and weather forecast models with observed snow information.

The Shuttle Radar Topography Mission science team generated detailed topographic data for South America in FY 2003. This recently released topographic data set sheds fresh light on the diverse characteristics of South America and paves the way for a wide variety of scientific investigations and practical applications.

A NASA-Department of Energy (DOE) jointly funded study concludes that Earth has been greening over the past 20 years. The article, appearing in the journal Science, states that climate changes have provided extra doses of water, heat, and sunlight in areas where one or more of those ingredients may have been lacking. The authors constructed a global map of the Net Primary Productivity (NPP) of plants from satellite data of vegetation greenness and solar radiation absorption. NPP is the difference between the carbon dioxide absorbed by plants during photosynthesis and the carbon dioxide lost by plants during respiration. NPP is the foundation of food, fiber, and fuel derived from plants, without which life on Earth could not exist.

NASA satellite observations have provided the first evidence that the rate of ozone depletion in Earth's upper atmosphere is decreasing. This may indicate the first stage of ozone layer recovery. From an analysis of ozone observations from NASA's first and second Stratospheric Aerosol and Gas Experiment and the

Halogen Occultation Experiment satellite instruments, scientists have found less ozone depletion in the upper stratosphere (22- to 28-mile altitude) after 1997. This decrease in the rate of ozone depletion is consistent with the decline in the atmospheric abundance of humanmade chlorine- and bromine-containing chemicals that have been documented by satellite-, balloon-, aircraft-, and ground-based measurements.

NASA and the Department of Agriculture (USDA) have joined forces on a series of programs drawing on NASA's capabilities in monitoring, mapping, modeling, and systems engineering to help protect the environment and enhance American agriculture's ability to compete in the world market. These programs, identified as national priorities of mutual interest, include carbon management, agricultural competitiveness, air quality, water management and conservation, and management of invasive species. On May 30, 2003, NASA Administrator Sean O'Keefe and USDA Secretary Ann Veneman signed an agreement inaugurating these collaborations.

In FY 2003, NASA satellites provided scientists and fire managers with powerful monitoring tools needed to understand how fires behave before, during, and after damage has been done. Instruments such as the Moderate Resolution Imaging Spectroradiometer (MODIS) on the Terra satellite provide daily, nearly global observations of the extent and relative intensity of fires and altitude estimates of smoke plumes. Another instrument keeps daily track of the carbon monoxide plumes from fires and the scope of pollution produced regionally and globally. After a fire is contained, imagery from space can help classify the burn area into levels of severity and prioritize rehabilitation work. The imagery can also be used over the longer term to keep tabs on the "green-up" of previously burned areas and to monitor the effectiveness of various treatments. NASA is testing a semiautonomous system dubbed "sensor web." In this system, various satellites will have the ability to communicate with each other and provide interactive layers of images. One satellite might detect a fire starting and then signal another satellite to take detailed or specialized images for better monitoring.

Aerospace Technology Enterprise

In FY 2003, the Aerospace Technology Enterprise accomplished many successes in the areas of aviation safety, environmental protection, air transportation efficiency, space access, and revolutionary new capabilities and technologies.

In an effort to decrease the rate of fatal aircraft accidents, reduce the vulnerability of the air transportation system to hostile threats, and mitigate the consequences of accidents and hostile acts, the Enterprise has developed software systems for an advanced fuel-measurement system, developed a neural network verification software tool, and evaluated the effects of neutron particles on flight-critical systems. In addition, the Enterprise demonstrated a Smart Icing System that detects and mitigates ice problems and provides feedback to pilots.

The Enterprise completed combustor sector tests on two different technologies for large engines in order to establish a guide for future investment decisions on the path to decreasing aircraft emissions. Aircraft noise reduction is another Agency goal, and the Enterprise completed an interim technology assessment in order to decide which technologies should be developed further. The key factor in making that decision is the impact of these technologies, on both a component and a system level, toward the overall noise-reduction goal. NASA developed initial physics-based noise-prediction models to provide the capability for predicting aviation noise sources, including the effects of flap, slat, and landing gear noise; fuselage and wing shielding effects; physics-based fan noise; and propagation of engine noise within a nacelle. These models will allow the identification of a suite of technologies that will have the highest probability of meeting NASA's noise-reduction objective.

NASA is committed to improving aviation efficiency—to enable more people and goods to travel farther and faster, with fewer delays. Toward this goal, the Aerospace Technology Enterprise completed the development and demonstration of initial functionality, as well as an evaluation of human factors, for a Traffic Management Advisor-Multi-Center (TMA-MC), a decision-support tool for complex airspace. The results of TMA-MC simulations indicated that 1) metering for Philadelphia appears to be viable in the Boston Air Traffic Control Center (ARTCC), 2) more delay-absorption capacity exists in the Boston, MA, ARTCC than in the New York, NY, or Washington, DC, ARTCCs, 3) TMA-MC's internal departure scheduling is important, and 4) significant metering issues exist in the Boston ARTCC. NASA also completed the development and demonstration of the active terminal-area Expedited Departure Path decision-support tool, along with a related evaluation of human factors. Additionally, NASA completed and validated a state-of-the-art airspace model toolbox, the Airspace Concept Evaluation System, with the ability to assess the economic impact of new technology and National Airspace System operational performance, as well as the ability to model the dynamic effects of interactive agents. Nor was technology NASA's only focus; the Agency also provided strategies for improving training and procedures to reduce misunderstandings between pilots and air traffic controllers.

NASA sought to increase aviation mobility as measured by accessibility, doorstep-to-destination transit time, system and user costs, and related trip reliability and safety metrics. These flight experiments evaluated, at the subsystem level, the impact of selected technologies on lowering required landing minimums and increasing the volume of operations at nontowered landing facilities in nonradar airspace during meteorological conditions under which instruments must be used instead of flying by sight. As part of the NASA/FAA/National Consortium of Aviation Mobility Small Aircraft Transportation System (SATS) Alliance, NASA accomplished the goal of increased mobility by agreeing to the suite of technologies and procedures to be included in the project flight experiments. These technologies and procedures include 1) higher volume operations (sequencing and self-separation algorithms); 2) lower landing minima (synthetic vision with highway-in-the-sky and velocity-vector guidance, enhanced vision, head-up display); 3) single pilot performance (integrity monitoring, decision aiding); and 4) en route integration (procedures for facilitating air traffic controller interaction).

In addition to improving aviation, NASA worked to improve space access. In January 2003, the NASA Headquarters Executive Council approved the Orbital Space Plane (OSP) Program Level 1 requirements. These requirements were extensively reviewed by outside sources and across NASA's Enterprises. The OSP Program Office placed the requirements under configuration control. Additionally, NASA established formal agreements with the ISS program and the KSC Launch Services Provider to ensure an integrated developmental effort for the OSP system. Demonstration of Autonomous Rendezvous Technology (DART) successfully completed the Design Certification Review (DCR) on July 31, 2003, and included approval of the verification approach. Results of the DCR are documented and available through the DART Project Manager's Office at MSFC.

Looking ahead to space access in the future, NASA completed its initial Integrated Technology Plan (ITP) for the Next Generation Launch Technology (NGLT) Program in order to establish an investment strategy to guide future space-transportation investment decisions. The ITP, a cooperative effort between NASA and DOD organizations, includes technology needs from both agencies and is now the baseline for defining the technology investment strategies for the National Aerospace Initiative (NAI), as well as the NGLT. The ITP will be reviewed and updated annually.

NASA also completed the Conceptual Design Review (CoDR) of the Rocket-Based Combined Cycle (RBCC)/Integrated Systems Test of an Air-breathing Rocket (ISTAR) ground test engine (GTE). The conceptual design was thoroughly reviewed by a technical team consisting of representatives from MSFC, Glenn Research Center (GRC), LaRC, and the three companies of the RBCC Consortium.

Demonstrating progress toward the development of a million-pound-thrust-class prototype engine, NASA tested configurations of liquid/liquid preburner injector elements and gas/liquid main-chamber injectors in the Single Element Test Rig at the Santa Susana Test Facility in California. Data were used to select the primary and secondary configurations for the RS-84 engine design.

Another goal during FY 2003 was the development of new technologies for enabling revolutionary capabilities. NASA created system concepts and demonstrated technologies intended to make possible new science measurements and scientific missions. In the area of advancing the state of the art in automated science data analysis, NASA accomplished the following:

- found a novel feature in data discovery methods from known and new candidate ocean climate indices that show predictive power for land surface dynamics;
- demonstrated tools and techniques for automated feature extraction from large datasets by using a robust, novel clustering method;
- demonstrated distributed analysis and data processing to support new problem-solving paradigms through the application of various grid tools and

resources to aerospace vehicle design, data subsetting for feature identification, ground truthing, and wind dynamics applications; and

- demonstrated component autonomy technologies in planning and scheduling, supporting Mars mission operations by conducting the first full operations readiness test of a science-planning tool for the MERs running on Mars time using the MER engineering model and involving mission-planning teams.

In order to improve mission command data delivery, NASA demonstrated the following:

- technology capable of doubling the performance of Mars-to-Earth communications by executing an analytical comparison between the existing state-of-the-art 35-watt Traveling Wave Tube (TWT) and the NASA-developed 100-watt TWT; the analysis proved that the NASA-developed 100-watt TWT would improve data rates from Mars by a factor of 2.85;
- technology capable of 10-fold improvement in Earth-orbit-to-ground communications via the development of a miniaturized 20-watt Ka-band TWT that could increase the data rates by a factor of 15 over the existing NASA 150-megabits-per-second (Mbps) Earth-orbit-to-ground link; and
- the capability for ad hoc space and surface networking via a demonstration of the Dynamic Source Routing (DSR) Protocol.

In the area of improving science sensors and detectors, NASA accomplished the following:

- demonstrated molecular-level sensors for environmental health monitoring via demonstration of a gas sensor capable of detecting gas and organic vapors at room temperature;
- demonstrated a high-efficiency, tunable, narrow-line, 2-micron laser transmitter with a record 1-joule pulse energy for a 2-micron Ho:Tm:LuLF (holmium and thulium ions doped in lutetium lithium fluoride) laser transmitter; and
- characterized the mercury-cadmium-tellurium infrared detector, analyzed the spectral response and current versus voltage curves, and presented results at the International Society for Optical Engineering (SPIE) AeroSense Conference.

NASA furthered the state of the art in advanced power and electric propulsion systems by accomplishing the following:

- demonstrating a twofold increase in thruster lifetime compared to Deep Space 1's NASA Solar-electric-power Technology Application Readiness (NSTAR) thruster with titanium and molybdenum ion optics;
- completing Hall thruster lifetime and operating point correlations with 10-kilowatt and 50-kilowatt thrusters;
- completing Hall thruster modeling at the Massachusetts Institute of Technology;
- successfully growing two key parts of high-efficiency multibandgap solar cell: a gallium-arsenic cell on graded silicon-to-germanium substrate, and a two-junction Light Microscopy Module (LMM) cell on gallium-arsenic substrate; and
- demonstrating a two-flywheel system for regulating power bus voltage while simultaneously providing a commanded output torque for attitude control.

NASA also progressed in the area of micro- and multipurpose spacecraft components and systems. The Agency demonstrated 1) the Vaporizing Liquid Micro-Thruster (VLM) chip integrated with a commercial valve and 2) the operation of micro-inductors applicable to direct current (DC)-DC boost converters (circuits that translate low-voltage current to higher usable voltage) between 1 and 10 megahertz. NASA also integrated a three-axis inertial measurement unit for microspacecraft using microgyros and commercial accelerometers. Furthermore, the Agency assembled and demonstrated a Sun sensor on a chip using microelectromechanical system (MEMS)-fabricated silicon apertures and active pixel sensors. NASA also fabricated and tested a liquid-compatible microvalve, a component for microspacecraft propulsion systems. Although the Agency also fabricated and characterized battery cells, their integration into structural panels has been delayed. In the area of large and distributed space systems concepts, NASA accomplished the following:

- demonstrated attitude determination of individual spacecraft using GPS receivers;
- developed simplified equations of motion for an uncontrolled system of spacecraft;

- evaluated various joint designs to enable in-space assembly of inflatable truss elements and fabricated inflatable truss components;
- completed fabrication and initial radio frequency (RF) testing of subscale tensioned membrane eight-element waveguide array and feed network;
- fabricated an isogrid column using ultraviolet curable resin and unidirectional carbon fiber tows; test results show 95 percent plus curing using only outdoor sunlight;
- fabricated and deployed a 7-meter shape-memory composite boom for solar sails; and
- fabricated proof-of-concept electronic circuits on membrane.

NASA achieved several accomplishments in the area of space environments and effects. The Agency developed 1) a physics-based meteoroid environment flux model for the inner solar system, 2) a semi-empirical engineering model of electrons and ions that included thermal plasma distributions and bulk flow effects in the distant magnetotail; and 3) an initial version of a knowledge base for thin-film materials. Furthermore, NASA determined the electrical properties for a wide array of spacecraft materials and integrated data into spacecraft charging models. The Agency also developed and published the low-Earth orbit portion of the Spacecraft Charging Guidelines Document. Finally, NASA and the U.S. Air Force (USAF) completed joint development of the NASACAP-2K spacecraft charging model.

NASA continued to work toward the production of robotic systems that can reason, make decisions, adapt to change, and cooperate among themselves and with humans to provide safe and successful aerospace processes and mission functions with greatly reduced human participation by successfully demonstrating individual autonomy components. NASA demonstrated these component technologies to be included in a larger, integrated demonstration. Component capabilities demonstrated for integrated rover autonomy include 1) mixed-initiative path planning for devising paths to desired science targets, 2) autonomous contingent planning and sequence generation, and 3) robust onboard rover execution of contingent plans.

Biological and Physical Research Enterprise

Since its inception, the Biological and Physical Research Enterprise (BPRE) has conducted interdisciplinary, peer-reviewed, fundamental, and applied research to address opportunities and challenges provided by the space environment and the human exploration of space. As such, BPRE manages laboratory research on Earth and in space in the following areas: Fundamental Space Biology, Bioastronautics, Physical Science Research, and Commercial Space Product Development.

BPRE implements its research programs at 8 NASA Centers, as well as through the participation of 15 Research Partnership Centers, the National Space Biomedical Research Institute, and the National Center for Microgravity Research on Fluids and Combustion. BPRE also relies upon an extensive external community of academic, commercial, and Government scientists and engineers for the implementation of its programs. Research in Earth laboratories precedes flight research and employs NASA facilities such as drop towers, centrifuges, aircraft flying low-gravity parabolic trajectories, and bed-rest facilities. The flight research programs use the full spectrum of free-flying satellites, the Space Shuttle, and now the ISS.

In support of NASA's Vision "to improve life here, to extend life to there, to find life beyond," BPRE developed a comprehensive strategy to guide and prioritize all research and other activities throughout the Enterprise. The strategy focuses our efforts to answer a set of five organizing questions:

1. How can NASA ensure the survival of humans traveling far from Earth?
2. How does life respond to gravity and space environments?
3. What new opportunities can research bring to expand humanity's understanding of the laws of nature and enrich lives on Earth?
4. What technology must NASA create to enable the next explorers to go beyond where humans have already been?
5. How can NASA educate and inspire the next generation to take the journey?

These questions determine our research strategy, the laboratories and programs to execute the science, the applications for the research, and the metrics to measure progress.

The year 2003 was a challenging time for BPRE. We sadly remember the loss of Columbia and mourn the deaths of seven dedicated astronauts. Perhaps the greatest legacy of the crew of STS-107 is the outstanding science performed on this mission, which will serve as an inspiration for the next generation of space researchers and explorers.

NASA has invented a device called a bioreactor that has changed research on cell growth not only in space, but also on Earth. The bioreactor helps researchers turn cell cultures into functional tissue that can be used for experiments, transplantation, and drug development. Without a bioreactor, cells fall to the bottom of a petri dish and grow as a sheet one cell layer thick—thinner than a human hair. In NASA's space bioreactor, the cells stay suspended and form the kind of large samples researchers need. On the Space Shuttle Columbia's final mission, STS-107, astronauts helped scientists study how prostate cancer cells and bone cells come together. The goal was to learn about how the cells might interact in the early stages of when cancer begins to spread. During the Columbia mission, the cell "assembly" grew to the size of a roll of pennies—much larger than anything researchers have seen before. The Shuttle experiment was so successful that at the end of FY 2003, NASA was planning on flying similar, longer-term experiments on the ISS in the future.

NASA's bioreactor has yielded 25 patents and more than 20 licenses, and over 6,000 units are now in universities, medical centers, and the National Institutes of Health.

Space flight research is changing our understanding of how and why things burn—a phenomenon scientists thought they understood thoroughly. For example, one hydrogen experiment aboard STS-107 produced the weakest flames ever created, 100 times weaker than a birthday candle. That research—improving the burning of hydrogen—could result in cleaner-burning car fuel in the future and other fuels in engines and furnaces. Two major corporations, Pratt & Whitney and General Electric, have already used space flight combustion research to improve their jet engines.

Shifting Sands, a materials science experiment, collected data on how granular materials such as sand respond to physical stimuli, yielding new knowledge that can be applied to predicting how soils settle and react in earthquakes and how shorelines evolve.

In a search for nontoxic alternative ways to extinguish fires, the Columbia crew worked diligently on a commercial experiment that focused on the formation of flames and the use of water droplets to quench the flames.

Perhaps the most unexpected data collected from the mission were the specimens that were recovered in the debris of Columbia. Samples of moss from an experiment studying the effects of microgravity on plant growth were found. The moss had been preserved in a chemical fixative in orbit. The recovered samples yielded the same unpredicted growth pattern observed in moss grown on a previous space flight and may uncover information about the cause of this behavior. Finally, in another unexpected discovery, live worms (*C. elegans*, a small roundworm often used in biological research) were found after the accident. They had flown on STS-107 as part of a technology demonstration project to test a new medium that could be used in future space experiments to grow the worms. Not only did the discovery of the live samples demonstrate the ability of the growth medium to support and sustain the worms, but the specimens also are being studied to determine what other changes may have occurred as a result of their space flight.

Additional examples of BPRE accomplishments on both the ISS and the Space Shuttle advanced our ability to develop technologies for applications on Earth and for the human exploration of space:

- In FY 2003, NASA joined in the fight against crime through its continued work with the FBI/Technical Support Working Group whose members include the DOD, Central Intelligence Agency (CIA), Secret Service, and Department of State (DOS). NASA delivered hyperspectral sensors in visible/near-infrared, ultraviolet, and shortwave infrared systems to the FBI Academy for use in forensics science research.
- On the ISS, BPRE investigated the complex properties of magnetorheological (MR) fluids via its Investigating the Structure of Paramagnetic Aggregates from Colloidal Emulsions (InSPACE) experiment. MR fluids are liquids that become more viscous (behave like syrup) near a magnet but flow easily again (like water), when the magnet is removed. Suspensions of paramagnetic particles in a nonmagnetic fluid are part of an exciting new class of controllable fluids. Advances in MR fluid research and technology have inspired new applications for products such as active vibration systems for large structures like buildings and bridges, as well as actuators for robots

for space- and Earth-based applications. InSPACE's planned series of tests was completed on the ISS in July 2003.

- The data from another experiment on the ISS are helping NASA understand the basic nature of liquid-to-solid transitions (e.g., water freezing to become ice). Using different types of colloids (a mixture between a liquid and a large number of specially designed solid particles), the Physics of Colloids in Space (PCS) experiment gathered data on the basic physical properties of colloids with the objective of understanding how colloidal structures grow, the rates at which they grow, and the structures that they form. The knowledge gained from the PCS experiment will guide future attempts to fabricate advanced, novel materials and devices with unique physical properties that could lead to improvements in optical and computer components, ceramics, and both food and drug delivery products.
- Diseases like cancer are strongly tied to cell division and growth, as well as the effect of environmental changes on both. Cell cultures that are synchronized so that all of the cells divide at once are important in studying these diseases. BPRE-funded investigators developed a new cell culture technology designed to minimize disturbances in the culture environment. BPRE demonstrated that the experimental cell lines could achieve the multiple, synchronized cell cycles that medical researchers need. This technology provides a better method to study the cell cycle in human, mouse, and bacterial populations; the balance system in the inner ear; and the development of the skeleton.
- The NSBRI is a consortium of 12 institutions working in partnership with NASA to prevent or solve health problems related to long-duration space travel and prolonged exposure to microgravity. However, much of NSBRI's research also has the potential to provide great benefits here on Earth. NSBRI research highlights for this year include the following:
  - Identifying early indications that nutritional supplements may reduce muscle atrophy brought on by space travel, prolonged bed confinement, or immobility.
  - Developing a new technology to characterize unknown bacteria. Its immediate application will be to identify bacteria in space, but it may

eventually aid in diagnosing medical conditions and detecting biological hazards on Earth.

- In 2003, NASA and our partners brought the excitement of space closer to home. A highlight of this year's activities included partnering with the American Library Association and Apple Computers to launch a 2-year national tour to share space research with the general public. The exhibit shows how NASA has contributed to every aspect of American life and explains how the Space Shuttle and ISS, people, inanimate objects, and American industry work in the microgravity of space. Over 400 libraries competed for 120 opportunities to take part in the national tour. Launched in July 2003, the exhibit will tour five locations per month. Estimated traffic through the five libraries in the opening month was 250,000. An average of 20 additional books on space also were added to each library's permanent collection through NASA grants.
- Over this past year, numerous Principal Investigators funded through BPRE research were featured on the covers of prestigious journals, including Science, Nature, Proceedings of the National Academy of Sciences, Cell Cycle, Journal of Cell Science, and Journal of Neurophysiology.

Department of Defense

DOD

In FY 2003, the USAF supported NASA in a wide range of activities. The four major areas of cooperation were centered on upper level management coordination, science and technology development, space operations, and human space flight activities.

The Partnership Council (consisting of USAF Undersecretary Peter B. Teets; NASA Administrator Mr. Sean O'Keefe; ADM James O. Ellis, Jr., Commander, United States Strategic Command; Dr. Ron Sega, Director, Defense Research and Engineering (DDR&E); and GEN Lance Lord, Commander, Air Force Space Command) is the primary forum for high-level discussions on management coordination. During 2003, the council held two semiannual meetings and three special sessions. The most important accomplishment at these meetings was an examination of transformational options for space access. In particular, the group looked at options advanced by DDR&E (which proposed an air-breathing hypersonic first stage) and Air Force Space Command (which proposed a version of its Operationally Responsive Spacelift (ORS), which is a new start to analyze concepts and assess military utility for responsive on-demand access to, through, and from space. ORS encompasses the spacelift missions of delivering payloads to or from mission orbit and changing the orbit of existing systems to better satisfy new mission requirements).

In the area of science and technology development, one of the most important joint collaborative efforts currently underway between NASA and the Air Force is the National Polar-Orbiting Operational Environment System (NPOESS), a tri-agency program involving NASA, the DOD, and the

Department of Commerce (DOC) that converges the DOD and DOC-NOAA polar-orbiting weather satellite programs. Working with the NPOESS Integrated Program Office (IPO), NASA provided preoperational risk-reduction demonstration and validation tests for four critical NPOESS sensors that will fly on the NPOESS Preparatory Project (NPP). NPP is a primary NASA mission that serves as a "bridge" between the Earth Observation System (EOS) mission and NPOESS. NPP is also a risk-reduction mission for the Visual Infrared Imager Radiometer Suite (VIIRS), the Cross-track Infrared Sounder (CrIS), the Advanced Technology Microwave Sounder (ATMS), and the Ozone Mapper/Profiler Suite (OMPS) sensors; it also serves as an end-to-end test for the Command, Control, and Communication (C3) and data-processing systems for NPOESS. NPP is on schedule to launch in October 2006.

As part of the effort to provide risk reduction to the NPOESS system, the DOD Space Test Program launched the Navy Coriolis Mission in January 2003. This mission hosted both a solar mass ejection imager and WindSat sensor. The WindSat sensor is new sensing technology from the Naval Research Laboratory that will be evaluated for use on the NPOESS system.

NASA also assisted the Space Test Program in tests of a new Vibro-Acoustic Launch Protection Experiment (VALPE). NASA supported two successful sounding rocket launches from the Wallops Island launch facility. The Air Force supported the launch of several NASA payloads from the Eastern and Western Ranges, the most notable being the Spirit and Opportunity rovers now investigating Mars.

In more basic research and development, the Air Force and NASA continued to collaborate in several major research projects and have set up several fora to facilitate science and technology (S&T). Three major coordination fora for collaborative work are the national Thermal Protection Systems Working Group, which is led by the Air Force and NASA with participation by the Army, the Navy, DOE, industry, and academia and which fosters the development of new and advanced thermal protection materials and systems; the National Space and Missile Materials Symposium, which fosters increased communication and understanding in pursuing key materials technology challenges for space and missiles; and the Air Force Research Laboratory (AFRL)-JPL Annual Summit, which is held to discuss and coordinate research efforts.

Other areas of research in FY 2003 ranged across the complete spectrum of S&T activities. NASA and the Air Force worked to track and characterize orbital debris, as well as performing asteroid surveys to detect any large objects at risk of striking Earth. Many materials science experiments were carried out to look at environmental effects of space exposure, as in the DOD Space Test Program Materials International Space Station Experiment (MISSE) experiments, as well as high-stress/high-cycle experiments on airframe or fuel-tank materials. MISSE will test the durability of hundreds of samples ranging from lubricants to solar cell technologies. The samples, engineered to better withstand the punishing effects of the Sun, extreme temperatures, and other elements, will be flown 220 miles above Earth—outside the ISS and unprotected by Earth's atmosphere. By examining how the coatings fare in the harsh environment of space, researchers seek new insight into developing materials for future spacecraft, as well as making materials last longer on Earth. Managed by LaRC in Hampton, VA, MISSE is a collaborative effort among NASA Centers, the USAF, and private industry. By pooling resources, these groups can reap the rewards of collaborating on advanced material-science research, while minimizing the total investment of any one participant.

In the Integrated High Payoff Rocket Propulsion Technology (IHPRPT) Program, AFRL and NASA have worked to develop a spiral improvement system to the Space Shuttle Main Engines with technology benefits that will help all U.S. next-generation rocket engines. In addition to all of these areas, NASA and the Air Force collaborated on at least 17 other S&T programs that touched on almost every facet of both aviation and space technologies.

Even NASA's Mars exploration mission benefited from Air Force collaboration with NASA by utilizing Air Force-developed Rad-6000 32-bit microprocessors, as well as Air Force-developed lithium-ion batteries, in both planetary rovers. In addition, Air Force operational studies provided expertise on human-fatigue-related performance issues that will help provide counter-fatigue strategies for rover operators.

In the area of space operations, the Air Force and NASA have existing Memoranda of Agreement establishing partnerships to support NASA launches with Spacelift Range assets and to pursue advanced launch and test range technologies. In FY 2003, the Air Force's Spacelift Ranges continued to support all launch operations for NASA-piloted and robotic launches from KSC or Vandenberg AFB. Also, at the recommendation of the Interagency Working Group on Future Management and Use of the U.S. Space Launch Bases and Ranges, the Air Force and NASA established the Advanced Range Technology Working Group (ARTWG), co-chaired by Air Force Space Command and NASA KSC. The ARTWG charter focuses on improving safety, increasing flexibility and capacity, and lowering range costs in support of future generations of reusable and expendable launch vehicles. The Joint Base Operating Support Contract (JBOSC) is a procurement effort between KSC and the AF 45th Space Wing to provide unified base support services for KSC, Cape Canaveral Air Force Station, and Patrick AFB. Space Gateway Support, LLC, currently operates the JBOSC, which has a total value in excess of $2.2 billion over a 10-year period of performance.

In the area of human space flight, Air Force Space Command provided support to NASA (via United States Strategic Command (USSTRATCOM) and United States Northern Command (USNORTHCOM)) on the Columbia accident response and subsequent investigation. BG Duane Deal, USAF, Commander of the 21st Space Wing at Peterson AFB, which is responsible for operating the space surveillance network and which assisted in the Columbia investigation, served on the CAIB. Approximately 20 AFRL personnel from six technology directorates participated in the CAIB via the DOD Columbia Investigation Support Team. Subject-matter expertise was provided in the fields of nondestructive inspection and test of critical composite structures, space weather, atmospheric space chemistry and physics, reentry physics, high-speed aerodynamics, aerothermal environments, Kapton insulated wiring, ceramic materials, structural fatigue/fracture failure, and human behavior “group think” decisionmaking.

In an effort to assist NASA in its Return to Flight activities for the Shuttle fleet, the Air Force is assisting in developing and evaluating leading-edge repair concepts that can be applied by astronauts in orbit. To date, 20 specimens from seven different organizations have been tested, with three concepts surviving thermal conditions representative of flight heat flux and temperature. These three will be studied further to fully characterize the performance of the repair methods and materials and certify the concepts for flight. The Air Force is also assisting in analyzing and improving the manual foam-spraying operation previously used on the Space Shuttle Columbia External Tanks.

In the operational arena of human space flight, NASA and the Space Test Program successfully completed experiments on both STS-112 and STS-113. While the Shuttle fleet was grounded in the aftermath of Columbia, NASA assisted the Air Force in securing cargo space for Space Test Program experiments on the Russian Progress resupply vehicles.

FEDERAL AVIATION ADMINISTRATION

FAA

The Federal Aviation Administration (FAA) Office of the Associate Administrator for Commercial Space Transportation (AST) licenses and regulates U.S. commercial space launch and reentry activities; ensures public health and safety, as well as the safety of property; and protects national security and foreign policy interests of the United States. AST also licenses the operation of non-Federal launch and reentry sites and encourages, facilitates, and promotes U.S. commercial space launches and reentries by the private sector. During FY 2003, AST licensed eight commercial launches, including the first launch of the Delta IV, built and marketed by The Boeing Company. Three Atlas vehicles, built by Lockheed Martin, were launched from Cape Canaveral Air Force Station. In addition, Sea Launch, a multinational company that provides the Zenit 3SL, launched three vehicles from a platform in the Pacific Ocean. One Pegasus XL was also launched. The Pegasus XL, built by Orbital Sciences Corporation, carried the OrbView 3 remote sensing satellite to low-Earth orbit.

On November 4, 2003, AST established the Commercial Space Transportation Safety Office, located at Patrick AFB in Florida, as a result of the study on the Future Uses of U.S. Launch Bases and Ranges. This office supports the mission partnership between the FAA and the USAF; coordinates and participates in inspections and evaluations of flight hardware; resolves requests for relief from common safety requirements; and facilitates a better understanding of issues that arise among the FAA, the range, and the launch operators. In FY 2003, the office worked with USAF Range Safety to implement a temporary flight-restricted area for expendable launch vehicle activities that was previously used only by the Space Shuttle program.

The office increased its focus on licensing activities related to new reusable launch vehicles. On May 22, 2003, AST conducted a reusable launch vehicle mission license workshop for potential commercial reusable launch vehicle launch license applicants and related organizations. The workshop provided detailed information on reusable launch vehicle application requirements and procedures. In September, AST released the Guide to Reusable Launch Vehicle Safety Validation and Verification Planning to provide information of interest to potential reusable launch vehicle developers.

AST strengthened its training and development program in FY 2003 with the addition of a dedicated training specialist and the creation of technical courses on "Thin Walled Pressure Vessels," "Introduction to Reentry Debris Survivability," "Introduction to Systems Engineering," "Mobile Range Safety System Fundamentals," and "Introduction to Explosives and FTS Ordnance."

AST released multiple reports in FY 2003, including 2003 U.S. Commercial Space Transportation Developments and Concepts: Vehicles, Technologies, and Spaceports and 2003 Commercial Space Transportation Forecasts. The forecasts, prepared by the FAA and its Commercial Space Transportation Advisory Committee, projected an average worldwide demand of 18.6 launches per year to geosynchronous orbit and 5.1 launches per year to nongeosynchronous orbits between 2003 and 2012. AST also hosted its sixth annual commercial space transportation forecast conference. Reports and other documents can be found on the FAA/AST Web site at *http://ast.faa.gov*.

In 2003, as the world celebrated the hundredth anniversary of Orville and Wilbur Wright's first flight, the next generation of aviation researchers forged ahead to ensure the safety and efficiency of the next hundred years of flight. In 1903, our greatest research challenge was to master powered flight. One hundred years later, the Federal Aviation Administration's research and development accomplishments span the globe.

For several years, the research community has been advocating the need to begin planning for the development of a flexible, efficient future air transportation system, and recently, FAA researchers have supported a number of intergovernmental and industry planning groups, such as the Federal Transportation Advisory Group, which produced Vision 2050: An Integrated National Transportation System. We also jointly sponsored the National Research Council Aeronautics and Space Engineering Board to assess the Federal Transportation Advisory Group (FTAG) and Air Transportation Advisory Group (ATAG) reports and recommend enabling technology and research for the future aviation system. They published their report, Securing the Future of U.S. Air Transportation—A System in Peril, in November 2003. Several of our senior researchers devoted over a year to supporting the Presidential Commission on the Future of the United States Aerospace Industry. Both the Aeronautics and Space Engineering Board (ASEB) and Commission reports called for the establishment of a national program to transform the future of the air transportation system.

In FY 2003, the FAA's research community began participating in a new collaborative activity with the DOT, NASA, the DOD, the DHS, and the DOC as part of the FAA's Joint Planning and Development Office; the purpose of the collaboration was to develop a strategy for creating the future air transportation system—a system that will offer the flying public greater choices, lower prices, and fewer delays. As part of this planning effort, funded by the FAA's Research, Engineering, and Development budget, FAA researchers have been integral in identifying new strategies and R&D needs and undertaking critical systems analysis work to facilitate the transformation of the present system to the future one.

As they work to create the future aerospace system, FAA's researchers continue to make great safety advances for today's system. In response to an industry challenge to develop a practical and reliable fuel-tank inerting system to prevent fuel-tank explosions, FAA's researchers succeeded in developing a practical and cost-effective prototype inerting system. In the summer of 2003, the FAA and Airbus conducted flight tests of this inerting system in an A320 aircraft in Toulouse, France. Data from these tests are being used to enhance the inerting system's design. Also, in July 2003, Boeing began a flight-test program to certify an onboard inert-gas-generating system based on the FAA design. FAA supported these tests with instrumentation (as described in A Description and Analysis of the FAA Onboard Oxygen Analysis System, *http://research.faa.gov/aar/tech/docs/techreport/FY2003/DOTFAAARTN0352.pdf*. Boeing announced its intent to begin installing these systems on its 747 aircraft in FY 2005.

As a result of FAA flammability tests of aircraft thermal acoustic insulation, the FAA adopted new and improved flammability test standards for the thermal acoustic insulation used in transport airplanes. The standards include new flammability tests for in-flight fire ignition resistance and postcrash fire burn-through resistance. These standards will improve aircraft safety by reducing the incidence and severity of cabin fires by delaying the entry of postcrash fires into the cabin, thereby allowing passengers more time for evacuation. To establish the new flammability test method, FAA researchers created a new test apparatus comprising two main components: a large burner that simulates a jet fuel fire and a sample holder representative of the fuselage structure. The FAA's new test method, called the radiant panel test, subjects a material heated by a radiant panel to a pilot flame. The pass/fail criteria require that any flaming not extend beyond a 2-inch length from the point of flame application or continue flaming after removal of the pilot flame.

Loss-of-control data indicate that 40 percent of accidents include a propulsion malfunction in the chain of events that lead to a crash. The FAA initially established flight-deck instrumentation requirements for piston-engine airplanes. Those requirements now need to be reassessed as turbine engines mature into highly reliable and complex power plants. Hence, researchers are reviewing the current data presented to the pilot and are examining the value of those data to identify when the data are used, what limits are in place for the data's use, and the expected pilot response to an out-of-range value.

As part of this work, researchers evaluated new technologies that can take the propulsion-system data, currently available to the pilot via cockpit gauges, and create a means to turn that information into communications that direct the crew to the proper procedure when action is required. Currently, propulsion engineers, flight-deck engineers, and human factors specialists are taking a global look at propulsion indicators in the cockpit to understand how pilots become aware of engine malfunctions. Researchers are categorizing the malfunctions and phases of flight to develop a set of potential alerts that can address the various malfunctions. Analysis of events and real event data indicate that technology to provide indications in a meaningful amount of time to aid the pilot is feasible.

Most atmospheric aircraft icing is a result of supercooled liquid droplets freezing on aircraft surfaces. Many clouds, however, contain both supercooled droplets and ice particles. The National Transportation Safety Board has recommended that the FAA examine whether or not aircraft icing certification requirements should be expanded to include mixed-phase icing conditions. Since there is only limited scientific information available about mixed-phase icing conditions, FAA researchers are undertaking the necessary work to assess whether certification requirements should be changed. In recent tests using a wing section equipped with a thermal ice protection system, FAA researchers, in collaboration with Wichita State University, Cox & Company, and NASA GRC scientists, made great strides in understanding supercooled droplets by discovering that in mixed-phase icing conditions, supercooled water droplets present in the mixed-phase cloud cause ice accretion. For glaze ice, which occurs at temperatures close to 32 °F, the ice particles in the mixed-phase clouds actually reduce the overall size of the ice accretion. The performance of the thermal ice protection system, when used in an evaporative mode, did not seem to be adversely affected by the presence of ice particles in the cloud. However, testing the system in a running wet mode indicated that the power requirements at the leading edge are much higher when ice particles are present in the simulated cloud.

The FAA's Aviation Weather Research Program made significant contributions to the safety of the national airspace system by working collaboratively with industry, Government, and academia to improve aviation weather forecasting abilities. For example, in FY 2003, the National Weather Service's Graphical Turbulence Guidance product went into operational use. This automated software product provides a color forecast of turbulence at any user-selected flight level above 20,000 feet. The Current Icing Potential for Alaska product also went into operational use. This product graphically depicts areas of icing at user-selected flight levels in Alaska and is a variation of the already operational Current Icing Potential product. The FAA also installed the Weather Support to De-icing Decision Making system at Denver International Airport. This system tracks and predicts snow accumulation so that operators can make better decisions regarding de-icing fluids and the times in which aircraft de-icing must be repeated so that runway plowing can be done more efficiently.

In FY 2003, the FAA, in collaboration with the Volpe National Transportation Systems Center, the Massachusetts Institute of Technology, and the Logistics Management Institute, developed a unique capability to estimate aircraft emissions ranging from a single flight to regional and worldwide scales. Although aircraft are not a primary source of emissions resulting from fossil-fuel combustion, they are the only contributor to directly deposited pollutants in the upper troposphere and lower stratosphere. Aviation is a global enterprise, and the System for Assessing Aviation's Global Emissions (SAGE) offers the unprecedented capability to vary base year inputs and operational, policy, and technology-related scenarios to assess aviation global emissions.

SAGE is a computer tool to aid in estimating and assessing aircraft emissions on a technological, operational, and geographical basis, considering emissions levels through all phases of flight. At the heart of the model are technical modules, including aircraft performance, aircraft movements, capacity and delay, forecasting, fuel burn, and emissions. One typical application allows users to develop emissions inventories based upon fleet forecasts. However, the model also has the capability to estimate emissions, taking into account aircraft routing and flight trajectories and outputting emissions levels by geographic location. The model, currently limited in use to research applications, signifies a major achievement in capturing the logistical complexities of global aviation operations.

FAA researchers also enhanced the Model for Assessing Global Exposure from Noise of Transport Airplanes (MAGENTA) to include satellite geographic information system capability to identify imagery-derived land-use classifications. This update provides an enhanced capability to assess the impact of development projects on numbers of people exposed to noise. Developed by the FAA and Wyle Laboratories, MAGENTA provides the capability for global assessments of aircraft noise and the impact of mitigation measures. The MAGENTA software and its database allow the estimation of global noise exposure caused by civil aircraft operations. It does this by computing noise exposure contours around a large number of civil airports and counting the number of people residing within them. The model includes information on more than 1,700 civil airports that handle jet traffic and offers a landmark capability to assess global benefits of noise-mitigation policy options.

In March 2003, the FAA released an upgrade to its Layered Elastic Design—FAA (LEDFAA) airport-pavement-thickness design software. Among its significant improvements, the new version adds the Airbus A380 and A340-500/600 aircraft families to the design aircraft library. A change to all 32-bit programming improves speed and makes the software compatible with all current Windows operating systems. LEDFAA version 1.3 can be downloaded from the FAA's Web site at *http://www2.faa.gov/arp/engineering/software.cfm*. The new software can be used to design airport pavements for traffic mixes that include the new generation of super-heavy aircraft.

The FAA is currently exploring the role satellite technology can play in providing communications, navigation, and surveillance to improve the capacity, efficiency, safety, and security of the national airspace system by providing both air- and ground-based personnel with improved real-time situational awareness of the entire flying environment. Under an FAA contract, Boeing's Air Traffic Management business unit is working with the Agency to conduct several proof-of-concept studies to demonstrate technologies that could be used by the FAA to help modernize America's air transportation system. In February 2003, using Boeing's Connexion 737-400 demonstration aircraft, researchers tested up- and downlinked weather awareness, an aircraft deviation alerting system, ground display of aircraft flight data monitoring links using an onboard wireless local area network. Researchers are currently developing the demonstration plan for the FY 2004 series of flights.

In early 2003, the FAA's Civil Aerospace Medical Institute (CAMI) worked with the National Academy of Sciences National Research Council to establish a postdoctoral research associate program in support of FAA commercial space research activities. FAA selected its first postdoctoral scholar, who is studying the "Minimum Requirements for Environmental Control and Life Support System (ECLSS) on Manned Commercial RLVs." This research effort supports safety work being done by the FAA's Office of Commercial Space Transportation to understand better the limits of reusable launch vehicle equipment.

CAMI's vision researchers conducted a study to evaluate the vision requirements for persons maintaining and inspecting aircraft. Frequently recurring inspections and maintenance are crucial for ensuring that aircraft and engines are kept in safe operating condition. This research will form the basis for the development of a uniform vision standard for personnel performing these duties. In FY 2003, the research team completed the survey phase of the Vision Standards Study. The team conducted surveys at nine aircraft maintenance facilities and developed a vision task analysis and demographic profile of aircraft maintenance and inspection workers. Depending on the age of the workers, a vision screen was proposed.

FAA researchers also further refined the Human Factors Analysis and Classification System (HFACS). This tool is used to investigate and analyze human error associated with aviation accidents and incidents. Previous HFACS research has shown that this system can reliably be used to analyze the underlying human factors causes of both commercial and general aviation accidents. Furthermore, these analyses have helped to identify general trends in the types of human factors issues and aircrew errors that have contributed to civil aviation accidents. In FY 2003, researchers used HFACS to determine the global human error categories associated with aviation accidents. They developed a detailed analysis of each of the different error forms (decision, violations, skill-based, and perceptual errors) to determine the exact nature of their genesis and relative importance in the causal sequence of events. As in previous studies using HFACS analysis, researchers found that skill-based error was consistently the most common type of error leading to a general aviation accident and, in most cases, was the precipitating error form as well. Furthermore, when violations were associated with a general aviation accident, they were more likely to result in a fatality.

Current FAA policy allows pilots to complete 10 hours of instrument training using an approved personal computer aviation training device. FAA researchers are comparing the effectiveness of Personal Computer Aviation Training Device (PCATD) against training and performance in an aircraft. As part of this effort, human factors specialists use an incremental transfer of training research design to measure the effectiveness of a flight training device (FTD) and a PCATD to determine the point at which additional training in an FTD or a PCATD is no longer effective. The data enable certification personnel to determine what credit to award for different classes of FTDs within an instrument training curriculum. Preliminary results suggest that FTDs and PCATDs are effective; however, definitive statements cannot be made until the sample is completed.

Free Flight Phase 2 established a mandate for the FAA's continued pursuit of research into new automation tools. In collaboration with NASA Ames Research Center and MITRE's Center for Advanced Aviation System Development (CAASD), researchers are undertaking priority research on targeted air and surface traffic-flow management.

The Problem Analysis, Resolution, and Ranking (PARR) tool, developed by CAASD, is an extension of the Free Flight Phase 1 User Request Evaluation Tool (URET). The Initial PARR Assisted Resolution Tool (ART), a part of Free Flight Phase 2, provides the radar associate controller (D-side) with a set of tools to support the development of strategic resolutions to URET-predicted aircraft-to-aircraft and aircraft-to-airspace problems. In January 2003, the FAA conducted controller-in-the-loop simulations of PARR/ART to further refine the operational concept of use for ART.

The purpose of the Traffic Management Advisor-Multi-Center (TMA-MC) tool is to assist traffic management coordinators in planning and managing streams of traffic into selected airspace, as well as into selected Terminal Radar Approach Control (TRACON) facilities that receive traffic from two or more en route centers. Multicenter metering will enable controllers and traffic management specialists operating within different centers to establish optimal arrival sequences across center boundaries. Research focused on the Northeast corridor, with the goal of improving the arrival flows into Philadelphia International Airport. During FY 2003, the FAA conducted extensive field trials with participants from the New York, NY, Cleveland, OH, Boston, MA, and Washington, DC, centers and the Philadelphia TRACON. These efforts provided the FAA and NASA with an understanding of the multicenter collaborative environment. Researchers successfully integrated the lessons learned from these trials into the TMA-MC Concept of Operations. TMA-MC operational trial evaluation is the next critical milestone and is currently scheduled for the summer of 2004.

The Surface Management System (SMS) tool is expected to address air traffic controller needs while providing the airlines with collaborative decisionmaking information that should make both air traffic control and airline operations safer and more efficient. In FY 2003, researchers demonstrated SMS in the Memphis, TN, airline ramp tower and in the Memphis TRACON. The latter demonstration allowed air traffic controllers and traffic manager coordinators to perform a preliminary assessment in preparation for an operational field trial. The field trial will allow air traffic controllers and the airlines to evaluate SMS benefits in an operational environment while incorporating previous airline ramp tower capabilities for an overall surface management system benefit. The completion of a new research management plan supported the successful transition of SMS Build 1 research products to the Free Flight Phase 2 Program Office for operational use.

The En Route Descent Advisor (EDA) is an automated decision-support tool intended for use by the en route controller to handle traffic in transition airspace. EDA builds on the NASA Ames (ARC) Center-TRACON Automation

System (CTAS) to provide controllers with maneuver advisories to enable arrival aircraft to cross TRACON metering fixes in accordance with scheduled time-of-arrival and sequence constraints derived from CTAS while guaranteeing separation assurance and maximizing fuel efficiency. In FY 2003, the FAA and NASA conducted initial operational demonstrations of EDA in the NASA ARC development laboratory to refine further the EDA operational concept.

Direct-To is a decision-support tool for the radar controller (R-side) that will provide advisories for traffic conflicts and direct routes. It includes an interactive trial planning function that allows the controller to quickly visualize, evaluate, and enter route and altitude changes. In FY 2003, the FAA and NASA further refined the FAA's operational concept of use for Direct-To by conducting operational evaluations in the FAA's Integration and Interoperability Facility.

The Integrated Aircraft Data Collection and Reporting (iADCR) project is a prototyping effort to evaluate the benefits and advisability of collecting and downlinking operating data to a ground station for real-time or near-real-time monitoring and postflight analysis. Technology assessments, feasibility studies, and a series of prototype systems have led to refinements in the concept of operations. In FY 2003, the FAA demonstrated a prototype iADCR.

The FAA looks forward to even greater accomplishments in FY 2004. Please visit *http://research.faa.gov* to keep apprised of the FAA's ongoing work.

Department of Commerce

DOC

In FY 2003, the DOC engaged in a wide variety of activities that furthered U.S. interests in aeronautics and space, including satellite operations and licensing, technology development, international cooperation, trade promotion, and civilian and commercial space policy support.

At the Department-wide level, DOC continued its active role on the National Security Council's Space Policy Coordinating Committee (Space PCC), with direct participation from Deputy Secretary of Commerce Samuel Bodman and staff from NOAA, the International Trade Administration (ITA), the Technology Administration's Office of Space Commercialization (OSC), and the National Telecommunications and Information Administration (NTIA). Among the Space PCC's accomplishments was the release of the new U.S. Commercial Remote Sensing Space Policy in April 2003. The policy offers guidance on U.S. Government use of remote sensing capabilities, NOAA's licensing of commercial remote sensing systems, foreign access to U.S. capabilities, and government-to-government intelligence, defense, and foreign policy relationships that involve U.S. commercial remote sensing. During its development, ITA's Office of Aerospace (OA) arranged briefings to U.S. industry to ensure that the new policy would address their needs. Upon its release, NOAA immediately initiated efforts toward the policy's implementation. In the following months, the U.S. remote sensing industry found itself better able to compete internationally and also increased its sales to the U.S. Government.

In November 2002, DOC hosted the final public meeting of the Commission on the Future of the U.S. Aerospace Industry, established by the President and Congress to study issues related to the competitiveness of the U.S.

aerospace industry. The Commission released its final report at the meeting, then met privately with the Secretary and Deputy Secretary of Commerce to discuss its recommendations. ITA's OA, which had co-led the study team responsible for global market and trade issues, played a key role in the followup and implementation of the Commission's recommendations, including organizing discussions of the recommendations among Federal agencies and U.S. aerospace industry representatives, participating in an interagency review of Federal investments in aerospace research and development, preparing a new national plan for transforming the Nation's air transportation system, hosting roundtable discussions with industry to identify workforce and education concerns and create a coordinated Government-industry workforce action plan, and contributing to the Administration's review of the U.S. export control regime.

In February 2003, DOC hosted the Space at the Crossroads Conference, a well-attended event that addressed the balance between commercial and military space. ITA's OA coordinated the conference with several industry associations, including the U.S. Space Foundation and the Satellite Industry Association. In April 2003, Deputy Secretary Bodman spoke at the National Space Symposium in Colorado Springs, CO, the commercial space industry's most widely attended conference. He took the opportunity to meet with numerous representatives from the U.S. remote sensing, Global Positioning System (GPS), satellite communications, and launch industries to hear their views on key commercial space issues. The OA and NOAA coordinated these events.

In May 2003, the Secretary of Commerce and the NOAA Administrator opened the first Commercial Satellite Remote Sensing Symposium, organized by NOAA with support from NASA and the U.S. Geological Survey (USGS). The well-attended meeting, which included many experts from overseas, examined the challenges and opportunities of the growing global commercial remote sensing satellite industry. It included moderated panel sessions on the current market, products and services, U.S. and foreign commercial remote sensing policies and practices, and financing and investment issues. The meeting also coincided with the release of the new U.S. Commercial Remote Sensing Space Policy, which was briefed to participants by the Space Policy Director for the National Security Council.

In June 2003, DOC sponsored the U.S. Pavilion at the Paris Air Show. ITA Under Secretary Grant Aldonas and U.S. Ambassador to France Howard Leach officially opened the Pavilion and held senior-level meetings with foreign government and industry officials, as well as U.S. industry executives. Among other issues, Under Secretary Aldonas encouraged the development of a forum to discuss areas of aerospace cooperation between the United States and the European Union.

Also at the departmental level, DOC continued to play a key role on the Interagency GPS Executive Board (IGEB), representing the interests of commercial, scientific, and governmental users of GPS technology during meetings of the IGEB and its associated management bodies. DOC continued to host the offices and meetings of the IGEB, with NOAA providing an employee to serve as the staff director and the Technology Administration providing additional personnel and resources.

Within NOAA, space-related activities occurred across its entire organization in FY 2003. Most notably, NOAA played a key role in organizing the first ministerial-level Earth Observation Summit, held July 2003 in Washington, DC. At the Summit, over 30 countries and 20 international organizations committed to work toward the establishment of an international, comprehensive, coordinated, and sustained Earth-observation system or set of systems. The new system will provide critical scientific data to decisionmakers around the world so that they can make more informed decisions regarding climate, the environment, and a host of other economic and social issues. By bringing together ministerial-level representatives from developed and developing countries with an interest and significant role in observing systems, as well as representatives from international organizations such as the World Meteorological Organization, the Summit raised visibility and commitment for the issue among governmental decisionmakers. It also marked the establishment of the Group on Earth Observations, which will develop a 10-year implementation plan for the global Earth-observation system(s).

During 2003, NOAA chaired both the Committee on Earth Observation Satellites (CEOS) and the Integrated Global Observing Strategy (IGOS). Comprising 23 space agencies and 21 associated national and international organizations, CEOS is recognized as the major international forum for the coordination of Earth-observation satellite programs and for the interaction of these programs with users of satellite data worldwide. IGOS brings together the major in situ and spaced-based systems for global environmental observations in an integrated planning process for funding and management decisionmaking. During 2003, IGOS coordinated the identification of user requirements in five areas: oceans, global carbon cycle, global water cycle, geohazards, and coral reefs.

In March 2003, NOAA was certified as an official Emergency on-Call Officer (ECO) by the Executive Secretariat of the International Charter "Space and Major Disasters." The International Charter aims at providing a unified system of space data acquisition and delivery to those affected by natural or humanmade disasters. Initial ECO duty for NOAA commenced during the week of March 31 through April 7, 2003. For the balance of FY 2003, NOAA provided data-acquisition support for eight separate Charter activations in response to worldwide disasters, including an earthquake in Turkey; wildfires in France, Canada, and Portugal; volcanic eruptions in Montserrat; flooding in Nepal; and damage assessment for Hurricane Isabel.

During 2003, NOAA's two Geostationary Operational Environmental Satellites (GOES), GOES-East and GOES-West, continued to monitor the Western Hemisphere for severe weather "triggers" in the atmosphere and to provide the kind of continuous data necessary for intensive analysis during hurricanes, tropical storms and depressions, tornadoes, floods, and other severe weather conditions. NOAA successfully completed testing of its newest environmental satellite, GOES-12, which is standing by in orbit, ready to replace one of the older satellites when needed. NOAA also continued to provide space weather monitoring and forecasts to protect spacecraft and power grids.

During the 2003 outbreak of Western U.S. wildfires, NOAA provided special satellite coverage for the firefighting community, land managers, and air-quality-monitoring personnel. Efforts included switching channels on the Advanced Very High Resolution Radiometer (AVHRR) to get better daytime infrared data on the Western U.S. and integrating detections from GOES AVHRR and Moderate Resolution Imaging Spectroradiometer (MODIS) automated algorithms to provide a twice-daily product, as well as a new Geographic Information System site on the Internet.

Under an agreement with the Japan Meteorological Agency (JMA), NOAA moved its GOES-9 satellite over the Western Pacific to replace Japan's aging GMS-5 satellite. This action ensured continuity of geostationary satellite services to support severe weather forecasting for Japan, for U.S. assets and territories in the Western Pacific, and for other regional allies. Prior to the operation, JMA funded upgrades to NOAA's Fairbanks Command and Data Acquisition Station, as well as related operations costs.

NOAA's second polar-orbiting environmental satellite, NOAA 17, provided improved product capabilities with new solid-state recorders. The satellite continued to perform functions critical to virtually all of NOAA's missions, such as weather, climate, oceans, fisheries, and ecosystem monitoring.

During FY 2003, work continued toward consolidating NOAA and DOD assets into the NPOESS. The program successfully transitioned existing Government-held sensor contracts to its new prime contractor, Northrop Grumman, which took full ownership of the contracted activities. Northrop Grumman assumed full responsibility for development and performance of the instruments and data-processing algorithms. NOAA completed an agreement with NASA for the NPOESS Preparatory Project, a test and proof-of-concept satellite that will validate performance of three major NPOESS instruments, the complete command and control system, and the data processing/distribution system. In January 2003, the Navy successfully launched Coriolis/Windsat, a proof-of-concept satellite developed with NPOESS funding. The year 2003 also saw the successful completion of all NPOESS sensor design activities, delivery of sensor test models, and beginning of production for the first flight units of some sensors. Using test units, NPOESS sensor performance was verified, with all sensors successfully meeting their key requirements.

NOAA and NASA collaborated in the formulation of a Memorandum of Agreement with the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) to ensure sustained geostationary coverage from EUMETSAT's Meteosat Second Generation-1 (MSG-1) satellite for U.S. Government and private-sector users. Focusing on improved system efficiency, the Memorandum stipulates a cost-effective method using a domestic relay satellite to disseminate high-resolution digital MSG data to users within the United States.

In September 2003, the relay of preliminary satellite data and products between the United States and India commenced under the auspices of a revised Memorandum of Understanding for Scientific Cooperation in the Areas of Earth and Atmospheric Sciences involving NOAA, NASA, and India's Department of Space and Department of Science and Technology.

During FY 2003, NOAA developed new satellite products to enhance the Nation's ability to predict weather, monitor climate change, observe ocean conditions, and detect natural hazards. NOAA developed and implemented a processing system to provide data from NASA's Atmospheric Infrared Sounder to major weather forecast centers worldwide within a few hours after its collection. NOAA also developed new experimental remote sensing and advanced software products used at the National Hurricane Center as it monitored Hurricane Isabel's approach to the U.S. coast. NOAA transmitted experimental real-time satellite products to help track Isabel. Based on both GOES geostationary and NOAA polar-orbiter observations, the products included estimates of environmental wind shear, storm intensity, and vortex wind structure.

Supporting the above operations, NOAA provided a suite of services including data rescue, information technology, and scientific data stewardship. Under data rescue, for instance, the University of Wisconsin completed the transfer of 120 terabytes of GOES satellite data from over 10,000 tapes to modern media, which are to be transferred to the NOAA archives. NOAA also completed the overall design of top-level architecture for its Comprehensive Large-Array Data Stewardship System, including requirements, interface control, concept of operations, and management plans and procedures.

During FY 2003, the Joint Center for Satellite Data Assimilation, formed by NOAA and NASA to accelerate the use of satellite observations in numerical weather and climate prediction, continued its ongoing efforts and welcomed the U.S. Navy and Air Force as new, active partners in the Center.

In the area of GPS data services, NOAA acquired and installed all necessary hardware and communications systems to enable the Continuously Operating Reference Stations (CORS) west parallel site in Boulder, CO, to collect and deliver Coast Guard and FAA data. This enabled NOAA's Forecast Systems Laboratory in Boulder to access these data in an expedited manner. In addition, the parallel Internet site for distributing these data to the public came online in 2003.

Also in FY 2003, NOAA continued to use GPS and remote sensing technologies to map the national shoreline, produce airport obstruction charts, and monitor and analyze coastal and landscape changes. Similar functionality was achieved where the Citation aircraft was utilized to support homeland security efforts by providing 12 LIDAR datasets of major cities to the Army Joint Precision Strike Demonstration Program Office and NIMA. These datasets allowed for three-dimensional modeling of cityscapes for a variety of homeland security needs. This unique relationship with the U.S. Army and NIMA provided NOAA with access to LIDAR systems for research and development and met the need for a continental United States (CONUS) response capability within 6 hours of an event. This capability did not exist before September 11, 2001.

Finally, NOAA continued to support the FAA-led Safe Flight 21 program by providing accurate runway and taxiway data referenced to the National Spatial Reference System. The joint Government/industry program demonstrates the capabilities of new technology coupled with accurate, detailed airport surveys to increase ground safety and situational awareness for all personnel in the airport ground movement area.

Outside NOAA, DOC organizations participated in a variety of other aeronautics and space activities. The Technology Administration engaged in many space-related areas through its OSC and National Institute of Standards and Technology (NIST). OSC continued to serve as the principal coordinating unit within DOC on space-related issues, coordinating positions with and disseminating information to various bureaus with separate space-related responsibilities and authorities, including NIST, NOAA, ITA, the National Telecommunications and Information Administration, and the Bureau of Industry and Security.

In December 2002, OSC published a report on Suborbital Reusable Launch Vehicles and Applicable Markets. The study was a followup to OSC's November 2001 Government-industry workshop on market opportunities in space, which identified suborbital space transportation as a potentially viable business area. The report examined the technical aspects of 14 different suborbital vehicles and identified potential markets that such systems may enable. In February 2003, OSC published *Market Opportunities in Space: The Near-Term Roadmap*, a summary of issues discussed at the November 2001 workshop. These included the use of space to enhance existing cargo delivery, tourism, biotechnology, pharmaceuticals, power generation, and media businesses. The same month, OSC published a separate report on Space Economic Data, which offered recommendations for making economic data about the space industry more accurate, reliable, and available.

During FY 2003, OSC continued to serve on the U.S. delegation, led by the State Department, that negotiated with the European Community toward cooperation between GPS and Europe's planned Galileo satellite navigation system. OSC, along with NOAA, ITA, and NTIA, participated in several major strategy development efforts in this regard, representing the interests of U.S. industry and the end users of GPS technology, particularly with respect to nondiscrimination and fair trade. OSC personnel delivered key messages to Europe on behalf of the U.S. Government regarding the GPS-Galileo relationship. OSC also participated in U.S. consultations with Japan to continue ongoing bilateral cooperation related to GPS. These talks, held in October 2002 in Tokyo, resulted in new cooperation to ensure interoperability between GPS and Japan's planned Quasi-Zenith Satellite System.

NIST was highly active in FY 2003, performing a broad range of aeronautics and space-related measurement and standards research, technology transfer, and industry support. Notably, NIST engaged in numerous radiometric calibration activities in support of Government and commercial space projects. Radiometric calibration is the measurement and adjustment of sensors to improve their accuracy, sensitivity, and traceability to standards through an unbroken chain of comparisons. NIST's radiometric calibration activities included testing and improvement of several facilities to support the Missile Defense Agency's Exoatmospheric Kill Vehicle program, which aims to detect and intercept dim objects in space such as missiles; onsite calibrations of Raytheon remote sensing instruments; measurement of the radiance of blackbody sources used by DOD to calibrate space-borne strategic infrared sensors; characterization of the spectroradiometer system used by the USGS's Robotic Lunar Observatory, which collects radiometric images of the Moon; calibration of NASA's EOS sensors used for global remote sensing; calibration of NOAA's Marine Optical Buoy, which helps validate ocean color measurements taken by NOAA satellites to determine phytoplankton distributions and evaluate ocean health; and cooperation with NASA and the Scripps Institute to enable the Deep Space Climate Observatory satellite to measure the absolute irradiance of the sunlit Earth.

NIST collaborated with NOAA, NASA, and the National Center for Atmospheric Research to address problems of calibration and validation of microwave radiometers for remote sensing. Measurement-based methods were developed to evaluate uncertainty due to both detector nonlinearity and calibration target proximity. A public Web site was also developed to serve as an international forum for standardization of radiometry terminology.

NIST obtained new NASA support for the production and compilation of atomic spectroscopic data needed by space astronomers. To support space observations in the vacuum ultraviolet, x-ray, and infrared spectral regions, NIST measured relevant areas of the electromagnetic spectrum, including the spectra of iron (Fe I and Fe II) and other spectra of high cosmic abundance. NIST's synchrotron III was used as a source of soft x rays and vacuum ultraviolet light to calibrate mirrors, detectors, and spectrometers used in NASA spacecraft that study solar flares and astronomical bodies, as well as the Solar Radiation and Climate Experiment. NIST also played a critical role in the analysis of x-ray data from NASA's Near Earth Asteroid Rendezvous mission and helped to develop new tools for determining particle-size distribution on the surface of the asteroid.

NIST provided state-of-the-art laser stabilization technologies to NASA. It performed preflight, ground-based research to explore emerging new techniques in optical frequency measurement, atomic and molecular spectroscopy, solid-state laser development, and timekeeping and distance ranging. These areas are vital to NASA's goal of exploring space-based interferometry as a means of determining the precise orbital positions of spacecraft. Eventual applications include gravity-wave detection and enhanced extragalactic imaging. NIST activities also included consultation with NASA on space qualifications of various laser components and stabilization circuitry for future NASA missions, as well as emerging ideas on the use of a single phase-stabilized ultrafast laser for both timekeeping and distance ranging in space.

With NASA funding, NIST continued to collaborate with JPL, the University of Colorado, and the Harvard-Smithsonian Center for Astrophysics on the development of an atomic clock system for the ISS, completing its Preliminary Design Review in 2003. The experiment aims to test aspects of relativity theory and demonstrate the viability of operating a primary frequency standard in space. Space-based clocks have the potential to be about 10 times more accurate than the best current ground-based clocks, and they could be used to study gravitational waves and relativity, enhance space-based astronomical observations, and improve navigation and communication. NIST also continued to conduct ground-based experiments to investigate the development of new space-based atomic clocks based on optical rather than microwave transitions. Using optical transitions could potentially improve atomic clock performance by a thousandfold and shrink size, weight, and power consumption to a tiny fraction of current levels. NIST investigated both neutral atom and trapped ion clocks; these investigations including demonstrating multiple-stage laser cooling of neutral calcium atoms and the characterization of a new trapped mercury-ion clock.

In collaboration with the U.S. Naval Observatory, the University of Colorado, and other partners, NIST conducted research on improving the accuracy of time signals received from GPS for the most demanding military and civilian applications, including telecommunications synchronization, secure communications, frequency standards for advanced radar and surveillance systems, and improvements to the international time scale. Using the microwave GPS carrier frequency as the timing source instead of the GPS time code, NIST and its partners demonstrated time-transfer uncertainties as small as 20 trillionths of a second.

NIST developed a time-domain measurement system to characterize ultra-wideband (UWB) emissions of commercially available UWB devices. A key application is to investigate potential interference between UWB devices and GPS, radar, and communications systems. NIST tested prototype UWB signal sources for signal fidelity and continued to refine design guidelines for UWB antennas.

NIST continued to work with JPL on the Condensate Laboratory Aboard the Space Station project, which will develop microgravity measurement instruments using Bose-Einstein Condensates—a fifth state of matter discovered using NIST's Nobel Prize-winning laser cooling technique. In FY 2003, the project demonstrated molecule production in a condensate and constructed a multi-arm interferometer.

Furthermore, NIST continued its collaboration with NASA's Goddard Space Flight Center (GSFC) to develop cryogenic transition-edge-sensor microcalorimeter x-ray detectors for use by the future Constellation-X mission. This mission involves an array of orbiting x-ray telescopes collecting observations of black holes, dark matter, and other cosmic mysteries. NIST also continued work with NASA to apply NIST micropositioners to optical beam direction for deep space communications. A target NASA application for this is the Realistic Interstellar Explorer.

NIST worked with an industrial partner to develop a cryocooler prototype that achieved temperatures of about 17 kelvin. The partner plans to use this technology to subcool liquid hydrogen to 15 kelvin for use in next-generation space vehicles. NIST also provided NASA with information on the physical properties of substances at cryogenic temperatures as part of the Space Shuttle Columbia investigation.

With the sponsorship of Boeing and the FAA/Transportation Security Administration, NIST developed efficient techniques and methodologies for measuring the electromagnetic radiation shielding of aircraft, which, among other things, reduces interference to avionics from external radiation and onboard laptops and cell phones. NIST developed new time-domain techniques to enable fast, reliable in situ measurements, even in high-scatter environments. The new techniques were successfully demonstrated on a Boeing aircraft at a manufacturing plant and on an Airborne Warning and Control System (AWACS) aircraft that had undergone extensive shielding enhancement.

To support NASA's need for nondestructive evaluation of aircraft and spacecraft structures, NIST worked to enhance the acoustic emission (AE) technique. The work included experimentally and analytically characterizing AE signals from multiple sources, identifying sources of uncertainty, and developing reliable approaches for practical application of the technique.

NIST's Advanced Technology Program (ATP) funded a project by Acellent Technologies, Inc., to develop new technology in the field of structural health monitoring, with an initial focus on evaluating new and aging aircraft. NIST also gave an ATP award to GSE, Inc., to develop a new diesel-engine design that will tolerate the low cetane rating and physical properties of JP5, JP8, and Jet-A fuel. When commercialized, the engine could be made in a wide range of sizes for civilian and military aviation.

NIST's Manufacturing Extension Partnership continued to help U.S. manufacturers of aerospace parts and systems increase productivity and reduce costs through the adoption of lean manufacturing and other business process improvements.

In April 2003, in cooperation with NASA and the European Space Agency, NIST hosted the fifth annual International Workshop on Aerospace Product Data

Exchange, a forum for discussing methods and technology for reliable exchange and long-term archival of aerospace product data, particularly through the use of open standards.

NIST continued to provide the tools, methodologies, standards, and measurement services needed by aerospace parts manufacturers and assemblers 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 provided calibration services in areas of electrical measurements and microwave parameters to numerous aerospace corporations such as Boeing, General Dynamics, Lockheed Martin Astronautics, McDonnell Douglas Corporation, Northrop Grumman, and TRW Space and Electronics. As another example, NIST provided standards and calibrations for antennas used with a variety of satellites, spacecraft, and radar systems. NIST also performed calibrations of length standards for U.S. aerospace companies to ensure that the dimensions of their manufactured parts conformed to design specifications. For example, NIST developed and deployed the Laser Rail Calibration System (LARCS) for calibrating laser tracker measuring systems, which are becoming the tool of choice among aerospace manufacturers for inspecting large manufactured parts. The NIST LARCS system reduces the calibration cycle for laser tracking measuring machines from 5 days to just over 5 hours, making it economical to calibrate these instruments more frequently and increasing confidence in the measurements and their results.

DOC's ITA also engaged in numerous activities related to space and aeronautics, primarily through its OA. As noted earlier, ITA supported several marquee space events at the departmental level. The OA also continued to represent commercial remote sensing industry interests in the policymaking process as part of the DOS-led Remote Sensing Interagency Working Group (RSIWG). The RSIWG is charged with coordinating policy for the export of remote sensing satellite systems and negotiating government-to-government agreements covering the safeguarding of those systems' technology. The group held consultations with several countries on remote sensing satellite cooperation, including Canada and France.

In June 2003, ITA participated in the fourth meeting of the Russian-American Commercial Aerospace Working Group, established under the umbrella of the Russian-American Business Dialogue and co-chaired by DOC, the American Chamber of Commerce in Russia, and the Russian Aviation and Space Agency. The objective of the working group is to foster and facilitate aerospace trade and investment between the two countries. The June meeting resulted in progress on market access and investment issues as the Russians indicated that aircraft import tariffs would be lowered and restrictions on foreign ownership of aerospace joint ventures would be lowered or eliminated.

In February 2003, ITA participated in a meeting in Moscow between U.S. and Russian officials to share how the United States implements the World Trade Organization (WTO) Agreement on Trade in Civil Aircraft (ATCA) in regards to customs administration and the U.S. approach to dual-use and customs fraud issues.

The OA continued to play a critical role on the U.S. team seeking to resolve aircraft noise and emissions disputes between the United States and the European Union. The OA also continued to monitor and draw attention to European government loans to Airbus for the development of the A380 super jumbo jet, which the United States views as illegal subsidies. At the same time, ITA continued to seek avenues for cooperation with European governments on aerospace issues of mutual interest, holding senior-level discussions on possible aerospace cooperation with Germany, France, and the United Kingdom.

The OA and the Civil Aviation Administration of China successfully carried out two activities under the 2003 Aviation and Airport Subgroup Work Plan, part of the U.S.-China Joint Commission on Commerce and Trade. In conjunction with the U.S. Air Traffic Control Association, the OA organized an Executive Aerospace Trade Mission to Beijing and Chengdu in September 2003, including participation in the Aviation Expo trade fair in Beijing. The mission introduced U.S. executives from 10 air traffic control and airport equipment firms to senior-level Chinese aviation officials at a critical time when China has turned over most airport operations to local government officials across the country. The mission also identified the requirements for airport and air traffic management upgrades needed to support the 2008 Olympics, as well as those which require long lead times to accomplish. In addition, over 100 Chinese participants from various aerospace sectors participated in airport certification training sponsored by the FAA. These events continued to foster an increasingly stronger relationship between the American and Chinese aerospace industries.

The OA played an instrumental role in pushing the United States to sign and ratify the Cape Town Convention, an international treaty designed to facilitate asset-based financing and leasing of high-value equipment, including aircraft and aircraft engines, by reducing risks to the seller, lender, and/or lessor. The United States signed the Convention in May 2003, with ratification by the Senate expected in 2004. To stimulate international interest in ratifying and implementing the Cape Town Convention, the OA organized a June 2003 seminar on the benefits of the Convention to other nations. The seminar was cosponsored by DOC, DOS, DOT, FAA, the Export-Import Bank of the United States, and the Aviation Working Group. Following the seminar, Panama and Ethiopia ratified and implemented the Cape Town Convention.

The OA coordinated the signing ceremony for the sale of eight Boeing aircraft worth $1.7 billion to Pakistan International Airlines. Deputy Secretary Samuel Bodman oversaw the event, which included Members of Congress, Pakistan's ambassador to the United States, Pakistan's Secretary of Defense, and senior management from Boeing and Pakistan International Airlines.

In October 2002, the OA organized and managed an airport-focused Executive Trade Mission to South Africa. Eight U.S. business representatives participated in the mission, which featured high-level meetings with South African industry and Government officials and enabled several participants to negotiate sales contracts or identify local representatives, agents, and distributors.

During FY 2003, the OA, in coordination with ITA's Advocacy Center and overseas offices, continued to advocate in support of U.S. companies in international aerospace competitions, including commercial sales for aircraft, helicopters, airport construction, communications and remote sensing satellites, commercial space projects, and air traffic management projects. The OA also sponsored an Aerospace Products Literature Center at the Paris Air Show and a similar operation at the Beijing Aviation Expo. These events provided large numbers of trade leads for participating companies—approximately 800 for the Paris Air Show alone.

As the lead advisory agency for Federal Government telecommunications issues, DOC's NTIA undertook a number of policy initiatives regarding satellites and other space-based communications systems. NTIA provided policy guidance on issues concerning the International Telecommunications Satellite

Organization and the International Mobile Satellite Organization. NTIA also continued to manage the Federal Government's assignments, nationally and internationally, for use of the radio spectrum for NOAA, NASA, DOD, and other Government agencies with satellite programs.

NTIA worked closely with other U.S. regulatory authorities and commercial satellite users to achieve a successful outcome at the International Telecommunication Union World Radiocommunication Conference in 2003. The results included updating satellite regulations and protecting existing and new spectrum allocations for GPS.

Department of the Interior

DOI

President George W. Bush signed a U.S. Commercial Remote Sensing Space Policy (CRSSP) on April 25, 2003. CRSSP goals include advancing and protecting U.S. national security and foreign policy interests by maintaining the Nation's leadership in remote sensing space activities and sustaining and enhancing the U.S. remote sensing industry. The policy directs the U.S. Government to rely on U.S. commercial remote sensing space capabilities to the maximum extent possible for fulfilling imagery and geospatial needs for military, intelligence, foreign policy, homeland security, and civil users.

The Secretaries of Interior and Commerce and the NASA Administrator were directed to construct an implementation plan for the Federal civil community. The DOI's USGS led an interagency team in writing the plan, which directs agencies to work collectively to identify and share their requirements for remote sensing products, consolidate procurement through cost-effective contracts, and develop a data library to facilitate the broadest possible dissemination and reuse. Existing agency infrastructure will be leveraged to accelerate plan execution. The plan identifies USGS as the lead civil agency, with distributed responsibilities assigned to NOAA and the USDA. A committee of senior executives from departments and independent agencies will provide high-level guidance for implementation and operation of these capabilities.

April 15, 2003, marked the fourth anniversary of Landsat 7 operations under USGS management. The U.S. archive of Landsat 7 data contains a wealth of cloud-free land observations, with over 30 percent of archived scenes having less than 10-percent cloud cover. The extensive network of Landsat International Cooperator stations has augmented the global archive of Landsat 7 data with extensive unique coverage over their individual geographic regions. Over the last 4 years, the U.S. Landsat project has produced and distributed over 55,000 scenes to the Landsat user community.

On May 31, 2003, unusual artifacts began to appear within image data collected by the Landsat 7 Enhanced Thematic Mapper Plus (ETM+) instrument. These artifacts were caused by a failure of the instrument's Scan Line Corrector (SLC), an electromechanical device that compensates for the forward motion of the spacecraft. Repair attempts were unsuccessful. Landsat 7 is now collecting the full complement of daily global coverage. These data collected without the SLC are still of very high radiometric and geometric fidelity, but they leave a gap between some scans, resulting in a loss of about 25 percent of the data in a scene. Landsat 5, which was launched in 1984, achieved an important milestone when it completed its 100,000th orbit on December 19, 2002.

USGS supported the Earth Observing-1 (EO-1) Extended Mission during 2003, in cooperation with NASA, by providing data reception and ground-system operations. NASA GSFC continued to provide flight operations, additional data reception sites, and program management. The EO-1 Extended Mission continued to collect and distribute Advanced Land Imager (ALI) multispectral and Hyperion hyperspectral products in response to acquisition requests placed by public and Federal customers. Data are archived by the USGS Earth Resources Observation Systems (EROS) Data Center and placed in the public domain. ALI data are similar to those from Landsat 7 ETM+ but utilize a newer sensor technology; ALI is a prototype sensor for the Landsat Data Continuity Mission.

For decades, the USGS has maintained contracts for collecting new remotely sensed data for its mapping and science needs and for those of its Federal and State agency partners. Now the USGS has established complimentary contracts needed to procure "off-the-shelf" commercial data. These data may have already been collected on speculation or for specific clients and are offered for resale under negotiated licensing agreements. These new USGS contracts provide access to a wide variety of high-quality optical and radar data collected from aerial platforms. The contracts include flexible data use and distribution terms to support The National Map and other USGS and civil community needs. The National Imagery and Mapping Agency (NIMA) was the first customer to place an order through the contract. Their order encompassed 22,753 square miles and was procured for urban-area photo mapping in support of homeland security. The data will remain licensed for Government use for 1 year, at which time it will be placed in the public domain. Centralized Federal procurement has proven to be cost-effective for the Government through volume discounts, reduction of redundant contract administration costs, and avoidance of duplicate purchases.

The USGS is working with NASA, NIMA, industry, and academia to independently validate and characterize commercial remote sensing space data products. The results of these tests, administered by the Joint Agency Commercial Imagery Evaluation team, assure that the data sources meet the specialized needs of Government applications. Test results have also proven to be highly informative to commercial satellite vendors, as well as current and potential users of the technology. Findings are presented annually at the High Spatial Resolution Commercial Imagery Workshop. The third annual workshop was held in the spring of 2003 at the USGS in Reston, VA, featuring the results of the evaluations of QuickBird-2 satellite data. The USGS and its partners in the City of Sioux Falls and Minnehaha County, SD, determined that the data met geometric specifications and could support a number of local government applications.

The USGS has the mission to provide basic cartographic information for the United States. A primary source for these data is airborne film mapping cameras. Since 1973, the USGS Optical Science Laboratory has been responsible for calibrating these cameras for the aerial mapping community. Over the years, the lab has been recognized nationally for providing this essential service. The USGS calibrated 107 cameras during 2003. Today's digital technology offers the aerial mapping community a choice of using film cameras or increasingly sophisticated all-digital cameras. The USGS established a Digital Camera Calibration Laboratory and other advanced methodologies at the USGS EROS Data Center in 2003 to address emerging sensor technologies. The lab is equipped with a target cage, hardware, and software for calibrating small- to medium-format digital cameras. The USGS also signed an agreement with NASA's Stennis Space Center (SSC) to start characterizing large-format digital cameras by utilizing their field-calibration test range. USGS awarded a grant to The Ohio State University for delivery of software and results of system tests over their field test range. The USGS is working to establish standards for commercial digital aerial mapping cameras.

The USGS EROS Data Center has established joint agency agreements with NOAA and the USDA to become part of five different instrumentation networks. These networks were established at the USGS EROS Data Center in 2003 to support calibration and validation of remotely sensed data. The networks collect information about key Earth surface properties needed to calibrate data and ensure product validity. These properties include high-precision GPS reference data, complete meteorological microclimate data, soil temperature and moisture data, and surface solar radiation data. USGS will also provide continued support for the field instruments/networks and tools required to calibrate and validate commercial remote sensing data. The recently established USGS instrumentation network site includes 1) the NOAA National Ocean Service Geodetic Survey Operating Reference Station Network, 2) the NOAA Forecast Systems Laboratory GPS Surface Observation System Network, 3) the USDA Natural Resources Conservation Service (NRCS) Soil Climate Analysis Network, 4) the NOAA Surface Radiation Research Branch Surface Radiation Budget Network, and 5) the NOAA National Climatic Data Center Climate Reference Network.

The capability to collect images having both high spatial and high spectral resolution on very short notice is critical to Earth science applications that deal with short-lived events. The temporal and spatial resolutions of existing civilian satellite imaging systems are typically not sufficient for these types of applications, so USGS scientists in Flagstaff, AZ, designed and developed a compact, portable, airborne digital-imaging system during 2003. The main use of the new imaging system was to detect and monitor, on short notice, 1) dust storms in the Southwestern United States to study their impact on visibility, air quality, and climate in the region and 2) on-land sediment runoff onto coral reefs in Hawaii to help study the impact on coral health. Besides these two applications, the airborne digital-imaging system was used to collect data to investigate potential applications to map and monitor the benthic habitat of the Colorado River in the Grand Canyon region; map the wildland/urban interface in mountain communities to generate fire-hazard and tree-density maps around a community, with possible use for near-real-time monitoring and imaging of wildfires; and map and monitor vegetation at a very high spatial resolution in national parks in Hawaii in cooperation with the National Park Service (NPS). Approximately 60,000 digital images were collected with spatial resolutions ranging from 1.2 to 0.1 m. Various image maps and digital image products were generated for use by ongoing research and mapping projects.

The USGS EROS Data Center continued to support the AmericaView Consortium, a nationwide collaboration of State organizations working in partnership with the USGS to foster remote sensing education, research, and geospatial applications. As part of that support, the Data Center staff made improvements to the USGS Global Visualization (GloVis) Web-based image browser. GloVis allows a user to browse the entire USGS archive of Landsat Thematic Mapper (TM) and ETM+ data through the Internet. Enhancements included adding map reference layers and improving navigation tools. The source code for GloVis was released to the AmericaView Consortium and the general public, and technical assistance was provided to individual States (Texas, Alaska, and South Dakota) in using the code to set up their own data portals. Operations also continued for the Moderate Resolution Imaging Spectroradiometer (MODIS) Direct Broadcast project. The operations team received and archived 908 passes with a 99.5-percent capture success rate. The team improved the reliability of the EROS Data Center ground station by adding additional backup equipment. They also created additional Web interfaces to distribute MODIS datasets. Finally, they added the capability to display the MODIS U.S. composite data sets in the USGS seamless server, allowing the user to select an area of interest and download the corresponding data.

The NPS used data from Landsat, QuickBird, Satellite Probatoire d'Observation de la Terre (SPOT), and IKONOS satellites, along with conventional aerial photographs and digital orthophotographs to map and monitor land cover, vegetation, and cultural features; produce high-resolution digital elevation maps; and map other specific features in many national parks. Light Detection And Ranging (LIDAR) data were used to acquire baseline data from coastal parks including Colonial National Historic Park, George Washington Birthplace National Monument, Thomas Stone National Historic Site, and Sagamore Hill. LIDAR also was used to acquire data on bathymetric surfaces and coral reefs in Florida parks. In Alaska, LIDAR data were being evaluated as a means to produce highly detailed topographic maps in areas with nearly complete canopy cover.

High-resolution IKONOS satellite data were evaluated for use as a means to monitor resource damage by illegal immigrants in border parks, with prototype studies conducted primarily at Organ Pipe Cactus National Monument. The NPS Pacific Island Network partnered with other Federal and State agencies to acquire data from Landsat, IKONOS, QuickBird, EMERGE (a commercial digital aerial sensor), and aerial photographs for applications such as mapping, change detection, and long-term resource monitoring. National park units used land-cover data derived from Landsat data through the interagency Multi-Resolution Land Characteristics (MRLC) Consortium for temporal ecosystem and change-detection studies and for providing context for analysis of higher spatial-resolution data. The NPS fire management program relies on Landsat data to map burn intensity and burn parameters in Western parks, along with extensive use of aerial photography.

The USGS continued to cooperate with NASA to apply airborne LIDAR methods to aid natural resource management in national parks and national seashores. A preliminary LIDAR submarine digital elevation model (DEM) of a portion of the Florida reef tract within Biscayne National Park was created.

Between June and September 2003, the USGS, in cooperation with the NPS, collected several thousand oblique aerial photographs of glacier and coastal features in the Glacier Bay National Park/Wrangell-St. Elias National Park area of Alaska. Both digital and film images were collected, most tied to the aircraft GPS navigation log. These images are used as part of long-term studies to document the response of Alaskan glaciers to changing climate and to document coastal natural hazards and long-term shoreline change.

The Bureau of Land Management (BLM) used Landsat, QuickBird, and IKONOS satellite data; LIDAR data; and conventional aerial photography and digital orthophotography to inventory, monitor, and address concerns about energy and mineral resource extraction, as well as urban growth, on public lands. Satellite data were supplemented with GPS and geographic information system (GIS) analysis to support on-the-ground resource management and decisionmaking activities.

High-resolution QuickBird and IKONOS satellite data were used to evaluate BLM lands in the Western States, including Alaska, as well as BLM lands in Florida, Virginia, and Maryland. These data were being used in conjunction with GPS data for endangered species habitat management; management and activity planning; vegetation classification; invasive plant species issues; cultural resource analysis; and wildfire forecasting, analysis, and smoke dispersion. Projects requiring higher resolution data were more evident this year, as satellites were tasked for submeter panchromatic and 2-meter multispectral resolution for projects to be initiated in 2004. LIDAR data were analyzed over a mining area south of Turquoise Lake, CO. The location and elevation data were used for determining size, volume, and location of abandoned mine dumps; exploring use in measuring biomass, both at ground surface and in tree tops; and addressing potential hydrology issues.

Numerous BLM field offices have acquired natural-color aerial photography (scanned, rectified, and geo-referenced) to be used in vegetation evaluations for land health assessments, habitat evaluations, road network updates, land appraisals, off-highway vehicle information capture, abandoned mine site locations, contaminated springs source locations, and stream assessments to determine proper functioning condition. For example, aerial photo interpretation was completed over the George River Basin in Western Alaska to assess the proper functioning condition of stream segments. This was validated during the field season. Digital airborne 1-meter data from visible and near-infrared sensors were orthorectified and mosaicked for a 43-square-mile burned area near Timbered Rock, OR, to develop an environmental impact statement. BLM also conducted a pilot project to scan historical aerial photography and to develop an interactive Web site in order to ensure that BLM's Aerial Photography Archive was readily available to State and field offices and would eventually be available to the general public.

BLM continued to use digital orthophoto quadrangles (DOQs) for monitoring the health of rangelands and riparian areas, planning field travel, and evaluating proposed land exchanges. Partnerships were formed to acquire new black-and-white and color-infrared DOQs throughout BLM and to work cooperatively to make these data available to the public on the Internet. These new data are used for the evaluation of potential Southwest Willow Flycatcher habitat in riparian areas along the Conejos River in South-Central Colorado; travel inventory and the evaluation of sites for fuel reduction in Grand Junction, CO; the study of coal-bed methane activity and subsequent urban planning and growth; transportation planning; watershed management; and the tracking of extraction and production of this natural resource in the Powder River Basin, WY.

BLM has continued its partnership with the Colorado Division of Wildlife to classify vegetation by watershed using Landsat TM data for the State of Colorado. Data generated by this project have been used for fuel modeling and habitat evaluation. BLM continued its partnership with the USDA NRCS and the NPS to use value-added band ratio products derived from Landsat data for predictive soil mapping. BLM also contributed data and funding to support a Powder River Basin, WY, temporal change map in conjunction with the Wyoming State Game and Fish Department.

During 2003, the Bureau of Indian Affairs (BIA) used high-resolution satellite remote sensing and GPS to support BIA and tribal initiatives to map land use, inventory natural resources, conduct environmental assessments, support Safety of Dams program initiatives, and map and inventory irrigation systems. Application specialists used digital orthophotographs, National Aerial Photography Program aerial photography, the National Elevation Dataset, Digital Raster Graphics, and high-resolution IKONOS satellite data as backdrops for modeling inundation zones associated with the potential catastrophic failure of earthen dams. BIA personnel also collected GPS data on high-priority dams under BIA jurisdiction. In addition, they developed inundation maps for input to Emergency Action Plans for 10 dams during the reporting period.

BIA used commercial GPS receivers to collect data for 3,042 ditch miles and 28,700 associated structures in BIA-managed irrigation systems. In addition, digital aerial photographs with GPS coordinates were collected for all structures. These datasets were combined to map the condition of irrigation systems and structures on seven major BIA irrigation projects on Indian reservations in the Western United States. Aerial photographs and satellite data were also key components in the mapping process in both the irrigation and Safety of Dams projects. The U.S. Fish and Wildlife Service (USFWS) used remotely sensed data in FY 2003 to create and update vegetation maps for use in comprehensive conservation planning for National Wildlife Refuges in areas of the United States as diverse as New Mexico, Hawaii, and Alaska. The maps are also used in managing lands within the National Wildlife Refuge System, as well as to make critical habitat determinations for endangered species. USFWS specialists are also beginning to explore the use of these data for wildland fire control, following the example of other Federal agencies working in this area.

USGS scientists continued to evaluate data from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) imaging system. Applications of ASTER data have been made to a wide range of geological topics, including volcano monitoring, glacier dynamics studies, mineral resource assessment, and geological mapping. USGS scientists also served on the ASTER U.S. Science Team that provides guidance on instrument calibration requirements, selection of data acquisition targets, and the development of standards for data products.

USGS scientists used ASTER and Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data to map distributions of hydrothermally altered rocks on the major Cascade stratovolcanoes in the Pacific Northwest. Such rocks form potentially unstable masses that can be dislodged by volcanic eruptions or large earthquakes to produce hazardous rock avalanches and mudflows. The remotely sensed data are being used in conjunction with other geological data to aid in making volcano hazard assessments in the Cascades. Techniques developed in the course of this work also should have applications in other volcanic regions.

USGS scientists, in cooperation with researchers from the Ground-Water Research Program (GWRP) of Abu Dhabi Emirate, United Arab Emirates, used Landsat ETM+ data to map irrigated land and agricultural crops in the Emirate. Hydrologists in the GWRP use irrigation status and crop type data, along with crop water use coefficients, to calculate groundwater usage. The government of Abu Dhabi Emirate is implementing many irrigation projects throughout the Emirate, and the monitoring of groundwater usage is a critical part of resource management.

An important issue in coral reef environments is the impact of on-land pollution, including the amount of sediment delivered to the reef by water erosion caused by rainstorms. The USGS, NPS, USDA, and Hanalei River Heritage Hui in Hawaii are cooperating to assess soil-erosion impacts on coral reefs in Hawaii. Many parameters determine the effect of a single runoff event or the accumulative impact over a prolonged period of time, with three of the main parameters being slope, soil type, and vegetation type and cover. Data layers representing these three parameters, along with multitemporal Landsat TM and USGS airborne images, were acquired for one site during 2003 and are being used to develop the algorithms and model to generate a digital landscape erosion vulnerability map.

Dust emission in the Southwest United States is a concern with respect to soil loss and its effects on air quality, as well as on human health and safety. The USGS continued to collaborate with the California Desert Studies Consortium, the Naval Postgraduate School, the Clark County Air Quality Group, and the NPS to investigate methods to detect dust events, assess wind-erosion potential, forecast dust emissions, and evaluate the likelihood of dustborne outbreaks of infectious disease. The methods include 1) analyzing remotely sensed satellite, airborne, and ground-based images of land surfaces and dust plumes and 2) monitoring meteorological, vegetation, and soil conditions and changes, including aeolian sediment movement and flux at three sites of dust generation. Data collected and analyzed over the last 3 years have shown that interannual variations in the frequency of springtime dust emission from the central Mojave Desert were related to variations in winter precipitation and wind strength that apparently reflected different Northern Hemispheric zonal flow patterns.

Office of Surface Mining Reclamation and Enforcement (OSMRE) specialists continued to use IKONOS 1-meter-resolution pan-sharpened multispectral stereo satellite data. They also evaluated and exploited other high-resolution data, including QuickBird data, pan-sharpened multispectral monoscopic satellite data at 2-meter resolution, and LIDAR data with associated color-infrared aerial photography. The various data formats were employed to monitor five active western coal mines on a quarterly basis for regulatory purposes, including reviewing coal-mining permits, making topographic measurements, and ensuring that mine operators comply with regulations. OSMRE specialists orthorectified the data using high-accuracy GPS ground control. They also generated DEM products from the IKONOS stereo pairs on a photogrammetric workstation. They monitor over 500 square kilometers of surface coal mines quarterly.

The OSMRE Technical Innovation and Professional Services Program trained 45 State and Federal employees to generate orthoimagery and topographic data by photogrammetric processing of aerial and satellite data; they deployed a number of photogrammetric workstations in three States for stereo viewing and data processing. OSMRE analysts used aerial photography at a scale of 1:24,000 covering 100 square kilometers in Oklahoma for topographic mapping and reclamation of an Environmental Protection Agency Superfund site.

In 2003, OSMRE scientists tested a commercial thermal infrared camera for mapping and monitoring coal-seam fires and locating hot spots and vents. The technology proved worthwhile, and OSMRE purchased a camera. The instrument was already quite in demand; it was used in Utah for monitoring coal venting in abandoned mine areas near Price; in New Mexico for mapping a fire occurring in a coal spoil; and in Washington, where an underground coal-seam fire near a residential neighborhood impacted a forest of large 100-year-old trees.

OSMRE continued to expand its use of GPS for surface mine reclamation verification, technical assistance projects, and Abandoned Mine Land (AML) reclamation designs. Mine inspectors employed GPS to verify jurisdictional boundaries of large western mines; to field-verify locations of mine features such as hydrologic structures, surface depressions, and reclaimed topography; and to perform contemporaneous evaluation of reclamation effectiveness. AML specialists and contractors used GPS receivers to map subsidence complaints and acid mine drainage discharges and to locate and inventory abandoned mine features nationwide.

DOI scientists and resource managers continued to use both the DOD Navstar GPS Precise Positioning Service (PPS) and augmented differential GPS for real-time positioning in wildland areas in 2003. DOI currently maintains about 1,300 PPS receivers. To support growing DOD needs, DOI has acted upon a request from the Warner Robbins Air Force Base to make excess PPS equipment available. Over 1,500 Precise Lightweight GPS Receiver (PLGR) units have been identified for transfer to assist with world events. The demand for trained GPS technical specialists to conduct fire mapping continues to grow due to this skill category's shortage in available fire personnel and the frequent occurrence of large wildland fires across the United States. In response, GPS training courses were taught in Florida and at Joshua Tree National Park, CA. New real-time differential and existing PLGR and PLGRII units were tested for position accuracy and performance under tree canopies on a forested test network near Denver.

The NPS staff used approximately 400 GPS receivers for mapping and navigation to support a variety of NPS resource-management, law-enforcement, and park-maintenance applications. New geodetic survey equipment was purchased to provide accurate georeferencing for new remotely sensed data, and a database of NPS control points, locations, and descriptions was being implemented online at the end of the fiscal year. Digital photography is often collected and integrated with GPS databases to provide a visual presentation of crime scenes, park resources, and historic and other park structures.

During 2003, USGS biologists collaborated with Boise State University (BSU) to use the Argos satellite system in six projects. They completed 4 years of fieldwork for determining the survival, dispersal, long-range movements, and use of the landscapes by prairie falcons that nest in Snake River Birds of Prey National Conservation Area in Idaho. The USGS-BSU team worked with the Massachusetts Audubon Society and used satellite telemetry to track snowy owls moving from the Boston area in the winter to Northeastern Canada during the breeding season. Also in 2003, the team began the second year of tracking white-faced ibis from their nest colony in central Nevada to their wintering areas from the central valley of California to central Mexico. This study of the source of contamination of the birds is conducted with Earthspan, Inc., and Mexican colleagues, with the support of the DOD Legacy Resource Management Program. The Program provides financial assistance to protect and enhance natural and cultural resources (such as monitoring and predicting migratory patterns of birds in this study) while supporting military readiness on military lands. USGS, BSU, and the Nevada Department of Wildlife (NDOW) have used satellite telemetry to study the mortality of relocated bighorn sheep in remote areas of Nevada. The USGS-BSU group joined the BLM and NDOW to track the annual movements of ferruginous hawks. In 2003, they also began research on annual sage grouse movements with BLM, NDOW, and Idaho State University.

USGS scientists used ECOSEARCH, a computer-based modeling procedure, to predict species occurrences for 332 New England wildlife species using defined natural history habitat-selection models. Predictions made within ECOSEARCH are currently based on geospatial data for wetlands, soils, topography, and vegetative structure. Information for wetlands, soils, and topography comes from readily available National Wetlands Inventory maps, NRCS maps, and USGS maps, respectively. Vegetation structure, such as vegetation composition and height, is estimated from aerial photographs of point intercepts for a sampling grid containing 50-meter pixel cells. LIDAR data are also being used to estimate vegetative structure. This technology should not only facilitate further development of more accurate species-habitat models at increased efficiencies, but also will be useful for such constituents as the forest products industry in assessing their management activities. LIDAR data were collected at several sites in Maine and New Hampshire, on private lands (International Paper, Inc.) and on public lands such as USFWS refuges, and on USDA National Forests lands that have well-established bird survey routes; these data were used to create Version 2 of ECOSEARCH using statistical models for New England wildlife species. GPS was used to mark plot locations at Badlands National Park and to map the extent of invasive plant species at Mississippi River National Recreation Area and St. Croix National Scenic River.

USGS Missouri Field Station, the University of Missouri, and the Missouri Department of Conservation continued using color-infrared aerial photographs to map vegetation within Ozark National Scenic Riverways in Missouri. Color-infrared aerial photos were taken in October 2003 at a scale of 1:12000, with GPS center points, then digitally scanned, orthorectified, and mosaicked, yielding a spatial resolution of 25 centimeters and a maximum spatial error of 5 meters. Data from more than 1,000 pre-existing vegetation-monitoring plots (all sampled within the past 5 years) and 343 new plots will form the basis for developing photo-signatures for vegetation communities within the study area. All plots have associated GPS coordinates, and most have detailed vegetation and environmental data. Analysts will also incorporate 1:24,000 and 1:12,000 color photographs of the study area, all flown within the last 7 years and all processed as above. They will use automated, supervised classification and on-screen three-dimensional techniques to delineate communities.

During 2003, as part of a study of relative sea-level rise, marsh dynamics, habitat changes, and effects on waterbirds, USGS scientists acquired aerial photography and Landsat data at study sites within Cape Cod National Seashore in Massachusetts, Forsythe National Wildlife Refuge in southern New Jersey, and three sites within the Virginia Coast Reserve along Virginia's Eastern Shore. They performed a comparison of rates of change from the 1930–1940 period to the 1970s and finally to the 1990s. They noted evidence of significant marsh loss and habitat changes at all but one of the sites, suggesting that sea-level rise may seriously affect too many species of nesting waterbirds.

Populations of seaducks along the Atlantic Flyway are declining, and little is known of the critical habitats used by these species. During 2003, USGS scientists conducted the Atlantic Seaduck Project, a research project involving the migration, habitat selection, and ecology of one species—scoters—that winters on the Chesapeake Bay. During the year, satellite transmitters were surgically implanted in scoters captured on the Chesapeake Bay and on the Restigouche River in New Brunswick, Canada. Once released, the birds were tracked using the "Service Argos" system on NOAA satellites. Data such as coordinates and transmitter information were transmitted from each bird. Subsequently, GIS techniques were used to interpret and analyze the data, and ducks were tracked as they began their migration along the coast and into various areas of Canada. During the summer, scientists went to Quebec and Labrador to evaluate the breeding habitats selected by these scoters. Once all the data for the year were compiled, a more detailed picture was produced of the staging, breeding, and molting areas used by scoters, as well as their associated habitats. Information from this study will assist wildlife managers in locating and conserving these critical scoter habitats.

Scientists at the USGS Southwest Biological Science Center/Colorado Plateau Field Station used low-level, high-resolution, rectified aerial photography of Roosevelt Lake, AZ, for a variety of purposes in conjunction with the Bureau of Reclamation (BOR). Researchers located and mapped flycatchers, along with their breeding territories and nests, on the photographs and repeatedly returned to the territories to track flycatcher nest success and productivity. Scientists also marked locations of radio-tracked birds on the photographs and compared these locations with available habitat. Overall, these photos are essential tools in this type of research.

Scientists from the USGS Great Lakes Science Center regularly used GPS technologies to supplement scientific research conducted in 2003. GPS receivers and aerial photographs were used to determine sample locations, provide geographic reference for geographic information system datasets, and assist navigation during wetland restoration projects on USFWS National Wildlife Refuges. Side-scan sonar surveys conducted throughout the Great Lakes basin and habitat-mapping projects in the Detroit River required GPS technology to locate sample sites and provide geographic reference for biological data. Larval fish habitat preference studies in Lake Erie used GPS to guide sampling procedures and simplify navigation in open water. GPS was also used during native clam research in several national parks in Michigan. A mapping-grade GPS receiver was used to determine precisely the geographic coordinates of wetland plant sampling transects located at specific elevations along the U.S. shore of Lake Ontario. Correctly identifying sampling locations was a critical part of the binational wetland research efforts included in the International Joint Commission's reevaluation of the water-level regulation plan for Lake Ontario. High-resolution IKONOS multispectral data and ASTER data provided the detail necessary to map sensitive habitats on islands in the Great Lakes. Landsat 7 images were also a valuable addition to the wetland research conducted in Michigan's Upper Peninsula.

The first National Land Cover Dataset (NLCD 1992) for the conterminous United States was completed in 1999 and is the current land-cover layer for the National Map. An updated land-cover layer for all 50 States and Puerto Rico is being developed using Landsat 7 data. MRLC (*http://www.mrlc.gov*), a partnership of Federal agencies, sponsored the acquisition of the source satellite data and the land-cover mapping. Mapping is being done in regional mapping zones to facilitate processing. Mapping for the conterminous United States is scheduled for completion in FY 2006.

The USGS and the FS developed new remote sensing monitoring tools and methods to detect and map the onset and progression of oak mortality in hardwood forests of the Mark Twain National Forest in the Central United States. Researchers analyzed data from Landsat ETM+, ASTER, EO-1 ALI, and EO-1 Hyperion (the first hyperspectral data from a civil satellite) instruments. Study results included data on the percent occurrence of hardwood and conifer tree stands and black and red oak trees (the affected oak species), the level of oak mortality, and a database of satellite data and products derived from the research.

The five-State Re-Gap Team, including the USGS-led Arizona team, used Landsat 7 data to help develop a regional land-cover map of the Southwest Regional Gap Analysis Program. The data also form a base for derivation of the modeled land cover.

A team of USGS and BOR investigators mapped vegetation at Sunset Crater, Wupatiki, and Walnut Canyon National Monuments using aerial photography. A USGS and NPS team has also acquired aerial photography for vegetation mapping at Mesa Verde and Petrified Forest National Parks and Canyon de Chelly National Monument.

A USGS team used Landsat 7 and MODIS data to study perennial and annual vegetation change in the Mojave National Preserve on a seasonal and interannual basis and to attempt to map nonnative annual grasses. Also, Landsat 7 data from 1987 to 2000 were used to study long-term landscape changes in the south-central Mojave ecosystem.

Satellite observation is a critical component of the USGS programs addressing wildland fire mapping and monitoring. In 2003, the USGS used coarse- and moderate-resolution satellite data in a three-tier approach to wildland fire management. At the coarse-resolution level, USGS used Advanced Very High Resolution Radiometer (AVHRR) data to monitor vegetation condition in order to forecast fire danger nationwide. The USGS provided weekly updates of vegetation condition information throughout the 2003 fire season. The National Interagency Fire Center and others used the fire-danger forecast information to plan and allocate firefighting resources.

The USGS used the moderate-resolution Landsat data to map the effects of active wildland fires and to map fire fuel condition. In 2003, the USGS prepared burn-severity maps for approximately 60 fires that occurred on DOI land and provided Landsat data to the FS to map approximately 80 fires on FS land. The burn-severity maps are used for assessing the extent and degree of landscape change resulting from fire.

USGS astrogeology scientists have been heavily involved with the MER mission that landed two rovers on the surface of Mars in January 2004. Team members developed high-resolution topographic maps of the potential landing sites for safety analysis and general geologic context for science objectives. The team also had responsibility for the microscopic imager, part of the imaging system deployed on an arm on the rover. That system allows high-resolution (30-micron) panchromatic images to be taken of natural materials and rock surfaces that have been ground down with a rock abrasion tool on the rovers. The team conducted a number of mission rehearsals at JPL to understand exactly how the mission will proceed. The team developed a computer system to mosaic and analyze images that will be taken from a mast-mounted stereo imaging system. The system has been extensively tested and debugged to make it fully operational.

USGS scientists are conducting a major data-recovery activity in which 1960s-vintage Lunar Orbiter images of the Moon are being converted to digital data and mosaicked. A film system on the Orbiter was used to take pictures that were then scanned and transmitted to Earth, where they were used to prepare for the

Apollo landings. The original analog data are no longer recoverable, so first-generation negatives are being scanned and reassembled into digital images. Because of the technology of the time, each frame consists of about 20 segments that now must be independently scanned and reassembled. The individual frames are in turn being mosaicked into a complete lunar image. These photographs represent some of the highest resolution data available for the Moon. Because they were taken specifically to see surface detail, they provide an unparalleled dataset to examine the small-scale features on the lunar surface. Since 1975, the USGS has chaired the Civil Applications Committee (CAC) to facilitate the use of national systems data for applications central to civil agency missions, such as mapping, charting, and geodesy; environmental monitoring, studies, and analyses; resource management; homeland security; natural hazards; and emergency response applications.

To represent civil community interests and advocate for civil requirements for access to National Systems data and related technologies, the CAC participated on a regular basis in 2003 with the National Security Space Architect (NSSA) to represent civil requirements related to future space remote sensing architectures; with the Federal Law Enforcement Working Group to provide advice and consultation on issues related to law-enforcement applications of remote sensing; with the Department of Homeland Security to explore how civil agencies will use national systems data in support of homeland security activities; and with the USNORTHCOM Interagency Directorate to explore how the civil community can facilitate USNORTHCOM access to and application of national systems data for homeland defense activities.

The CAC Secretariat completed a document entitled the *Civil Community Capabilities Requirements Document for 2005–2009*, based on input from CAC member agencies. This is the first time in the 28-year history of the CAC that civil community capabilities and requirements for exploiting national systems have been assembled in a single document. The document will serve as a baseline and roadmap for upgrading civil community infrastructure to prepare for the next generation of national systems.

Federal Communications Commission

FCC

Federal Communications Commission (FCC) accomplishments during FY 2003 were related primarily to commercial communications and Earth-observation satellites. The FCC formulates rules to facilitate the provision of commercial satellite services in the United States; it also issues licenses for launch and operation of all non-governmental U.S. satellites. Internationally, the FCC coordinates satellite radio-frequency usage with other countries. The FCC's accomplishments for FY 2003 are outlined below.

In FY 2003, the FCC authorized a number of commercial communication satellite launches and operations. On March 27, 2003, the FCC granted PanAmSat Licensee Corporation authority to launch and operate the Galaxy XII satellite in the fixed satellite service in the C-band as a replacement for its Galaxy VI satellite at the longitude 74° west orbit location; it was successfully launched on April 9, 2003. On June 24, 2003, the FCC authorized The Boeing Company to change its 2-gigahertz Mobile Satellite Services (MSS) license from a nongeostationary to geostationary authorization and to launch and operate a geosynchronous orbit (GSO) satellite. On August 1, 2003, the FCC authorized EchoStar Satellite Corporation to modify its Ku-band and Ka-band licenses to allow launch and operation of a hybrid Ku-/Ka-band satellite, EchoStar 9. That satellite also included a C-band payload (commonly referred to as Telstar 13) authorized by Papua New Guinea. It was successfully launched on August 8, 2003. On September 30, 2003, the FCC authorized PanAmSat Licensee Corp. to launch and operate a satellite operating at C-band, Galaxy XIII. That satellite also included a Ku-band payload authorized by Japan. It was successfully launched on September 30, 2003.

The FCC granted a number of Special Temporary Authorizations (STAs) for satellite networks. Many involved routine testing and redeployment of satellites within a multiple-satellite system. Several actions, however, were notable. On February 24, 2003, the FCC granted Intelsat LLC the authority to relocate the Intelsat 702 satellite from the longitude 156.9° east orbit location to the longitude 55° east orbit location in order to provide the Indian Space Research Organization with the capacity needed to maintain service pending launch of the INSAT-3E satellite. On April 28, 2003, the FCC authorized PanAmSat Licensee Corporation to drift the Galaxy III-R satellite, a hybrid C/Ku-band satellite, from the longitude 74° west orbit location to the longitude 111.1° west orbit location in order to provide Telesat (a Canadian satellite operator) with the capacity to provide continued service from that location. Beginning in April 2003, the FCC issued a series of Special Temporary and other Authorizations for the Iridium system to operate its "Big LEO" MSS satellites in the 1620.10- to 1621.35-megahertz band. The additional authorized spectrum was to support stated satellite communications needs of U.S. and Coalition Forces in the Middle East.

The FCC granted a number of launch authorizations and STAs for Direct Broadcast Satellites (DBSs). The FCC also added a number of non-U.S.-licensed space stations to the Commission's permitted space station list to allow these space stations to provide domestic and international satellite service in the United States. On December 18, 2002, the FCC added a Canadian satellite, Anik F2, to its permitted list with certain conditions in order to allow U.S. Earth stations with routine technical parameters to communicate with Anik F2 in the C-band and Ku-band frequencies. On March 6, 2003, the FCC added Hispasat S.A.'s satellite, Hispasat-1B, to its permitted list with certain conditions in order to allow U.S. Earth stations with routine technical parameters to communicate with Hispasat-1B in certain Ku-band frequencies. On July 11, 2003, the FCC added Spacecom Satellite Communications Services S.C.C. Ltd.'s AMOS-2 satellite, licensed by Israel, to its permitted list with certain conditions in order to allow U.S. Earth stations with routine technical parameters to communicate with AMOS-2 in certain Ku-band frequencies. On August 8, 2003, the FCC added Telstar 13, licensed by

Papua New Guinea, to its permitted list to allow Loral Spacecom Corporation to operate Telstar 13 in the C-band frequencies. On August 19, 2003, the FCC added Binariang Satellite Systems SDN BHD's MEASAT-2 satellite, licensed by Malaysia, to its permitted list with certain conditions in order to allow U.S. Earth stations with routine technical parameters to access MEASAT-2 in the certain C-band frequencies.

The FCC granted a number of applications for use of Mobile Earth Terminals (METs). On March 7, 2003, the FCC granted Richtec Incorporated blanket authority to operate up to 10,000 half-duplex METs to provide MSS in the United States via Inmarsat, Ltd., satellites in portions of the lower L-band for a term of 2 years. On March 14, 2003, the FCC authorized SkyBitz Incorporated to increase the total number of METs in its current blanket authorization from 20,000 to 100,000 in order to meet escalating demand for its global locating system. On May 13, 2003, the FCC granted GlobalStar USA, LLC, authority to add 500,000 METs for communication with the GlobalStar Big LEO non-geostationary satellites of the MSS systems for remote telemetry and aeronautical and air-based or ground-based MSS. On July 14, 2003, the FCC granted Vistar Data Communications, Inc., the authority to increase its authorized METs from 20,000 to 100,000 and extended its license from 2 years to 15 years in the L-band for transportation logistics and asset-monitoring purposes.

During FY 2003, the FCC was also active in international satellite coordination. In the first quarter of FY 2003, the FCC reached Operator-to-Operator Coordination Arrangements with the United Kingdom, Russian, Papua New Guinean, Canadian, and Singaporean satellite operators for 226 U.S. satellite systems. In the area of Administration-to-Administration Coordination Agreements, the FCC reached agreements with Spanish, Brazilian, and Netherlandic satellite operators for 21 U.S. satellite systems.

In the second quarter of FY 2003, the FCC reached Administration-to-Administration Coordination Agreements with the Australian satellite operators for four U.S. satellite systems.

In the third quarter of FY 2003, the FCC reached Operator-to-Operator Coordination Arrangements with the Saudi Arabian and Singaporean satellite operators for 11 U.S satellite systems. In the area of Administration-to-

Administration Coordination Agreements, the FCC reached agreements with Spanish satellite operators for two U.S. satellite systems.

In the fourth quarter of FY 2003, the FCC reached Operator-to-Operator Coordination Arrangements with the European Space Agency and Brazilian, Canadian, and Indian Satellite operators for 81 U.S. satellite systems. In the area of Administration-to-Administration Coordination Agreements, the FCC reached agreements with Australian, Papua New Guinean, and Maltese Administrations for 12 U.S. satellite systems.

Department of Agriculture

USDA

In FY 2003, the USDA used remote sensing data and related technologies to support a broad range of research and operational activities. Several agencies applied these data and technologies, including agencies within the Farm and Foreign Agricultural Services mission area, the Natural Resources and Environment mission area, and the Research, Education, and Economics mission area. Following are brief summaries from these agencies, describing how these data and technologies were applied to accomplish various departmental goals and objectives.

The Cooperative State Research, Education, and Extension Service (CSREES) is the extramural research arm of USDA. CSREES primarily provides financial assistance in the form of grants to conduct high-priority agricultural research and education. Many grants awarded by CSREES utilize NASA data products to solve complex environmental problems on topics such as water quality, air quality, and land-use change. A few examples of research supported by the CSREES National Research Initiative that utilize NASA data products include sustainable ecosystem management in Flathead County, MT; regional patterns of biological nitrogen fixation in the Pacific Northwest; invasion potential of non-native trees in the eastern deciduous forest; quantification of carbon and nitrogen fluxes at a regional level from organic farming sites; and host/vector/environmental interactions in epizootic bovine abortion in California and Nevada. CSREES also funded long-term studies in Mississippi, Kentucky, and Alabama that utilize remote sensing and geospatial technologies to develop precision management techniques for various agricultural production strategies. CSREES cooperated with the Applications Division of the ESE at NASA to create geospatial extension programs at land-grant and space-grant institutions. This ongoing outreach program has helped train local and regional technologists to better utilize NASA data products and geospatial technologies.

The Foreign Agricultural Service (FAS) Production Estimates and Crop Assessment Division (PECAD) is the focal point within FAS and USDA for assessing the global agricultural production outlook and conditions that affect world food security. During FY 2003, the FAS satellite remote sensing program continued to provide timely, accurate, and unbiased estimates of area, yield, and production for a variety of crops worldwide. For example, PECAD analysts used satellite-derived data to quickly identify unusual crop conditions and production in several countries, thereby enabling USDA experts to more rapidly and precisely determine global supply and demand. FAS exploited many global imagery data sets during this process, including global Advanced Very High Resolution Radiometer (AVHRR) data from NOAA and global SPOT-VEGETATION data from Spot Image. In FY 2003, cooperative agreements with NASA enabled the use of near-real-time MODIS imagery, as well as TOPEX/Poseidon and Jason-1 data to measure reservoir levels. FAS had standing orders for Landsat 5 and 7 imagery for selected paths and rows; however, operations were severely impaired by Landsat sensor problems and the lack of Landsat program continuity. Budget constraints limited the use of Space Imaging IKONOS and DigitalGlobe QuickBird data. Many of the data products produced for global crop production intelligence by FAS are available at *http://www.pecad.fas.usda.gov/cropexplorer/*. FAS also continued to house and manage the USDA Imagery Archive. Through this archive, FAS distributed thousands of satellite scenes to other USDA agencies. This archive has helped USDA save hundreds of thousands of dollars each year by eliminating duplicate data purchases among agencies.

The FS provided the majority of the more than 4,000 Federal incident management personnel involved with the Space Shuttle Columbia recovery effort that took place in February and March 2003. Crews searched 12 hours a day, 7 days a week over territory located in Louisiana, Texas, and New Mexico. Their goal was to find as much material as possible before spring vegetation growth made the search more difficult. FS personnel were primarily involved in searching the ground, recording the coordinates of debris sites, creating maps, recovering and transporting debris, and patrolling for possible theft of material. In addition to personnel, other resources provided by FS included helicopters for aerial reconnaissance, all-terrain vehicles, weather stations, satellite phones, imaging and GPS equipment, food caterers, and showers. Jim Moseley, Deputy Secretary of USDA, and Dale Bosworth, Chief of the FS, toured the sites, surveying the recovery effort and thanking everyone for their help.

FS continued to process data from NASA's MODIS sensor and to use these data to produce active wildland fire maps for the entire United States three times a day. FS acquired MODIS imagery of the Western United States from a receiving station located at the agency's Remote Sensing Applications Center (RSAC) facility in Salt Lake City, UT. Imagery of the Eastern United States was acquired by GSFC. RSAC used a fire-detection algorithm developed by the University of Maryland to identify active fire locations. These locations were overlaid on a cartographic base map that showed State boundaries, topography, major cities, and interstate highways. These maps were posted on the Internet (*http://activefiremaps.fs.fed.us*), where they were accessible to national fire managers and the general public.

The Active Fire Mapping Web site was accessed by a large number of users during the 2003 western fire season. The maps provided the interagency firefighting community with a synoptic view of the wildland fire situation, aiding in the strategic allocation of firefighting resources and assets throughout the country. This service has been provided on a daily basis since July 4, 2001, and is a collaborative effort with GSFC and the University of Maryland. In addition, the maps and fire-detection data were used by several major media entities, including the Washington Post, the Cable News Network (CNN), the Associated Press, and the Los Angeles Times. Between October 26 and November 1, 2003, which was the most active week for southern California wildland fires, nearly 750,000 individuals accessed the Active Fire Mapping Web site to view maps of fire activity.

At the request of the FS, NASA provided emergency imagery-acquisition services over fires in southern California in late October 2003. Images from the MODIS Airborne Simulator (MAS) sensor, the Airborne InfraRed Disaster Assessment System (AIRDAS) sensor, the Advanced Land Imager (ALI), and Landsat 5 were used by FS to map postfire conditions in support of the Burned Area Emergency Response program teams, who are responsible for rehabilitation and restoration of the burned areas.

During FY 2003, the FS continued to work with both NASA ARC and NASA GSFC on a number of fire-related technologies. ARC work included advanced sensor design and image processing from airborne platforms, as well as unpiloted aerial vehicle development and mission profiling for tactical wildland fire mapping. GSFC work involved preliminary designs of both air-to-ground and air-to-satellite communications systems that will enable rapid transmission of FS airborne thermal-image products to incident command personnel.

The mission of the National Agricultural Statistics Service (NASS) is to provide timely, accurate, and useful statistics in service to U.S. agriculture. These statistics cover virtually every facet of U.S. agriculture, from the production and supply of food and fiber to the prices paid and received by farmers and ranchers. Significantly, NASS conducts the Census of Agriculture, which provides a comprehensive statistical summary of many aspects of U.S. agriculture, every 5 years. NASS personnel have found remote sensing data and technologies to be valuable in improving the accuracy of some statistics.

During FY 2003, NASS used remote sensing data to construct and sample area frames for statistical surveys, estimate crop area, and create crop-specific land-cover data layers for Geographic Information Systems (GIS). NASS used Landsat imagery, digital orthophoto quadrangles, and other remotely sensed inputs for 27 States to select the yearly sample. In addition, NASS constructed new frames in Kentucky and Oregon. The Kentucky frame will be used for the first time in 2004, while the Oregon frame will be used in 2005. The remote sensing acreage estimation project analyzed Landsat data from the 2002 growing season to produce crop acreage estimates for major crops at State and county levels. These data were used to create a crop-specific categorization in the form of a digital mosaic of TM scenes, which was distributed to users on a CD-ROM. Data used in this project were obtained from Arkansas, Illinois, Indiana, Iowa, Mississippi, the Missouri boot heel, Nebraska, New Mexico, North Dakota, and a pilot area in Wisconsin. During FY 2003, NASS headquarters and several NASS field offices continued partnership agreements with State organizations, decentralizing Landsat processing and analysis tasks and expanding the area analyzed into central Wisconsin. Data for the 2003 acreage estimation analysis were collected in Arkansas, Illinois, Indiana, Iowa, Mississippi, Missouri, Nebraska, New Mexico, North Dakota, and the entire State of Wisconsin.

NASS, in partnership with the Florida Department of Citrus, tested the feasibility of using high-resolution imagery such as QuickBird to count citrus trees remotely. NASS, in conjunction with the USDA Agricultural Research Service, continued research on MODIS data from the Terra satellite, examining the potential to replace AVHRR data with MODIS data in generating vegetation condition images. If successful, MODIS data would provide an additional input for setting yield estimates. A specific pilot was conducted for the State of Iowa.

The Natural Resources Conservation Service (NRCS) is the primary Federal agency working with private landowners to help them protect and conserve their natural resources. Much of the land management business conducted by NRCS has been accomplished using geospatial and remote sensing data and technologies. For over 50 years, NRCS has used aerial photography to carry out conservation programs. Today, the NRCS exclusively uses digital orthoimagery and GIS at county field service centers nationwide.

NRCS purchased all aerial photography and derivative digital orthoimagery products from commercial sources by coordinating and cost-sharing, to the maximum extent possible, with other Federal and State agencies. In FY 2003, NRCS acquired 1-meter or better resolution orthoimagery for 20 States and Puerto Rico. Most of the orthoimagery was acquired by cost-sharing with the Farm Service Agency (FSA) through the National Agriculture Imagery Program (NAIP). This program helped NRCS increase the amount of data acquired while reducing the funds necessary, supporting agency efforts to refresh the orthoimagery at the county field services on a 3- to 5-year cyclic schedule. Another successful means for acquiring imagery was through partnerships formed between NRCS and various State agencies. In previous years, NRCS cooperated with member agencies of both the National Aerial Photography Program (NAPP) and the National Digital Orthophoto Program (NDOP). During the past couple of years, however, the USGS-led NAPP/NDOP programs have been unsuccessful in maintaining consistent funding levels for carrying out a national program, and as a result, NRCS participation in NAPP/NDOP was limited to a couple of States in FY 2003.

In response to USDA conservation programs, homeland security, e-Government, and county service center GIS requirements, NRCS worked in conjunction with the USDA and FSA to establish a Geospatial Data Warehouse and a Geospatial Data Gateway to provide agency users and the public with online, 24/7 access to archived geospatial data, including imagery, developed or purchased by FSA and NRCS. All imagery purchased by NRCS resided in the public domain, permitting NRCS to freely distribute data and imagery internally and externally without costly and restrictive use licenses.

In FY 2003, NRCS extensively used 1-meter orthoimagery nationwide for conducting soil surveys as part of the National Cooperative Soil Survey program. Soil scientists used digital orthoimagery as the base for mapping and digitizing soil surveys. Approximately 60 percent of the Nation's detailed soil surveys have been converted to a nationally consistent digital geospatial format.

NRCS continued to contract for high-resolution aerial photography (less than 1-foot ground resolving distance) as a source for collecting data for the annual continuous National Resources Inventory (NRI) program. The NRI required high-resolution imagery over confidential statistical sampling sites. NRCS purchased NRI imagery for approximately 70,000 sites nationwide. Six aerial firms acquired the natural-color imagery within short photo-periods during the growing season. The USDA-FSA Aerial Photography Field Office contracted for the imagery because of its responsibility for contracting aerial photography for USDA.

NRCS increased its use of satellite imagery by accessing Landsat imagery archived in the FAS-managed USDA Imagery Archive. In FY 2003, NRCS purchased additional commercial off-the-shelf remote sensing and GIS software licenses. NRCS resource planners were able to use satellite and other digital imagery on a daily basis because this software had become more user-friendly and readily available on personal workstations.

In FY 2003, NRCS completed its purchase of Nationwide Differential GPS (NDGPS) receivers from a USDA GPS contract. At the conclusion of the fiscal year, over 4,100 GPS receivers were being used in everyday applications by soil scientists, engineers, and resource-planning specialists at the county level.

The NRCS was well represented on Federal remote sensing, GPS, and geodata coordinating committees. NRCS devoted much time and many resources to support the work of the Federal Geographic Data Committee's Geospatial One Stop initiative as well as NAIP, NAPP, and NDOP coordination.

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. NSF, through the Division of Astronomical Sciences and, to a lesser extent, the Division of Physics and the Office of Polar Programs, 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 the nearby stars and planets just being formed. A sample of these activities is presented below.

The NSF also supported the development of advanced technologies and instrumentation for astronomical sciences and provides core support for optical and radio observatories that maintain state-of-the-art instrumentation and observing capabilities accessible to the community on the basis of scientific merit. The NSF's national astronomical facilities include the National Radio Astronomy Observatory, the National Astronomy and Ionosphere Center, the National Optical Astronomy Observatory, and the National Solar Observatory (NSO). The NSF also provides for the United States' share and serves as the Executive Agency for the Gemini Observatory, an international partnership operating optical/infrared telescopes in both the Northern and Southern Hemispheres. FY 2003 saw the second year of construction of the Atacama Large Millimeter Array, an interferometer located near San Pedro de Atacama, Chile, being constructed in partnership with Europe and Canada.

One of the most stunning scientific findings of the 20th century was that "normal" matter—the atoms, protons, neutrons, and electrons that compose our material existence—makes up just a tiny fraction of our universe. Most of the matter in the universe is "dark matter," thought to be in the form of some as yet undiscovered particle that neither emits nor blocks light and passes right through "normal" matter as if it were not there. Even more surprising is the recent discovery, now reached from numerous independent methods of investigation, that the universe is dominated by "dark energy." Much research activity is now directed toward understanding the nature of both of these invisible components of the universe.

NSF-funded investigators have conducted an inventory of the amount and distribution of this dark matter by measuring its subtle gravitational effects on the light of distant galaxies. The pattern of dark matter they probe is accepted as consistent with the theory that all the structures in the universe are descendants of the tiny fluctuations in the early universe that are seen by cosmic background radiation measurements such as the Wilkinson Microwave Anisotropy Probe satellite. These tiny "seeds" accumulate more and more matter under the influence of gravity until they become galaxies and clumps of galaxies hundreds of millions of light-years across. So now we can "see" the dark matter and understand how it fills the universe and builds galaxies—but we still do not know what it is made of.

The Sloan Digital Sky Survey (SDSS) continues to yield results that are changing our view of the evolution of the universe. The SDSS team has found the most distant objects in the universe, with newly discovered quasars at redshifts 6.05, 6.2, and 6.4. Last year saw the announcement of the detection of the Gunn-Peterson (GP) trough in a quasar at z=6.3, the almost complete absence of blue light in the spectrum, due to large quantities of neutral hydrogen in the intergalactic medium. To see any blue light, most of the hydrogen in the universe must be ionized, presumably by the hot stars that arise when galaxies form. Looking to great distances is looking back in time; we are probing back to a time less than 1 billion years after the Big Bang and proving by the GP trough that most galaxies had not yet formed. This effect is now seen in a second quasar, the newly discovered object at z=6.4, greatly strengthening the evidence that the universe finished its transition from a neutral to an ionized state at a redshift of about 6, some 800 million years after the Big Bang, and pinning down the time of galaxy formation.

For technical reasons having to do with the properties of the night sky and the spectral energy distributions of the galaxies themselves, it has been difficult to study galaxies at the intermediate redshifts of 1 to 2, a key period in galaxy formation. Now, an international team has equipped the Gemini telescopes with a unique and powerful technique that counteracts the fluorescence that contaminates the far-red end of the optical spectrum in the night sky. The result of this work is that Gemini can obtain much deeper spectra in this far region than ever before possible. Called "nod & shuffle," this method synchronizes a small shift in the telescope's pointing on the sky with a precise shuffling of the images on the charge-coupled device detector to significantly increase the signal-to-noise ratio of the data. Using this technique, Gemini astronomers have discovered that the apparent "redshift desert" of galaxies that was thought to exist at an epoch of about one-third to one-half the age of the universe is actually well populated with galaxies.

One of the competing theories of how our galaxy formed is that it has been built up primarily by the agglomeration of many smaller pieces through a process called hierarchical clustering. A number of NSF-funded researchers have developed simulations of the accretion of subgalactic pieces or of smaller galaxies as they merge with larger, more massive galaxies like the Milky Way. Stars from these accreted systems are stripped off by the tidal gravitational field of the Milky Way and form trails and streams that may still exist today. If a realistic number of merging events are included, it is possible to build up something that looks very similar to the stellar halo of our own galaxy.

Through the efforts of several NSF-funded teams, just such evidence of old merger events is starting to be found in our Milky Way galaxy and our neighbor the Andromeda galaxy. The most recent and intriguing evidence of such a merger close to home has come from a team of scientists using the SDSS. They have discovered a previously unseen band of stars in the outer disk of the Milky Way galaxy. Hidden from view because it is behind the stars and gas on the same visual plane as the Milky Way, this ring could help to explain how our own galaxy was assembled.

The large ground-based data archives that are accumulating are enabling astronomers to explore many new areas of astronomy and space science. The developing National Virtual Observatory (NVO) will provide access to a vast array of astronomical databases and archives, uniting the data from both ground-based and space-based facilities. An NVO prototype, developing a new approach to finding undiscovered objects buried in immense astronomical databases, has produced an early and unexpected payoff: a new instance of a hard-to-find type of star known as a brown dwarf. The star emerged from a computerized search of information on millions of astronomical objects in two separate astronomical databases. That search, formerly an endeavor requiring weeks or months of human attention, took approximately 2 minutes. NVO researchers emphasized that a single new brown dwarf added to a list of approximately 200 known brown dwarfs is not as scientifically exciting as the timing of the new discovery and the tantalizing hint it offers to the potential of NVO. The discovery came at a stage when organizers were simply hoping to use NVO to confirm existing science, not make new findings.

An NSF-funded group has detected a planetary companion in orbit around the primary star of the double star system Gamma Cephei. The team used high-precision radial velocity measurements in four independent data sets spanning the time interval 1981–2002 to find a long-lived variation in radial velocity. The measured effect has a period of 2.47 years and a semiamplitude of 27 meters per second. This corresponds to a minimum planetary mass of 1.59 times the mass of Jupiter and an orbital semimajor axis of 2.03 Astronomical Units, just twice the Earth-Sun distance. Gamma Cephei is the shortest period binary star system for which an extrasolar planet has been found, and it may provide insights into the relationship between planetary and binary star formation.

Other NSF-funded researchers are studying collisions that shaped the solar system. In particular, they have developed the "Giant Impact" theory, in which the Moon formed from debris ejected when Earth collided with a Mars-sized body about 4.5 billion years ago. These researchers have also produced a model in which the Pluto-Charon system formed from a grazing impact between like-sized objects.

NSF continued a joint activity with the USAF Office of Scientific Research to provide the U.S. astronomical community with access to state-of-the-art facilities at the Advanced Electro-Optical System telescope on Maui, HI. The Improved Solar Observing Optical Network (ISOON) telescope at the NSO on Sacramento Peak, NM, a joint USAF/NSO project, is now fully operational. ISOON collects data on a daily basis and makes it available on the Web for the tracking and prediction of solar activity.

The NSO Synoptic Optical Long-term Investigations of the Sun Spectral Vector Magnetograph is now producing full-disk magnetograms and vector magnetograms. These data are being added to the NSO Digital Library and will be a major product in the Virtual Solar Observatory when it comes online. Regular vector magnetographs of the full solar disk permit early identification of solar regions that are likely to produce activity in the form of flares and coronal mass ejections.

Department of State

DOS

The DOS supports U.S. space activities through the negotiation of bilateral and multilateral agreements on scientific and technical cooperation with partner countries and through outreach programs designed to support key U.S. foreign policy objectives, including sustained growth, transportation safety, and sound environmental management.

In FY 2003, DOS conducted successful negotiations with the Japanese Government to reach an understanding concerning current and future space launch vehicle cooperation. This resulted in the removal of longstanding policy obstacles that had impeded the export of U.S. components for Japanese space launch vehicles.

In advance of European implementation of its planned Galileo satellite navigation system, DOS proposed a new draft framework agreement on satellite navigation systems between the United States and the European Community and its member states. The parties achieved significant progress toward an agreement when the European side addressed a major security concern for the United States by proposing a signal structure for Galileo's Public Regulated Service that would not directly overlay the U.S. GPS military code. Other issues remained to be resolved.

Through new outreach activities, DOS continued to harness U.S. leadership in geospatial technologies, including GPS, remote sensing, and Web-based mapping, in support of transportation safety and sustainable development applications. Under DOS leadership and with funding from the Interagency GPS Executive Board, the GPS outreach team developed an exhibit to promote GPS technology and applications that traveled to the India 2003 Global Navigation Satellite Systems (GNSS) Conference in New Delhi, India, and the World Radio

Conference in Geneva, Switzerland. As a followup to the initiative on Geographic Information for Sustainable Development that the United States brought to the Johannesburg World Summit on Sustainable Development, DOS promoted the distribution of global Landsat datasets for environmental and agricultural applications through regional conferences in the developing world.

DOS continued work with the United Nations (U.N.) Office of Outer Space Activities for the development and exploitation of GNSS applications. DOS provided funding for the last in a series of four regional GNSS workshops held under the auspices of the United Nations and the United States. The two final workshops were held in Santiago, Chile, for the Latin American region, and in Lusaka, Zambia, for the African region. The workshops brought together regional experts and decisionmakers to advance awareness and support for the use of GNSS applications for sustained growth, transportation safety, and environmental management.

Through the coordinated efforts of DOS and NASA, the number of countries participating in the U.S.-led GLOBE program was expanded to 105. Formerly known as the Global Learning and Observations to Benefit the Environment program, GLOBE is a hands-on science and education program that involves primary and secondary school students around the world in scientific research on Earth's environment. The Principality of Liechtenstein, Gabon, the Republic of Rwanda, and the Republic of Maldives joined the program in 2003.

During FY 2003, DOS again led U.S. Government participation in the U.N.'s Committee on the Peaceful Uses of Outer Space. The committee undertook significant work in areas such as global navigation satellite systems, the problem of orbital space debris, meteorology, astronomy and astrophysics, space transportation, human space flight, planetary exploration, and environmental monitoring. The committee also considered legal issues related to international liability and responsibility of launching nations, international financial security interests in space equipment, and equitable access to the geostationary orbit.

DEPARTMENT OF ENERGY

DOE

In FY 2003, the DOE's Office of Science (SC) cooperated with NASA in a wide variety of activities, such as developing experimental techniques of fundamental physics for use in outer space, using plasma science to devise new propulsion systems, engaging in joint efforts to understand atmospheric and environmental phenomena, and entering into a working partnership in advanced computing research. These activities were carried out under a Memorandum of Understanding (MOU) between NASA and DOE signed by NASA Administrator Daniel Goldin and DOE Secretary James Watkins in 1992.

Through an Implementing Arrangement with NASA signed in 1995, the SC continued in 2003 to build the Alpha Magnetic Spectrometer (AMS) for use on the ISS. The AMS is an international experiment designed to use the unique environment of space to search for and measure various unusual types of matter with a greater sensitivity than previously possible. AMS will study the properties and origin of cosmic particles and nuclei, including antimatter and dark matter. Discovering the presence of either material will increase scientists' understanding of the early universe and could lead to a clearer understanding of the actual origin of the universe. Funding in FY 2003 was used for the analysis of data acquired during a 10-day Space Shuttle flight in 1998 and for the planning and fabrication for an upcoming Shuttle flight for eventual deployment on the ISS in 2007.

DOE's SC and NASA's Space Science Enterprise have worked together since FY 2000 to build the Large Area Telescope (LAT), the primary instrument for NASA's Gamma-ray Large Area Space Telescope mission currently scheduled for launch in 2006. An Implementing Arrangement was signed in early 2002 for cooperation on the LAT project, which has continued in FY 2004. This device, using the techniques of experimental particle-physics research, is to detect gamma rays emitted by the most energetic objects and phenomena in the universe. Stanford University and the Stanford Linear Accelerator Center (SLAC) are responsible to the SC and NASA for overall project direction. SLAC, a DOE facility at Stanford University, is responsible for the overall management of the LAT project, the data-acquisition system, software development, the tracker detector, and the assembly and integration of the complete instrument. Researchers funded by DOE-SC at the University of California Santa Cruz are building the tracker detector. DOE provided funding in FY 2002–03 for research and development (R&D), as well as for the design and fabrication of the telescope, in conjunction with NASA and international partners.

The SC continued to make available to NASA the Alternating Gradient Synchrotron (AGS), part of the Relativistic Heavy Ion Collider (RHIC) complex at Brookhaven National Laboratory (BNL). The AGS is the only accelerator in the United States capable of providing heavy ion beams at energies of interest for space radiobiology. Since the fall of 1995, experiments in radiobiology have been performed using beams of iron, gold, or silicon ions from the AGS. NASA funded these experiments as part of its Space Radiation Health Program. A new NASA-funded facility has been completed at the RHIC complex, the Booster Applications Facility. This new user facility, renamed "NASA Space Radiation Laboratory," is being used to continue NASA's radiation biology studies more effectively, specifically to serve as a radiation simulation facility for human space exploration. SC and NASA continued working together to expand the range of technical resources available for experimentation and analysis of experimental results at BNL.

Astrophysicists, supported in part by the DOE Office of High Energy and Nuclear Physics, use the National Energy Research Scientific-computing Center (NERSC), funded by the DOE Office of Advanced Scientific Computing Research, to run computer simulations and analyze data. In 2002, this effort produced the first three-dimensional simulation of an exploding supernova, the first observation of asymmetric supernova explosions (using data collected by the HST), and the first computer model of the spiraling merger of two black holes. Projected funding for computational astrophysics is expected to grow from $7+ million in FY 2003 to about $8 million in FY 2004.

Researchers at several DOE labs receive NASA support for their work. This support includes an "early career" grant and an astrophysics theory grant for an astrophysicist working on supernova modeling in NERSC at Lawrence Berkeley National Laboratory (LBNL), as well as support for the cosmology and astrophysics group at LBNL, which is working in several areas of cosmic microwave background research and technology development. NASA funds also support some members of the astrophysics theory group at Fermi Laboratory. In FY 2001 and FY 2002, LBNL received funds from NASA as work-for-others toward the development of charged-coupled devices, which are used for optical imaging in telescopes. Also in FY 2002, LBNL received NASA funds for scientific analysis using data from the HST. These funds are based on the number of HST orbits a researcher has been awarded.

In a number of NASA-funded research activities, both the transfer of knowledge to NASA and NASA's use of research capabilities developed in the fusion energy program continued in FY 2003. These activities have the potential to revolutionize interplanetary space travel through the use of plasma and fusion propulsion.

Fusion propulsion concepts based upon the spherical torus (ST) and plasma-jet-driven magneto-inertial fusion are leading concepts being studied by NASA for advanced interplanetary missions. ST is being investigated by DOE-SC for magnetic fusion energy applications in the National Spherical Torus Experiment (NSTX) at Princeton Plasma Physics Laboratory (PPPL). Plasma-jet-driven magneto-inertial fusion is being investigated theoretically by DOE-SC for magnetic fusion energy applications at General Atomics, Lawrence Livermore National Laboratory, and the University of Wisconsin at Madison. Researchers at the University of Wisconsin completed a preliminary computational study on the feasibility of the plasma-jet-driven magneto-inertial fusion for space propulsion for NASA MSFC using a computer code developed for inertial fusion by DOE.

The two fusion rocket concepts based upon the spherical torus and the magneto-inertial fusion have the potential to reduce traveling times to the planets by a factor of 10 or more compared with chemical propulsion, and by a factor of 4 or more compared with nuclear fission electric propulsion.

PPPL researchers also worked on a high-power Hall thruster, a form of electric thruster. The high-power Hall thruster has potential performance levels that are relevant to sending advanced NASA science missions to the outer planets.

PPPL worked on several other, basic plasma science projects that complement and enhance the space science activities at NASA. These projects focused on magnetic reconnection and on ionosphere and space-related plasma physics topics, and they are partially funded under the DOE/NSF Plasma Science Partnership. In magnetic reconnection, experimental investigation continues on the coupling between microscale reconnection layers and global forcing and plasma topology evolution.

The SC and NASA worked together to calculate the daily primary productivity of terrestrial ecosystems at diverse sites in the Northern and Central States. Research initiated in FY 2002 will continue with the DOE-supported AmeriFlux Program that resides in the SC. It will provide real-time meteorological and solar radiation data for these calculations, where NASA provides data from the MODIS platform on gross primary productivity and leaf area. This joint work investigates continental-scale seasonal and geographic patterns of productivity. The AmeriFlux program produces unique ground-based measurements of carbon dioxide exchange, which is a measure of net ecosystem production, from some 20 locations across the United States. These results provide an independent collaboration of NASA's productivity calculations based on data derived from remote sensing.

The NASA Aqua Satellite was launched in May 2002. One of the instruments on board is the Atmospheric Infrared Sounder (AIRS). The NASA AIRS Instrument Team requires profiles of atmospheric thermodynamic variables in order to validate the performance of the AIRS instrument. These data were provided by Atmospheric Radiation Measurement (ARM) ground-based instruments and balloon launches from three OS ARM sites (Barrow, AK; Lamont, OK; and the Republic of Nauru) all equipped for advanced radiosonde operations. Additional balloon launches were conducted for the acquisition of data during AIRS overpasses.

The SC, NSF, and NASA continued close three-way collaboration on the development and implementation of climate models. All three agencies support a variety of collaborative activities associated with the Community Climate System Model. The NASA Earth-System Modeling Framework project is coordinated with the OS Scientific Discovery through Advanced Scientific Computing effort in climate modeling to develop software frameworks and implement efficient software engineering practices for complex climate models.

The OS Low Dose Radiation Research Program continued to have an ongoing interaction with the Space Radiation Health Program in NASA's BPRE. The focus of research in the DOE Low Dose Radiation Research Program continued to be on doses of radiation that are at or below current workplace exposure limits. The primary area of emphasis of the NASA Space Radiation Health Program continued to be understanding the biological effects of space radiation that account for radiation risks. In FY 2001, NASA and DOE developed a Memorandum of Agreement (MOA) to better coordinate their common interests. This close collaboration between NASA and DOE enhances progress in understanding and predicting the effects and health risks resulting from low-dose radiation. DOE and NASA also issued joint Requests for Applications in FY 2002 and 2003 for research that addressed both DOE and NASA needs to understand the human health effects and risks of exposures to low doses of radiation.

In the computing area, the SC and NASA continued their collaboration on "Grids," a way to connect geographically dispersed computer systems so that they can work together to solve science and engineering problems. Two SC laboratories, the LBNL and the Argonne National Laboratory, set up experimental Grids with NASA ARC in order to identify and resolve the technical and configuration issues that arise from cross-institutional operation of the authentication and security infrastructure and cross-operation of the directory services that provide central information service for Grids. The SC and NASA also conducted the Global Grid Forum, a technology definition and standards organization that is providing an invaluable contribution to the field.

Many of the NASA-funded activities listed above enter the DOE system through Work for Others program. This program allows non-DOE sponsors access to the SC laboratories' unique and specialized facilities and expertise. Other areas supported by NASA through this program include research in the space radiation environment and its implications for human presence in space, aerogel-based materials, combustion under microgravity conditions, the biological impact of solar and galactic cosmic radiation exposure on astronaut health, and the genetic and epigenetic effects produced by high-energy heavy ions.

DOE has continued to support NASA's space exploration program by maintaining the necessary program and nuclear facilities infrastructure to provide radioisotope power systems and heater units. DOE is developing advanced radioisotope power systems that will expand the ability of NASA to broaden NASA's conventional missions and mission objectives. DOE personnel provided nuclear safety analysis to support the launch-approval process for the NASA missions to Mars that were launched in 2003. Through the competitive procurement process, DOE awarded a contract for the development, fabrication, and qualification of a new multimission radioisotope thermoelectric generator suitable for use in a variety of environments, including environments encountered on the surface of Mars and in deep space. Additionally, DOE has resumed the procurement of plutonium-238 to fuel these radioisotope power systems from Russia. The resumption of these procurements stabilized the supply of plutonium-238 from Russia and ensured that the supply will be available to support missions into the future.

Smithsonian Institution

The Smithsonian Institution continued to contribute to national aerospace goals through the activities of the Smithsonian Astrophysical Observatory (SAO), which is joined with the Harvard College Observatory in Cambridge, MA, to form the Harvard-Smithsonian Center for Astrophysics. Here, more than 300 scientists engage in a broad program of research in astronomy, astrophysics, 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.

As a result of the success of the Chandra X-Ray Observatory, NASA has extended SAO's contract to provide scientific and operational support via the Chandra X-Ray Center through July 31, 2010. Chandra's revelations about black holes continued to create excitement, making the most noise in the press, in the scientific community, as well as in the public, with a story about sound waves generated by a supermassive black hole. An image of the center of the galaxy Perseus A showed what appeared to be a series of pressure waves—sound waves—expanding outward from the putative black hole at the galaxy's center. In musical terms, the pitch or frequency of the sound generated by explosive activity occurring around the center of Perseus A translates into a note 57 octaves below middle C. At a frequency more than a million billion times deeper than the limits of human hearing, this is the deepest note ever inferred from observations of an object in the universe, aside from the immediate aftermath of the Big Bang. Also attracting intense public and scientific interest was the Chandra observation of the galaxy NGC 6240. This galaxy was found to have not one, but two supermassive black holes orbiting each other in the nucleus of the galaxy; this was the first definitive identification of a binary supermassive black hole system.

Chandra has shown that black holes are much more common in the universe than previously thought, but they are apparently not the predominant form of matter in the universe. In FY 2003, astronomers reported that they used Chandra observations of the galaxy cluster Abell 2029 to make the most detailed probe yet of the distribution of dark matter in a massive cluster of galaxies. Their results indicate that about 80 percent of the matter in the universe consists of cold dark matter—mysterious matter as yet undetectable except via its gravitational effect.

In FY 2003, a team of researchers made a key find in the field of extrasolar planets, or planets around other stars. They discovered a planet that transits, or passes in front of, its star as seen from Earth. While other extrasolar planets were known to transit, this was the first planet discovered using the transit method. Another planet was found using the Doppler shift ("wobble") technique; then astronomers later realized that it also transited the star. This was the first found using the transit technique. That discovery opened the door to finding Earth-like worlds using the same technique. The newfound world also is notable for orbiting so close to its star that its year is only 29 hours long; its proximity to its star bakes it to such high temperatures that the atmosphere is thought to rain not water, but liquid iron. In FY 2003, SAO scientists using the MMT were the first conclusively to link exploding stars (supernovae) to a mysterious phenomenon known as gamma-ray bursts. Also, a group of astronomers including SAO staff presented evidence that we live in a "stop and go" universe whose expansion slowed for billions of years before suddenly accelerating under the influence of so-called dark energy—which is, if anything, even more mysterious than dark matter.

Solar scientists at SAO continued to study the electrically charged atoms (ions) that the Sun expels into the solar system. These ions occur in sudden bursts called coronal mass ejections (CMEs) and in a steadier stream called the solar wind. New observations from SAO's UltraViolet Coronagraph Spectrometer (UVCS) aboard the SOHO spacecraft allowed scientists to probe the physical processes that produce CMEs, which can have a strong impact on Earth's local space environment, on radio frequency communications with aircraft, and on electrical power grids. SOHO observations have permitted early detection of such eruptions, providing warning for satellite operators to shut down vital systems before CMEs reach Earth.

In FY 2003, SAO scientists discovered a bubble of hot (5-million-degree-Celsius) plasma that formed near the Sun in the wake of CMEs associated with the most energetic X-class flares. Also, UVCS studies of bright, ray-like coronal streamers provided evidence that the physical processes that produce the slowest speed wind may be similar to those producing the highest speed solar wind. These measurements are coordinated with those of other SOHO instruments, with the extreme ultraviolet images from the Transition Region and Coronal Explorer satellite, and with hard x-ray images from the Ramaty High Energy Solar Spectroscopic Imager satellite.

Construction of SAO's Submillimeter Array on Mauna Kea, HI, was nearly completed in FY 2003, and the dedication of the instrument was scheduled for November 22, 2003. All eight of the receiving elements were operational by the end of FY 2003, and preliminary observations were made on a variety of astronomical objects. Because of the large number of spectral lines from molecules in the submillimeter part of the spectrum, the Array has already proven to be particularly useful in probing the chemical composition of the atmospheres of planets and moons, as well as in regions of high-mass star formation. The first scientific paper based on observations with the Array was published this year. It reported on the flaring emission from the radio source surrounding the black hole in the center of our galaxy. Access to the instrument will be opened to the general astronomical community next year.

The Science Education Department (SED) at the Center for Astrophysics continued to host workshops designed to train teachers in the use of the Department's many curriculum programs for grades 3 through 12. The "Cosmic Questions" traveling museum exhibit developed by SED staff was visited by more than a third of a million people at the Boston Museum of Science (MOS) before moving on to the Midland Center for the Arts in Midland, MI. As the fiscal year ended, "Cosmic Questions" was about to open at the National Geographic Explorer's Hall in Washington, DC. "Cosmic Questions" is designed to engage the public and school audiences in high-quality exploration of the theme that the story of the universe is the story of us. Total attendance over the 5-year lifetime of the exhibit is expected to be 3 to 4 million visitors. In conjunction with its "Cosmic Questions" traveling exhibit, the Structure and Evolution of the Universe (SEU) Forum partnered with the MOS to create materials and programs that help teachers of grades 7 through 12 (and museum docents) to enhance their own content knowledge and prepare them to use the exhibit effectively to meet science and mathematics education standards. All museums or science centers that hosted the exhibit received a supply of "Cosmic Questions" educator guides for teachers, a train-the-trainers session for professional development providers, and a set of workshop templates that outlined an adaptable professional development syllabus.

SED activities also included the MicroObservatory Program, a curriculum of investigations using four online, fully robotic telescopes, which provides authentic inquiry for students and high-quality professional development for pre- and inservice teachers. Using the MicroObservatory telescopes and the "From the Ground UP!" curriculum, students can plan observations, take data, and share their results with other schools. In FY 2003, users in 20 States took more than 20,000 images, including more than 4,000 requested by visitors to "Cosmic Questions" at the MOS and more than 3,500 requested at the exhibit's appearance in Michigan.

SED's Science Media Group (SMG) has completed "Essential Science for Teachers: Life Science," a professional development course for elementary school teachers. Two other 8-hour series ("Earth and Space Science" and "Physical Science") currently are in production. Work has begun on new projects including collaborating with the NASA Forum on DVD-based professional development materials for high school teachers; contributing to the NSF National Science Digital Library; and, with funding from NSF, conducting research and development for a large-format film (IMAX) about the history of Earth. Additionally, the SMG continued to manage the Annenberg/CPB Channel, a satellite/Web service broadcasting free, educational programming nationwide to schools, colleges, and communities with a reach of 86,000 schools and 64 million households.

SAO continued to offer its popular Observatory Night lectures and telescope observation to the public on a monthly basis. In the summer of 2003, SAO held a total of six special events at facilities in Cambridge and Harvard, MA, offering lectures and observation during the close approach of the planet Mars. Attendance exceeded 2,500 and was limited only by space constraints. For younger audiences, SAO provided a cutting-edge Children's Night program on the search for planets around other stars. Requests for tickets exceeded available space by a factor of more than three. SAO also continued to offer Sci-fi Movie Nights to explore the theme "Everything I Learned About Science, I Learned at the Movies."

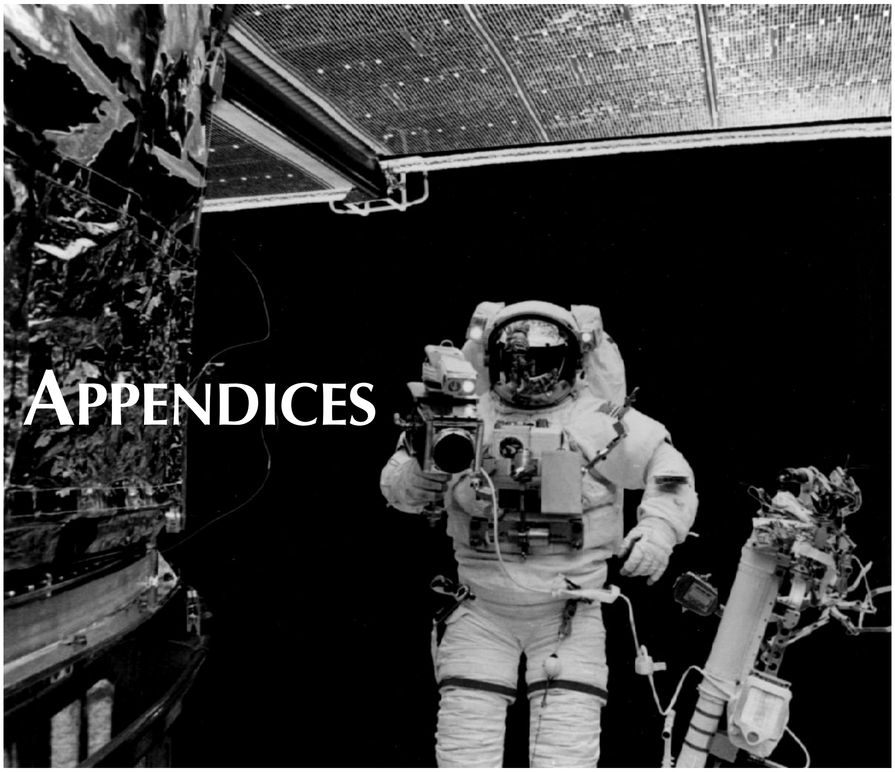
In FY 2003, NASM worked toward the completion of a major exhibition on the 100th anniversary of the Wright brothers' achievement and toward the construction of a new museum, the Steven F. Udvar-Hazy Center, both of which are scheduled to open early in the next fiscal year. The new Udvar-Hazy Center is a 70,611-square-meter building that will house more than 200 aircraft and 135 spacecraft.

Staff members in the Center for Earth & Planetary Studies (CEPS) at NASM continued to participate on the science teams of several spacecraft missions in FY 2003. Dr. John Grant is a Participating Scientist on the 2003 MER missions and will be coordinating a team that will direct the rovers on Mars. He also is a Co-Investigator for the High Resolution Imaging Science Experiment (HiRISE) on the 2005 Mars Reconnaissance Orbiter. Dr. Bruce Campbell is a member of the science team for the Shallow Subsurface Sounding Radar (SHARAD) on the 2005 Mars Reconnaissance Orbiter. Dr. Thomas Watters is a Participating Scientist on the Mars Advanced Radar for Subsurface and Ionosphere Sounding (MARSIS) instrument on the Mars Express orbiter and is also a member of the imaging team for MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER), a mission to orbit Mercury in 2009. CEPS staff were further involved in planetary mission planning through cochairing the Mars Landing Site Steering Group, which advised NASA on landing sites for the MERs that will achieve maximum scientific return within safety and engineering constraints.

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 Mercury, Venus, the Moon, and Mars, as well as corresponding field studies in terrestrial analog regions. CEPS staff studied a variety of geologic processes such as volcanism, tectonics, fluvial processes on early Mars, and sand transport and deposition on Earth and Mars. CEPS research topics that gained attention in the national media included sand ripples on Mars, interactions of impact craters and valley networks on Mars, and Earth-based radar studies of the lunar south pole that provided the most detailed data so far on the question of the presence of water ice.

In addition, CEPS staff participated in the development and presentation of exhibits and public programs, including special events and outreach activities in the community. As a NASA Regional Planetary Imagery Facility (RPIF), CEPS continued to house an extensive collection of images of the planets and their satellites that serves as a reference library for science researchers and the public in 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.)

Calendar	Earth Orbit[a]		Earth Escape[a]	
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 *(through September 30, 2003)*	24 [c, g]	0	2	0
TOTAL	1,548	153	99	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 the five orbital debris radar calibration spheres that were launched from STS-63 as one set of spacecraft.
e. This includes the SSTI Lewis spacecraft that began spinning out of control shortly after it achieved Earth orbit.
f. Counts OCS, OPAL, FALCONSAT, and ASUSAT microsatellites as one set, and the Picosats 4–8 as another set.
g. 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.)

Calendar Year	United States	USSR/ CIS	France[a]	Italy[a]	Japan	People's Republic of China	Australia	United Kingdom	European Space Agency	India	Israel
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 [b]	1	1					
1971	30	83	1	2 [b]	2	1		1			
1972	30	74		1	1						
1973	23	86									
1974	22	81		2 [b]	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 [c]	62			2	1			9	1	
1992	31 [c]	55			2	3			7 [b]	2	
1993	24 [c]	45			1	1			7 [b]		
1994	26 [c]	49			2	5			6 [b]	2	
1995	27 [c]	33 [b]			1	2 [b]			12 [b]		1
1996	32 [c]	25			1	3 [d]			10	1	
1997	37	19			2	6			11	1	
1998	36	25			2	6			11		
1999	30	29				4			10	1	
2000	29	36				5			12		
2001	25	31				1			8	1	
2002	18	23			3	4			12	1	1
2003 *(through September 30, 2003)*	21 [e]	14			2	1			4	1	
TOTAL	1,279	2,702	10	8	59	70	1	1	154	14	4

a. Since 1979, all launches for ESA member countries have been joint and are listed under ESA.
b. Includes foreign launches of U.S. spacecraft.
c. This includes commercial expendable launches and launches of the Space Shuttle, but because this table records launches rather than spacecraft, it does not include separate spacecraft released from the Shuttle.
d. This includes the launch of ChinaSat 7, even though a third-stage rocket failure led to a virtually useless orbit for this communications satellite.
e. Launches from U.S.-Russia joint platform included in U.S. totals.

APPENDIX B

Successful Launches to Orbit on U.S. Launch Vehicles
October 1, 2002–September 30, 2003

Launch Date Spacecraft Name COSPAR* Designation Launch Vehicle	Mission Objectives	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
Oct. 7, 2002 STS-112 2002-47A Space Shuttle	ISS assembly	405 km 273 km 91.3 min 51.6°	
Nov. 20, 2002 W5** 2002-051A Delta 4	Communications satellite	Geosynchronous	Maiden flight of the Delta 4 rocket.
Nov. 24, 2002 STS-113 2002-052A Space Shuttle	ISS assembly	397 km 379 km 92.3 min 51.6°	
Dec. 5, 2002 TDRS 10 2002-055A Atlas 2A	Geostationary tracking and data relay satellite	Geosynchronous	
Jan. 6, 2003 Coriolis 2003-001A Titan 2	Military scientific satellite	842 km 822 km 101.6 min 98.7°	Study of ocean surface winds and solar mass ejections.
Jan. 13, 2003 CHIPS (Cosmic Hot Interstellar Plasma Spectrometer) 2003-002B Delta 2	Scientific satellite	594 km 578 km 96.4 min 94°	Astrophysics spectrograph.
Jan. 13, 2003 ICESAT 2003-002A Delta 2	Earth-observing satellite	595 km 579 km 96.4 min 94°	Study of ice sheets.
Jan. 16, 2003 STS-107 2003-003A Space Shuttle	Science	285 km 270 km 90.1 min 39°	Lost during reentry; no survivors; 80 microgravity experiments conducted in Spacehab module.
Jan. 25, 2003 SORCE (Solar Radiation and Climate Experiment) 2003-004A Pegasus XL	Scientific satellite	652.5 km 612.8 km 93.4 min 40.0°	Sun-Earth Connection satellite.
Jan. 29, 2003 XSS 10 2003-005B Delta 2	AFRL/DOD technology demonstration satellite	805 km 518 km 98 min 39.75°	

APPENDIX B

(Continued)

Successful Launches to Orbit on U.S. Launch Vehicles

October 1, 2002–September 30, 2003

Launch Date Spacecraft Name COSPAR Designation Launch Vehicle	Mission Objectives	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
Jan. 29, 2003 Navstar 51 2003-005A Delta 2	DOD GPS satellite	20,351 km 173 km 356 min 39.1°	Also known as USA 166 and GPS 2R-8.
Mar. 11, 2003 USA 167 2003-008A Delta 4	Military communications satellite	Geosynchronous	
Mar. 31, 2003 Navstar 52 2003-010A Delta 2	Global Positioning System satellite	20,228.8 km 187.83 km 355.6 min 39.0°	Also known as USA 168 and GPS 2R-9.
Apr. 8, 2003 USA 169 2003-012A Titan 4	Military communications satellite	Geosynchronous	Also known as Milstar 6.
Apr. 12, 2003 Asiasat 4** 2003-014A Atlas 3B	Communications satellite	Geosynchronous	
Apr. 28, 2003 GALEX (GALaxy Evolution eXplorer) 2003-017A Pegasus XL	Scientific satellite	697 km 691 km 98.6 min 29.0°	Carries an ultraviolet (UV) telescope.
May 13, 2003 Hellas-Sat** 2003-020A Atlas 5	Communications satellite	Geosynchronous	Satellite for Greece and Cyprus.
June 10, 2003 MER-A (Mars Exploration Rover) 2003-027A Delta 2	Mars Exploration Probe and Rover		Mars mission; also known as Spirit.
June 26, 2003 Orbview 3** 2003-030A Pegasus	Photo-imaging satellite	429 km 365.7 km 92.5 min 97.3°	

* UN Committee on Space Research
** Commerical launch licensed as such by the Federal Aviation Administration. More launch information is available at *http://ast.faa.gov/linfo_vsite/launch_info.cfm* on the Web.

APPENDIX B

(Continued)

Successful Launches to Orbit on U.S. Launch Vehicles
October 1, 2002–September 30, 2003

Launch Date Spacecraft Name COSPAR Designation Launch Vehicle	Mission Objectives	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
July 8, 2003 MER-B (Mars Exploration Rover) 2003-032A Delta 2	Mars Exploration Probe and Rover		Mars mission; also known as Opportunity.
July 17, 2003 Rainbow 1** 2003-033A Atlas 5	Communications satellite	Orbital parameters unknown	
Aug. 13, 2003 SCISAT 1 2003-036A Pegasus XL	Atmospheric research satellite	655 km 642 km 97.7 min 73.9°	Canadian satellite.
Aug. 25, 2003 SIRTF 2003-038A Delta 2	Scientific satellite	Heliocentric orbit 363 d 0.0°	One of NASA's Great Observatories.
Aug. 29, 2003 USA 170 2003-040A Delta 4	Military communications satellite	Geosynchronous	Also known as DSCS 3B6.
Sept. 9, 2003 USA 171 2003-041A unknown	Military satellite	Geosynchronous	National Reconnaissance Office satellite.

* UN Committee on Space Research

** Commerical launch licensed as such by the Federal Aviation Administration. More launch information is available at *http://ast.faa.gov/linfo_vsite/launch_info.cfm* on the Web.

U.S. and Russian Human Space Flights

1961–September 30, 2003

Spacecraft	Launch Date	Crew	Flight Time (d:h:min)	Highlights
Vostok 1	Apr. 12, 1961	Yury A. Gagarin	0:1:48	First human flight.
Mercury-Redstone 3	May 5, 1961	Alan B. Shepard, Jr.	0:0:15	First U.S. flight, suborbital.
Mercury-Redstone 4	July 21, 1961	Virgil I. Grissom	0:0:16	Suborbital; capsule sank after landing; astronaut safe.
Vostok 2	Aug. 6, 1961	German S. Titov	1:1:18	First flight exceeding 24 h.
Mercury-Atlas 6	Feb. 20, 1962	John H. Glenn, Jr.	0:4:55	First American to orbit.
Mercury-Atlas 7	May 24, 1962	M. Scott Carpenter	0:4:56	Landed 400 km beyond target.
Vostok 3	Aug. 11, 1962	Andriyan G. Nikolayev	3:22:25	First dual mission (with Vostok 4).
Vostok 4	Aug. 12, 1962	Pavel R. Popovich	2:22:59	Came within 6 km of Vostok 3.
Mercury-Atlas 8	Oct. 3, 1962	Walter M. Schirra, Jr.	0:9:13	Landed 8 km from target.
Mercury-Atlas 9	May 15, 1963	L. Gordon Cooper, Jr.	1:10:20	First U.S. flight exceeding 24 h.
Vostok 5	June 14, 1963	Valery F. Bykovskiy	4:23:6	Second dual mission (with Vostok 6).
Vostok 6	June 16, 1963	Valentina V. Tereshkova	2:22:50	First woman in space; within 5 km of Vostok 5.
Voskhod 1	Oct. 12, 1964	Vladimir M. Komarov Konstantin P. Feoktistov Boris G. Yegorov	1:0:17	First three-person crew.
Voskhod 2	Mar. 18, 1965	Pavel I. Belyayev Aleksey A. Leonov	1:2:2	First extravehicular activity (EVA), by Leonov, 10 min.
Gemini 3	Mar. 23, 1965	Virgil I. Grissom John W. Young	0:4:53	First U.S. two-person flight; first manual maneuvers in orbit.
Gemini 4	June 3, 1965	James A. McDivitt Edward H. White II	4:1:56	21-min EVA (White).
Gemini 5	Aug. 21, 1965	L. Gordon Cooper, Jr. Charles Conrad, Jr.	7:22:55	Longest human flight to date.
Gemini 7	Dec. 4, 1965	Frank Borman James A. Lovell, Jr.	13:18:35	Longest human flight to date.
Gemini 6-A	Dec. 15, 1965	Walter M. Schirra, Jr. Thomas P. Stafford	1:1:51	Rendezvous within 30 cm of Gemini 7.
Gemini 8	Mar. 16, 1966	Neil A. Armstrong David R. Scott	0:10:41	First docking of two orbiting spacecraft (Gemini 8 with Agena target rocket).
Gemini 9-A	June 3, 1966	Thomas P. Stafford Eugene A. Cernan	3:0:21	EVA; rendezvous.
Gemini 10	July 18, 1966	John W. Young Michael Collins	2:22:47	First dual rendezvous (Gemini 10 with Agena 10, then Agena 8).
Gemini 11	Sept. 12, 1966	Charles Conrad, Jr. Richard F. Gordon, Jr.	2:23:17	First initial-orbit docking; first tethered flight; highest Earth-orbit altitude (1,372 km).
Gemini 12	Nov. 11, 1966	James A. Lovell, Jr. Edwin E. "Buzz" Aldrin, Jr.	3:22:35	Longest EVA to date (Aldrin, 5 h.).
Soyuz 1	Apr. 23, 1967	Vladimir M. Komarov	1:2:37	Cosmonaut killed in reentry accident.
Apollo 7	Oct. 11, 1968	Walter M. Schirra, Jr. Donn F. Eisele R. Walter Cunningham	10:20:9	First U.S. three-person mission.
Soyuz 3	Oct. 26, 1968	Georgiy T. Beregovoy	3:22:51	Maneuvered near uncrewed Soyuz 2.
Apollo 8	Dec. 21, 1968	Frank Borman James A. Lovell, Jr. William A. Anders	6:3:1	First human orbit(s) of Moon; first human departure from Earth's sphere of influence; highest speed attained in human flight to date.
Soyuz 4	Jan. 14, 1969	Vladimir A. Shatalov	2:23:23	Soyuz 4 and 5 docked and transferred two cosmonauts from Soyuz 5 to Soyuz 4.
Soyuz 5	Jan. 15, 1969	Boris V. Volynov Aleksey A. Yeliseyev Yevgeniy V. Khrunov	3:0:56	
Apollo 9	Mar. 3, 1969	James A. McDivitt David R. Scott Russell L. Schweickart	10:1:1	Successfully simulated (in Earth orbit) operation of Lunar Module to landing and takeoff from lunar surface and rejoining with command module.

APPENDIX C

(Continued)

U.S. and Russian Human Space Flights

1961–September 30, 2003

Spacecraft	Launch Date	Crew	Flight Time (d:h:min)	Highlights
Apollo 10	May 18, 1969	Thomas P. Stafford John W. Young Eugene A. Cernan	8:0:3	Successfully demonstrated complete system, including Lunar Module to 14,300 m from the lunar surface.
Apollo 11	July 16, 1969	Neil A. Armstrong Michael Collins Edwin E. "Buzz" Aldrin, Jr.	8:3:9	First human landing on lunar surface and safe return to Earth. First return of rock and soil samples to Earth and human deployment of experiments on lunar surface.
Soyuz 6	Oct. 11, 1969	Georgiy Shonin Valery N. Kubasov	4:22:42	Soyuz 6, 7, and 8 operated as a group flight without actually docking. Each conducted certain experiments, including welding and Earth and celestial observation.
Soyuz 7	Oct. 12, 1969	A. V. Filipchenko Viktor N. Gorbatko Vladislav N. Volkov	4:22:41	
Soyuz 8	Oct. 13, 1969	Vladimir A. Shatalov Aleksey S. Yeliseyev	4:22:50	
Apollo 12	Nov. 14, 1969	Charles Conrad, Jr. Richard F. Gordon, Jr. Alan L. Bean	10:4:36	Second human lunar landing explored surface of Moon and retrieved parts of Surveyor 3 spacecraft, which landed in Ocean of Storms on Apr. 19, 1967.
Apollo 13	Apr. 11, 1970	James A. Lovell, Jr. Fred W. Haise, Jr. John L. Swigert, Jr.	5:22:55	Mission aborted; explosion in service module. Ship circled Moon, with crew using Lunar Module as "lifeboat" until just before reentry.
Soyuz 9	June 1, 1970	Andriyan G. Nikolayev Vitaliy I. Sevastyanov	17:16:59	Longest human space flight to date.
Apollo 14	Jan. 31, 1971	Alan B. Shepard, Jr. Stuart A. Roosa Edgar D. Mitchell	9:0:2	Third human lunar landing. Mission demonstrated pinpoint landing capability and continued human exploration.
Soyuz 10	Apr. 22, 1971	Vladimir A. Shatalov Aleksey S. Yeliseyev Nikolay N. Rukavishnikov	1:23:46	Docked with Salyut 1, but crew did not board space station launched Apr. 19. Crew recovered Apr. 24, 1971.
Soyuz 11	June 6, 1971	Georgiy T. Dobrovolskiy Vladislav N. Volkov Viktor I. Patsayev	23:18:22	Docked with Salyut 1, and Soyuz 11 crew occupied space station for 22 days. Crew perished in final phase of Soyuz 11 capsule recovery on June 30, 1971.
Apollo 15	July 26, 1971	David R. Scott Alfred M. Worden James B. Irwin	12:7:12	Fourth human lunar landing and first Apollo "J" series mission, which carried Lunar Roving Vehicle. Worden's in-flight EVA of 38 min, 12 s was performed during return trip.
Apollo 16	Apr. 16, 1972	John W. Young Charles M. Duke, Jr. Thomas K. Mattingly II	11:1:51	Fifth human lunar landing, with roving vehicle.
Apollo 17	Dec. 7, 1972	Eugene A. Cernan Harrison H. Schmitt Ronald E. Evans	12:13:52	Sixth and final Apollo human lunar landing, again with roving vehicle.
Skylab 2	May 25, 1973	Charles Conrad, Jr. Joseph P. Kerwin Paul J. Weitz	28:0:50	Docked with Skylab 1 (launched uncrewed May 14) for 28 days. Repaired damaged station.
Skylab 3	July 28, 1973	Alan L. Bean Jack R. Lousma Owen K. Garriott	59:11:9	Docked with Skylab 1 for more than 59 days.
Soyuz 12	Sept. 27, 1973	Vasiliy G. Lazarev Oleg G. Makarov	1:23:16	Checkout of improved Soyuz.

APPENDIX C

(Continued)

U.S. and Russian Human Space Flights

1961–September 30, 2003

Spacecraft	Launch Date	Crew	Flight Time (d:h:min)	Highlights
Skylab 4	Nov. 16, 1973	Gerald P. Carr Edward G. Gibson William R. Pogue	84:1:16	Docked with Skylab 1 in long-duration mission; last of Skylab program.
Soyuz 13	Dec. 18, 1973	Petr I. Klimuk Valentin V. Lebedev	7:20:55	Astrophysical, biological, and Earth resources experiments.
Soyuz 14	July 3, 1974	Pavel R. Popovich Yury P. Artyukhin	15:17:30	Docked with Salyut 3; Soyuz 14 crew occupied space station.
Soyuz 15	Aug. 26, 1974	Gennady V. Sarafanov Lev S. Demin	2:0:12	Rendezvoused but did not dock with Salyut 3.
Soyuz 16	Dec. 2, 1974	Anatoly V. Filipchenko Nikolay N. Rukavishnikov	5:22:24	Test of Apollo-Soyuz Test Project (ASTP) configuration.
Soyuz 17	Jan. 10, 1975	Aleksey A. Gubarev Georgiy M. Grechko	29:13:20	Docked with Salyut 4 and occupied station.
Soyuz 18A (Anomaly)	Apr. 5, 1975	Vasiliy G. Lazarev Oleg G. Makarov	0:0:20	Soyuz stages failed to separate; crew recovered after abort.
Soyuz 18	May 24, 1975	Petr I. Klimuk Vitaliy I. Sevastyanov	62:23:20	Docked with Salyut 4 and occupied station.
Soyuz 19	July 15, 1975	Aleksey A. Leonov Valery N. Kubasov	5:22:31	Target for Apollo in docking and joint experiments of ASTP mission.
Apollo	July 15, 1975	Thomas P. Stafford Donald K. Slayton Vance D. Brand	9:1:28	Docked with Soyuz 19 in joint (ASTP) experiments of ASTP mission.
Soyuz 21	July 6, 1976	Boris V. Volynov Vitaliy M. Zholobov	48:1:32	Docked with Salyut 5 and occupied station.
Soyuz 22	Sept. 15, 1976	Valery F. Bykovskiy Vladimir V. Aksenov	7:21:54	Earth resources study with multispectral camera system.
Soyuz 23	Oct. 14, 1976	Vyacheslav D. Zudov Valery I. Rozhdestvenskiy	2:0:6	Failed to dock with Salyut 5.
Soyuz 24	Feb. 7, 1977	Viktor V. Gorbatko Yury N. Glazkov	17:17:23	Docked with Salyut 5 and occupied station.
Soyuz 25	Oct. 9, 1977	Vladimir V. Kovalenok Valery V. Ryumin	2:0:46	Failed to achieve hard dock with Salyut 6 station.
Soyuz 26	Dec. 10, 1977	Yury V. Romanenko Georgiy M. Grechko	37:10:6	Docked with Salyut 6. Crew returned in Soyuz 27; crew duration 96 d, 10 h.
Soyuz 27	Jan. 10, 1978	Vladimir A. Dzhanibekov Oleg G. Makarov	64:22:53	Docked with Salyut 6. Crew returned in Soyuz 26; crew duration 5 d, 22 h, 59 min.
Soyuz 28	Mar. 2, 1978	Aleksey A. Gubarev Vladimir Remek	7:22:17	Docked with Salyut 6. Remek was first Czech cosmonaut to orbit.
Soyuz 29	June 15, 1978	Vladimir V. Kovalenok Aleksandr S. Ivanchenkov	9:15:23	Docked with Salyut 6. Crew returned in Soyuz 31; crew duration 139 d, 14 h, 48 min.
Soyuz 30	June 27, 1978	Petr I. Klimuk Miroslaw Hermaszewski	7:22:4	Docked with Salyut 6. Hermaszewski was first Polish cosmonaut to orbit.
Soyuz 31	Aug. 26, 1978	Valery F. Bykovskiy Sigmund Jaehn	67:20:14	Docked with Salyut 6. Crew returned in Soyuz 29; crew duration 7 d, 20 h, 49 min. Jaehn was first German Democratic Republic cosmonaut to orbit.
Soyuz 32	Feb. 25, 1979	Vladimir A. Lyakhov Valery V. Ryumin Nikolay N. Rukavishnikov	108:4:24	Docked with Salyut 6. Crew returned in Soyuz 34; crew duration 175 d, 36 min.
Soyuz 33	Apr. 10, 1979	Georgi I. Ivanov	1:23:1	Failed to achieve docking with Salyut 6 station. Ivanov was first Bulgarian cosmonaut to orbit.
Soyuz 34	June 6, 1979	(unmanned at launch)	7:18:17	Docked with Salyut 6, later served as ferry for Soyuz 32 crew while Soyuz 32 returned without a crew.

APPENDIX C

(Continued)

U.S. and Russian Human Space Flights

1961–September 30, 2003

Spacecraft	Launch Date	Crew	Flight Time (d:h:min)	Highlights
Soyuz 35	Apr. 9, 1980	Leonid I. Popov Valery V. Ryumin	55:1:29	Docked with Salyut 6. Crew returned in Soyuz 37. Crew duration 184 d, 20 h, 12 min.
Soyuz 36	May 26, 1980	Valery N. Kubasov Bertalan Farkas	65:20:54	Docked with Salyut 6. Crew returned in Soyuz 35. Crew duration 7 d, 20 h, 46 min. Farkas was first Hungarian to orbit.
Soyuz T-2	June 5, 1980	Yury V. Malyshev Vladimir V. Aksenov	3:22:21	Docked with Salyut 6. First crewed flight of new-generation ferry.
Soyuz 37	July 23, 1980	Viktor V. Gorbatko Pham Tuan	79:15:17	Docked with Salyut 6. Crew returned in Soyuz 36. Crew duration 7 d, 20 h, 42 min. Pham was first Vietnamese to orbit.
Soyuz 38	Sept. 18, 1980	Yury V. Romanenko Arnaldo Tamayo Mendez	7:20:43	Docked with Salyut 6. Tamayo was first Cuban to orbit.
Soyuz T-3	Nov. 27, 1980	Leonid D. Kizim Oleg G. Makarov Gennady M. Strekalov	12:19:8	Docked with Salyut 6. First three-person flight in Soviet program since 1971.
Soyuz T-4	Mar. 12, 1981	Vladimir V. Kovalenok Viktor P. Savinykh	74:18:38	Docked with Salyut 6.
Soyuz 39	Mar. 22, 1981	Vladimir A. Dzhanibekov Jugderdemidiyn Gurragcha	7:20:43	Docked with Salyut 6. Gurragcha first Mongolian cosmonaut to orbit.
Space Shuttle Columbia (STS-1)	Apr. 12, 1981	John W. Young Robert L. Crippen	2:6:21	First flight of Space Shuttle; tested spacecraft in orbit. First landing of airplane-like craft from orbit for reuse.
Soyuz 40	May 14, 1981	Leonid I. Popov Dumitru Prunariu	7:20:41	Docked with Salyut 6. Prunariu first Romanian cosmonaut to orbit.
Space Shuttle Columbia (STS-2)	Nov. 12, 1981	Joe H. Engle Richard H. Truly	2:6:13	Second flight of Space Shuttle; first scientific payload (OSTA 1). Tested remote manipulator arm. Returned for reuse.
Space Shuttle Columbia (STS-3)	Mar. 22, 1982	Jack R. Lousma C. Gordon Fullerton	8:0:5	Third flight of Space Shuttle; second scientific payload (OSS 1). Second test of remote manipulator arm. Flight extended 1 day because of flooding at primary landing site; alternate landing site used. Returned for reuse.
Soyuz T-5	May 13, 1982	Anatoly Berezovoy Valentin Lebedev	211:9:5	Docked with Salyut 7. Crew duration of 211 d. Crew returned in Soyuz T-7.
Soyuz T-6	June 24, 1982	Vladimir Dzhanibekov Aleksandr Ivanchenkov Jean-Loup Chrétien	7:21:51	Docked with Salyut 7. Chrétien first French cosmonaut to orbit.
Space Shuttle Columbia (STS-4)	June 27, 1982	Thomas K. Mattingly II Henry W. Hartsfield, Jr.	7:1:9	Fourth flight of Space Shuttle; first DOD payload; additional scientific payloads. Returned July 4. Completed testing program. Returned for reuse.
Soyuz T-7	Aug. 19, 1982	Leonid Popov Aleksandr Serebrov Svetlana Savitskaya	7:21:52	Docked with Salyut 7. Savitskaya second woman to orbit. Crew returned in Soyuz T-5.
Space Shuttle Columbia (STS-5)	Nov. 11, 1982	Vance D. Brand Robert F. Overmyer Joseph P. Allen William B. Lenoir	5:2:14	Fifth flight of Space Shuttle; first operational flight; launched two commercial satellites (SBS 3 and Anik C-3); first flight with four crewmembers. EVA test canceled when spacesuits malfunctioned.
Space Shuttle Challenger (STS-6)	Apr. 4, 1983	Paul J. Weitz Karol J. Bobko Donald H. Peterson F. Story Musgrave	5:0:24	Sixth flight of Space Shuttle; launched TDRS-1.

APPENDIX C

(Continued)

U.S. and Russian Human Space Flights

1961–September 30, 2003

Spacecraft	Launch Date	Crew	Flight Time (d:h:min)	Highlights
Soyuz T-8	Apr. 20, 1983	Vladimir Titov Gennady Strekalov Aleksandr Serebrov	2:0:18	Failed to achieve docking with Salyut 7 station.
Space Shuttle Challenger (STS-7)	June 18, 1983	Robert L. Crippen Frederick H. Hauck John M. Fabian Sally K. Ride Norman T. Thagard	6:2:24	Seventh flight of Space Shuttle; launched two commercial satellites (Anik C-2 and Palapa B-1); also launched and retrieved SPAS 01; first flight with five crew members, including first female U.S. astronaut.
Soyuz T-9	June 28, 1983	Vladimir Lyakhov Aleksandr Aleksandrov	149:9:46	Docked with Salyut 7 station.
Space Shuttle Challenger (STS-8)	Aug. 30, 1983	Richard H. Truly Daniel C. Brandenstein Dale A. Gardner Guion S. Bluford, Jr. William E. Thornton	6:1:9	Eighth flight of Space Shuttle; launched one commercial satellite (Insat 1-B); first flight of U.S. Black astronaut.
Space Shuttle Columbia (STS-9)	Nov. 28, 1983	John W. Young Brewster W. Shaw Owen K. Garriott Robert A.R. Parker Byron K. Lichtenberg Ulf Merbold	10:7:47	Ninth flight of Space Shuttle; first flight of Spacelab 1; first flight of six crewmembers, one of whom was West German; Merbold was first non-U.S. astronaut to fly in U.S. space program.
Space Shuttle Challenger (STS 41-B)	Feb. 3, 1984	Vance D. Brand Robert L. Gibson Bruce McCandless Ronald E. McNair Robert L. Stewart	7:23:16	Tenth flight of Space Shuttle; two communication satellites failed to achieve orbit; first use of Manned Maneuvering Unit in space.
Soyuz T-10	Feb. 8, 1984	Leonid Kizim Vladimir Solovev Oleg Atkov	62:22:43	Docked with Salyut 7 station. Crew set space duration record of 237 d. Crew returned in Soyuz T-11.
Soyuz T-11	Apr. 3, 1984	Yury Malyshev Gennady Strekalov Rakesh Sharma	181:21:48	Docked with Salyut 7 station. Sharma first Indian in space. Crew returned in Soyuz T-10.
Space Shuttle Challenger (STS 41-C)	Apr. 6, 1984	Robert L. Crippen Francis R. Scobee Terry J. Hart George D. Nelson James D. van Hoften	6:23:41	Eleventh flight of Space Shuttle; deployment of Long-Duration Exposure Facility (LDEF-1) for later retrieval; Solar Maximum Satellite retrieved, repaired, and redeployed.
Soyuz T-12	July 17, 1984	Vladimir Dzhanibekov Svetlana Savistskaya Igor Volk	11:19:14	Docked with Salyut 7 station. First EVA by a woman.
Space Shuttle Discovery (STS 41-D)	Aug. 30, 1984	Henry W. Hartsfield Michael L. Coats Richard M. Mullane Steven A. Hawley Judith A. Resnik Charles D. Walker	6:0:56	Twelfth flight of Space Shuttle. First flight of U.S. nonastronaut.
Space Shuttle Challenger (STS 41-G)	Oct. 5, 1984	Robert L. Crippen Jon A. McBride Kathryn D. Sullivan Sally K. Ride David Leestma Paul D. Scully-Power Marc Garneau	8:5:24	Thirteenth flight of Space Shuttle; first with seven crewmembers, including first flight of two U.S. women and one Canadian (Garneau).

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(Continued)

U.S. and Russian Human Space Flights

1961–September 30, 2003

Spacecraft	Launch Date	Crew	Flight Time (d:h:min)	Highlights
Space Shuttle Discovery (STS 51-A)	Nov. 8, 1984	Frederick H. Hauck David M. Walker Joseph P. Allen Anna L. Fisher Dale A. Gardner	7:23:45	Fourteenth flight of Space Shuttle; first retrieval and return of two disabled communications satellites (Westar 6, Palapa B2) to Earth.
Space Shuttle Discovery (STS 51-C)	Jan. 24, 1985	Thomas K. Mattingly Loren J. Shriver Ellison S. Onizuka James F. Buchli Gary E. Payton	3:1:33	Fifteenth STS flight. Dedicated DOD mission.
Space Shuttle Discovery (STS 51-D)	Apr. 12, 1985	Karol J. Bobko Donald E. Williams M. Rhea Seddon S. David Griggs Jeffrey A. Hoffman Charles D. Walker E.J. Garn	6:23:55	Sixteenth STS flight. Two communications satellites. First U.S. Senator in space (Garn).
Space Shuttle Challenger (STS 51-B)	Apr. 29, 1985	Robert F. Overmyer Frederick D. Gregory Don L. Lind Norman E. Thagard William E. Thornton Lodewijk van den Berg Taylor Wang	7:0:9	Seventeenth STS flight. Spacelab-3 in cargo bay of Shuttle.
Soyuz T-13	June 5, 1985	Vladimir Dzhanibekov Viktor Savinykh	112:3:12	Repair of Salyut-7. Dzhanibekov returned to Earth with Grechko on Soyuz T-13 spacecraft, Sept. 26, 1985.
Space Shuttle Discovery (STS 51-G)	June 17, 1985	Daniel C. Brandenstein John O. Creighton Shannon W. Lucid John M. Fabian Steven R. Nagel Patrick Baudry Prince Sultan Salman Al-Saud	7:1:39	Eighteenth STS flight. Three communications satellites. One reusable payload, Spartan-1. First U.S. flight with French and Saudi Arabian crew members.
Space Shuttle Challenger (STS 51-F)	July 29, 1985	Charles G. Fullerton Roy D. Bridges Karl C. Henize Anthony W. England F. Story Musgrave Loren W. Acton John-David F. Bartoe	7:22:45	Nineteenth STS flight. Spacelab-2 in cargo bay.
Space Shuttle Discovery (STS 51-I)	Aug. 27, 1985	Joe H. Engle Richard O. Covey James D. van Hoften William F. Fisher John M. Lounge	7:2:18	Twentieth STS flight. Launched three communications satellites. Repaired Syncom IV-3.
Soyuz T-14	Sept. 17, 1985	Vladimir Vasyutin Georgiy Grechko Aleksandr Volkov	64:21:52	Docked with Salyut 7 station. Viktor Savinykh, Aleksandr Volkov, and Vladimir Vasyutin returned to Earth Nov. 21, 1985, when Vasyutin became ill.
Space Shuttle Atlantis (STS 51-J)	Oct. 3, 1985	Karol J. Bobko Ronald J. Grabe Robert L. Stewart David C. Hilmers William A. Pailes	4:1:45	Twenty-first STS flight. Dedicated DOD mission.

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U.S. and Russian Human Space Flights

1961–September 30, 2003

Spacecraft	Launch Date	Crew	Flight Time (d:h:min)	Highlights
Space Shuttle Challenger (STS 61-A)	Oct. 30, 1985	Henry W. Hartsfield Steven R. Nagel Bonnie J. Dunbar James F. Buchli Guion S. Bluford, Jr. Ernst Messerschmid Reinhard Furrer Wubbo J. Ockels	7:0:45	Twenty-second STS flight. Dedicated German Spacelab D-1 in Shuttle cargo bay.
Space Shuttle Atlantis (STS 61-B)	Nov. 26, 1985	Brewster H. Shaw Bryan D. O'Connor Mary L. Cleave Sherwood C. Spring Jerry L. Ross Rudolfo Neri Vela Charles D. Walker	6:21:4	Twenty-third STS flight. Launched three communications satellites. First flight of Mexican astronaut (Neri Vela).
Space Shuttle Columbia (STS 61-C)	Jan. 12, 1986	Robert L. Gibson Charles F. Bolden, Jr. Franklin Chang-Díaz Steve A. Hawley George D. Nelson Robert Cenker Bill Nelson	6:2:4	Twenty-fourth STS flight. Launched one communications satellite. First member of U.S. House of Representatives in space (Bill Nelson).
Soyuz T-15	Mar. 13, 1986	Leonid Kizim Vladimir Solovyov	125:1:1	Docked with Mir space station on May 5/6, transferred to Salyut 7 complex. On June 25/26, transferred from Salyut 7 back to Mir.
Soyuz TM-2	Feb. 5, 1987	Yury Romanenko Aleksandr Laveykin	174:3:26	Docked with Mir space station. Romanenko established record of 326 days for long-distance stay in space.
Soyuz TM-3	July 22, 1987	Aleksandr Viktorenko Aleksandr Aleksandrov Mohammed Faris	160:7:16	Docked with Mir space station. Aleksandr Aleksandrov remained in Mir 160 days; returned with Yury Romanenko. Viktorenko and Faris returned in Soyuz TM-2 on July 30 with Aleksandr Laveykin, who experienced medical problems. Faris first Syrian in space.
Soyuz TM-4	Dec. 21, 1987	Vladimir Titov Musa Manarov Anatoly Levchenko	180:5	Docked with Mir space station. Crew of Yury Romanenko, Aleksandr Aleksandrov, and Anatoly Levchenko returned Dec. 29 in Soyuz TM-3.
Soyuz TM-5	June 7, 1988	Viktor Savinykh Anatoly Solovyev Aleksandr Aleksandrov	9:20:13	Docked with Mir space station. Crew returned June 17 in Soyuz TM-4.
Soyuz TM-6	Aug. 29, 1988	Vladimir Lyakhov Valery Polyakov Abdul Mohmand	8:19:27	Docked with Mir space station; Mohmand first Afghanistani in space. Crew returned Sept. 7 in Soyuz TM-5.
Space Shuttle Discovery (STS-26)	Sept. 29, 1988	Frederick H. Hauck Richard O. Covey John M. Lounge David C. Hilmers George D. Nelson	4:1	Twenty-sixth STS flight. Launched TDRS-3.
Soyuz TM-7	Nov. 26, 1988	Aleksandr Volkov Sergei Krikalev Jean-Loup Chrétien	151:11	Docked with Mir space station. Soyuz TM-6 returned with Chrétien, Vladimir Titov, and Musa Manarov. Titov and Manarov completed 366-d mission on Dec. 21. Crew of Krikalev, Volkov, and Valery Polyakov returned Apr. 27, 1989, in Soyuz TM-7.

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U.S. and Russian Human Space Flights

1961–September 30, 2003

Spacecraft	Launch Date	Crew	Flight Time (d:h:min)	Highlights
Space Shuttle Atlantis (STS-27)	Dec. 2, 1988	Robert "Hoot" Gibson Guy S. Gardner Richard M. Mullane Jerry L. Ross William M. Shepherd	4:9:6	Twenty-seventh STS flight. Dedicated DOD mission.
Space Shuttle Discovery (STS-29)	Mar. 13, 1989	Michael L. Coats John E. Blaha James P. Bagian James F. Buchli Robert C. Springer	4:23:39	Twenty-eighth STS flight. Launched TDRS-4.
Space Shuttle Atlantis (STS-30)	May 4, 1989	David M. Walker Ronald J. Grabe Norman E. Thagard Mary L. Cleave Mark C. Lee	4:0:57	Twenty-ninth STS flight. Venus orbiter Magellan launched.
Space Shuttle Columbia (STS-28)	Aug. 8, 1989	Brewster H. Shaw Richard N. Richards James C. Adamson David C. Leestma Mark N. Brown	5:1:0	Thirtieth STS flight. Dedicated DOD mission.
Soyuz TM-8	Sept. 5, 1989	Aleksandr Viktorenko Aleksandr Serebrov	166:6:46	Docked with Mir space station. Crew of Viktorenko and Serebrov returned in Soyuz TM-8 on Feb. 9, 1990.
Space Shuttle Atlantis (STS-34)	Oct. 18, 1989	Donald E. Williams Michael J. McCulley Shannon W. Lucid Franklin R. Chang-Díaz Ellen S. Baker	4:23:39	Thirty-first STS flight. Launched Jupiter probe and orbiter Galileo.
Space Shuttle Discovery (STS-33)	Nov. 22, 1989	Frederick D. Gregory John E. Blaha Kathryn C. Thornton F. Story Musgrave Manley L. "Sonny" Carter	5:0:7	Thirty-second STS flight. Dedicated DOD mission.
Space Shuttle Columbia (STS-32)	Jan. 9, 1990	Daniel C. Brandenstein James D. Wetherbee Bonnie J. Dunbar Marsha S. Ivins G. David Low	10:21:0	Thirty-third STS flight. Launched Syncom IV-5 and retrieved LDEF.
Soyuz TM-9	Feb. 11, 1990	Anatoly Solovyov Aleksandr Balandin	178:22:19	Docked with Mir space station. Crew returned Aug. 9, 1990, in Soyuz TM-9.
Space Shuttle Atlantis (STS-36)	Feb. 28, 1990	John O. Creighton John H. Casper David C. Hilmers Richard H. Mullane Pierre J. Thuot	4:10:19	Thirty-fourth STS flight. Dedicated DOD mission.
Space Shuttle Discovery (STS-31)	Apr. 24, 1990	Loren J. Shriver Charles F. Bolden, Jr. Steven A. Hawley Bruce McCandless II Kathryn D. Sullivan	5:1:16	Thirty-fifth STS flight. Launched Hubble Space Telescope (HST).
Soyuz TM-10	Aug. 1, 1990	Gennady Manakov Gennady Strekalov	130:20:36	Docked with Mir space station. Crew returned Dec. 10, 1990, with Toyohiro Akiyama, Japanese cosmonaut and journalist in space. See listing for Soyuz TM-11.

APPENDIX C

(Continued)

U.S. and Russian Human Space Flights

1961–September 30, 2003

Spacecraft	Launch Date	Crew	Flight Time (d:h:min)	Highlights
Space Shuttle Discovery (STS-41)	Oct. 6, 1990	Richard N. Richards Robert D. Cabana Bruce E. Melnick William M. Shepherd Thomas D. Akers	4:2:10	Thirty-sixth STS flight. Ulysses spacecraft to investigate interstellar space and the Sun.
Space Shuttle Atlantis (STS-38)	Nov. 15, 1990	Richard O. Covey Frank L. Culbertson, Jr. Charles "Sam" Gemar Robert C. Springer Carl J. Meade	4:21:55	Thirty-seventh STS flight. Dedicated DOD mission.
Space Shuttle Columbia (STS-35)	Dec. 2, 1990	Vance D. Brand Guy S. Gardner Jeffrey A. Hoffman John M. "Mike" Lounge Robert A.R. Parker Samuel T. Durrance Ronald A. Parise	8:23:5	Thirty-eighth STS flight. Astro-1 in cargo bay.
Soyuz TM-11	Dec. 2, 1990	Viktor Afanasyev Musa Manarov Toyohiro Akiyama	175:1:52	Docked with Mir space station. Toyohiro Akiyama returned Dec. 10, 1990, with previous Mir crew of Gennady Manakov and Gennady Strekalov.
Space Shuttle Atlantis (STS-37)	Apr. 5, 1991	Steven R. Nagel Kenneth D. Cameron Linda Godwin Jerry L. Ross Jay Apt	6:0:32	Thirty-ninth STS flight. Launched Gamma Ray Observatory to measure celestial gamma rays.
Space Shuttle Discovery (STS-39)	Apr. 28, 1991	Michael L. Coats Blaine Hammond, Jr. Gregory L. Harbaugh Donald R. McMonagle Guion S. Bluford, Jr. Lacy Veach Richard J. Hieb	8:7:22	Fortieth STS flight. Dedicated DOD mission.
Soyuz TM-12	May 18, 1991	Anatoly Artsebarskiy Sergei Krikalev Helen Sharman	144:15:22	Docked with Mir space station. Helen Sharman first from United Kingdom to fly in space. Crew of Viktor Afanasyev, Musa Manarov, and Helen Sharman returned May 20, 1991. Artsebarskiy and Krikalev remained aboard Mir, with Artsebarskiy returning Oct. 10, 1991, and Krikalev doing so Mar. 25, 1992.
Space Shuttle Columbia (STS-40)	June 5, 1991	Bryan D. O'Connor Sidney M. Gutierrez James P. Bagian Tamara E. Jernigan M. Rhea Seddon Francis A. "Drew" Gaffney Millie Hughes-Fulford	9:2:15	Forty-first STS flight. Carried Spacelab Life Sciences (SLS-1) in cargo bay.
Space Shuttle Atlantis (STS-43)	Aug. 2, 1991	John E. Blaha Michael A. Baker Shannon W. Lucid G. David Low James C. Adamson	8:21:21	Forty-second STS flight. Launched fourth Tracking and Data Relay Satellite (TDRS-5).
Space Shuttle Discovery (STS-48)	Sept. 12, 1991	John Creighton Kenneth Reightler, Jr. Charles D. Gemar James F. Buchli Mark N. Brown	5:8:28	Forty-third STS flight. Launched Upper Atmosphere Research Satellite (UARS).

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U.S. and Russian Human Space Flights

1961–September 30, 2003

Spacecraft	Launch Date	Crew	Flight Time (d:h:min)	Highlights
Soyuz TM-13	Oct. 2, 1991	Aleksandr Volkov Toktar Aubakirov Franz Viehboeck	90:16:00	Docked with Mir space station. Crew returned Oct. 10, 1991, with Anatoly Artsebarskiy in the TM-12 spacecraft.
Space Shuttle Atlantis (STS-44)	Nov. 24, 1991	Frederick D. Gregory Tom Henricks Jim Voss F. Story Musgrave Mario Runco, Jr. Tom Hennen	6:22:51	Forty-fourth STS flight. Launched Defense Support Program (DSP) satellite.
Space Shuttle Discovery (STS-42)	Jan. 22, 1992	Ronald J. Grabe Stephen S. Oswald Norman E. Thagard David C. Hilmers William F. Readdy Roberta L. Bondar Ulf Merbold	8:1:15	Forty-fifth STS flight. Carried International Microgravity Laboratory-1 in cargo bay.
Soyuz TM-14	Mar. 17, 1992	Aleksandr Viktorenko Aleksandr Kaleri Klaus-Dietrich Flade	145:15:11	First piloted CIS space mission. Docked with Mir space station on Mar. 19. The TM-13 capsule with Flade, Aleksandr Volkov, and Sergei Krikalev returned to Earth on Mar. 25. Krikalev had been in space 313 d. Viktorenko and Kaleri remained on the Mir space station.
Space Shuttle Atlantis (STS-45)	Mar. 24, 1992	Charles F. Bolden Brian Duffy Kathryn D. Sullivan David C. Leestma Michael Foale Dirk D. Frimout Byron K. Lichtenberg	8:22:9	Forty-sixth STS flight. Carried Atmospheric Laboratory for Applications and Science (ATLAS-1).
Space Shuttle Endeavour (STS-49)	May 7, 1992	Daniel C. Brandenstein Kevin P. Chilton Richard J. Hieb Bruce E. Melnick Pierre J. Thuot Kathryn C. Thornton Thomas D. Akers	8:21:18	Forty-seventh STS flight. Reboosted a crippled INTELSAT VI communications satellite.
Space Shuttle Columbia (STS-50)	June 25, 1992	Richard N. Richards Kenneth D. Bowersox Bonnie Dunbar Ellen Baker Carl Meade Lawrence J. DeLucas Eugene H. Trinh	13:19:30	Forty-eighth STS flight. Carried U.S. Microgravity Laboratory-1.
Soyuz TM-15	July 27, 1992	Anatoly Solovyov Sergei Avdeyev Michel Tognini	189:17:43	Docked with Mir space station July 29. Tognini returned to Earth in TM-14 capsule with Aleksandr Viktorenko and Aleksandr Kaleri. Solovyov and Avdeyev spent over six months in the Mir orbital complex and returned to Earth in the descent vehicle of the TM-15 spacecraft on Feb. 1, 1993.

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U.S. and Russian Human Space Flights

1961–September 30, 2003

Spacecraft	Launch Date	Crew	Flight Time (d:h:min)	Highlights
Space Shuttle Atlantis (STS-46)	July 31, 1992	Loren J. Shriver Andrew M. Allen Claude Nicollier Marsha S. Ivins Jeffrey A. Hoffman Franklin R. Chang-Díaz Franco Malerba	7:23:16	Forty-ninth STS flight. Deployed Tethered Satellite System-1 and Eureca 1.
Space Shuttle Endeavour (STS-47)	Sept. 12, 1992	Robert L. Gibson Curtis L. Brown, Jr. Mark C. Lee Jerome Apt N. Jan Davis Mae C. Jemison Mamoru Mohri	7:22:30	Fiftieth STS flight. Carried Spacelab J. Jemison first African American woman to fly in space. Mohri first Japanese to fly on NASA spacecraft. Lee and Davis first married couple in space together.
Space Shuttle Columbia (STS-52)	Oct. 22, 1992	James D. Wetherbee Michael A. Baker William M. Shepherd Tamara E. Jernigan Charles L. Veach Steven G. MacLean	9:20:57	Fifty-first STS flight. Studied influence of gravity on basic fluid and solidification processes using U.S. Microgravity Payload-1 in an international mission. Deployed second Laser Geodynamics Satellite and Canadian Target Assembly.
Space Shuttle Discovery (STS-53)	Dec. 2, 1992	David M. Walker Robert D. Cabana Guion S. Bluford, Jr. James S. Voss Michael Richard Clifford	7:7:19	Fifty-second STS flight. Deployed the last major DOD classified payload planned for Shuttle (DOD 1) with 10 different secondary payloads.
Space Shuttle Endeavour (STS-54)	Jan. 13, 1993	John H. Casper Donald R. McMonagle Gregory J. Harbaugh Mario Runco, Jr. Susan J. Helms	5:23:39	Fifty-third STS flight. Deployed Tracking and Data Relay Satellite-6. Operated Diffused X-ray Spectrometer Hitchhiker experiment to collect data on stars and galactic gases.
Soyuz TM-16	Jan. 24, 1993	Gennady Manakov Aleksandr Poleschuk	179:0:44	Docked with Mir space station Jan. 26. On July 22, 1993, the TM-16 descent cabin landed back on Earth with Manakov, Poleschuk, and French cosmonaut Jean-Pierre Haignere from Soyuz TM-17 on board.
Space Shuttle Discovery (STS-56)	Apr. 8, 1993	Kenneth D. Cameron Stephen S. Oswald C. Michael Foale Kenneth D. Cockerell Ellen Ochoa	9:6:9	Fifty-fourth STS flight. Completed second flight of Atmospheric Laboratory for Applications and Science and deployed Spartan-201.
Space Shuttle Columbia (STS-55)	Apr. 26, 1993	Steven R. Nagel Terence T. Henricks Jerry L. Ross Charles J. Precourt Bernard A. Harris, Jr. Ulrich Walter Hans W. Schlegel	9:23:39	Fifty-fifth STS flight. Completed second German microgravity research program in Spacelab D-2.
Space Shuttle Endeavour (STS-57)	June 21, 1993	Ronald J. Grabe Brian J. Duffy G. David Low Nancy J. Sherlock Peter J.K. Wisoff Janice E. Voss	9:23:46	Fifty-sixth STS flight. Carried Spacelab commercial payload module and retrieved European Retrievable Carrier, which had been in orbit since Aug. 1992.

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U.S. and Russian Human Space Flights

1961–September 30, 2003

Spacecraft	Launch Date	Crew	Flight Time (d:h:min)	Highlights
Soyuz TM-17	July 1, 1993	Vasiliy Tsibliyev Aleksandr Serebrov Jean-Pierre Haignere	196:17:45	Docked with Mir space station July 3. Haignere returned to Earth with Soyuz TM-16. Serebrov and Tsibliyev landed in TM-17 spacecraft on Jan. 14, 1994.
Space Shuttle Discovery (STS-51)	Sept. 12, 1993	Frank L. Culbertson, Jr. William F. Readdy James H. Newman Daniel W. Bursch Carl E. Walz	9:20:11	Fifty-seventh STS flight. Deployed ACTS satellite to serve as test bed for new communications satellite technology and U.S./German ORFEUS-SPAS.
Space Shuttle Columbia (STS-58)	Oct. 18, 1993	John E. Blaha Richard A. Searfoss Shannon W. Lucid David A. Wolf William S. McArthur Martin J. Fettman M. Rhea Seddon	14:0:29	Fifty-eighth STS flight. Carried Spacelab Life Sciences-2 payload to determine the effects of microgravity on M. Rhea Seddon and animal subjects.
Space Shuttle Endeavour (STS-61)	Dec. 2, 1993	Richard O. Covey Kenneth D. Bowersox Tom Akers Jeffrey A. Hoffman Kathryn C. Thornton Claude Nicollier F. Story Musgrave	10:19:58	Fifty-ninth STS flight. Restored planned scientific capabilities and reliability to the Hubble Space Telescope.
Soyuz TM-18	Jan. 8, 1994	Viktor Afanasyev Yuri Usachev Valery Polyakov	182:0:27	Docked with Mir space station on Jan. 10. Afanasyev and Usachev landed in the TM-18 spacecraft on July 9, 1994. Polyakov remained aboard Mir in the attempt to establish a new record for endurance in space.
Space Shuttle Discovery (STS-60)	Feb. 3, 1994	Charles F. Bolden, Jr. Kenneth S. Reightler, Jr. N. Jan Davis Ronald M. Sega Franklin R. Chang-Díaz Sergei K. Krikalev	8:7:9	Sixtieth STS flight. Carried the Wake Shield Facility to generate new semiconductor films for advanced electronics. Also carried SPACEHAB. Krikalev's presence signified a new era in cooperation in space between Russia and the United States.
Space Shuttle Columbia (STS-62)	Mar. 4, 1994	John H. Casper Andrew M. Allen Pierre J. Thuot Charles D. Gemar Marsha S. Ivins	13:23:17	Sixty-first STS flight. Carried U.S. Microgravity Payload-2 to conduct experiments in materials processing, biotechnology, and other areas.
Space Shuttle Endeavour (STS-59)	Apr. 9, 1994	Sidney M. Gutierrez Kevin P. Chilton Jerome Apt Michael R. Clifford Linda M. Godwin Thomas D. Jones	11:5:50	Sixty-second STS flight. Carried the Space Radar Laboratory-1 to gather data on Earth and on the effects humans have on its carbon, water, and energy cycles.
Soyuz TM-19	July 1, 1994	Yuri I. Malenchenko Talgat A. Musabayev	125:22:53	Docked with Mir space station on July 3. Both Malenchenko and Musabayev returned to Earth with the Soyuz TM-19 spacecraft, landing in Kazakhstan on Nov. 4 with Ulf Merbold of Germany, who went up aboard Soyuz TM-20 on Oct. 3, 1994. Merbold gathered biological samples on the effects of weightlessness on the human body in the first of two ESA missions to Mir to prepare for the International Space Station.

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U.S. and Russian Human Space Flights

1961–September 30, 2003

Spacecraft	Launch Date	Crew	Flight Time (d:h:min)	Highlights
Space Shuttle Columbia (STS-65)	July 8, 1994	Robert D. Cabana James D. Halsell, Jr. Richard J. Hieb Carl E. Walz Leroy Chiao Donald A. Thomas Chiaki Naito-Mukai	14:17:55	Sixty-third STS flight. Carried International Microgravity Laboratory-2 to conduct research into the behavior of materials and life in near-weightlessness.
Space Shuttle Discovery (STS-64)	Sept. 9, 1994	Richard N. Richards L. Blaine Hammond, Jr. J.M. Linenger Susan J. Helms Carl J. Meade Mark C. Lee	10:22:50	Sixty-fourth STS flight. Used LIDAR In-Space Technology Experiment to perform atmospheric research. Included the first untethered spacewalk by astronauts in over 10 years.
Space Shuttle Endeavour (STS-68)	Sept. 30, 1994	Michael A. Baker Terrence W. Wilcutt Thomas D. Jones Steven L. Smith Daniel W. Bursch Peter J. K. Wisoff	11:5:36	Sixty-fifth STS flight. Used Space Radar Laboratory-2 to provide scientists with data to help distinguish human-induced environmental change from other natural forms of change.
Soyuz TM-20	Oct. 3, 1994	Aleksandr Viktorenko Yelena Kondakova Ulf Merbold	*	Soyuz TM-19 returned to Earth on Nov. 4, 1994, with Yuri Malenchenko, Talgat Musabayev, and Ulf Merbold. Valeriy Polyakov remained aboard Mir.
Space Shuttle Atlantis (STS-66)	Nov. 3, 1994	Donald R. McMonagle Curtis L. Brown, Jr. Ellen Ochoa Joseph R. Tanner Jean-François Clervoy Scott E. Parazynski	10:22:34	Sixty-sixth STS flight. Three main payloads: the third Atmospheric Laboratory for Applications and Science (ATLAS-3), the first Cryogenic Infrared Spectrometers and Telescopes for the Atmosphere-Shuttle Pallet Satellite (CRISTA-SPAS-1), and the Shuttle Solar Backscatter Ultraviolet (SSBUV) spectrometer. Astronauts also conducted protein crystal growth experiments.
Space Shuttle Discovery (STS-63)	Feb. 3, 1995	James D. Wetherbee Eileen M. Collins Bernard A. Harris, Jr. C. Michael Foale Janice E. Voss Vladimir G. Titov	8:6:28	Sixty-seventh STS flight. Primary objective: first close encounter in nearly 20 years between American and Russian spacecraft as a prelude to establishment of the International Space Station. (Shuttle flew close by Mir.) Main payloads: SPACEHAB 3 experiments and Shuttle Pointed Autonomous Research Tool for Astronomy (Spartan) 204, Solid Surface Combustion Experiment (SSCE), and Air Force Maui Optical Site (AMOS) Calibration Test. Also launched very small Orbital Debris Radar Calibration Spheres (ODERACS).
Space Shuttle Endeavour (STS-67)	Mar. 2, 1995	Stephen S. Oswald William G. Gregory John M. Grunsfeld Wendy B. Lawrence Tamara E. Jernigan Ronald A. Parise Samuel T. Durrance	16:15:8	Sixty-eighth STS flight. Longest Shuttle mission to date. Primary payload was a trio of ultraviolet telescopes called Astro-2.

* Mir crew members stayed for various and overlapping lengths of time.
** Flew up on Space Shuttle; remained in space aboard Russian Mir space station.
*** Returned to Earth via Space Shuttle from Russian Mir space station.

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U.S. and Russian Human Space Flights

1961–September 30, 2003

Spacecraft	Launch Date	Crew	Flight Time (d:h:min)	Highlights
Soyuz TM-21	Mar. 14, 1995	Vladimir Dezhurov Gennadi Strekalov Norman Thagard	*	Thagard was the first American astronaut to fly on a Russian rocket and to stay on the Mir space station. Soyuz TM-20 returned to Earth on Mar. 22, 1995, with Valeriy Polyakov, Alexsandr Viktorenko, and Yelena Kondakova. Polyakov set world record by remaining in space for 438 days.
Space Shuttle Atlantis (STS-71)	June 27, 1995	Robert L. Gibson Charles J. Precourt Ellen S. Baker Gregory Harbaugh Bonnie J. Dunbar	9:19:22	Sixty-ninth STS flight and 100th U.S. human space flight. Docked with Mir space station. Brought up Mir 19 crew (Anatoly Y. Solovyev and Nikolai M. Budarin). Returned to Earth with Mir 18 crew (Vladimir N. Dezhurov, Gennady M. Strekalov, and Norman Thagard).Thagard set an American record by remaining in space for 115 days.
Space Shuttle Discovery (STS-70)	July 13, 1995	Terence Henricks Kevin R. Kregel Nancy J. Currie Donald A. Thomas Mary Ellen Weber	8:22:20	Seventieth STS flight. Deployed Tracking and Data Relay Satellite (TDRS). Also conducted various biomedical experiments.
Soyuz TM-22	Sept. 3, 1995	Yuri Gidzenko Sergei Avdeev Thomas Reiter	*	Soyuz TM-21 returned to Earth on Sept. 11, 1995, with Mir 19 crew (Anatoliy Solovyev and Nikolay Budarin).
Space Shuttle Endeavour (STS-69)	Sept. 7, 1995	David M. Walker Kenneth D. Cockrell James S. Voss James H. Newman Michael L. Gernhardt	10:20:28	Seventy-first STS flight. Deployed Wake Shield Facility (WSF-2) and Spartan 201-03.
Space Shuttle Columbia (STS-73)	Oct. 20, 1995	Kenneth D. Bowersox Kent V. Rominger Catherine G. Coleman Michael Lopez-Alegria Kathryn C. Thornton Fred W. Leslie Albert Sacco, Jr.	15:21:52	Seventy-second STS flight. Carried out micro-gravity experiments with the U.S. Microgravity Laboratory (USML-2) payload.
Space Shuttle Atlantis (STS-74)	Nov. 12, 1995	Kenneth D. Cameron James D. Halsell, Jr. Chris A. Hadfield Jerry L. Ross William S. McArthur, Jr.	8:4:31	Seventy-third STS flight. Docked with Mir space station as part of International Space Station (ISS) Phase I efforts.
Space Shuttle Endeavour (STS-72)	Jan. 11, 1996	Brian Duffy Brent W. Jett, Jr. Leroy Chiao Winston E. Scott Koichi Wakata Daniel T. Barry	8:22:1	Seventy-fourth STS flight. Deployed OAST Flyer. Retrieved previously launched Japanese Space Flyer Unit satellite. Crew performed spacewalks to build experience for ISS construction.
Soyuz TM-23	Feb. 21, 1996	Yuri Onufrienko Yuri Usachyou	*	Soyuz TM-22 returned to Earth on Feb. 29, 1996, with Mir 20 crew (Yuri Gidzenko, Sergei Avdeev, and Thomas Reiter).

APPENDIX C

(Continued)

U.S. and Russian Human Space Flights

1961–September 30, 2003

Spacecraft	Launch Date	Crew	Flight Time (d:h:min)	Highlights
Space Shuttle Columbia (STS-75)	Feb. 22, 1996	Andrew M. Allen Scott J. Horowitz Jeffrey A. Hoffman Maurizio Cheli Claude Nicollier Franklin R. Chang-Díaz Umberto Guidoni	13:16:14	Seventy-fifth STS flight. Deployed Tethered Satellite System, U.S. Microgravity Payload (USMP-3), and protein crystal growth experiments.
Space Shuttle Atlantis (STS-76)	Mar. 22, 1996	Kevin P. Chilton Richard A. Searfoss Linda M. Godwin Michael R. Clifford Ronald M. Sega Shannon W. Lucid**	9:5:16	Seventy-sixth STS flight. Docked with Mir space station and left astronaut Shannon Lucid aboard Mir. Also carried SPACEHAB module.
Space Shuttle Endeavour (STS-77)	May 19, 1996	John H. Casper Curtis L. Brown Andrew S.W. Thomas Daniel W. Bursch Mario Runco, Jr. Marc Garneau	10:2:30	Seventy-seventh STS flight. Deployed Spartan/Inflatable Antenna Experiment, SPACEHAB, and PAMS-STU payloads.
Space Shuttle Columbia (STS-78)	June 20, 1996	Terrence T. Henricks Kevin Kregel Richard M. Linnehan Susan J. Helms Charles E. Brady, Jr. Jean-Jacques Favier Robert B. Thirsk	16:21:48	Seventy-eighth STS flight. Set Shuttle record for then-longest flight. Carried Life and Microgravity Sciences Spacelab.
Soyuz TM-24	Aug. 17, 1996	Claudie Andre-Deshays Valery Korzun Alexander Kaleri	*	Soyuz TM-23 returned to Earth on Sept. 2, 1996, with Claudie Andre-Deshays, Yuri Onufrienko, and Yuri Usachev.
Space Shuttle Atlantis (STS-79)	Sept. 16, 1996	William F. Readdy Terrence W. Wilcutt Jerome Apt Thomas D. Akers Carl E. Walz John E. Blaha** Shannon W. Lucid***	10:3:19	Seventy-ninth STS flight. Docked with Mir space station. Picked up astronaut Shannon Lucid and dropped off astronaut John Blaha.
Space Shuttle Columbia (STS-80)	Nov. 19, 1996	Kenneth D. Cockrell Kent V. Rominger Tamara E. Jernigan Thomas David Jones F. Story Musgrave	17:15:53	Set record for longest Shuttle flight. At age 61, Musgrave became oldest person to fly in space. He also tied record for most space flights (six) by a single person. Crew successfully deployed ORFEUS-SPAS II ultraviolet observatory and Wake Shield Facility payloads.
Space Shuttle Atlantis (STS-81)	Jan. 12, 1997	Michael A. Baker Brent W. Jett Peter J.K. "Jeff" Wisoff John M. Grunsfeld Marsha S. Ivins Jerry M. Linenger** John E. Blaha***	10:4:56	Fifth Shuttle mission to Mir. Jerry Linenger replaced John Blaha as U.S. resident on Mir.

* Mir crew members stayed for various and overlapping lengths of time.
** Flew up on Space Shuttle; remained in space aboard Russian Mir space station.
*** Returned to Earth via Space Shuttle from Russian Mir space station.

APPENDIX C

(Continued)

U.S. and Russian Human Space Flights

1961–September 30, 2003

Spacecraft	Launch Date	Crew	Flight Time (d:h:min)	Highlights
Soyuz TM-25	Feb. 10, 1997	Vasily Tsibliev Aleksandr Lazutkin Reinhold Ewald	*	Soyuz TM-24 returned to Earth on Mar. 2, 1997, with Reinhold Ewald, Valery Korzun, and Aleksandr Kaleri.
Space Shuttle Discovery (STS-82)	Feb. 11, 1997	Kenneth D. Bowersox Scott J. Horowitz Joseph R. Tanner Steven A. Hawley Gregory J. Harbaugh Mark C. Lee Steven L. Smith	9:23:36	Crew successfully performed second servicing mission of the Hubble Space Telescope.
Space Shuttle Columbia (STS-83)	Apr. 4, 1997	James D. Halsell, Jr. Susan L. Still Janice Voss Michael L. Gernhardt Donald A. Thomas Roger K. Crouch Gregory T. Linteris	3:23:34	Crew deployed a Spacelab module configured as the first Microgravity Science Laboratory. Shuttle fuel cell malfunction necessitated an early termination of the mission.
Space Shuttle Atlantis (STS-84)	May 15, 1997	Charles J. Precourt Eileen Marie Collins Jean-François Clervoy Carlos I. Noriega Edward Tsang Lu Elena V. Kondakova Michael Foale** Jerry M. Linenger***	9:5:21	Sixth Shuttle mission to Mir. Michael Foale replaced Jerry Linenger on Mir.
Space Shuttle Columbia (STS-94)	July 1, 1997	James D. Halsell, Jr. Susan L. Still Janice Voss Michael L. Gernhardt Donald A. Thomas Roger K. Crouch Gregory T. Linteris	15:16:45	Reflight of STS-83 and the same payload, the Microgravity Science Laboratory. Mission proceeded successfully.
Soyuz TM-26	Aug. 5, 1997	Anatoly Solovyev Pavel Vinogradov	*	Soyuz TM-25 returned to Earth on August 14, 1997, with Vasily Tsibliev and Aleksandr Lazutkin.
Space Shuttle Discovery (STS-85)	Aug. 7, 1997	Curtis L. Brown, Jr. Kent V. Rominger N. Jan Davis Robert L. Curbeam, Jr. Stephen K. Robinson Bjarni V. Tryggvason	11:20:27	Crew successfully deployed two payloads: CRISTA-SPAS-2 on infrared radiation and an international Hitchhiker package of four experiments on ultraviolet radiation. The crew also successfully performed the Japanese Manipulator Flight Demonstration of a robotic arm.
Space Shuttle Atlantis (STS-86)	Sept. 25, 1997	James D. Wetherbee Michael J. Bloomfield Scott E. Parazynski Vladimir Titov Jean-Loup Chrétien Wendy B. Lawrence David A. Wolf** C. Michael Foale***	10:19:21	Seventh Shuttle docking with Mir. David Wolf replaced Michael Foale on Mir. Parazynski and Titov performed a spacewalk to retrieve four Mir Environmental Effects Payload experiments from the exterior of the docking module and left a solar array cover cap for possible future repair of the damaged Spektr module.

APPENDIX C

(Continued)

U.S. and Russian Human Space Flights

1961–September 30, 2003

Spacecraft	Launch Date	Crew	Flight Time (d:h:min)	Highlights
Space Shuttle Columbia (STS-87)	Nov. 19, 1997	Kevin R. Kregel Steven W. Lindsey Kalpana Chawla Winston E. Scott Takao Doi Leonid K. Kadenyuk	15:16:34	Payloads included USMP-4, Spartan 201-04 free-flyer, Collaborative Ukrainian Experiment (CUE) in space biology, and several other "hitchhiker" payloads.
Space Shuttle Endeavour (STS-89)	Jan. 22, 1998	Terrence W. Wilcutt Joe F. Edwards, Jr. James F. Reilly II Michael P. Anderson Bonnie J. Dunbar Salizhan S. Sharipov Andrew S. Thomas** David A. Wolf***	8:19:47	Eighth Shuttle docking mission to Mir. Andrew Thomas replaced David Wolf on Mir. Shuttle payloads included SPACEHAB double module of science experiments.
Soyuz TM-27	Jan. 29, 1998	Talgat Musabayev Nikolai Budarin Leopold Eyharts	*	Soyuz TM-26 left Mir and returned to Earth on Feb. 19 with Anatoly Solovyev, Pavel Vinogradov, and Leopold Eyharts.
Space Shuttle Columbia (STS-90)	Apr. 17, 1998	Richard A. Searfoss Scott D. Altman Richard M. Linnehan Kathryn P. Hire Dafydd Rhys Williams Jay Clark Buckey, Jr. James A. Pawelczyk	15:21:50	Carried Neurolab module for microgravity research in the human nervous system. Secondary goals included measurement of Shuttle vibration forces, demonstration of the bioreactor system for cell growth, and three Get Away Special payloads.
Space Shuttle Discovery (STS-91)	June 2, 1998	Charles J. Precourt Dominic L. Pudwill Gorie Franklin R. Chang-Díaz Wendy B. Lawrence Janet Lynn Kavandi Valery V. Ryumin Andrew S. Thomas***	9:19:48	Last of nine docking missions with Mir, this one brought home Andrew Thomas. Payloads included DOE's Alpha Magnetic Spectrometer to study high-energy particles from deep space, four Get Away Specials, and two Space Experiment Modules.
Soyuz TM-28	Aug. 13, 1998	Gennady Padalka Sergei Avdeev Yuri Baturin	*	Docked to Mir using manual backup system because of prior failure of one of two automatic systems. Soyuz TM-27 left Mir and returned to Earth with Talgat Musabayev, Nikolai Budarin, and Yuri Baturin.
Space Shuttle Discovery (STS-95)	Oct. 29, 1998	Curtis L. Brown, Jr. Steven W. Lindsey Scott E. Parazynski Stephen K. Robinson Pedro Duque Chiaki Mukai John H. Glenn	8:21:44	Payloads included a SPACEHAB pressurized module, the Pansat communications amateur satellite, and the Spartan 201-05 solar observatory. Performed biomedical experiments on space flight and aging. Second flight of John Glenn.
Space Shuttle Endeavour (STS-88)	Dec. 4, 1998	Robert D. Cabana Frederick W. Sturckow James H. Newman Nancy J. Currie Jerry L. Ross Sergei K. Krikalev	11:19:18	Payloads included Unity (Node 1), the first U.S. module of the ISS, as well as SAC-A and Mightysat 1.
Soyuz TM-29	Feb. 20, 1999	Viktor Afanasyev Jean-Pierre Haignere Ivan Bella	*	Soyuz mission to Mir.

* Mir crew members stayed for various and overlapping lengths of time.
** Flew up on Space Shuttle; remained in space aboard Russian Mir space station.
*** Returned to Earth via Space Shuttle from Russian Mir space station.

APPENDIX C

(Continued)

U.S. and Russian Human Space Flights

1961–September 30, 2003

Spacecraft	Launch Date	Crew	Flight Time (d:h:min)	Highlights
Space Shuttle Discovery (STS-96)	May 27, 1999	Kent V. Rominger Rick D. Husband Daniel T. Barry Valery I. Tokarev Ellen Ochoa Julie Payette Tamara E. Jernigan	9:19:13	ISS supply and repair mission; also launched the Starshine student passive reflector satellite.
Space Shuttle Columbia (STS-93)	July 23, 1999	Eileen M. Collins Jeffrey S. Ashby Michel Tognini Steven A. Hawley Catherine G. Coleman	4:22:50	Deployed Chandra X-Ray Observatory. Collins was first female commander of a Shuttle mission.
Space Shuttle Discovery (STS-103)	Dec. 19, 1999	Curtis L. Brown Scott J. Kelly Steven L. Smith C. Michael Foale John M. Grunsfeld Claude Nicollier Jean-Francois Clervoy	7:23:11	Third Hubble Space Telescope servicing mission.
Space Shuttle Endeavour (STS-99)	Feb. 11, 2000	Kevin Kregel Dominic Gorie Gerhard P.J. Thiele Janet Kavandi Janice Voss Mamoru Mohri	11:5:38	Shuttle Radar Topography Mission (SRTM). The main objective of STS-99 was to obtain the most complete high-resolution digital topographic database of Earth, using a special radar system.
Soyuz TM-30	Apr. 4, 2000	Sergei Zalyotin Alexander Kaleri	72:19:43	Final Soyuz mission to Mir.
Space Shuttle Atlantis (STS-101)	May 19, 2000	James Halsell, Jr. Scott Horowitz Susan Helms Yury V. Usachev James Voss Mary Ellen Weber Jeff Williams	9:20:9	Second crew visit to the International Space Station (ISS) (2A.2a) to deliver supplies, perform maintenance, and reboost its orbit.
Space Shuttle Atlantis (STS-106)	Sept. 8, 2000	Terrence Wilcutt Scott Altman Daniel Burbank Edward T. Lu Yuri I. Malenchenko Rick Mastracchio Boris V. Morukov	11:19:11	Third logistics/outfitting flight to ISS (2A.2b) to prepare the station for its first resident crew.
Space Shuttle Discovery (STS-92)	Oct. 11, 2000	Brian Duffy Pamela A. Melroy Leroy Chiao William S. McArthur Peter J.K. Wisoff Michael E. Lopez-Alegria Koichi Wakata	12:21:43	Discovery's was the 100th mission in the Shuttle program's history. ISS assembly mission.
Soyuz TM-31	Oct. 31, 2000	William Shepherd Yuri Gidzenko Sergei Krikalev	136:17:9	Launch of first resident crew (Expedition 1) to the ISS.
Space Shuttle Endeavour (STS-97)	Nov. 30, 2000	Brent W. Jett Michael J. Bloomfield Joseph R. Tanner Marc Garneau Carlos I. Noriega	10:19:58	Mission to the ISS.

U.S. and Russian Human Space Flights
1961–September 30, 2003

Spacecraft	Launch Date	Crew	Flight Time (d:h:min)	Highlights
Space Shuttle Atlantis (STS-98)	Feb. 7, 2001	Kenneth D. Cockrell Mark L. Polansky Robert L. Curbeam Marsha S. Ivins Thomas D. Jones	12:21:20	Delivered U.S. Laboratory module Destiny to the ISS.
Space Shuttle Discovery (STS-102)	Mar. 8, 2001	James D. Wetherbee James M. Kelly Andrew S.W. Thomas Paul W. Richards James S. Voss (up) Susan J. Helms (up) Yuri V. Usachev (up) William Shepherd (down) Yuri P. Gidzenko (down) Sergei Krikalev (down)	12:19:49	Delivered Expedition 2 crew to the ISS and returned the Expedition 1 crew to Earth.
Space Shuttle Endeavour (STS-100)	Apr. 19, 2001	Kent V. Rominger Jeffrey S. Ashby Chris A. Hadfield John L. Phillips Scott E. Parazynski Umberto Guidoni Yuri V. Lonchakov	11:21:30	Mission to the ISS.
Soyuz TM-32	Apr. 28, 2001	Talgat A. Musabaev Yuri M. Baturin Dennis Tito	7:22:4	Launch of the first "taxi" flight to the ISS, bringing a "fresh" Soyuz crew return vehicle for the ISS crew. This mission also carried the first commercial space tourist, U.S. businessman Dennis Tito.
Space Shuttle Atlantis (STS-104)	July 12, 2001	Steven W. Lindsey Charles O. Hobaugh Michael L. Gernhardt Janet L. Kavandi James F. Reilly	12:18:35	Mission to the ISS.
Space Shuttle Discovery (STS-105)	Aug. 10, 2001	Scott J. Horowitz Frederick W. Sturckow Patrick G. Forrester Daniel T. Barry Frank L. Culbertson (up) Vladimir N. Dezhurov (up) Mikhail Tyurin (up) Yury V. Usachev (down) James S. Voss (down) Susan J. Helms (down)	11:21:13	Returned the Expedition 2 crew to Earth.
Soyuz TM-33	Oct. 21, 2001	Victor M. Afanasyez Konstantin M. Kozeev Claudie Haigneré	9:18:58	Launch of the second "taxi" flight to the ISS, bringing a "fresh" Soyuz crew return vehicle for the ISS crew. Crew returned 8 d later on older Soyuz TM-32.
Space Shuttle Endeavour (STS-108)	Dec. 5, 2001	Dominic L. Gorie Mark E. Kelly Linda M. Godwin Daniel M. Tani Yuri I. Onufrienko (up) Carl E. Walz (up) Daniel W. Bursch (up) Frank L. Culbertson (down) Mikhail Turin (down) Vladimir N. Dezhurov (down)	11:19:36	Delivered Expedition 4 crew to the ISS. Returned Expedition 3 crew to Earth.

APPENDIX C

(Continued)

U.S. and Russian Human Space Flights

1961–September 30, 2003

Spacecraft	Launch Date	Crew	Flight Time (d:h:min)	Highlights
Space Shuttle Columbia (STS-109)	Mar. 1, 2002	Scott D. Altman Duane G. Carey John M. Grunsfeld Nancy J. Currie James H. Newman Richard M. Linnehan Michael J. Massimino	10:22:11	Fourth Hubble Space Telescope servicing mission.
Space Shuttle Atlantis (STS-110)	Apr. 8, 2002	Michael J. Bloomfield Stephen N. Frick Jerry L. Ross Steven L. Smith Ellen Ochoa Lee M.E. Morin Rex J. Walheim	10:19:43	Thirteenth ISS flight. Installation of the S0 (S-Zero) Truss. Jerry Ross became the first human to fly in space seven times.
Soyuz TM-34	Apr. 25, 2002	Yuri Gidzenko Roberto Vittori Mark Shuttleworth	9:21:25	Launch of the third "taxi" flight to the ISS, bringing a "fresh" Soyuz crew return vehicle for the ISS crew. Crew returned 8 d later on older Soyuz TM-33. This mission also carried the second commercial space tourist, Mark Shuttleworth.
Space Shuttle Endeavour (STS-111)	June 5, 2002	Kenneth Cockrell Paul Lockhart Franklin Chang-Diaz Philippe Perrin Valeri Korzun (up) Peggy Whitson (up) Sergei Treschev (up) Yuri Onufriyenko (down) Carl E. Walz (down) Daniel W. Bursch (down)	13:20:35	Delivered Expedition 5 crew to ISS. Returned Expedition 4 crew to Earth.
Space Shuttle Atlantis (STS-112)	Oct. 7, 2002	Jeff Ashby Pam Melroy Sandy Magnus Piers Sellers David Wolf Fyodor Yurchikhin	10:19:58	Delivered S1 Truss segment to the ISS.
Soyuz TMA-1	Oct. 30, 2002	Sergei Zalyotin Yuri Lonchakov Frank Dewinne	10:20:53	Launch of fourth Soyuz "taxi" flight, bringing a "fresh" Soyuz crew return vehicle for the ISS crew.
Space Shuttle Endeavour (STS-113)	Nov. 25, 2002	Jim Wetherbee Paul Lockhart John Herrington Michael Lopez-Alegria Ken Bowersox (up) Don Pettit (up) Nikolai Budarin (up) Valery Korzun (down) Sergei Treschev (down) Peggy Whitson (down)	13:18:47	Delivered Expedition 6 crew to ISS. Returned Expedition 5 crew to Earth. Also delivered the P1 Truss segment to the ISS. Expedition 6 crew returned on May 3, 2003, on Soyuz TMA-1.

APPENDIX C
(Continued)

U.S. and Russian Human Space Flights

1961–September 30, 2003

Spacecraft	Launch Date	Crew	Flight Time (d:h:min)	Highlights
Space Shuttle Columbia (STS-107)	Jan. 16, 2003	Rick Husband William McCool Michael Anderson Dave Brown Kalpana Chawla Laurel Clark Ilan Ramon	15:22:20	Science mission with 80 microgravity experiments. Foam strike on left wing's Reinforced Carbon Carbon panel during launch was responsible for Columbia's breakup during reentry, resulting in the loss of both orbiter and crew.
Soyuz TMA-2	Apr. 25, 2003	Yuri Malenchenko Ed Lu	184:21:47	Launch of Expedition 7 crew.

U.S. Space Launch Vehicles

Vehicle	Stages: Engine/Motor	Propellant[a]	Thrust (kilonewtons)[b, c]	Max. Dia. x Height (m)	Max. Payload (kg)[d] 185-km Orbit	Geosynch. Transfer Orbit	Sun-Synch. Orbit[e]	First Launch[f]
Pegasus				6.71x15.5[h]	380 280[e]	—	210	1990
	1. Orion 50S	Solid	484.9	1.28x8.88				
	2. Orion 50	Solid	118.2	1.28x2.66				
	3. Orion 38	Solid	31.9	0.97x1.34				
Pegasus XL				6.71x16.93	460	—	335	1994[g]
	1. Orion 50S-XL	Solid	743.3	1.28x10.29	350[e]			
	2. Orion 50-XL	Solid	201.5	1.28x3.58				
	3. Orion 38	Solid	31.9	0.97x1.34				
Taurus				2.34x28.3	1,400	255	1,020	1994
	0. Castor 120	Solid	1,687.7	2.34x11.86	1,080[e]			
	1. Orion 50S	Solid	580.5	1.28x8.88				
	2. Orion 50	Solid	138.6	1.28x2.66				
	3. Orion 38	Solid	31.9	0.97x1.34				
Delta II (7920, 7925) Delta-7925				2.44x29.70	5,089	1,842[i]	3,175 3,890[e]	1990,
	1. RS-270/A	LOX/RP-1	1,043.0 (SL)	3.05x38.1				[1960, Delta]
	Hercules GEM (9)	Solid	487.6 (SL)	1.01x12.95				
	2. AJ10-118K	N204/A-50	42.4	2.44x5.97				
	3. Star 48B[j]	Solid	66.4	1.25x2.04				
Atlas E				3.05x28.1	820[e] 1,860[e, k]	—	910[k]	1968, Atlas F [1958, Atlas LV-3A]
	1. Atlas: MA-3	LOX/RP-1	1,739.5 (SL)	3.05x21.3				
Atlas I				4.2x43.9	—	2,255	—	1990, I [1966, Atlas-Centaur]
	1. Atlas: MA-5	LOX/RP-1	1,952.0 (SL)	3.05x22.16				
	2. Centaur I: RL10A-3-3A (2)	LOX/LH_2	73.4/engine	3.05x9.14				
Atlas II				4.2x47.5	6,580 5,510[e]	2,810	4,300	1991, II [1966, Atlas-Centaur]
	1. Atlas: MA-5A	LOX/RP-1	2,110.0 (SL)	3.05x24.9				
	2. Centaur II: RL10A-3-3A (2)	LOX/LH_2	73.4/engine	3.05x10.05				
Atlas IIA				4.2x47.5	6,828 6,170[e]	3,062	4,750	1992, Atlas IIA [1966, Atlas-Centaur]
	1. Atlas: MA-5A	LOX/RP-1	2,110.0 (SL)	3.05x24.9				
	2. Centaur II: RL10A-4 (2)	LOX/LH_2	92.53/engine	3.05x10.05				
Atlas IIAS				4.2x47.5	8,640 7,300[e]	3,606	5,800	1993, IIAS [1966, Atlas-Centaur]
	1. Atlas: MA-5A	LOX/RP-1	2,110.0 (SL)	3.05x24.9				
	Castor IVA (4)[j]	Solid	433.6 (SL)	1.01x11.16				
	2. Centaur II: RL10A-4 (2)	LOX/LH_2	92.53/engine	3.05x10.05				

Appendix D

(Continued)

U.S. Space Launch Vehicles

Vehicle	Stages: Engine/Motor	Propellant[a]	Thrust (kilonewtons)[b, c]	Max. Dia. x Height (m)	Max. Payload (kg)[d]: 185-km Orbit	Max. Payload (kg)[d]: Geosynch. Transfer Orbit	Max. Payload (kg)[d]: Sun-Synch. Orbit[e]	First Launch[f]
Athena								
	1. Athena	Solid	1,450	2.36x19.8	520	245		1995
Titan II				3.05x42.9	1,905[e]	—	—	1988, Titan II SLV [1964, Titan II Gemini]
	1. LR-87-AJ-5 (2)	N204/A-50	1,045.0	3.05x21.5				
	2. LR-91-AJ-5	N204/A-50	440.0	3.05x12.2				
Titan III				3.05x47.3	14,515	5,000[l]	—	1989, Titan III [1964, Titan IIIA]
	0. Titan III SRM (2) (5$\frac{1}{2}$ segments)	Solid	6,210.0	3.11x27.6				
	1. LR87-AJ-11 (2)	N204/A-50	1,214.5	3.05x24.0				
	2. LR91-AJ-11	N204/A-50	462.8	3.05x10.0				
Titan IV				3.05x62.2	17,700	6,350[m]	—	1989, Titan IV
	0. Titan IV SRM (2) (7 segments)	Solid	7,000.0	3.11x34.1	14,110[e]			
	1. LR87-AJ-11 (2)	N204/A-50	1,214.5	3.05x26.4				
	2. LR91-AJ-11	N204/A-50	462.8	3.05x10.0				
Titan IV				4.3x62.2	—	5,760[a]	—	1994, Titan IV Centaur
	0. Titan IV SRM (2) (7 segments)	Solid	7,000.0	3.11x34.1				
	1. LR87-AJ-11 (2)	N204/A-50	1,214.5/engine	3.05x26.4				
	2. LR91-AJ-11(1)	N204/A-50	462.5	3.05x10.0				
	3. Centaur: RL-10A-3-3A	LOX/LH_2	73.4	4.3x9.0				
	4. SRMU (3 segments)		7,690	3.3x34.3				
Space Shuttle[n]				23.79x56.14[h]	24,900[o]	5,900[p]	—	1981, Columbia
	1. SRB: Shuttle SRB (2)	Solid	11,790.0 (SL)	3.70x45.46				
	2. Orbiter/ET: SSME (3)	LOX/LH_2	1,668.7 (SL)	8.41x47.00 (ET) 23.79x37.24[h] (orbiter)				
	3. Orbiter/OMS: OMS engines (2)	N_2O_4/MMH	26.7	23.79x37.24[h]				
Delta III								
	1. RS-27A	LOX/RP-1	1,043.0 (SL)	4x39.1	8,292	3,810	6,768	1998[g]
	Alliant GEM (9)	Solid	608.8	1.16x14.7				
	2. RL-10B-2	LOX/LH_2	110	4x8.8				
	3. Star 48B	Solid	66.4	1.25x2.04				

APPENDIX D

(Continued)

U.S. Space Launch Vehicles

NOTES:

a. Propellant abbreviations used are as follows:
A-50 = Aerozine 50 (50% Monomethyl Hydrazine, 50% Unsymmetrical Dimethyl Hydrazine)
RP-1 = Rocket Propellant 1 (kerosene)
Solid = Solid Propellant (any type)
LH_2 = Liquid Hydrogen
LOX = Liquid Oxygen
MMH = Monomethyl Hydrazine
N_2O_4 = Nitrogen Tetroxide

b. Thrust at vacuum except where indicated at sea level (SL).

c. Thrust per engine. Multiply by number of engines for thrust per stage.

d. Inclination of 28.5° except where indicated.

e. Polar launch from Vandenberg AFB, CA.

f. First successful orbital launch [ditto of initial version].

g. First launch was a failure.

h. Diameter dimension represents vehicle wingspan.

i. Applies to Delta II-7925 version only.

j. Two Castor IVA motors ignited at liftoff. Two Castor IVA motors ignited at approximately 57 seconds into flight.

k. With TE-M-364-4 upper stage.

l. With Transfer Orbit Stage.

m. With appropriate upper stage.

n. Space Shuttle Solid Rocket Boosters fire in parallel with the Space Shuttle Main Engines (SSME), which are mounted on the aft end of the Shuttle Orbiter Vehicle and burn fuel, as well as oxidizer from the External Tank. The boosters stage first, with SSMEs continuing to fire. The External Tank stages next, just before the orbiter attains orbit. The Orbiter Maneuvering Subsystem is then used to maneuver or change the orbit of the Orbiter Vehicle.

o. 204-km circular orbit.

p. With Inertial Upper Stage or Transfer Orbit Stage.

***NOTE:* Data should not be used for detailed NASA mission planning without concurrence of the Director of Space Transportation System Support Programs.**

APPENDIX E-1A

Space Activities of the U.S. Government

HISTORICAL BUDGET SUMMARY—BUDGET AUTHORITY
(in millions of real-year dollars)

FY	NASA Total	NASA Space[b]	DOD	Other[c]	DOE[d]	DOC	DOI	USDA	NSF[a]	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	1,196	169	644	74	31	266	12	30,807
2003	15,364	14,360	19,388	1,305	191	649	74	42	337	12	35,053

a. NSF has recalculated its space expenditures since 1980, making them significantly higher than reported in previous years.
b. Includes $2.1 billion for replacement of Space Shuttle Challenger in 1987.
c. Other column is the total of the non-NASA, non-DOD budget authority figures that appear in 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).
d. DOE has recalculated its space expenditures since 1998, making them slightly different.

SOURCE: Office of Management and Budget

* Transition Quarter

APPENDIX E-1B

Space Activities of the U.S. Government

BUDGET AUTHORITY IN MILLIONS OF EQUIVALENT FY 2003 DOLLARS
(adjusted for inflation)

FY	Inflation Factors	NASA Total	NASA Space[b]	DOD	Other[c]	DOE[d]	DOC	DOI	USDA	NSF[a]	DOT	Total Space
1959	5.1487	1,704	1,344	2,523	175	175						4,042
1960	5.0663	2,655	2,341	2,842	218	218				0		5,401
1961	5.0090	4,829	4,638	4,077	341	341						9,056
1962	4.9398	9,015	8,877	6,412	983	731	252					16,272
1963	4.8854	17,944	17,714	7,572	1,256	1,045	210					26,542
1964	4.8216	24,590	24,185	7,710	1,027	1,013	14					32,922
1965	4.7656	25,019	24,486	7,501	1,149	1,091	57					33,135
1966	4.6830	24,235	23,719	7,910	1,002	876	126					32,631
1967	4.5842	22,765	22,142	7,628	976	843	133					30,746
1968	4.4427	20,379	19,681	8,539	774	644	124	0.9	4			28,994
1969	4.2879	17,113	16,388	8,632	731	506	86	0.9	4	134		25,750
1970	4.1022	15,367	14,551	6,883	578	423	33	4	4	115		22,012
1971	3.8891	12,877	12,060	5,880	630	369	105	8	4	144		18,570
1972	3.7032	12,246	11,373	5,210	494	204	115	22	7	146		17,077
1973	3.5377	12,049	10,942	5,742	521	191	142	35	7	146		17,205
1974	3.3873	10,287	9,346	5,982	535	142	203	30	10	149		15,863
1975	3.1621	10,210	9,218	5,983	499	95	202	25	6	170		15,699
1976	2.8653	10,172	9,241	5,682	482	66	206	29	11	170		15,405
TQ*	2.6763	2,494	2,272	1,231	115	13	59	8	3	32		3,618
1977	2.5942	9,905	8,924	6,257	502	57	236	26	16	167		15,683
1978	2.4893	10,107	9,019	6,816	563	85	256	25	20	177		16,397
1979	2.3297	10,707	9,389	7,073	578	137	228	23	19	170		17,039
1980	2.1548	11,291	10,084	8,292	498	86	200	26	30	155		18,874
1981	1.9789	10,920	9,879	9,554	464	81	172	24	32	155		19,896
1982	1.8040	10,903	9,973	12,049	564	110	262	22	27	144		22,586
1983	1.6859	11,591	10,668	15,205	551	66	300	8	34	143		26,425
1984	1.6149	12,044	11,075	16,464	637	55	381	5	31	166		28,176
1985	1.5575	11,795	10,786	19,886	909	53	659	3	23	171		31,581
1986	1.5077	11,771	10,803	21,298	719	53	466	3	35	162		32,819
1987	1.4722	16,081	14,441	23,978	686	71	409	12	28	165	1	39,104
1988	1.4328	12,984	11,924	25,330	1,062	345	504	20	26	165	1	38,316
1989	1.3874	15,218	14,009	24,843	777	135	418	24	29	168	4	39,628
1990	1.3361	16,466	15,312	20,865	676	106	325	41	33	165	5	36,852
1991	1.2876	18,047	16,798	18,259	994	323	323	37	33	272	5	36,052
1992	1.2394	17,744	16,359	18,620	989	276	405	42	36	224	5	35,967
1993	1.2078	17,284	15,779	17,037	883	199	391	40	30	217	5	33,699
1994	1.1796	17,187	15,361	15,531	746	87	368	37	37	212	6	31,637
1995	1.1546	15,996	14,482	12,290	876	69	406	36	37	321	7	27,648
1996	1.1302	15,692	14,205	13,013	936	52	533	41	42	261	7	28,154
1997	1.1080	15,190	13,802	12,994	875	39	496	47	43	243	7	27,671
1998	1.0868	14,833	13,390	13,432	912	112	473	47	42	232	7	27,735
1999	1.0717	14,632	13,352	14,150	1,052	113	616	63	40	214	6	28,554
2000	1.0576	14,384	13,242	13,686	1,116	173	608	63	47	219	6	28,045
2001	1.0376	14,765	13,804	14,865	1,102	150	599	62	37	241	12	29,771
2002	1.0128	15,058	14,049	15,941	1,211	171	652	75	31	269	12	31,201
2003	1	15,364	14,360	19,388	1,305	191	649	74	42	337	12	35,053

a. NSF has recalculated its space expenditures since 1980, making them significantly higher than reported in previous years.
b. Includes $2.1 billion for replacement of Space Shuttle Challenger in 1987.
c. Other column is the total of the non-NASA, non-DOD budget authority figures that appear in 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).
d. DOE has recalculated its space expenditures since 1998, making them slightly different.

SOURCE: Office of Management and Budget

* Transition Quarter

APPENDIX E-2

Federal Space Activities Budget

(in millions of dollars by fiscal year)

Federal Agencies	Budget Authority				Budget Outlays	
	2002 Actual	2003 Actual	2004 Est.	2005 Est.	2002 Actual	2003 Actual
NASA[1]	13,871	14,360	14,317	15,297	13,449	13,553
Defense	15,740	19,388	20,019	21,677	14,906	18,612
Energy	169	191	198	195	170	191
Commerce	644	649	761	829	579	579
Interior[2]	74	74	73	74	74	74
Agriculture	31	42	48	55	31	39
Transportation	12	12	12	12	12	12
NSF[3]	266	337	369	354	244	256

1. NASA's totals do not include the Office of Inspector General's budget.
2. Beginning in 2003, DOI is reporting the U.S. Geological Survey's digital orthoimagery program within its totals.
3. Beginning in 2003, NSF is reporting the Antarctic aeronomy and astrophysics program budget within its totals.

SOURCE: Office of Management and Budget

APPENDIX E-3

Federal Aeronautics Budget

(in millions of dollars by fiscal year)

Federal Agencies	Budget Authority				Budget Outlays	
	2002 Actual	2003 Actual	2004 Est.	2005 Est.	2002 Actual	2003 Actual
NASA[1]	997	1,004	1,034	919	956	974
Defense	6,995	9,432	10,505	10,470	6,655	8,314
Transportation	2,940	2,924	3,004	2,601	2,799	2,839

1. NASA's totals do not include the Office of Inspector General's budget.

ACRONYMS

A

AE	acoustic emission
AFB	Air Force Base
AFRL	Air Force Research Laboratory
AGS	Alternating Gradient Synchrotron
AIRDAS	Airborne InfraRed Disaster Assessment System
AIRS	Atmospheric Infrared Sounder
ALI	Advanced Land Imager
AML	Abandoned Mine Land
AMS	Alpha Magnetic Spectrometer
AMSU	Advanced Microwave Sounding Unit
ARC	Ames Research Center
ARM	Atmospheric Radiation Measurement
ART	Assisted Resolution Tool
ARTCC	Air Traffic Control Center
ARTWG	Advanced Range Technology Working Group
ASEB	Aeronautics and Space Engineering Board
AST	FAA Office of the Associate Administrator for Commercial Space Transportation
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ASTRA	Advanced Systems, Technologies, Research, and Analysis
ATAG	Air Transportation Advisory Group
ATCA	Agreement on Trade in Civil Aircraft
ATMS	Advanced Technology Microwave Sounder
ATP	Advanced Technology Program
AVHRR	Advanced Very High Resolution Radiometer
AVIRIS	Airborne Visible/Infrared Imaging Spectrometer
AWACS	Airborne Warning and Control System

B

BIA	Bureau of Indian Affairs
BLM	Bureau of Land Management
BNL	Brookhaven National Laboratory
BOR	Bureau of Reclamation
BPRE	Biological and Physical Research Enterprise
BSU	Boise State University

C

C3	Command, Control, and Communication
CAASD	Center for Advanced Aviation System Development (MITRE)
CAC	Civil Applications Committee
CAIB	Columbia Accident Investigation Board
CAMI	Civil Aerospace Medical Institute
CEOS	Committee on Earth Observation Satellites
CEPS	Center for Earth & Planetary Studies

CHIPS	Cosmic Hot Interstellar Plasma Spectrometer
CIA	Central Intelligence Agency
CME	coronal mass ejection
CNN	Cable News Network
CoDR	Conceptual Design Review
CONUS	continental United States
CORS	Continuously Operating Reference Stations
CrIS	Cross-track Infrared Sounder
CRSSP	Commercial Remote Sensing Space Policy
CSREES	Cooperative State Research, Education, and Extension Service
CTAS	Center-TRACON Automation System

D

DART	Demonstration of Autonomous Rendezvous Technology
DBS	Direct Broadcast Satellites
DC	direct current; District of Columbia
DCR	Design Certification Review
DDR&E	Defense Research and Engineering
DEM	digital elevation model
DHS	Department of Homeland Security
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DOI	Department of the Interior
DOQ	digital orthophoto quadrangle
DOS	Department of State
DOT	Department of Transportation
DSR	Dynamic Source Routing

E

ECLSS	Environmental Control and Life Support System
ECO	Emergency on-Call Officer
EDA	En Route Descent Advisor
EO-1	Earth Observing-1
EOS	Earth Observing System; Earth Observation Satellite
EROS	Earth Resources Observation Systems
ESE	Earth Science Enterprise
ETM+	Enhanced Thematic Mapper Plus
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites

F

FAA	Federal Aviation Administration
FAS	Foreign Agricultural Service
FBI	Federal Bureau of Investigation
FCC	Federal Communications Commission
FS	Forest Service (USDA)
FSA	Farm Service Agency
FTAG	Federal Transportation Advisory Group

FTD	**flight training device**
FY	**Fiscal Year**

G

GALEX	**Galaxy Evolution Explorer**
GIS	**Geographic Information Systems; Geospatial Information System**
GLOBE	**Global Learning and Observations to Benefit the Environment (long form not really used any more but still correct)**
GloVis	**Global Visualization**
GNSS	**Global Navigation Satellite Systems**
GOES	**Geostationary Operational Environmental Satellites**
GP	**Gunn-Peterson**
GPS	**Global Positioning System**
GRACE	**Gravity Recovery And Climate Experiment**
GRC	**Glenn Research Center**
GSFC	**Goddard Space Flight Center**
GSO	**geosynchronous orbit**
GTE	**ground test engine**
GWRP	**Ground-Water Research Program**

H

HFACS	**Human Factors Analysis and Classification System**
HiRISE	**High Resolution Imaging Science Experiment**
HST	**Hubble Space Telescope**

I

IADCR	**Integrated Aircraft Data Collection and Reporting**
ICESat	**Ice, Cloud and Land Elevation Satellite**
IGEB	**Interagency GPS Executive Board**
IGOS	**Integrated Global Observing Strategy**
IHPRPT	**Integrated High Payoff Rocket Propulsion Technology**
InSPACE	**Investigating the Structure of Paramagnetic Aggregates from Colloidal Emulsions**
IPO	**Integrated Program Office (NPOESS)**
ISM	**Interstellar Medium**
ISOON	**Improved Solar Observing Optical Network**
ISS	**International Space Station**
ISTAR	**Integrated Systems Test of an Air-breathing Rocket**
ITA	**International Trade Administration**
ITP	**Integrated Technology Plan**

J

JBOSC	**Joint Base Operating Support Contract**
JMA	**Japan Meteorological Agency**
JPL	**Jet Propulsion Laboratory**
JSC	**Johnson Space Center**

K

KSC	**Kennedy Space Center**

L

LaRC	**Langley Research Center**
LARCS	**Laser Rail Calibration System**
LAT	**Large Area Telescope**
LBNL	**Lawrence Berkeley National Laboratory**
LEDFAA	**Layered Elastic Design—FAA**
LIDAR	**Light Detection And Ranging**
LMM	**Light Microscopy Module**

M

MAGENTA	**Model for Assessing Global Exposure from Noise of Transport Airplanes**
MARSIS	**Mars Advanced Radar for Subsurface and Ionosphere Sounding**
MAS	**MODIS Airborne Simulator**
MBPS	**megabits per second**
MCC	**Mission Control Center**
MEMS	**microelectromechanical system**
MER	**Mars Exploration Rover**
MESSENGER	**MErcury Surface, Space ENvironment, GEochemistry, and Ranging**
MET	**Mobile Earth Terminal**
MISSE	**Materials International Space Station Experiment**
MMT	**Used to stand for Multiple Mirror Telescope; now just the name of the telescope**
MOA	**Memorandum of Agreement**
MODIS	**Moderate Resolution Imaging Spectroradiometer**
MOS	**(Boston) Museum of Science**
MOU	**Memorandum of Understanding**
MR	**magnetorheological**
MRLC	**Multi-Resolution Land Characteristics**
MSFC	**Marshall Space Flight Center**
MSG	**METEOSAT Second Generation**
MSS	**Mobile Satellite Services**

N

NAI	**National Aerospace Initiative**
NAIP	**National Agriculture Imagery Program**
NAPP	**National Aerial Photography Program**
NASM	**National Air and Space Museum**
NASS	**National Agricultural Statistics Service**
NDGPS	**Nationwide Differential Global Positioning System**
NDOP	**National Digital Orthophoto Program**
NDOW	**Nevada Department of Wildlife**
NERSC	**National Energy Research Scientific-computing Center**
NESC	**NASA Engineering and Safety Center**
NESDIS	**National Environmental Satellite, Data, and Information Service**

NGDC	National Geophysical Data Center
NGLT	Next Generation Launch Technology
NGS	National Geodetic Survey
NIMA	National Imagery and Mapping Agency
NIST	National Institute of Standards and Technology
NLCD	National Land Cover Dataset
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service (NOAA)
NPOESS	National Polar-Orbiting Operational Environmental Satellite System
NPP	Net Primary Productivity; NPOESS Preparatory Project
NPS	National Park Service
NRCS	Natural Resources Conservation Service
NRI	National Resources Inventory
NSBRI	National Space Biomedical Research Institute
NSF	National Science Foundation
NSO	National Solar Observatory
NSSA	National Security Space Architect
NSTAR	Solar Electric Power Technology Application Readiness
NSTX	National Spherical Torus Experiment
NTIA	National Telecommunications and Information Administration
NVO	National Virtual Observatory

O

OA	Office of Aerospace (DOC)
OMPS	Ozone Mapper/Profiler Suite
ORA	Office of Research and Applications (NESDIS)
ORNL	Oak Ridge National Laboratory
ORS	Operationally Responsive Spacelift
OSC	Office of Space Commercialization (DOC)
OSMRE	Office of Surface Mining Reclamation and Enforcement (DOI)
OSP	Orbital Space Plane

P

PARR	Problem Analysis, Resolution, and Ranking
PCATD	Personal Computer Aviation Training Device
PCS	Physics of Colloids in Space
PECAD	Production Estimates and Crop Assessment Division
PLGR	Precise Lightweight GPS Receiver
PPPL	Princeton Plasma Physics Laboratory
PPS	Precise Positioning Service

R

R&D	research and development
RBCC	Rocket-Based Combined Cycle
RF	radio frequency
RHIC	Relativistic Heavy Ion Collider
RLV	reusable launch vehicle
RPIF	Regional Planetary Imagery Facility

RSAC	Remote Sensing Applications Center
RSIWG	Remote Sensing Interagency Working Group

S

S&T	science and technology
SAGE	System for Assessing Aviation's Global Emissions
SAO	Smithsonian Astrophysical Observatory
SATS	Small Aircraft Transportation System
SC	Office of Science (DOE)
SDSS	Sloan Digital Sky Survey
SED	Science Education Department
SEU	Structure and Evolution of the Universe
SHARAD	Shallow Subsurface Sounding Radar
SI	International System of Units
SIRTF	Space InfraRed Telescope Facility (renamed Spitzer Space Telescope)
SLAC	Stanford Linear Accelerator Center
SLC	Scan Line Corrector
SLEP	Service Life Extension Program (Space Shuttle)
SMA	Safety and Mission Assurance
SMG	Science Media Group
SMS	Surface Management System
SOHO	Solar and Heliospheric Observatory
SORCE	Solar Radiation and Climate Experiment
Space PCC	Space Policy Coordinating Committee
SPIE	International Society for Optical Engineering
SPOT-VEGETATION	"SPOT" is the name of the imagery company; the use of all capitals is convention
SSC	Stennis Space Center
ST	spherical torus

T

TDRS	Tracking and Data Relay Satellite
TM	Thematic Mapper (Landsat)
TMA-MC	Traffic Management Advisor-Multi-Center
TOPEX	TOPography EXperiment
TRACON	Terminal Radar Approach Control
TWT	Traveling Wave Tube

U

U.N.	United Nations
U.S.	United States
URET	User Request Evaluation Tool (Free Flight Phase 1)
USAF	United States Air Force
USDA	U.S. Department of Agriculture
USFWS	U.S. Fish and Wildlife Service

USGS	**U.S. Geological Survey**
USNORTHCOM	**U.S. Northern Command**
USSTRATCOM	**U.S. Strategic Command**
UV	**ultraviolet**
UVCS	**Ultraviolet Coronagraph Spectrometer**
UWB	**ultrawideband**

V

VALPE	**Vibro-Acoustic Launch Protection Experiment**
VIIRS	**Visual Infrared Imager Radiometer Suite**
VLM	**Vaporizing Liquid Micro-Thruster**
VPP	**Voluntary Protection Program**

W

WMAP	**Wilkinson Microwave Anisotropy Probe**
WTO	**World Trade Organization**

National
Aeronautics and
Space
Administration

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