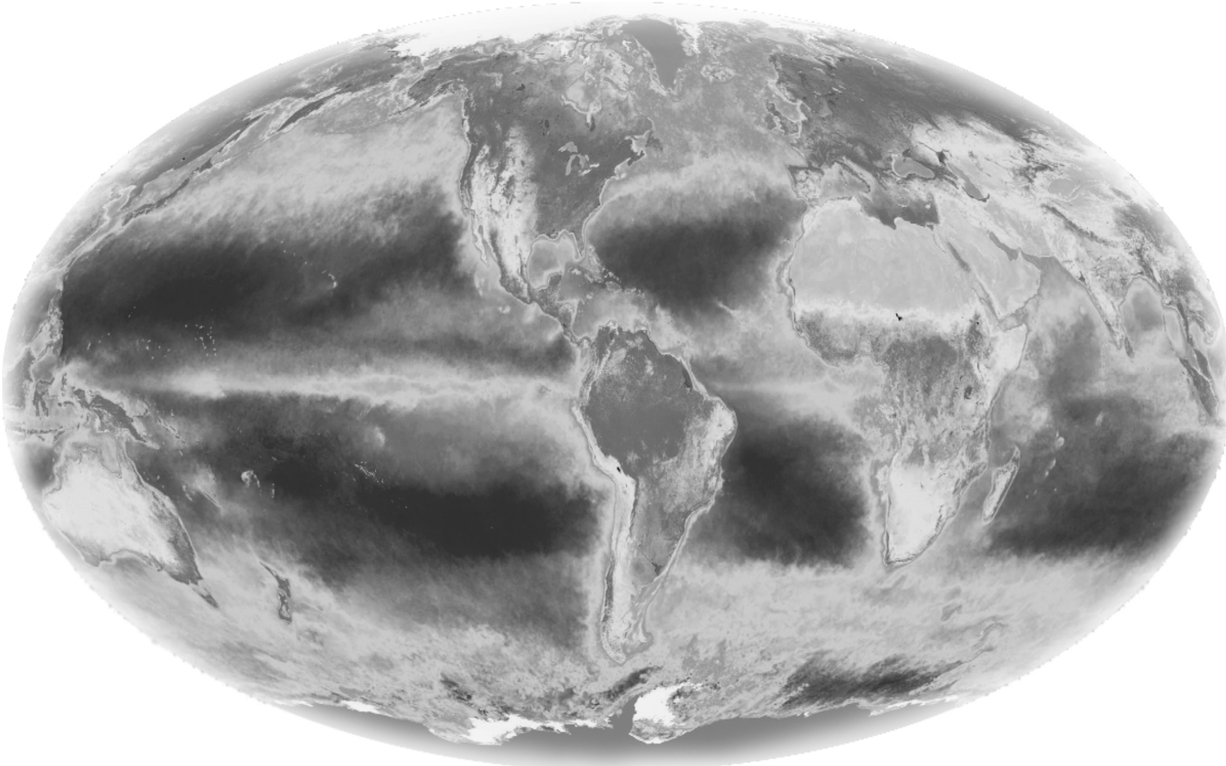
Aeronautics and Space Report of the President



Fiscal Year 2000 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, 1999, through September 30, 2000.

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NASA

NASA accomplished four extremely successful Space Shuttle missions in FY 2000. STS-103 serviced the Hubble Space Telescope with three Extravehicular Activities (EVA) to renew and refurbish the Telescope. In addition to replacing all six gyroscopes, the crew also installed a refurbished Fine Guidance Sensor, a new spacecraft computer, a Voltage/Temperature Improvement Kit to protect spacecraft batteries from overcharging and overheating, and a new S-Band Single Access Transmitter. The crew also replaced the degraded outer telescope insulation with the New Outer Blanket and Shell/Shield Replacement Fabric. STS-103 carried several hundred thousand student signatures as part of a student outreach program. This mission was launched on December 19, 1999, and landed on December 27, 1999.

STS-99 was the Shuttle Radar Topography Mission (SRTM), as part of an international project spearheaded by the National Imagery and Mapping Agency and NASA, with participation from the German Aerospace Center and the Italian Space Agency. SRTM consisted of a modified radar system that flew onboard the Space Shuttle during the 11-day mission. SRTM used C-band and X-band interferometric synthetic aperture radars to acquire topographic data of Earth's land mass between 60 degrees north latitude and 54 degrees south latitude. The Shuttle's radar covered 99.98 percent of the planned mapping area at least once. Besides contributing to the production of better maps, the SRTM measurements could lead to improved water drainage modeling, more realistic flight simulators, better locations for cell towers, and enhanced navigation safety. The STS-99 mission was launched on February 11, 2000, and landed on February 22, 2000.

STS-101 delivered supplies to the International Space Station that included water, a docking mechanism accessory kit, film and videotape for documentation, office supplies, personal items, exercise equipment, medical support supplies, and a passive dosimetry system. Flight objectives included ISS ingress/egress to take air samples, monitor carbon dioxide, measure air flow, rework/modify ISS ducting, replace air filters, and replace emergency and power equipment. The crew also assembled the Strela crane, conducted a spacewalk to install exterior handrails, and set up the centerline camera cable. Assembled parts, tools, and equipment for future missions were also transferred to the ISS. *Atlantis*' steering jets were fired in a series of three maneuvers to boost the Station's orbital altitude by 27 miles. This mission inaugurated the *Atlantis*' new Multifunction Electronic Display Subsystem known as the "glass cockpit." This mission was launched on May 19, 2000, and landed on May 29, 2000.

STS-106 was International Space Station (ISS) assembly flight ISS-2A.2b and utilized the SPACEHAB Double Module and the Integrated Cargo Carrier to bring supplies to the Station. The main goal of this flight was to prepare Russian-built ISS Service Module (SM) *Zvezda ("Star")* for the arrival of the first resident, or Expedition crew, in late 2000. Supplies transferred included clothing, medical kits, personal hygiene kits, laptop computers and a printer, household items, and critical life-support hardware such as an Elektron oxygen generation unit and a Vozdukh carbon dioxide removal unit. Major items unloaded from SPACEHAB included medical equipment for the ISS Crew Health Care System, which will serve as the heart of the Station's clinic for orbiting crews. Spacewalk activities included the hookup of electrical, communications, and telemetry cables between *Zvezda* and the *Zarya* Control Module.

In addition, NASA personnel worked with their colleagues in the Russian Aviation and Space Agency to support their launch of *Zvezda*, a *Progress* resupply ship, and to prepare for the first ISS Expedition crew launch in October 2000.

After the successful launch and mating of the first two ISS elements (Functional Cargo Block [FGB] *Zarya* or "Dawn" and Node 1 *Unity*) and the first logistics resupply mission to the ISS (2A.1/STS-96) in FY 1999, the ISS was further enlarged in FY 2000 and readied for the launch of the first permanent crew.

The third construction element of the ISS, the Russian-built Service Module (SM) *Zvezda* ("Star") had originally been scheduled for launch in 1998. After several delays, this launch was postponed until summer 2000, causing NASA to take measures to prolong the life of the orbiting FGB module beyond its original service certification. This was done by splitting the next Shuttle ISS logistics mission (2A.2) into two flights. The first of these missions, 2A.2a, was remanifested to perform FGB lifetime and maintenance tasks before SM arrival. The second, 2A.2b, was flown after delivery of the SM to perform SM outfitting for the Expedition One crew arrival. Thus, after a 2-year hiatus, FY 2000 was the year NASA returned to the business of assembling the ISS.

On May 19, 2000, NASA launched STS-101 (flight 2A.2a) to ferry supplies required by the Expedition One crew, as well as to replace electronics in the Russian-built *Zarya* module. This flight extended *Zarya*'s service life through December 2000, accommodating the SM schedule slip from November 1999 to July 2000. The SM provides propulsion capability, living quarters, and life support for the early ISS crews. With the successful SM launch on July 11 (flight 1R), the floodgate opened, and assembly and further resupply missions followed at a rapid pace. The SM docked with the orbiting ISS on schedule 2 weeks later (July 25, 2000), followed by the first Russian progress resupply mission (flight 1P) on August 6, 2000. Next, the STS-106 (flight 2A.2b) launched on September 6, delivered supplies, and outfitted the SM in preparation for the assembly mission STS-92 (flight 3A), with the Z1 Truss and PMA-3 (Pressurized Mating Adapter) on October 5, 2000.

While the ISS Program was returning to the task of ISS assembly, NASA's ground teams spent much of FY 2000 preparing for future assembly missions. NASA significantly reduced the amount of program risk by completing the first Multi-Element Integration Test (MEIT-1) early in 2000. MEIT-1 testing included ISS Flights 3A-6A (early truss segments, multipurpose logistics modules, initial power array, the U.S. Laboratory ("Destiny"), and the Canadian robotic arm, and verified element-to-element and element-to-orbiter interfaces). The MEIT-1 ground team completed the soft mate of power, avionics, and fluid connections with flight connectors or jumpers. The ground team systems tests included command and data handling, communications and tracking, electrical power system, thermal control system, and guidance, navigation, and control testing. End-to-end testing and mission sequence testing were completed in March, and critical U.S. Lab software-to-software and hardware-to-software interfaces were verified as well.

With MEIT-1 complete, MEIT-2 was able to begin on schedule in September 2000. Like MEIT-1, this test was being performed as close to the in-flight configuration as possible, with actual hardware and software response. It includes mission control-to-ISS interfaces, allowing engineers to validate operational flight plans and procedures. The test will include the mobile transporter, a movable base of the Station's Canadian mechanical arm that allows it to travel along the Station truss.

At the end of FY 2000, all major ISS elements through the end of Phase II, including the U.S. Laboratory and the U.S. Airlock had been delivered to NASA's Kennedy Space Center, as well as the truss segments and solar arrays through flight 12A. Of the projected 391,000 pounds of U.S. ISS hardware, 275,000 pounds (70 percent) had been delivered to the Kennedy Space Center or placed in orbit by the end of the fiscal year.

The Crew Return Vehicle (CRV) project continued its atmospheric vehicle and parafoil flight testing with a high success rate. The first of two 80-percent scale atmospheric vehicles was modified to match the expected production vehicle body shape and completed a captive carry test attached to the wing of a B-52 in early August. In September 2000, the full-scale parafoil completed its fourth flight test. Production of the operational CRV's was expected to begin in 2002 with delivery onorbit of the first CRV in early 2006.

The ISS research program also made tremendous progress during FY 2000. By the end of the fiscal year, the Human Research Facility and two EXPRESS Racks, with subrack payloads, had been delivered to Kennedy Space Center and were in final integration and test in preparation for launch on ISS flights 5A.1 and 6A. The third and fourth EXPRESS Racks completed final fabrication and assembly and are preparing for delivery to Kennedy Space Center in early FY 2001 for launch on 7A.1. The first three payloads were delivered to the ISS to begin on-orbit operations in late FY 2000. Crew training continued for the first four increments, and the payload operations support capabilities were delivered and tested in preparation to support payload operations beginning in FY 2001.

In addition, the first two commercial (reimbursable) agreements were negotiated and signed with Dreamtime Holdings, Inc., and SkyCorp, Inc. These two commercial (reimbursable) payloads were targeted for delivery to the ISS during FY 2001.

The primary goal of the Space Shuttle Safety Upgrade Program continued to be the improvement of crew flight safety and situational awareness, protect people both during flight and on the ground, and increase the overall reliability of the Shuttle system. To continue the accomplishment of this goal during FY 2000, NASA continued working on improving existing Space Shuttle operational mission assurance and reliability through several safety and supportability upgrade initiatives. To improve Shuttle safety, an effort was initiated to proactively upgrade the Shuttle elements and keep it flying safely and efficiently through FY 2012 and beyond to meet Agency commitments and goals for human access to space. The upgrades with the most benefit in decreasing Shuttle risk are the Electric Auxiliary Power Unit (EAPU), the Solid Rocket Booster (SRB) Thrust Vector Control/ Auxiliary Power Unit (SRB/APU), and the Advanced Health Management System (AHMS). A project to provide a Cockpit Avionics Upgrade (CAU) was also approved for program formulation to improve crew workload and situational awareness and provide an enhanced caution and warning system. During FY 2000, significant project formulation activities occurred for these four major upgrade projects. Conceptual planning and project formulation was also performed for several smaller upgrade projects to improve not only safety but supportability.

NASA began the Human Exploration and Development of Space (HEDS) Technology/ Commercialization Initiative (HTCI) to support future decisions by developing and validating highly innovative new technologies that make possible future revolutionary new systems and infrastructures of value to both human exploration and the commercial development of space. During FY 2000, NASA engaged a Nationwide team of innovators in the formulation of the HTCI, including over 100 participants in two workshops as well as numerous derivative working meetings. A broad framework for planning was defined that involved six major themes: space resources development; space utilities and power; habitation and bioastronautics; space assembly, inspection, and maintenance; exploration and expeditions; and space transportation. Within each of these themes, a range of focused technology "elements" were identified and prioritized, allowing a full assessment of NASA's ongoing programs in terms of how they support future human/robotic exploration and development of space. FY 2000 program formulation activities culminated in the definition of a program implementation plan, including an innovative competitive solicitation strategy to be implemented, beginning in FY 2001.

In summer of 2000, a new HEDS Strategic Plan was published, and for the first time in many years, NASA described plans to develop capabilities that will carry humans beyond low-Earth orbit. The new plan communicates the HEDS mission, challenges, strategic goals, and strategic roadmap with time-phased objectives for longer stays and more distant locations. In addition, the Strategic Plan carefully and successfully balanced current political realities dealing with a major human exploration effort with pursuing technology advances that will benefit the commercial space industry and NASA's Enterprises.

During FY 2000, the NASA Exploration Team studied various mission approaches for expanding human presence beyond low-Earth orbit. Each of these mission studies, referred to as an architecture, provides descriptive information of the overall exploration theme and its derivation from and links to driving national needs, including those articulated in the HEDS Strategic Plan. Example mission architectures to the Moon, Sun-Earth Libration Points, Near-Earth Asteroids, and Mars were developed during the study. The focus of the FY 2000 architectures was to determine the existence of common capabilities and core technologies between destinations. Specific key technologies and their resulting architectural benefits were identified in the areas of crew health and performance, advanced space transportation, advanced space power, advanced information, and operations. In addition, the capabilities of the Intelligent Synthesis Environment (ISE) HEDS Exploration Large-Scale Application were used by the design team to improve the speed and quality of the overall study results. Key system and strategic improvements to the ISE capabilities that can improve the exploration architecture study process were identified.

The first HEDS payload designed for operation on the Martian surface was completed in FY 2000. The Mars In situ propellant-production Precursor (MIP) Flight Demonstration payload successfully completed all acceptance tests and was certified ready for flight. MIP's principal objective is to demonstrate the production of pure, propellant-grade oxygen using Martian atmospheric carbon dioxide as feedstock in a robust, efficient chemical process. With NASA's cancellation of the Mars Surveyor 2001 Lander, MIP has been placed indefinitely into environmentally controlled storage at the NASA Johnson Space Center.

There were 22 U.S. Expendable Launch Vehicle launches in FY 2000. Five of the 22 launches were NASA-managed missions, 9 were Department of Defense (DoD)-managed missions, and 8 were FAA-licensed commercial launches. In addition, NASA flew one payload as a secondary payload on one of the FAA-licensed commercial launches. This year, two new launch vehicles debuted: the Lockheed-Martin Atlas IIIA and the Boeing Delta III, each serving as transition vehicles leading the way for the new generation of Evolved Expendable Launch Vehicle family of vehicles.

In June 2000, the NASA Launch Services (NLS) contracts were awarded to Boeing and Lockheed Martin to enable access to space on the Nation's current and future Atlas and Delta launch services. These contracts include onramps for new launch vehicle providers as they become flight demonstrated and will be key contracts to address NASA launch requirements for the next decade. NASA also initiated a study to assess domestic alternatives for resupply and contingency missions to the ISS, to augment current international launch commitments and the Space Shuttle. The results of the industry studies are being used to formulate Agency strategy for assuring access to space for the ISS throughout its on-orbit life.

In the area of space communications, NASA's Space, Deep Space, and Ground networks successfully supported all NASA flight missions and numerous commercial, foreign, and other Government agency missions. Included were the launch of ISS hardware (including the Russian Service Module), NASA's Terra Earth Observation mission, GOES-L, planetary encounters, and the Galileo spacecraft's encounters of Jupiter's moons. The Tracking and Data Relay Satellite-H (TDRS-H) was also successfully launched, and checkout was initiated. The networks provided data delivery for all customers in excess of 98 percent.

The Consolidated Space Operations Contract (CSOC) completed its 21st month of a 5-year basic period of performance. Operations support continued at Johnson Space Center, the Jet Propulsion Laboratory, Goddard Space Flight Center, Marshall Space Flight Center, and Kennedy Space Center. Customer operations are meeting, and often exceeding, contractual expectations.

The Space Operations Management Office (SOMO)/CSOC commercialization program made significant progress in avoiding costs by outsourcing space communications data services to commercial providers. DataLynx, Universal Space Network, and Konsburg-Lockheed Martin were put under contract to provide data. The proportion of commercial Earth stations that support NASA missions rose to 33 percent. These service providers are making investments to establish the network, a cost that NASA avoids. Additionally, an Indefinite Delivery Indefinite Quantity contract relationship was established with 14 commercial firms qualified to provide both mission and data services.

Other significant activities included the automation of the orbit determination function for most Space Network missions, implementation of an X-Band uplink capability for the 70-meter antennas at Goldstone and Canberra, completion of the Mars communications infrastructure Phase A study, demonstration of the Low-Power Transceiver, initiation of the Ka-Band Transition project for the Space Network and Ground Network, completion of the White Sands Complex Alternate Resource Terminal, and preparations for the launch of TDRS-I and TDRS-J.

Finally, the development of a strategic and visionary architecture to support future Agency communication and navigation needs was initiated. An Agency-wide team was formed to investigate the architecture to address the evolution and unification of the Space, Ground, Deep Space, and Wide Area Networks.

In FY 2000, NASA continued its commitment to safety for the public, astronauts and pilots, the NASA workforce, and high-value equipment and property. NASA met its FY 2000 safety goal of 0.30 lost time incidents per 200,000 workhours. The NASA Centers conducted their annual occupational safety and health program performance evaluation assessments, which included a baseline performance assessment for system safety. The NASA Centers used the results of these assessments to develop plans for additional improvement in NASA safety programs. Several additional Centers announced their intent to pursue Star certification, using the Department of Labor's Voluntary Protection Program guidelines. NASA safety and mission assurance experts stepped up activities to support the increased flight rate of the Space Shuttle and the construction and permanent human habitation of the ISS, conducting the necessary assurance functions and providing independent evaluation of flight readiness. In addition, NASA experts assessed safety and likelihood of success for Expendable Launch

Vehicle missions, safety of aviation operations, impact of orbital debris, and safety and mission assurance considerations in operations and engineering processes. NASA initiated a new Safety and Mission Assurance (SMA) review process for spacecraft launches, the Integrated Mission Assurance Review. Also, NASA made safety and risk management a compelling priority and an expectation in the acquisition process through changes to the NASA Federal Acquisition Regulation Supplement and an aggressive training effort. All NASA sites were certified under ISO 9001 in FY 1999. In FY 2000, NASA passed the required audits for maintaining its ISO 9001 certification.

FY 2000 did not begin well for NASA's Space Science Enterprise. In December 1999, NASA had to declare the Mars Polar Lander/Deep Space 2 mission a failure, only a few months after the loss of the Mars Climate Orbiter in September. The failures were a great disappointment to NASA scientifically, and they also served as a wake-up call to take a long, hard look at its Mars Program. As part of this assessment, NASA convened several teams of experts to look at the Mars program from top to bottom. The result was that by the end of the fiscal year, NASA had unveiled a new and scientifically robust program for future Mars exploration.

Despite the two Mars failures, the Space Science Enterprise had many successes, and its programs delivered a wealth of compelling science, including Mars science. The Mars Global Surveyor (MGS) delivered a landmark discovery in the history of planetary exploration: scientists using imaging data from MGS observed features that suggest there may be current sources of water at or near the surface of the red planet. The images show the smallest features ever observed from Martian orbit, approximately the size of a sports utility vehicle. NASA scientists compared these features to those left by flash floods here on Earth.

Findings from the Near Earth Asteroid Rendezvous (NEAR) mission confirmed that asteroid 433 Eros is a consolidated, primitive sample from the solar system's beginnings: an undifferentiated asteroid with homogeneous structure, that never separated into a distinct crust, mantle, and core. NEAR is the first indepth study of an asteroid. Since entering Eros' orbit on February 14, 2000, the NEAR Shoemaker spacecraft has taken more than 100,000 images and extensive measurements of Eros' composition, structure, and landforms, at distances ranging from 22 to 220 miles (35 to 350 kilometers).

The Chandra X-Ray Observatory, launched in July 1999, has delivered a wealth of science in its relatively short history. One Chandra highlight is that it recently resolved a 37-year old mystery: the origin of the diffuse x-ray background. The diffuse x-ray background was originally discovered by the first x-ray rocket flight in 1967. The whole sky glows bright in x-rays, but until FY 2000, scientists had lacked the sharp imaging power to see if the glow is all due to unresolved individual point sources. Scientists now know that the glow is made up of discrete, individually distinct sources. These faraway sources include quasars, galaxies, and some mystery objects. The mystery objects shine brightly in x-rays but fail to show up as counterparts in optical light. Therefore, at the end of the fiscal year, NASA space scientists had no idea yet as to their nature or distance, except that they are point-like sources of x-radiation.

During FY 2000, scientists gathered data from a variety of sources to prove that long-suspected theory that the universe is flat and accelerating. Combining results from ground-based astronomy, the Hubble Space Telescope, and infrared observations from the Balloon Observations for Millimetric Extragalactic Radiation and Geomagnetics (BOOMERANG) balloon flight, scientists confirmed that the inflationary scenario of Big Bang cosmology is correct and that space is accelerating, implying a new phenomenon in nature called “dark energy.”

A week’s advance warning of potential bad weather in space is now possible thanks to the Solar and Heliospheric Observatory (SOHO) spacecraft. With a technique that uses ripples on the Sun’s visible surface to probe its interior, SOHO scientists have, for the first time, imaged solar storm regions on the far side of the Sun, the side facing away from Earth. Understanding solar variability is becoming an increasingly important topic both to researchers and to the public.

NASA’s Transition Region and Coronal Explorer (TRACE) mission delivered more important news about our Sun. Giant fountains of fast-moving, multimillion degree gas in the outermost atmosphere of the Sun revealed an important clue to a long standing mystery—the heating source that makes the corona 300 times hotter than the Sun’s visible surface. TRACE captured dramatic images of the immense coils of hot, electrified gas, known as coronal loops. A 30-year old theory assumed that the loops are heated evenly throughout their height. The TRACE observations show that instead, most of the heating must occur at the bases of the coronal loops, near where they emerge from and return to the solar surface.

In Origins news, planet-hunting astronomers crossed an important threshold in planet detection with the discovery of two planets that may be smaller in mass than Saturn. Of the 30 extra-solar planets around Sun-like stars detected previously, all have been the size of Jupiter or larger. The existence of these Saturn-sized candidates suggests that many stars harbor smaller planets, in addition to the Jupiter-sized ones.

Finding Saturn-sized planets reinforces the theory that planets form by a snowball effect of growth from small ones to large, in a star-encircling dust disk. The 20-year-old theory predicts there should be more smaller planets than large planets, and this is a trend the researchers have begun to see in their data.

In December 1999, the Hubble Space Telescope (HST) got its third visit from a Space Shuttle. The crew of *Discovery* installed new gyroscopes and a new computer and performed a host of other upgrades. The result was that HST is now more powerful and robust than at any other time in its 10-year history. It has continued to deliver the profound science and amazing images that we have come to expect from the most famous space-based observatory in history.

There were many other space science highlights during FY 2000. The Space Science Enterprise unveiled the details of two exciting new programs, the aforementioned New Mars Program and Living With a Star, a comprehensive program to learn more about our Sun and its effects on Earth. These new initiatives, together with our existing research and exploration programs, bode well for a continuation of exciting and ground-breaking new space science discoveries as we enter the new millennium.

The Aerospace Technology Enterprise continued to pioneer the identification, development, verification, transfer, application, and commercialization of high-payoff aeronautics and space transportation technologies, and plays a key role in maintaining a safe and efficient national aviation system and an affordable, reliable space transportation system. The Enterprise addressed 10 overarching objectives in aviation, space transportation, and technology innovation through a wide range of programs. This summary covers a small sample of significant accomplishments that will lead to improved aviation safety, increased air system capacity, reduced environmental impact from aviation operations, new technology innovations, and significant strides that were made toward achieving affordable space access for the Nation.

In aviation safety, a major flight demonstration of technologies for preventing runway incursions was held at Dallas-Fort Worth International Airport. NASA's Boeing 757 research aircraft was a testbed for auditory alerts and sophisticated cockpit visual displays (e.g., electronic moving maps to show real-time aircraft location on the airport runways, and head-up displays with enhanced runway information and runway incursion alerts) to improve pilot situational awareness. The integrated set of tools proved highly effective and will contribute to the safety of future generations of aircraft.

NASA has continued an intensive research program to mitigate the effects of icing on aviation safety. An interactive training program on CD-ROM has been developed for pilots of commuter and general aviation aircraft as a result of NASA icing research. Three of seven modules have been completed, teaching pilots the factors involved in aircraft icing and how to handle icing situations to avoid deadly accidents. The program has been well received by pilots. The remaining modules are expected by June 2001. In addition, NASA has also published a report entitled "Ice Accretions and Icing Effects for Modern Airfoils. "Prior to this effort, the NACA four-digit series airfoil sections, created in the 1950's, served as the state-of-the-art. This report has significantly advanced the state-of-the-art in aircraft icing-prediction tools by providing a broad base of information about ice accretions and the resulting effects on aerodynamic performance for airfoils being designed and used on today's aircraft. The report documents ice accretions formed over a wide range of aircraft icing conditions and resulting aerodynamic performance degradation for airfoils as represented in three classes of aircraft—commercial transport, business jet, and general aviation. It provides a database for development of ice accretion and aerodynamic performance codes for use in the development and application of ice-protection systems and the process of certifying aircraft for flight in icing conditions. NASA also has completed the concept design for a new ice management system to improve safety of aircraft operating in icing conditions and to advance state-of-the-art, in-flight deck information management and decision-making of onboard, in-flight icing operations. This will increase aviation safety by enabling the aircraft to identify hazardous icing conditions, manage and operate onboard ice protection systems, and provide flight crew near-real-time information on level of hazard to manage the icing encounter.

NASA also continued developing the technologies that will provide complete weather information and situational awareness to pilots and ground operators of any atmospheric condition that affects the operation and safety of an aircraft. In FY 2000, NASA flight tests demonstrated commercially ready graphical weather display systems that will now enter inservice evaluations with multiple airlines.

NASA also developed and documented a theoretical methodology for predicting error-vulnerability in design of human-automation systems. In particular, it focuses attention on the problem of ambiguities associated with pilot interaction with cockpit automation. Such ambiguities, which directly lead to so-called “automation surprises,“ are documented in many pilot incident reports. This report helped to define the precise connection between a machine’s behavior, the task specification, the required user interface, and the user-model for ensuring correct and unambiguous interaction between a user and a machine.

In aviation system capacity, low-visibility conditions cause delays of at least 15 minutes for 180,000 flights annually in the United States, while delays in excess of 15 minutes affect an additional 120,000 flights annually. Costs associated with these delays are estimated in excess of $3 billion. A major accomplishment for capacity research was the transfer to the FAA of three decision support tools for aircraft arrival and surface operations. The FAA is deploying the NASA-developed Passive Final Approach Spacing Tool, Traffic Management Advisor, and Surface Movement Advisor to key sites in the national airspace system as part of its next-generation air traffic management system. Airports with the tools in place have already shown improvements in the capacity of their extended terminal areas.

A second accomplishment in aviation system capacity was the completion of the Terminal Area Productivity (TAP) project, which developed ground and airborne technologies to reduce lateral and in-trail space separations for landing. The goal is to safely maintain good weather operating capacity during bad weather and low-visibility conditions. Several NASA technologies and operational concepts were field-demonstrated at the Dallas-Fort Worth and Atlanta Hartsfield airports. Together, the elements of TAP demonstrated throughput increases of up to 17 percent over current nonvisual operations for a single runway, the ability to land with only 2,500 feet of parallel runway separation even though current rules require a lateral spacing of 4,300 feet, and guidance, control, and situation awareness systems to reduce runway congestion while meeting FAA guidelines for safety.

In FY 2000, NASA completed the development of "FutureFlight Central" which is a world-class research facility dedicated to addressing the future needs of the Nation's airports. This facility will allow researchers to examine ways to increase the flow of aircraft through the national airspace system safely, efficiently, and under all weather conditions, and will permit integration of tomorrow's technologies in a risk-free simulation of any airport, airfield, and tower-cab environment. The three-dimensional visual model of an airport is viewed from the 360-degree windows of the tower cab. Up to 12 air traffic controllers in the tower cab interact in the live-action simulation through a simulated radio and telephone system with pilots and ramp controllers. The imaging system, powered by supercomputers, provides a realistic view of weather conditions, environmental and seasonal effects, and the movement of up to 200 active aircraft and ground vehicles.

NASA researchers continued their efforts to mitigate both the local and global environmental impacts of aviation operations. Building on the accomplishments of the past years, they have made significant advances in the reduction of aircraft noise and emissions. Last year, NASA successfully tested in laboratory flametube experiments, three fuel injector concepts that achieved NO_x (nitrogen oxide) reductions of greater than 75 perfect. In addition, NASA developed an innovative compressor flow-control concept. It was developed by selecting an inverse design technique for optimum blade shape and shock placement and by managing the flow between the blade tips and endwall (inner compressor liner) with the proper matching of highly loaded stages. Application of these techniques is reducing overall losses and enabling higher efficiency at higher aerodynamic loading on the compressor blades. These techniques could lead to compressor designs with fewer stages and a system that is lighter weight, thus attaining revolutionary gains in compressor performance. It is expected that these design methodologies will result in attaining the goals of reducing CO_2 (carbon dioxide) emissions and increasing efficiency of advanced aircraft engines. NASA also demonstrated "smart" turbomachinery concepts that have the potential to minimize pollutants throughout mission cycle by actively suppressing thermoacoustic-driven pressure oscillations. Successful development of this technology will enable lean combustors that will result in the reduction of NO_x and CO_2 throughout the mission cycle.

NASA also made significant strides toward its goals of confining aircraft noise within airport boundaries. Over the past several years, NASA has identified the sources of aircraft related noise and developed technologies to mitigate their effect. Last year, NASA conducted a systems analysis that indicated a 7 decibel (dB), with the potential of up to 9 dB, noise reduction from NASA-developed component technologies for large subsonic transport aircraft. These include a reduction of community noise of 3 to 7 dB, depending on aircraft suitability from engine cycle changes; 3 dB reduction from fan and stator geometry optimization; 3 dB from advanced low-noise engine nozzles; 2 to 3 dB reduction from engine inlet shape; 1 dB from active engine noise control; 4 dB from improved design of flap, slat, and landing gear systems; and 2 dB from advanced operations. Similar advances have been made for rotorcraft. The use of higher harmonic control, coupled with a low-noise approach, resulted in a 16.5 dB reduction of peak blade vortex interaction noise. NASA also demonstrated an active-control technology that achieved a 23 dB reduction in rotorcraft interior noise.

In the area of technology innovation, NASA completed the low-altitude testing of a solar-powered, Remotely Piloted Vehicle (RPV) aircraft that is designed to fly to 100,000 feet in altitude or have a flight duration of 100 hours once outfitted with high-performance solar cells. NASA also successfully demonstrated continous over-the-horizon control of a remotely piloted aircraft outside of controlled airspace using commercial satellite networks. The aircraft flew a series of direct commands from the ground station as well as a series of way point sets. On one demonstration, the ground controller sent up a simulated search pattern while the aircraft was over 200 nautical miles (nm) from base, and the aircraft tracked the pattern perfectly. The flexibility of the system was demonstrated when air traffic control directed a change from its planned altitude of 45,000 feet to 44,000 feet. The ground controller quickly uploaded a descent command to bring the aircraft to the new altitude.

NASA also developed and validated an apparatus for large scale rotor testing in the National Full-size Aerodynamics Complex 80'x120' wind tunnel at NASA Ames Research Center. This apparatus provides a unique national capability to test both helicopters and tiltrotors up to 50,000 pounds (lbs) thrust and 6,000 horsepower.

NASA's cooperative efforts to develop advanced engine technology to revitalize general aviation continued in FY 2000. Based on significant technical progress with the NASA-developed General Aviation Propulsion turbine engine, Eclipse, a new aircraft company, announced that it will utilize a derivative of this engine for the Eclipse 500 aircraft.

In the area of space transportation, thermal protection materials may radically change the design and performance of future aerospace vehicles, overturning the conventional wisdom that only blunt-body aerospace vehicles can survive the searing temperatures of reentry into Earth's atmosphere. The Slender Hypervelocity Aerothermodynamic Research Probe's second ballistc flight test successfully demonstrated performance of 1-millimeter (mm) radius, ultra-high temperature ceramic tiles with leading edges at speeds greater than Mach 22 and at altitudes greater than 43 kilometers (km). The use of sharp leading edges on hypersonic vehicles has the potential to increase spacecraft maneuverability (more like an airplane), eliminate the electromagnetic interference that causes the communications blackouts on reentry, and reduce propulsion requirements due to lowered drag.

Between April and August 2000, a 10-kilowatt (kw) Hall effect thruster, designated T-220, was subjected to a 1,000-hour life test evaluation. Hall effect thrusters are propulsion devices that electrostatically accelerate xenon ions to produce thrust. Hall effect propulsion has been in development for many years, and low-power devices (1.35 kw) have been used in space for satellite orbit maintenance. The T-220 produces sufficient thrust to enable efficient orbital transfers, saving hundreds of kilograms in propellant over conventional chemical propulsion systems. This test is the longest operation ever achieved on a high-power Hall thruster (greater that 4.5 kw) and is a key milestone leading to the use of this technology for future NASA, commercial, and military missions.

Another accomplishment in space transportation was the completion of 14 single-engine hot fire tests of the X-33 program's Linear Aerospike Engine. The unusual design allows the engine to be more efficient and effective than today's rocket engines.

NASA also completed NASA Solar electric propulsion Technology Application Readiness (NSTAR) ground testing of the sister engine used for the Deep Space-1 (DS-1) mission. The goal of demonstrating 100 percent of the engine design life was achieved on May 9, 2000, after the engine had accumulated 10,375 hours of operation. Approximately half of the 10,375 hours were intentionally spent at a throttle level corresponding to two-thirds of full power. Prior to the NSTAR project and over a timespan of more than 30 years, no ion engine to be used for primary propulsion had ever been successfully operated for more than a small fraction of its design life. The success of these tests, together with the success of the flight test on DS-1, has now made ion propulsion a legitimate option for deep space solar system exploration missions.

NASA's Earth Science Enterprise (ESE) continued to seek to understand the Earth system and the effects of natural and human-induced changes on the global environment. ESE continued to exploit the vantage point of space to conduct research on global and regional scale changes in the interactions among the atmosphere, land, oceans, ice, and life that comprise the Earth's system. Together with its partners, ESE provides a sound, scientific basis for economic investment and environmental policy decisions in both the public and private sectors. ESE's three goals in this period were to expand scientific knowledge about the Earth system, to disseminate knowledge about the Earth system, and to enable the productive use of ESE science and technology in the public and private sectors.

In December 1999, ESE launched the Terra satellite—the flagship mission of the Earth Observing System. Terra is the first satellite to monitor daily, simultaneously and on a global scale, the Earth's biosphere, cloud cover, atmospheric aerosols, land surface, and response to solar radiation. This approach enables scientists to study the interactions among these major Earth system components that determine the cycling of water and nutrients on Earth. One product is near-daily measurements of photosynthetic processes on the Earth's surface (both land and oceans) from which calculations of carbon uptake are made. Terra's instruments were activated for science operations in February 2000 and continued to operate normally. Data from Terra are publicly available from Goddard Space Flight Center's Distributed Active Archive Center.

Using the Landsat 7 satellite launched in 1999, ESE and the U.S. Geological Survey (USGS) completed the first update of the global maps of 30-meter resolution land cover data. Researchers undertook a variety of land cover studies around the world with these data, and practical application of these same data are being made in agriculture and forest management. NASA supplied both Landsat and Terra data to the U.S. Forest Service and regional authorities combating the large-scale fires that swept the Los Alamos region of New Mexico and the areas spanning the border of Montana and Idaho in the Northwest in 2000. In addition, USGS scientists used Landsat 7 data to provide a synoptic view of the landscape simultaneously with the outbreak of infectious diseases—most recently in the outbreak of the West Nile Virus in New York City during the summer of 2000.

The QuikSCAT satellite, also launched in 1999, began providing 25-kilometer resolution data on ocean surface winds. NASA provided these data to the National Oceanic and Atmospheric Administration (NOAA) in near real time, and researchers continued to employ these data to improve marine weather forecasting. The Tropical Rainfall Measurement Mission (TRMM) with Japan completed its nominal 3-year mission to provide the first measurements of global rainfall over the tropics. NASA managers extended the lifetime of TRMM to support additional research. Combining data from QuikSCAT and TRMM, researchers began experimenting with the capability to dramatically improve hurricane landfall prediction.

The balance of Earth Observing System satellites such as Aqua, Jason, ICEsat, and Aura proceeded in development in FY 2000 for launch in 2001–2003. In addition, a series of small, focused research satellites, which will provide the first precise measurements of the Earth's geoid, continued in development.

In February 2000, NASA flew the Shuttle Radar Topography Mission to produce the first intererometric synthentic aperture radar data set from space. The SRTM mission, cosponsored by the National Imagery and Mapping Agency, collected topographic data on the entire land surface of the Earth between 60°N and 56°S. These data will have a wide variety of applications in hydrology, flood plain mapping, civil engineering, and aviation safety. Germany and Italy contributed the experimental X-band radar system for the mission.

In addition to its satellite observations, NASA continued to operate research aircraft for in situ and remote sensing of the atmosphere and land surface. In some cases, these aircraft are operated in tandem with satellites in integrated research campaigns. In 2000, NASA flew its ER-2 aircraft into the North polar stratosphere to explore the processes of ozone destruction over the Arctic. Antarctic ozone processes are well understood; now for the first time, researchers have similar data for the Arctic. In fall 2000, NASA led an international campaign, Southern African Regional Science Initiative (SAFARI) 2000, to explore the interactions of land and atmosphere in southern Africa. This campaign mapped the appearance and transport of aerosols in the atmosphere resulting from large-scale fires on the ground.

Three major airborne scientific campaigns for research and validation of satellite measurements were carried out during FY 2000. The Stratospheric

Aerosol and Gas Experiment (SAGE) III Ozone Loss and Validation Experiment (SOLVE) campaign was conducted from December 1999 to March 2000. SOLVE was a field measurement campaign using NASA's ER-2 and DC-8 research aircraft, high altitude balloons, and ground-based instruments to examine the processes that control polar to midlatitude stratospheric ozone levels. The campaign included cooperation with Canada, Germany, Japan, Sweden, and Russia. The SAFARI 2000 effort included ground-based and airborne field campaigns in southern African nations, including Botswana, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Zambia, and Zimbabwe. The objective of the campaign was to identify and understand the relationships between the physical, chemical, biological, and anthropogenic processes that underlie the land and atmospheric systems of southern Africa. Researchers made measurements during the wet season (February–March 2000) to identify and quantify major sources of emissions and ecosystem processes during peak biomass. The dry-season episode of the campaign (August–September 2000) tracked the movement, transformations, and fallout of dry-season emissions from biomass burning. Finally, NASA's DC-8 aircraft carrying the NASA airborne synthetic aperture radar (AIRSAR) instrument, the Moderate-resolution Imaging Spectroradiometer and Advanced Spaceborne Thermal Emission and Reflection Radiometer MODIS/ASTER (MASTER) simulator, and other instrumentation flew from August to October 2000 in the Pacific Rim. This campaign, called PacRim II, involved extensive data collections over 18 countries, with NASA's aircraft operating out of American Samoa, Australia, French Polynesia, Guam, Japan, New Zealand, the Philippines, and Singapore before returning to the United States. The objective was to further advance Earth science research and applications in all the countries involved, specifically in the areas of agriculture, coastal processes, geology and tectonics, disaster management, forestry and vegetation, urban and regional development, and continued cooperation in Synthetic Aperture Radar (SAR) data and interferometry research. Topographic mapping, forest canopy analysis and mapping, volcano and tectonic research, geological research, and archaeology were all made possible with the data collected during the PacRim II campaign.

Together with the Canadian Space Agency, ESE initiated the second Antarctic Mapping Mission using the Radarsat-1 spacecraft to produce radar topographic maps of the south polar ice sheet. Researchers planned to compare these data with those from the first Antarctic Mapping Mission in 1997 to establish rates of change in diverse portions of Antarctica.

Regarding knowledge dissemination, ESE distributed 8.8 million data products in response to 1.5 million requests during the fiscal year. More than distributing data, however, NASA continued to try to ensure that these data are used broadly to improve Earth science education in the United States. ESE sponsored 340 workshops to train teachers in the use of Earth science information products in their curricula. NASA also awarded 51 new graduate fellowships.

ESE's third goal is the final step toward ensuring the benefits of its new scientific knowledge will extend beyond the science community to the broader economy and society. Through its Commercial Remote Sensing Program, ESE partnered with private companies in the remote-sensing information product business to develop 20 new products, such as oilspill containment software, models to predict wildfire behavior, and crop health information systems. ESE sponsored three U.S. regional assessments of the impacts of climate change, in concert with academia and regional authorities, to help them plan for the future. Finally, ESE demonstrated the ability of new technologies to make Landsat-type measurements far less expensively in the future and transferred new software technologies to academia and industry to manage large Earth science data sets.

After the end of FY 2000, NASA established a new Enterprise called the Biological and Physical Research Enterprise (BPRE) from the former Office of Life and Microgravity Sciences and Applications. For convenience's sake, this report will refer to this office as BPRE.

During FY 2000, BPRE executed a memorandum of understanding with the National Cancer Institute focusing on new approaches to detect, monitor, and treat disease. This cutting-edge effort uses biological models to develop medical sensors that will be smaller, more sensitive, and more specific than today's state of the art. The Enterprise established a pricing policy for a commercial demonstration program on the ISS and entered into two initial commercial agreements.

In FY 2000, BPRE continued to develop a robust scientific community to maximize return from future flight opportunities including the International Space Station. BPRE made awards under six NASA Research Announcements (NRA) in FY 2000 and built its investigator community to approximately 960 investigations as part of continuing preparations for ISS utilization. BPRE researchers published over 1,400 articles in peer-reviewed journals in FY 1999, with similar publication rates expected for FY 2000.

While BPRE researchers completed preparations for their next dedicated spaceflight research mission, BPRE ground-based research continued to provide important results. Investigators demonstrated that muscle healing is inhibited by a period of simulated microgravity before injury. Investigators also identified a key gene in the regulation of plant growth and the response of plants to gravity identified. BPRE research also showed that a parathyroid hormone modulates the response of bone-building cells to mechanical stimulation. A BPRE-supported researcher demonstrated that it is possible to amplify a beam of atoms, similar to the way a beam of light can be amplified, by increasing the number of atoms in an initial atom beam with light and a Bose-Einstein condensate. Researchers fabricated single-wall carbon nanotubes using flame synthesis.

In addition, BPRE made significant progress toward developing new, advanced life-support technologies and improved approaches for maintaining health in the hostile environment of space. BPRE completed utilities outfitting of its new BIOplex closed life-support test chamber system. Researchers produced the next generation of tunable diode lasers and continued testing of an advanced miniature mass spectrometer for monitoring spacecraft atmospheres. Ground-based research designed to simulate spaceflight demonstrated that the clinically approved drug, midodrine, prevented human orthostatic intolerance (or fainting on return to gravity). BPRE research implicated elevated levels of nitric oxide and decreased blood vessel contraction, thus identifying a target for the control of blood pressure changes associated with spaceflight.

BPRE's Space Product Development Program continued to market the benefits of space-based research to industry, facilitate industry's access to space, provide space research expertise and flight hardware, and advocate the commercial use of space. The program continued to be executed through Commercial Space Centers (CSC) that established industry partnerships with the objective of developing new commercial space products or dual-use technologies. The industry partners continued to invest substantial cash and/or in-kind resources in the projects.

There were a number of highlights of this CSC work during FY 2000. The Wisconsin Center for Space Automation and Robotics CSC received a Space Technology Hall of Fame 2000 Award from Space Foundation/NASA for innovative light-emitting diode (LED) technology for medical applications. Originally used to light space-flown plant chambers, the LED technology is finding uses in photodynamic cancer therapy and wound healing. Bristol-Myers Squibb (BMS) continued its strategic partnership with BioServe Space Technologies CSC on microgravity fermentation research for improved production of antibiotics. BMS and BioServe have had an ongoing collaboration on this research for several years and this research partnership was expected to continue on the ISS. Hewlett-Packard (HP) signed a membership agreement with the Center for Commercial Applications of Combustion in Space (CCACS) CSC. HP scientists in Colorado will work with CCACS scientists to develop techniques for in situ imaging of bone in-growth into porous ceramic implants. They and several other groups are partners in the CCACS biomaterials consortium. Two companies joined the Center for Advanced Microgravity Materials Processing (CAMMP) as full members: Polaroid Corporation and Busek Co., Inc. Researchers built a system to explore the growth of silver halides and began testing at CAMMP.

During FY 2000, NASA continued its international activities, expanding cooperation with its partners through new agreements, discussions in multilateral fora, and support for ongoing missions.

NASA concluded over 60 cooperative and reimbursable international agreements for projects in each of NASA's Strategic Enterprises. These agreements include ground-based research, aircraft campaigns, satellite missions, and agreements for research facilities and experiments to be flown on the ISS. One such agreement was a Memorandum of Understanding (MOU) signed between NASA and the Japanese Institute of Space and Astronautical Sciences for cooperation on the ASTRO-E mission, the fifth in a series of Japanese astronomy satellites devoted to observations of celestial X-ray sources. Another was a NASA-Australian Commonwealth Scientific and Industrial Research Organization MOU for cooperation on Australia's first satellite mission called Federation Satellite or FEDSAT. NASA will provide a scientific instrument for this experimental microsatellite to be launched in 2001. In addition, the ISS partners approved a Crew Code of Conduct for the ISS, paving the way for a permanent human presence. This Code of Conduct was called for in the Intergovernmental Agreement and Memoranda of Understanding for the ISS. Agreement on the text was reached in September 2000, followed by steps taken in each partner nation to enter it into force.

As part of the U.S. Government team, NASA continued its discussions with the Government of Japan to clarify the 1995 United States-Japan Cross-Waiver Agreement on Space Activities. The Cross-Waiver Agreement ensures that Japan and the United States agree to waive liability claims for cooperative U.S.-Japan space activities.

NASA participated in numerous international meetings designed to review ongoing or to foster new cooperation. These included the Committee on Earth Observing Satellites (CEOS) annual plenary meeting, the United Nations Committee on Peaceful Uses of Outer Space and its subcommittees, and the Inter-Agency Consultative Group for Space Science. NASA and Portugal held a workshop in Lisbon during December 1999 to exchange information with the goal of identifying opportunities for cooperation. In May 2000, NASA hosted a Space Science International Partnership Conference to exchange information on future plans for space science programs at which 20 space agencies participated.

NASA also engaged in discussions with current and potential future partners at the Senior Management level, hosting visitors from around the world. In addition, the NASA Administrator traveled overseas to review the status of ongoing cooperation or to promote new cooperation. In May 2000, the NASA Administrator gave a keynote address at the GNSS (Global Navigation Satellite System) 2000 conference in Edinburgh, Scotland, as part of a series of announcements by the U.S. Government concerning the President's decision to terminate selective availability on the GPS signals effective at midnight on May 1, 2000. The Administrator traveled to Rome and Padua, Italy, in June 2000, where he received an honorary doctorate from the University of Padua and held meetings with the Vatican and the Italian Space Agency. The Administrator led a NASA delegation to the launch of the first element of the International Space Station, the *Zvezda* Service Module on July 12, 2000, from the Baikonur launch facility in Kazakhstan. In August 2000, the Administrator visited Morocco where he signed four new agreements for cooperation with the Royal Remote Sensing Center of Morocco. These agreements provide for the installation of an Aerosol Robotic Network aerosol measurement station in Morocco and cooperation on coastal upwelling ecosystems, precipitation research, and desertification research. In late August and early September, the Administrator accompanied a U.S. congressional delegation, led by Congressman James Walsh of New York, Chairman of the House Appropriations Subcommittee to France, Russia, and Ireland.

DEPARTMENT OF DEFENSE

DoD

In the area of satellite control, the DoD, together with NASA and the National Oceanographic and Atmospheric Administration (NOAA), developed a comprehensive architecture for future Satellite Operations (SATOPS) in the 2020 timeframe. The SATOPS Architecture Transistion Plan includes conducting launch, early-orbit checkout anomaly resolution, and low data rate operations, using a single interoperable ground- and space-network for DoD, NASA, NOAA, and the National Reconnaissance Office (NRO). This Government network allows for increased interoperability and reduced ground infrastructure. Towards this goal, the Air Force Satellite Control Network began upgrading its remote tracking stations to be compatible with Unified S-Band (USB), the band in which NASA conducts its own satellite operations.

In terms of environmental monitoring, the National Polar-orbiting Operational Environmental Satellite System (NPOESS) is a tri-agency program of the Departments of Defense and Commerce (DOC) and NASA. In FY 2000, the NPOESS Integrated Program Office (IPO) awarded two system program definition and risk-reduction contracts. In addition, the IPO continued critical contract down-select activities for the suite of environmental sensors that will fly on NPOESS. The NPOESS Preparatory Project (NPP), an IPO and NASA joint mission, continued to progress in FY 2000. A joint DoD/NOAA/NASA working group conducted a successful mission requirements review on the way to the 2005 NPP launch.

DoD, NASA, NOAA, and other Federal agencies completed a Space Weather Architecture Transition Plan which received National Security Space Senior Steering Group (NSS SSG) approval during FY 2000. The plan outlines actions and activities which will start the implementation of the recommendations from the comprehensive 1999 National Security Space Architect Space Weather Architecture Study over the next several years, part of which is the Government's multiagency investment strategy. This study laid out the structure for a space weather architecture to meet all U.S. Government requirements and mitigate the adverse impacts of solar events by the year 2025. The NSS SSG, via an Architecture Implementation Memorandum, directed stakeholder organizations and agencies to start implementing actions.

The DOD successfully launched the Tri-Service Experiments Mission 5 (TSX-5) on a Pegasus launch vehicle in FY 2000. The TSX-5 mission operates two experimental payloads for 6 months to 1 year in support of two DoD Space Experiments Review Board experiments. The two experiments are the Space Technology Research Vehicle-2 (STRV-2) and the Compact Environmental Anomaly Sensor (CEASE). STRV-2 is a multinational, highly integrated suite of experiments designed to push the envelope of space-based imaging technology, satellite vibration suppression, and material science. STRV-2 is sponsored by the Ballistic Missile Defense Organization. CEASE is an environmental scanner, providing the spacecraft with essential knowledge about the surrounding space. CEASE used this flight to prove its near-spacecraft environmental assessment capabilities. Phillips Laboratory Geophysics Laboratory sponsors CEASE.

The DOD, via the U.S. Air Force, also successfully launched Defense Meteorological Satellite Program Satellite 15 (DMSP S-15) from Vandenberg Air Force Base, California, on a Titan II booster in FY 2000. This DoD polar-orbiting weather satellite mission will ultimately converge with NOAA's polar-orbiting mission to form NPOESS. S-15 is the first DMSP satellite whose post-launch checkout was conducted from NOAA's Satellite Operations Control Center in Suitland, Maryland. Previous DMSP postlaunch checkouts were conducted from Offutt Air Force Base, Nebraska. Last year, as part of the merger designed to promote efficiency and cut down public expense, the DoD transferred control of its weather satellites to NOAA and closed the 6th Space Operations Squadron at Offutt after nearly 35 years of continuous operations. The Air Force Reserve now operates a backup DMSP command and control facility at Schriever Air Force Base, Colorado. NOAA's Suitland facility is now the primary location for providing functions associated with command and control of all U.S. weather satellites, including early orbit checkout following launch operations, satellite state-of-health maintenance, and satellite sensor and payload management.

In the area of space-based communications, programs achieved several key milestones in FY 2000 with several launches and major programmatic decisions. The first

Defense Satellite Communications System (DSCS) satellite equipped with the Service Life Enhancement Program (SLEP) package was launched in January 2000. The second of four was successfully launched in October 2000. These satellites represent a significant increase in capability over the DSCS III satellites, with higher-powered transponders and greater total system capacity, up to a 200 percent increase. Regarding the highly protected SatCom systems, DoD will be accelerating the first satellite in the Advanced EHF satellite system to mitigate the loss of the the Milstar Flight 3 satellite in April 1999. For mobile communications, the UHF Follow-On (UFO) 10 satellite was launched in November 1999, ensuring the UFO constellation will continue to provide global UHF coverage well into the future.

In the area of positioning and navigation, as directed by President Clinton, Selective Availability (SA) was discontinued shortly after midnight on May 1, 2000. The currently planned Global Positioning System (GPS) modernization program will add new military signals (known as the M-code) and a second civil signal to some Block IIR and all Block IIF satellites, and will add a third civil signal on the Block IIF satellites. Since SA was discontinued, horizontal position errors of less than 10 meters have routinely been observed. Worldwide transportation safety, scientific, and commercial interests benefit from the increased accuracy.

Plans were put in place for a significant investment over the next several years to modernize GPS to enhance its ability to meet both military and civil needs for the foreseeable future. The currently planned GPS modernization program will add new military signals (known as the M-code) to Block IIR and IIF satellites, a second civil signal on IIR satellites, and a third civil signal (L5) on IIF satellites. Since the GPS modernization program will address both military and civil requirements, a Memorandum of Agreement (MOA) was signed with the Department of Transportation. This MOA provides for formal civil participation in the modernization activities.

The Secretaries of Defense and Transportation jointly signed the latest revision of the Federal Radionavigation Plan. This plan outlines future policies for Government-provided radionavigation services for the foreseeable future and is updated biennially.

The Department completed a Presidentially mandated Broad Area Review that resulted from the three consecutive launch failures of the Titan IV system in 1999. Several of the resultant recommendations have been completed with the remaining items at various stages of completion.

In September 2000, DoD also restructured its Evolved Expendable Launch

Vehicle (EELV) program to include additional risk-reduction efforts. It increased technical personnel to provide Government oversight of critical processes. In April 2000, contractor-defined Critical Design Reviews for EELV systems were completed. In August 2000, DoD completed and received approval from the Department of State to support importing of technical drawing and manufacturing processes required to support U.S. coproduction of the RD-180 engine, still awaiting approval from the Russian government for license to export required documentation.

The interagency report on Future Management and Use of U.S. Space Launch Bases and Ranges was released on February 8, 2000. This report identified several key recommendations that have been incorporated into near-term plans of several agencies, including DoD, DoT, DoC, and NASA.

The DoD successfully launched 12 satellites using the Pegasus, Minotaur, Delta, Atlas, and Titan IV vehicles. The DoD successfully demonstrated the Minotaur launch system in January 2000. The Minotaur is a derivative vehicle using components of the Minuteman II vehicle.

In the areas of intelligence, surveillance, and reconnaissance, the Space Based Infrared System (SBIRS) made significant progress toward fielding the followon system to the Nation's Defense Support Program (DSP) missile launch early warning satellites. SBIRS is fielded in three increments. The technical difficulties in 1999 that had set back the transition to a new mission control station have been resolved. The program is now on a clear path to declaring an initial operating capability for the "SBIRS Increment 1" in November of 2001. Increment 1 consolidated the DSP's overseas ground stations located in Europe and Australia, with the old U.S. ground station into a single mission-control station located at Buckley Air Force Base, Colorado. The overseas sites were replaced with minimally staffed relay ground stations in order to realize savings in staffing, operations, and maintenance. The addition of the SBIRS High component, also known as "SBIRS Increment 2," has made significant progress in detailed design work for the key components of the system.

The Highly Elliptical Orbit (HEO) sensor payload, and the mobile multimission processors, both passed successful critical design reviews, paving the way to begin fabrication of HEO flight payloads and SBIRS mobile ground stations. The DoD also conducted requirements definition and trade studies for SBIRS low.

An integrated DoD Intelligence, Surveillance, and Reconnaissance (ISR) capability advanced considerably in 2000 with the publishing of the ISR Integrated

Capstone Strategic Plan. This plan affects both space and airborne collection systems and their ground processing and exploitation segments.

The DoD Space Test Program (STP) continued its 35-year legacy of enabling future DoD space superiority. STP had six launches during FY 2000, including three major satellite missions, using four different boosters plus the Space Shuttle. One of the major missions was Tri-Service Experiments-5, which carried a BMDO payload that has already proven the ability to detect from space nonafterburning threats such as cruise missiles. The Multi-Spectral Thermal Imager satellite was launched by STP in a partnership with DoE; it is now demonstrating state-of-the-art imaging technology for treaty monitoring, bomb damage assessment, and battlefield intelligence. The Air Force Research Lab and STP collaborated on the Mightysat II.1 mission. That spacecraft is proving the utility of an experimental hyperspectral imager on a low-cost light satellite.

DoD also completed an extensive review of the Space Control Mission Area and began the implementation of several of the recommendations from the review that the Deputy Secretary of Defense had directed. The primary area of emphasis was in space surveillance with the designation of the Air Force as the lead system integrator. The space control technology effort within the Air Force continued to identify and develop critical technology to meet DoD requirements.

The successfully completed Space Control Broad Area Review that was directed by the Deputy Secretary of Defense resulted in 26 specific taskings in 5 major areas: space surveillance, space system protection, space prevention, space negation, and operations. Efforts continued to supervise and track tasking accomplishments. Completion and approval of the results of the Space Surveillance Task Force (SSTF) was one of the significant accomplishments.

Federal Aviation Administration

FAA

The FAA continued in its mission to assure a safe, secure, efficient, and environmentally friendly civil air navigation and commercial space transportation system. During FY 2000, the agency performed and sponsored research and development programs to enhance the effectiveness of its mission; issued regulations and guidelines for better flight standards, operations, and maintenance; and provided equipment and training for a modernized air traffic control system.

During FY 2000, the FAA and NASA signed the "FAA-NASA Integrated Safety Research Plan," a guide for future research collaboration between the two agencies. This plan builds on existing safety research initiatives. It introduces the ability to analyze the combined research portfolios in a simple, easy-to-understand format, including making needed programmatic adjustments. It describes how both NASA and FAA will achieve ongoing communication and coordination with respect to safety research in pursuit of common safety goals. This plan provides the framework to enable both agencies to make complementary, coordinated investment decisions.

In FY 2000, human factors scientists conducted research to enhance the safety and efficiency of the National Airspace System (NAS) through improved performance of air carrier crews, general aviation pilots, aviation maintenance technicians, air traffic controllers, and NAS system maintenance technicians. The agency conducted aeromedical research with a focus on improving the health, safety, and survivability of aircraft passengers. The aviation medicine research program continued to support the 5-year National Institute for Occupational Safety and Health cabin environment study ordered by Congress. Research was conducted to address the FAA's goal for an equivalent level of safety for all aircraft occupants with targeted areas including seats/restraints for infants and small children, and side-facing seats in corporate aircraft. Researchers continued to investigate the nature of in-flight medical emergencies and the use of defibrillators on commercial flights.

During the past year, the air carrier-training program conducted Line Oriented Safety Audits to collect data on antecedents to crew error, errors (including errors made in automation usage), and responses to error. Air carriers continued to use the results to understand crew performance, develop training programs, and analyze accidents and incidents. The model used in this program is an integral part of the Aviation Safety Analysis Program, a confidential reporting system that flight crews use to report incidents to their carriers. The air carrier-training program also conducted research to collect and analyze data regarding the relationship between simulator platform motion and its impact on training effectiveness. The general aviation research program produced two CD-ROMs that focus on preflight and inflight decisionmaking. Taken together, these training tools help to make pilots aware of methods to improve their judgment by developing personal strategies to control risk. Aviation maintenance research designed and delivered to air carriers a job aid, providing best practices for the design, production, and use of technical information with recommended incorporation of simplified English.

In FY 2000, the FAA initiated new research to adapt the military's Human Factors Analysis and Classification System to assess aviation incidents and accidents. This project is integrated with a research project on human error by EUROCONTROL, a body established to harmonize air traffic in Europe. Research also addressed human-factor issues in runway incursions and completed a congressionally ordered review of the effect of fatigue and shift patterns in the air traffic control workforce. A new booklet entitled *Human Factors for Air Traffic Control Specialists: A User's Manual for Your Brain*, provides helpful information on memory, pilot/controller communication, and threats to performance. The Human Factors program continued to enhance the performance of screeners through the development of Threat Image Projection software. This software, which is for both carry-on and checked baggage, improves screener training and enhances awareness. The program developed a networked Screener Readiness Test to be used in support of the proposed rule for the Certification of Screening Companies.

During FY 2000, the FAA released an upgraded version of the Emissions and Dispersion Modeling System (EDMS 3.2). EDMS is designed to assess the air quality impact of airport emission sources, particularly aviation sources consisting of aircraft, auxiliary power units, and ground-support equipment. The Environmental Protection Agency (EPA) has formally accepted EDMS as the preferred air quality guideline model—EPA's highest ranking. EDMS is FAA's required model to perform air quality analyses for aviation sources. The FAA began development of a modeling System for assessing Aviation's Global Emissions (SAGE). The SAGE model is planned as a forecasting system with a global aircraft emissions module as its main component. The FAA, in cooperation with the EPA, NOAA, and NASA, developed a fact sheet on condensation trails, or "contrails," that are formed by aircraft in flight, describing the formation, occurrence, and effects of "contrails." Also, the FAA released an upgraded version of the Integrated Noise Model (INM 6.0). INM is the FAA's standard tool for assessing aircraft noise in the vicinity of airports; this is the most widely used model of its kind in the world.

In FY 2000, the FAA continued in its mission to develop and deploy products that prevent explosives, weapons, and other threat material from being introduced on to aircraft. Major areas of concentration included certification testing, checked and carry-on baggage screening, using bulk and trace explosives detection, human factors, aircraft hardening, Aviation Security Technology Integration (ASTI), and airport deployment of systems by the security equipment integrated product team. The Aviation Security Laboratory (ASL) conducted certification tests on the InVision CTX 9000Dsi Explosives Detection System (EDS) production unit and the L3 eXaminer 3DX 6000 unit. Both systems passed agency tests. Bulk detection research included additional work in quadrupole resonance and x-ray diffraction techniques. The ASL evaluated 2 new Explosives Trace Detection (ETD) models that are now deployed at over 170 locations.

Other activities in FY 2000 included development of quality control standards for deployed ETD systems. As an alternative for EDSs at smaller airports, ASL conducted an evaluation of directed trace. This involves x-ray identification of target items to be directly screened by trace systems. As a follow-on, the ASL initiated the Argus program for the development of a lower-cost EDS. This system would also be automated and have the same performance requirements, except for lower throughput. In the area of personnel screening, three ETD portal prototypes and the evaluation of two bulk detection portals were completed. The ASL evaluated several large cargo inspection systems and a large bulk EDS for break-bulk cargo.

The agency also established an explosives standard system (Trace Personnel Standard-Dry Transfer Method) enabling the evaluation of emerging explosives trace detection technology. In addition, the FAA completed the screener selection test assessment and fielded 6 perceptual and cognitive tests at 18 major U.S. airports. The objective was to develop a screener aptitude test to predict future performance of checkpoint security screener candidates. The FAA provided over 250 copies of the BlastFX software tool to Government agencies. Blast/FX is a self-contained software package that can be used to model and analyze the effects of a blast on facilities. The FAA also conducted two Radio Frequency Identification (RFID) Baggage Tag trials in conjunction with United and Continental Airlines. The tests provided critical operational performance information to support airline efforts to develop an international standard for RFID Baggage Tag use.

In FY 2000, the Aircraft Hardening Program conducted a series of explosive tests on B-737 and B-747 aircraft under pressurized conditions for the purpose of refining the vulnerability criteria for carry-on luggage. The program evaluated hardened luggage containers following flight trials. Blast tests with containers holding mail also were completed. The ASTI Program is developing a Systems Security Architecture which looks at the integration of a total airport security system. Work continued on the Airport Security Construction Guidelines project to provide a ready reference for security issues in new airport construction or for major renovations. The SEIPT deploys equipment at our Nation's airports. This fiscal year, 24 EDS's and 118 ETD's were installed. In addition, 476 TIP Ready X-ray (TRX) systems were procured for future installation.

During the fiscal year, the agency worked with the aviation industry to update the National Airspace System Plan through the year 2015. The plan is based on the "Free Flight" operational concept in which pilots may choose the most efficient and economical routes to their destinations. The agency continued to acquire new automation systems for the national airspace system by installing the Host and Oceanic Computer System Replacement at its 20 air traffic control centers and 3 oceanic centers. The system provides information on aircraft move-ments throughout domestic and oceanic airspace and is faster and more reliable than the predecessor system. The agency also deployed the Display System Replacement to 8 en route centers, replacing 30-year-old equipment and providing enhanced capability to display aircraft position, identification, and weather information, as well as to monitor and control system equipment and support planned enhancements to the air traffic control environment.

Following the successful use in FY 2000 of a system called the Surface Movement Advisor, which optimizes vehicular activity on airport pavement, the FAA made two major upgrades to its User Request Evaluation Tool (URET) at the Indianapolis and Memphis air route traffic control centers. URET provides controllers with automatic conflict detection, trial planning for assistance with conflict resolution or user requests, conformance monitoring of current flight trajectory, and some electronic flight data capability. FAA and NASA researchers also continued joint efforts on air traffic management systems that will enhance the capacity and efficiency of the national airspace system and enable Free Flight Phase 1. In addition, Air Traffic Control/Airway Facilities research, through collaboration with NASA and the Volpe National Transportation Systems Center, continued assessing the impact of shared separation procedures in a Free Flight environment on pilot and controller performance, workload, and situation awareness.

The Safe Flight 21 program, a joint Government/industry initiative designed to validate the capabilities of advanced communication, navigation, and surveillance, as well as air traffic procedures associated with free flight, began demonstrating Automatic Dependent Surveillance-Broadcast (ADS-B) technology. In July 2000, 25 aircraft from the Cargo Airline Association, the FAA, avionics manufacturers, universities, the U.S. Navy, and NASA participated in a flight demonstration to begin testing ADS-B. UPS Aviation Technologies Inc., a subsidiary of United Parcel Service, demonstrated its proposed avionics equipment in Bethel, Alaska. As a result of that test, the FAA awarded a $3.9 million contract to UPS Aviation Technologies for state-of-the-art avionics systems, installation kits, terrain databases, ground-based transceivers, an avionics-training simulator, and training assistance.

The FAA continued progress toward implementation of the Wide Area Augmentation System (WAAS) that will provide availability, integrity, and accuracy for the Global Positioning System (GPS) to be used for en route navigation and precision civilian navigation. During the fiscal year, the agency completed a series of Category I precision approach test flights at Iceland's Keflavik Airport, using signals from both the FAA's WAAS testbed and the United Kingdom's Northern European Satellite Test Bed. The FAA leased three ground reference stations and a master station to the Chilean government for flight testing satellite navigation in Chile. The Chilean government outfitted an aircraft with a GPS receiver to fly precision and nonprecision Category 1 Instrument Flight Rules (IFR) conditions at the Arturo Merino Benitez International Airport in Santiago. With support from the Civil Aviation Authority of Singapore, the FAA also installed and tested a WAAS test reference station at Singapore Changi Airport.

In FY 2000, the FAA developed and installed in all FAA, DoD, and National Weather Service Next-Generation Weather Radar (NEXRAD) systems, an advanced algorithm that detects tornadoes early in their development and shows where they will move. The agency installed on the prototype Integrated Terminal Weather System at the Orlando Terminal Radar Control a convective growth and decay forecast product, which not only predicts thunderstorm movement, based on the storm's track, but also includes the effects of storm growth and decay.

The FAA transferred to industry its Weather Support to Deicing Decision Making (WSDDM) system, a stand-alone integrated display system developed in response to industry's need for accurate, local weather data to plan and conduct airport deicing operations. The FAA began using the system at LaGuardia Airport in New York City. WSDDM uses Doppler radar, surface weather station data, and snow gauges located at and near the airport to determine precipitation type, temperature, wind speed and direction, and the liquid water equivalent of snow. The agency, in conjunction with industry, installed the first commercial infrared deicing facility at Newark International Airport in New Jersey.

The agency continued its development of a centralized database of these icing conditions and acquired data from several foreign locations, including South America, in order to facilitate a better understanding of worldwide Supercooled Large Droplet (SLD) icing conditions which affect aircraft flight safety. Also, the FAA sponsored investigatory efforts to assess the time of effectiveness of aircraft deicing fluids during various freezing precipitation conditions and, in conjunction with Transport Canada and industry, provided time of effectiveness information in a set of holdover time guidelines which are used by airlines worldwide.

During the fiscal year, the FAA and NASA expanded integrated efforts to reduce the fatal commercial accident rate by 80 percent by the year 2026. As part of its safety efforts, the FAA continued advanced research activities in a number of critical aviation safety areas. Based on stringent fire test criteria developed by FAA researchers, the FAA issued two major regulatory changes in FY 2000 regarding aircraft thermal acoustic insulation. An airworthiness directive requires the replacement of insulation blankets in over 700 aircraft. Also, a Notice of Proposed Rulemaking proposed new insulation fire test criteria which address both inflight fire resistance and postcrash fuel fire burnthrough protection. The FAA's focus on ground-based measures for fuel tank explosion prevention was bolstered by the findings of a detailed cost analysis completed in FY 2000 that demonstrated the cost-effectiveness of this concept.

In partnership with the Naval Air Systems Command and the Office of Naval Research, the FAA began development of Arc Fault Circuit Breakers (AFCB) which will replace thermal circuit breakers currently in use. Unlike thermal breakers, AFCB's can detect electrical arcing and rapidly remove power to the affected circuit, drastically reducing the chances of fire and related damage. AFCB prototypes were successfully tested aboard the FAA B-727. Also, in support of the Aging Transport Systems Rulemaking Advisory Committee (ATSRAC), the FAA completed intrusive wiring inspections of six recently retired transport aircraft. Researchers removed samples from the aircraft and subjected them to an extensive battery of laboratory tests.

In October 1999, the FAA William J. Hughes Technical Center subjected a fully instrumented narrow-body transport airplane fuselage section with an on-board conformable auxiliary fuel tank to a vertical drop impact test. Postcrash fuel-fed fire is a major contributor to the fatal accident rate. The objective of the test was to determine the interaction between a typical transport airplane fuselage, particularly its floor structure, and this type of fuel tank under severe, but survivable, impact conditions.

The agency completed construction of the full-scale Aircraft Structural Test Evaluation and Research facility which is being used to test fuselage panel specimens under conditions representative of those seen by an aircraft in actual operation. In FY 2000, the FAA released a computerized design tool, the Repair

Assessment Procedure and Integrated Design for Commuters (RAPIDC), that will improve the safety of airframe structures of commuter-size airplanes by implementing damage tolerance analysis techniques. The release of RAPIDC is in direct support of the agency's Notice Of Proposed Rulemaking on aging airplane safety.

Also in FY 2000, the agency released a software code called Design Assessment of Reliability with Inspection that is designed to improve the structural integrity of turbine engine rotor disks used in commercial aircraft engines by assessing rotor design and life management. The FAA and the Helicopter Association International developed and released a Web-based Maintenance Malfunction Information Reporting system which allows helicopter operators and repair stations to fulfill FAA Service Difficulty Reporting requirements and create manufacturer warranty claim forms. Researchers at the Airworthiness Assurance Center of Excellence located at the FAA Technical Center completed a first-generation, PC-version of XRSIM, which simulates radiographic (X-ray) inspection of aircraft components and is used during the development of inspection procedures to optimize radiographic inspections. The agency also developed the Web-based Air Personnel Module of Safety Performance Analysis System, which expedites the Aviation Safety Inspector's activities in the areas of certification, recertification, surveillance, and investigation by providing readily accessible information from a variety of data sources and highlighting important information.

In May 2000, in cooperation with the rotorcraft industry, the FAA released the Rotorcraft Damage Tolerance R&D Roadmap, identifying 10 critical research areas to support the implementation of damage tolerance requirements in the design and certification of rotorcraft components. In June 2000, the FAA completed the integration of the U.S. Army, National Transportation Safety Board (NTSB), and FAA rotorcraft accident/incident databases. It also utilized several mining technologies to perform problem identification and countermeasure evaluation for rotorcraft.

The FAA and several Title 14 Code of Federal Regulations (CFR) Part 121 air carriers developed a system engineering model of the generic functions of air carrier operations, the Air Carrier Operations System Model (ACOSM), Version 1.0. The ACOSM serves to support a systems approach to aviation safety oversight since it was used in the development of safety performance measures, risk indicators, and data objects; work processes to support the collection of data for analysis; and analytical methods, including information presentation. The model also provides a common definition of air carrier processes and terminology to promote understanding of air carrier operational activities and functions.

In October 1999, the FAA and the Boeing Corporation completed the first set of full-scale pavement response tests at the National Airport Pavement Test Facility that was designed to provide high-quality, accelerated test data from rigid and flexible pavements subjected to simulated aircraft traffic. Full-scale traffic testing started in February 2000.

The FAA established a Video Landing Loads Facility at Atlantic City International Airport where high-resolution video images of typical landings are recorded. Researchers analyzed digitized images to obtain landing contact parameters, such as sink speed, velocity, pitch, roll, and yaw. This facility provides typical usage data to characterize the landing load environment for a wide variety of airplane models in both good and bad weather conditions at this airport. At the end of the fiscal year, over 800 video images had been captured.

The FAA published its initial commuter airplane Operational Loads Monitoring report, “Statistical Loads Data for BE-1900D Aircraft in Commuter Operation.” The output from the Operational Loads Monitoring research provides validation for airframe certification requirements and advisory materials. This research independently assesses the original equipment manufacturers’ design assumptions and aircraft usage analysis. Also in FY 2000, the FAA published an Operational Loads Monitoring report for the B-767ER airplane.

In conjunction with Sandia National Labs, the FAA completed a reliability study of an interlayer crack inspection technique commonly used on older aircraft. The study found that target flaw sizes around 0.2 inches were not being found reliably. Briefings with industry and the Aircraft Certification Office have led to efforts to reassess specific inspection requirements. FAA sponsored research that resulted in development of a new nondestructive testing technique and a prototype, the Meandering Winding Magnetometer. This technology has been proven to be superior to other techniques for finding cracks in areas of engine disks, which have experienced fretting damage. In addition, the FAA with Sandia National Labs, Textron, and Federal Express personnel installed composite doubler repairs on two DC-10 aircraft in the FedEx fleet. This is the first use of bonded composite doublers as permanent repairs for skin damage in commercial aircraft. Also, during the fiscal year, FAA with Iowa State University developed a prototype semiautomated tap test system with imaging capability and turned this system over to industry for beta testing.

The initial research effort by the FAA's Airworthiness Assurance Center of Excellence to investigate copper and silver sulfide deposits on fuel quantity indication systems (such as what apparently contributed to the TWA flight 800 accident) was completed and a report issued. The deposit growth mechanism has been characterized and reproduced in the laboratory, and ignition of fuel across the reproduced deposits with DC current has been demonstrated in the laboratory.

Research on the risk arising from an uncontained engine failure has resulted in the release of a beta version of the uncontained engine debris damage assessment model. This software tool utilizes engine fragment trajectory data derived from actual events to predict the risk to an aircraft's critical flight systems. Researchers continued to evaluate generic airplane designs with this tool in support of an Aviation Rulemaking Advisory Committee.

In FY 2000, the FAA issued a Wildlife Control Manual that provides means to mitigate the wildlife threat. This manual is based on extensive research over the last 10 years.

In FY 2000, the FAA and the general aviation industry continued their collaborative efforts to find a new fuel to replace current leaded aviation gasoline. The FAA role is testing and evaluating of industry-supplied fuels. FAA's piston engine testing capability was significantly upgraded at the William J. Hughes Technical Center with the addition of a new dynamometer and control system, as well as a temperature/humidity conditioned air supply for the main test cell. These improvements will enable more timely responses on the part of FAA as new fuel formulations are provided for evaluation. Testing began on an experimental fuel formulation supplied by Exxon Research.

FAA's Office of Commercial Space Transportation licensed two successful space launches by Sea Launch during the fiscal year. These were the first licensed launches without any involvement from a Federal launch range. Overall, there were 18 launches during the fiscal year that were FAA licensed as commercial, although 2 were failures. The agency also issued a launch operator license to Orbital Sciences Corporation for the first commercial launches from Kwajalein

Missile Range operated by the U.S. Army in the Marshall Islands, and renewed five launch operator licenses.

The FAA and NASA signed a Memorandum of Understanding Concerning Future Space Transportation Systems which describes the FAA/NASA cooperative activities that will be conducted under the category of Future Space Transportation Systems and Reusable Launch Vehicle (RLV) Technology, Research, and Development. Also, the agency and its Commercial Space Transportation Advisory Committee released the 1999 Commercial Space Transportation Forecasts, which projects an average total of 51 commercial space launches per year through 2010, an increase of over 40 percent from the 36 commercial launches conducted worldwide in 1998. In addition, the agency issued final rules on financial responsibility requirements for licensed launch activities and commercial transportation licensing regulation. FAA also issued Notices of Proposed Rulemaking on commercial space transportation reusable launch vehicle and reentry licensing regulation, licensing and safety requirements for operation of a launch site, and financial responsibility requirements for licensed reentry activities. Also in FY 2000, the FAA published a draft *Programmatic Environmental Impact Statement for Commercial Launch Vehicle Programs* as part of its responsibility under the National Environmental Policy Act.

Department of Commerce

DoC

In FY 2000, 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, civilian and commercial space policy support, and trade promotion. The National Oceanic and Atmospheric Administration (NOAA) was involved in many space activities. In September 2000, NOAA's National Environmental Satellite, Data, and Information Service (NESDIS) launched the Nation's newest polar-orbiting environmental satellite, NOAA-16, from Vandenberg Air Force Base in California. It replaced the 6-year-old NOAA-14 and improves weather forecasting and monitoring of environmental events around the world. In the United States, NOAA's National Weather Service uses the data primarily for long-range weather and climate forecasts. It is the second in a series of 5 polar-orbiting satellites with improved imaging and sounding capabilities that will operate over the next 10 years. The direct broadcast, on a free and open basis, of Advanced Very High Resolution Radiometer (AVHRR) instrument data provides imagery to scientific, commercial, and educational groups throughout the world. In addition, the search and rescue instruments on NOAA-16 will continue to support a global community that has established ground stations that "listen" for distress beacons relayed through the NOAA polar and Russian Cospas satellites. Also, new development of microwave instrumentation from NOAA-15 has enabled NOAA short-term weather forecasting and warning programs to measure moisture in the atmosphere for identifying conditions conducive to heavy precipitation.

Geostationary Operational Environmental Satellite (GOES)-11, launched on May 3, 2000, was stored in orbit, ready to replace GOES-8 or -10, which are stationed at 75 degrees east and 135 degrees west, respectively. If one of them fails, GOES-11 can be put into service without delay and provide expected delivery of data within 2 days of activation. GOES-8 continued to overlook the East Coast of North and South America and out over the Atlantic Ocean. GOES-10 continued to overlook the West Coast and out over the Pacific Ocean, including Hawaii. Similar to the other operational GOES, GOES-11 will be used to monitor Earth's atmosphere and surface to support NOAA's forecasting and warning programs. Following the launch and testing of the spacecraft, NOAA developed capability to process and disseminate the new data stream.

As part of NOAA's share of convergence of DoC and DoD meteorological satellite programs, NESDIS continued to operate the Defense Meteorological Satellite Program (DMSP) satellites. During the course of the year, five DMSP satellites provided atmospheric, ocean, and space weather measurements to operational forecast centers. In part from these satellites, NESDIS' data centers continued to provide useful new products for public and Government use. The National Geophysical Data Center (NGDC) used lights seen in DMSP images recorded at night to monitor possible power problems during the Y2K transition from December 31, 1999, to January 1, 2000. DMSP data were also used, for the first time, to support weather forecasts for the Olympic Games in Australia. DMSP nighttime imagery also was used to monitor wildfires in remote areas in Asia and middle America. NGDC also provided input on the near real-time transmittal of DMSP low-resolution Operational Linescan System (OLS) data to Singapore for use in the Program to Address ASEAN Regional Transboundary Smoke (PARTS). In addition, OLS data transmittal to Singapore commenced in March 2000 on a daily basis.

The Director of NESDIS' National Climatic Data Center (NCDC) was a coauthor of a chapter on climate variability and change in a report of the Intergovernmental Panel on Climate Change. Publication of the final report is expected to occur in May 2001. NCDC also continued its activities in climate monitoring by providing leadership in overseeing, as lead editor, the World Meteorological Organization (WMO) *Guide to Climatological Practices* and in coordinating the WMO Global Climate Statement.

NOAA, in collaboration with the U.S. Coast Guard, U.S. Air Force, and NASA, continued to lead the national Search and Rescue Satellite-Aided Tracking (SARSAT) and the international Cospas-Sarsat programs. The

SARSAT program uses search and rescue payloads on NOAA and Russian satellites to detect emergency beacons used by aviators and mariners in distress. In FY 2000, the SARSAT program contributed to the rescue of 227 lives. Since its inception in 1982 over 11,000 lives have been rescued as a result of the Cospas-Sarsat System. In October 1999, Cospas-Sarsat decided to phase out by 2009 satellite processing of 121.5 MHz emergency signals in response to international guidance, in favor of emergency beacons operating at 406 MHz.

In FY 2000, NOAA repositioned the surplus spacecraft GOES-7, which was launched in 1987, to 175 degrees east longitude. This was done to support the Pan-Pacific Education and Communications Experiment by Satellite (PEACESAT) program, which is a public service satellite telecommunications network that links educational institutions, regional organizations, and governments in the Pacific Islands region. The PEACESAT program, a partnership with the University of Hawaii, uses a NOAA command and telemetry processor that is no longer needed to operate the newer GOES satellites.

Within NOAA's Office of Oceanic and Atmospheric Research (OAR), a number of aeronautics and space activities occurred within the Space Environment Center (SEC) in Boulder, Colorado. The SEC provided real-time monitoring and forecasting of solar and geophysical events, conducted research in solar-terrestrial physics, and developed techniques for forecasting solar and geophysical disturbances. SEC's Space Weather Operations Center is jointly operated by NOAA and the U.S. Air Force and serves as the national and global warning center for disturbances that can affect people and equipment that operate in the space environment. This past fiscal year, the SEC continued to upgrade physics-based numerical models, which are used to produce operational space forecasts. The center also won a Hammer Award from Vice President Al Gore as part of the initiative for reinventing Government for its work incorporating data obtained from its sensors on NASA satellites into its operational forecasts and disseminating these data on the World Wide Web. The SEC also improved its Web site to distribute space weather information to interested users. It has the only full-time space weather forecasting office in the world, and the forecasts are crucial to the telecommunications industry, astronauts, power companies, weather satellite operations, and users of GPS. The SEC disseminated to the public the first real-time images of the magnetosphere/ionosphere response to changing space weather conditions. These images will enable new research and development activities that will lead to improved space weather monitoring and predictive capabilities. Additionally, OAR continued to use the wide range of satellite data products developed by NOAA and other agencies. Scientists continued to use these products in the fields of oceanography, air quality, water resource management, severe storm prediction, and climatology. Also, the NESDIS GOES and Polar-orbiting Environmental Satellite (POES) instruments monitored changes in the near-Earth space environment due to bursts of energetic particles and fields from the Sun. During a peak in solar cycles, GOES and POES measurements made critical contributions to space weather forecasts. Finally, in anticipation of improving weather monitoring and prediction, OAR continued using GPS with meteorological observations, including COSMIC (occultation) and the use of ground-based GPS sites Continuously Operating Reference System (CORS) to continuously measure the 3-D distribution of precipitable water vapor in Earth's atmosphere, to continuously measure total electron content in Earth's ionosphere, and to monitor other space weather phenomena.

NOAA continued its international activities and cooperation over the course of FY 2000. In particular, NESDIS involvement with activities associated with the Committee on Earth Observation Satellites (CEOS) contributed to the establishment of the ad hoc Disaster Management Support Group (DMSG). The objective of the group is to maintain momentum for activities in disaster management support and to move toward the demonstration of coordinated space agency responses and development of suitable response models. The Director of NESDIS's Office of Satellite Data Processing and Distribution (OSDPD) chairs the group. NESDIS also hosts the Secretariat in support of the DMSG. In September, NESDIS presented its activities in Earth observation education and training at a meeting and workshop of the CEOS ad hoc Working Group on Education and Training in Dehra Dun, India. This group is assessing technology trends and the consequent need for Earth observation education and training—especially in developing countries. In addition, NOAA provided continued support to the CEOS Working Group on Information Systems and Services and worked with the National Institute of Standards & Technology (NIST) to organize a working group meeting for the CEOS Calibration-Validation Working Group.

NOAA's CEOS involvement at the 5th Integrated Global Observing Strategy (IGOS) Partners Meeting contributed to progress on theme concept development. NESDIS' Oceanic Research and Applications Division Chief participated on the team that developed a prototype Oceans Theme, which NASA produced as a brochure. NESDIS, earlier in the year, had indicated its readiness to contribute to development of operations for follow-on Jason altimetry missions. NOAA scientists are participating in the development of IGOS Coral Reef/Coastal, Global Carbon Cycle, and Water Cycle Themes.

Throughout FY 2000, NESDIS responded to requests from the White House, U.S. Department of State, U.S. Agency for International Development (USAID), and in some instances, the United Nations or foreign governments, to provide data or information products for assistance in responding to various stages of disaster. The response activity included floods in Mozambique, Venezuela, and Vietnam; wildfires in Bolivia and Ethiopia; and drought in central Asia and the horn of Africa. NESDIS continued to support multiyear projects that are funded by USAID to work with colleagues in Brazil and Bolivia on satellite-derived wildfire applications. NESDIS was further involved in implementation of Hurricane Mitch recovery and development activities in Central America with the countries of Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, and Panama. NESDIS continued to play an important role in a number of interagency and international disaster-planning activities, such as the Subcommittee on Natural Disaster Reduction (SNDR), which is under the White House Committee on Environment and Natural Resources (CENR). At the request of USAID, NESDIS continued to participate in the U.S. Government-sponsored Hurricane Mitch reconstruction and development project in Central America. NESDIS' participation was part of a Department of Commerce initiative that involves installation of a regional satellite ground receiving station in Costa Rica. In addition, funding has been obtained to install a network of satellite display systems in six additional countries in Central America to display and analyze GOES satellite data and products from the Costa Rica ground station. This is meant to enhance access to, and use of, GOES satellite imagery by the national meteorological and hydrological agencies in Central America for weather and flood forecasting, and also disaster preparation, management, and mitigation. As requested by USAID in Brazil, NESDIS continued to work with the government of Brazil, using satellite imagery to detect wildfires that threaten the Amazon rainforest.

NESDIS staff gave presentations at the Third International Conference of the Global Disaster Information Network (GDIN) held in Ankara, Turkey. On

April 27, 2000, President Clinton signed an Executive Order that established GDIN activities within the United States and affirmed a commitment to support international GDIN activities. The Executive Order designated NOAA, the U.S. Department of State, and the Office of the Vice President as cochairs of an interagency committee to implement GDIN throughout the U.S. Government. NESDIS continued to serve an important role for support and implementation of GDIN.

The pace of NOAA's commercial remote sensing licensing work accelerated in FY 2000 and proved to be the busiest ever for such activities. NESDIS approved five foreign partnership agreements and six amendments to current licenses. In August 2000, NOAA issued its much-awaited new private remote-sensing regulations that provided the regulated community with increased transparency and predictability in the licensing process. The year also saw a major focus on outreach activities, with the Assistant Administrator meeting twice with NOAA licensee CEOs to discuss issues affecting the industry. This included hosting a Senior Executives Forum on Commercial Remote Sensing in conjunction with the United States Space Foundation and the National Space Symposium. Finally, the RAND Corporation conducted a commercial remote-sensing industry-wide risk assessment that will offer an objective view of the technical, regulatory, and market risks confronting this nascent industry.

NOAA's National Ocean Service (NOS) continued to use both remote sensing technology and the Global Positioning System (GPS) to meet its mission of mapping the national shoreline, producing airport obstruction charts, and monitoring and analyzing coastal and landscape changes. In its use of remote-sensing applications, the office has benefited from the development of high-performance, low-cost workstations and the advent of digital imagery, which has revolutionized the evolution of three-dimensional surface models and other derived products (such as orthophotographs) in support of NOAA's coastal mapping and airport survey programs. In FY 2000, NOS's National Geodetic Survey (NGS) collaborated with the U.S. Air Force to complete a high-resolution, three-dimensional mapping project at Cape Chiniak on Kodiak Island in Alaska. The goal was to explore the use of digital photogrammetric techniques of digitized aerial photographs for the production of a LEVEL-5 digital topographic elevation data product, in an area with complex terrain. NGS has demonstrated that photogrammetric procedures can deliver with ease, high-resolution digital surface model data that are accurate to the submeter level.

NGS has traditionally used only airborne photography for mapping missions. The advent of high-resolution, space-borne imagery is useful for precision (better than 5 meters) mapping projects. Beginning in FY 2000, NOAA/NGS acquired SPIN-2 data (a trademark for Russian digital ortho-rectified, geo-coded imagery data) with a resolution of approximately 2 meters, acquired from Microsoft's TerraServer. This server is an online database that offers free public access to maps and aerial photographs of the United States through partnership with the U.S. Geological Survey. NGS used this data to assess the need to acquire high-resolution, metric-quality photography over specific areas under their Coast and Shoreline Change Analysis Program. Such updated information will be used to aid in updating nautical charts produced by NOS's Coast Survey. Additionally, IKONOS and Indian Remote Sensing (IRS) satellite data, acquired from Space Imaging, are used in conjunction with SPIN-2 data. IRS 5-meter-resolution satellite data also was acquired to access shoreline mapping for Charleston, South Carolina.

Currently, Airborne Visible and Infrared Imaging Spectrometer (AVIRIS) data are being assessed for shoreline mapping, coastal change detection, and airport obstruction charting. This past year, the AVIRIS sensor was flown in the NOAA Twin Otter, which was the first low-altitude operational use of this sensor. The results provided 2- and 4-meter resolution. The integration of the image data with GPS and inertial navigation technologies enabled NASA Jet Propulsion Laboratory engineers to construct high quality scenes for NOAA.

Light Detection and Ranging (LIDAR) was tested in a wide variety of applications including assessing storm damage to beaches, mapping the Greenland ice sheet, and measuring heights within forest timber stands. NGS explored the possibility of integrating LIDAR into the production of shoreline mapping and airspace obstruction charts.

The NGS continued to evaluate the use of RADARSAT data to delineate shorelines. In addition, NGS experimented with satellite-based Synthetic Aperture Radar (SAR). Since SAR is largely unaffected by the presence of dense cloud cover, it can offer substantial benefit to acquisition of data for shoreline mapping in areas such as Alaska.

The largest effort for NGS in FY 2000 was active outsourcing of its photogrammetric processes, including the acquisition of aerial photography. This past year, NGS held its first outsourcing workshop, which allowed contractors to learn first-hand about NGS mapping and surveying programs. Topics covered included aerial photography over airports, aerial photography over U.S. shorelines, geodetic control at airports, shoreline mapping, and height modernization projects.

In addition, NOS's Coastal Services Center (CSC) utilized LANDSAT Thematic Mapper (TM) imagery to produce land cover data sets and to determine landscape changes in coastal Massachusetts, New Hampshire, Rhode Island, and North Carolina. CSC contributed to procurement of LANDSAT TM imagery for use in land cover analysis in Hawaii and brown marsh analysis activities in coastal Louisiana. NOAA's Coastal Change Analysis Project (CCAP) has also used this type of data in conjunction with aerial imagery, to assess the health of the Chesapeake Bay, and in particular, the land loss in the Blackwater area.

NGS also procured French Satellite Pour l'Observation de la Terre (SPOT) multispectral imagery for use in analyzing the brown marsh phenomenon. OrbImage SeaWiFS imagery, in conjunction with NOAA Coastwatch and NOAA National Centers for Coastal Ocean Science (NCCOS), assisted in determination and monitoring of harmful algae bloom transport within the Gulf of Mexico. NOAA Advanced Very High Resolution Radiometer imagery was also used to determine turbidity and sea surface temperature in coastal regions of the United States.

NOAA/NGS continued to advance the use of GPS for centimeter-level positioning through its National CORS Program. At the end of the fiscal year, the National CORS network contained over 200 sites and was increasing at a rate of approximately 3 new sites per month. In FY 2000, NOS initiated the Cooperative CORS program enabling States and local institutions that have established their own CORS sites to make their associated GPS data more accessible to the public. Space Weather Total Electron Content provides a measure of the ionospheric disturbance, which affects radio signals, including those used for navigation, such as GPS signals. NOS derives maps of Total Electron Content from the observations of GPS receivers in the National CORS network and from globally distributed International GPS Service for Geodynamics stations. The technique developed by NOS to model the ionosphere was a direct result of NOS efforts to account for positioning errors inherent in the GPS signal.

In addition, NGS continued leading a program, termed Height Modernization, which utilizes GPS to efficiently provide accurate, consistent elevation information for a wide variety of activities Nationwide. Traditionally, "elevation" meant height above mean sea level (technically referred to as orthometric height). In its most accurate definition, "elevation" is defined as a height above a surface called the "geoid." The geoid is a very complex surface, defined by variations in Earth's gravity field (encircling the entire planet) and which is nearly identical to mean sea level over the oceans. However, GPS elevations are heights above an "ellipsoid," a simple geometric surface that differs from the geoid in its simplicity. As such, one significant element of Height Modernization is to provide an accurate model between the ellipsoid and the geoid. The objective is to achieve GPS elevations that are consistent with the more traditional "elevation"—often known as sea level. Height Modernization and GPS will make significant strides in providing more robust height measurements for users of GPS. Activities relying on these height improvements include mapping vertical measurements—flood mapping, positioning of ships in three dimensions, and accurate port water-level information for safe and efficient transportation into U.S. ports, and air navigation.

NOS also computed precise GPS orbits (satellites location) to an accuracy of 7 centimeter (cm) Root Mean Square (RMS) in support of users of the National Spatial Reference System and is working toward achieving an accuracy of 5 cm RMS. Such orbits are needed for users requiring submeter positioning. NOS makes the orbits available in a timeframe that meets users' requirements, including a rapid product (8-14 cm accuracy) available within a 16-hour turnaround, and a more accurate product available within 7 to 10 days of data collection. The GPS orbits are computed using station coordinates and velocities derived in the International Earth Rotation Service (IERS) Terrestrial Reference Frame (ITRF). The GPS orbital data are available without cost and can be retrieved from the Internet.

Also at DoC, the Technology Administration (TA) continued to engage in a number of space-related activities through the Office of Space Commercialization (OSC) and NIST. During FY 2000, OSC concentrated the majority of its resources on issues related to satellite navigation and the U.S. GPS. This included participation in numerous interagency working groups, steering groups, review teams, and executive committees in support of the Interagency GPS

Executive Board (IGEB), established by President Clinton to manage GPS as a national asset. DoC, represented by TA and NOAA, serves on the IGEB as a key advocate for the commercial, scientific, and governmental users of GPS.

Through the IGEB process, both OSC and NOAA participated in interagency deliberations leading to major GPS-related decisions, including the deactivation of GPS Selective Availability (SA) in May 2000 and the acceleration of the GPS modernization program. The SA decision was announced at a White House press conference featuring remarks by NOAA Administrator James Baker and through a press release by Secretary of Commerce William Daley—both hailing it as an important advance for commercial GPS users. Afterwards, NOAA monitored and evaluated the newly improved GPS performance and published the results on its public Web site. This effort was important in promoting the global benefits of the White House decision.

OSC continued to participate in ongoing talks between the United States and Europe on potential cooperation in satellite navigation, helping develop negotiating strategies and draft agreement language, and serving on official U.S. delegations led by the Department of State (DoS). OSC hosted one round of the U.S.-European talks as well as several meetings with U.S. industry to hear its views on the subject. OSC also participated in a round of GPS-related consultations with Russia (again led by DoS) and a number of outreach missions to Belgium, Denmark, Sweden, Finland, Spain, and Portugal. During these international meetings, OSC provided educational briefings to Government and industry representatives on international GPS markets and applications.

OSC played a lead role in the implementation of the IGEB Executive Secretariat, the permanent office that provides day-to-day staff support to the IGEB and its working groups. With the support of the Under Secretary for Technology, OSC significantly increased its commitment of personnel, office space, and other resources to the IGEB Executive Secretariat, helping solidify its legitimacy and visibility within the national GPS management structure. Among other things, OSC provided a Director for the IGEB Executive Secretariat and funding to support a major GPS industry trade fair on Capitol Hill. OSC created and hosted the highly popular IGEB Web site. OSC also provided drafting assistance to congressional staff on legislation enabling DoC to accept funding from interagency sources in order to support the IGEB Executive Secretariat. NOAA also continued to support the IGEB Executive Secretariat by assigning personnel to serve in the office and participating in the GPS trade fair.

In the area of satellite imaging, OSC, NOAA, and the International Trade Administration's (ITA) Office of Aerospace (OA) continued to represent commercial interests as part of the Remote Sensing Interagency Working Group (RSIWG). Led by the DoS, 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 RSIWG completed agreements with Japan, Canada, and Spain in FY 2000.

OSC and OA continued to actively support the Office of the U.S. Trade Representative (USTR) and its working groups in developing options for handling trade with Russia, China, and Ukraine in the area of commercial space launch services. In June 2000, OA participated in the termination of the U.S.-Ukraine agreement and in annual consultations with Russia that led to its ultimate expiration on December 31, 2000. These efforts created a more open market environment in this important trade sector.

OSC and OA continued to support the ongoing work of the White House-led Interagency Working Group on Future Management and Use of the U.S. Space Launch Bases and Ranges. The review will examine the appropriate division of responsibilities for bases and ranges between the Government and commercial sectors. Working closely with the FAA, OSC and OA solicited and collected private-sector views on this subject and continued efforts to integrate these into a national strategy for launch range management.

During FY 2000, NIST delivered to NASA's Johnson Space Center an efficient, reliable laboratory version of a pulse-tube oxygen liquefier for use in rockets to bring rock samples from Mars to Earth. New concepts were used in the system, and it performed according to NIST models, yielding one of the highest efficiencies ever achieved in cryocoolers.

With support from the U.S. Air Force, NIST assisted in efforts to develop microscale heat exchangers for use in compact cryocoolers to cool infrared detectors on satellites. These heat exchangers should be at least an order of magnitude smaller and lighter than more conventional heat exchangers. NIST also provided technical guidance to Northrop Grumman and Lockheed Martin in their research and development of cryocoolers for the Spaced-Based InfraRed System in low-Earth orbit (SBIRS-Low).

Using cofunding from NIST's Advanced Technology Program (ATP), 3M and Lockheed Martin formed a joint venture to develop a nonhazardous alternative for aircraft exterior spray paint. This alternative, known as Paint Replacement Film (PRF), consists of an advanced "peel and stick" polymer film with a pressure-sensitive adhesive, and has a unique potential to reduce aircraft drag and reduce fuel consumption. A commercial long-haul aircraft, sheathed in the film, could save $250,000 or more a year in fuel, require less corrosion maintenance, and provide more color and pattern options for commercial aircraft. During FY 2000, PRF began undergoing large-scale flight evaluations on a variety of commercial and military aircraft.

In projects funded by the U.S. Air Force and FAA, NIST embarked on research to assess the flammability and physical properties of clay nanocomposites when used in aircraft parts. Clay nanocomposites improve the parts' mechanical properties, especially when subjected to extreme heat, and reduce the need for environmentally problematic flame-retardants. With funding from NASA, NIST continued its comprehensive research on fires and fire suppression in microgravity environments. These projects better characterize the ignition, spread, and suppression of fires in the microgravity of space, helping to protect astronauts and their spacecraft. With support from DoD, NIST continued to search for effective and environmentally friendly alternatives to halon for aircraft fire protection. In other work funded by NASA and FAA, NIST researchers evaluated the performance of new technologies for detecting fires in aircraft cargo spaces.

In the area of timing, NIST continued to support the Primary Atomic Reference Clock in Space (PARCS), a laser-cooled cesium clock being developed for deployment aboard the International Space Station. The PARCS project, which has completed its first two NASA reviews, was scheduled to fly in early 2005. In addition, NIST continued to provide synchronization support for NASA's Deep Space Network, used for space navigation.

The NIST force calibration facilities, which include a unique deadweight stack of 1 million pounds of weight, continued to allow NASA and other aerospace organizations to reliably measure propulsive force. This facility dates back to the original space race of the 1950's and 1960's. Other NIST facilities continued to provide the U.S. aerospace industry with world-class measurement services for the mechanical quantities of mass, acceleration, shock, sound pressure, and ultrasonic power.

OA took the lead role in seeking resolution of the dispute over a European Union (EU) regulation restricting the registration and operation of aircraft modified with noise-suppression technology, including aircraft engine "hush kits" and replacement engines. OA and other Federal agencies participated in bilateral negotiations with the EU seeking withdrawal of the regulation. In March 2000, following the failure of intensive high-level bilateral negotiations, the United States initiated dispute settlement proceedings in the International Civil Aviation Organization under Article 84 of the Chicago Convention.

OA participated in an interagency effort that led to the Czech government providing a tariff waiver for large civil aircraft, helicopters, and certain spare parts. The waiver eliminated for 1 year the 4.8-percent tariff differential between U.S. and EU aircraft. The Czech government confirmed its intention to join the WTO Trade in Civil Aircraft Agreement (which, among other things, binds tariffs on aircraft and parts to zero) as part of any future multilateral trade negotiations.

OA played an active role in the Export-Import Bank's approval of $143 million in financing to support the installation of U.S. engines, avionics, parts, and equipment into Russian-designed and manufactured Ilyushin-96T cargo aircraft. This action marked a milestone in aviation history and the final hurdle in the realization of a dream to foster U.S. and Russian aerospace cooperation. The ITA-established U.S.-Russia Business Development Committee Aerospace Subgroup had been working toward this goal since the opening of the Russian market.

In FY 2000, OA continued to assist the U.S. aerospace industry in competing in the global marketplace. To promote the export of U.S. aerospace products, OA sponsored Aerospace Product Literature Centers at major international exhibitions and air shows in China, Germany, Malaysia, Singapore, South Africa, Russia, the United Arab Emirates, and the United Kingdom. Trade leads generated through this program totaled more than 10,000. OA worked closely with the overseas posts to maximize the exposure of small- and medium-sized U.S. companies to the export market in these events.

In May 2000, OA organized and managed an aerospace executive trade mission to Rio de Janeiro, Brasilia, and Sao Paulo, Brazil. Over 20 U.S. business representatives attended the mission, which arranged high-level meetings with Brazilian government and industry aerospace officials. The program also arranged one-to-one meetings for each of the participants, and several identified local representatives, agents, or distributors, or negotiated sales contracts during the mission.

OA sponsored a Government briefing attended by over 100 U.S. aerospace industry representatives on the relationship between e-commerce and the aerospace industry. OA and the ITA Advocacy Center supported U.S. companies in international aerospace competitions, including helicopters, commercial transport aircraft, remote-sensing satellites, and space launch vehicles.

OA and ITA's Advocacy Center supported U.S. companies bidding for international aerospace contracts. The competitions spanned all areas of the aerospace industry including space launch vehicles, commercial aircraft, helicopters, and air traffic management projects.

The March 15, 1999, implementation of the 1998 National Defense Authorization Act provision that moved export licensing jurisdiction for commercial communications satellites from the DoC to the DoS has harmed U.S. satellite and related component manufacturers. The movement of jurisdiction has also resulted in substantial backlash from potential foreign buyers of U.S. satellites. U.S. satellite manufacturers continue to lose contracts and business to foreign suppliers. As an example, during 2000, publicly reported orders of U.S.-made geostationary satellites dropped from 16 in 1998 to 13, while orders for European spacecraft rose from 6 to 16 during the same period. Satellite and security experts believe that a weakened satellite industry will jeopardize America's global surveillance, reconnaissance, and communications network. Satellite manufacturers have detailed many of these problems in testimony to Congress. Lockheed Martin reported that long-time customers, such as Japan, are looking to European manufacturers for meeting future satellite requirements. Boeing Satellite Systems and Loral Space and Communications have reported similar foreign market reactions. Foreign buyers want to retain a choice in launch service providers, and they want predictability and timeliness in delivery schedules; this includes the licensing process.

The congressionally mandated movement of all commercial satellites to DoS's jurisdiction has resulted in the plummeting of U.S. global market share from 73 percent to 42 percent. The DoS's licensing function continues to be unable to process commercial satellite export license applications in a timely and certain manner. Under the monitoring provisions of the legislation, the DOD and DOS have been forced to require U.S. manufacturers to obtain DOS-issued Technology Transfer Agreements for the launch support of satellites previously licensed by the DoC, even when the customers or the launch service providers have been NATO allies.

Department of the Interior

DoI

The first full year of Landsat-7 operations under joint U.S. Geological Survey (USGS) and NASA Landsat Program Management was very successful. The USGS assumed responsibility from NASA for flight operations for the Landsat 7 satellite, expanding the long-standing role of the USGS in the Landsat program that includes processing, archiving, and distributing data from Landsats 1 through 7. Since its launch in April 1999, Landsat 7 has carried out the mission objective of building a seasonal global archive of data by capturing more than 300,000 scenes of Earth for the U.S. and a growing network of 14 ground stations operated by 8 international cooperators. Landsat 7 extends an important long-term record of Earth's land and near-shore areas for environmental research and applications such as forestry, agriculture, geology, land cover classification, and geographic research.

At the end of FY 2000, NASA and USGS were assessing four funding and management options for the follow-on to Landsat 7, known as the Landsat Data Continuity Mission (LDCM). As specified by the Land Remote Sensing Policy Act of 1992, these options were private-sector owned and operated; a U.S. Government-private sector cooperative effort; a U.S. Government-owned and -operated system (Landsat-7 model); and an international consortium. NASA and USGS drafted and distributed for public review a specification that defines the characteristics of data that would be expected from any LDCM operator, no matter which funding/management option is chosen.

The USGS Earth Resources Observation Systems (EROS) Data Center Earth Observing System (EOS) Distributed Active Archive Center (DAAC), which is funded by NASA, began receiving data successfully from the Terra satellite during FY 2000. Data from the Moderate Resolution Imaging Spectroradiometer (MODIS) and the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) sensors were processed by systems at the NASA-Goddard Space Flight Center and in Japan, respectively, and then sent to the EROS Data Center DAAC. MODIS data were released to the public in early spring 2000.

The USGS and Satellite Pour l'Observation de la Terre (SPOT) Image Corporation agreed to make more than 700,000 historical SPOT satellite images acquired over the United States from 1986 through 1998 available to other Federal agencies. These data are being permanently archived at the USGS EROS Data Center, where they will be distributed to Federal research and operational users at the cost of reproduction, plus a royalty fee paid to SPOT Image Corporation. SPOT data complement the USGS Landsat archive by substantially increasing the number of available low-cloud-cover images and by filling gaps in Landsat coverage. SPOT data are used for applications such as environmental research, forestry, agriculture, geology, and land-cover mapping.

DoI personnel continued to use both the DoD Navstar GPS Precise Positioning Service (PPS) and augmented differential GPS for real-time positioning in wildland areas. DoI assisted the DoT and DoD in their efforts to expand the Nationwide Differential GPS (NDGPS) by identifying project areas that are out of reach of current differential GPS methods. DoD turned off the Selective Availability feature that limited the accuracy of the Navstar Standard Positioning Service (SPS) signal in May 2000, making higher accuracy positioning available to all civil users. Now, DoI GPS coordinators are seeking suitable civilian GPS equipment that take advantage of this change in GPS signal access. At the end of FY 2000, tests were underway to determine if PPS performance is needed in areas of heavy vegetation cover and steep terrain.

The U.S. Fish and Wildlife Service (FWS) and the Federal Highway Administration continued to develop a digital baseline inventory of all public-use roads in the FWS National Wildlife Refuge System. The Refuge System explored ways to use GPS units to standardize some of the inventory and monitoring functions carried out on all refuge units. Remotely sensed data are not used as widely as other inventory and monitoring tools due both to cost and inconsistent availability, but the Pacific Islands were exploring the use of Landsat 7 and other new satellite data to define critical habitats for endangered species. Remotely sensed data may offer the only current method to collect data to designate critical habitat for over 200 species, many of them on inaccessible islands.

The National Park Service (NPS) used Landsat and SPOT satellite data, along with conventional aerial photography, Light Detection and Ranging (LIDAR), and digital orthophotography to map and monitor land cover, vegetation, cultural features, and other specific features in many national parks. The USGS continued to collaborate with NPS to map the vegetation and obtain uniform baseline data on the composition and distribution of vegetation types for 235 U.S. national park units. Vegetation mapping was completed at Devils Tower National Monument, Mount Rushmore National Memorial, Scotts Bluff National Monument, and Tuzigoot National Monument. In 2000, the program expanded its coverage to include two FWS National Wildlife Refuges in the Western United States. Approximately 400 GPS units were used to support NPS mapping and navigation needs for a variety of resource management and maintenance applications.

The Office of Surface Mining Reclamation and Enforcement (OSM) continued to use GPS technology in FY 2000 for project work and training. Restoration of Western U.S. surface mine topography has been field verified for GPS use. The Mountaintop Removal Environmental Impact Statement Task Force used GPS to classify and map ephemeral streams in surface mining areas of Appalachia. OSM personnel used GPS to map the location of monitoring points and subsidence features to support a project to monitor the hydrologic impacts of mine subsidence above underground longwall mining in southwestern Pennsylvania.

OSM continued prototyping the use of 1-meter IKONOS panchromatic data to map mine infrastructure, water features, active mining areas, and reclaimed land acreage. Stereo IKONOS data were used to generate digital elevation models, measure slopes, and create three-dimensional spatial databases of active surface coal mines. OSM also continued using the IKONOS 4-meter multispectral data to map vegetation health and vigor in reclaimed areas and to monitor water depth and sediment content.

The Bureau of Reclamation (BOR) used new remote-ensing technologies to develop inundation maps and emergency response plans for different scenarios of operational water releases from BOR dams and releases caused by potential dam failures. BOR scientists used LIDAR data acquired from aircraft to generate digital elevation models with submeter vertical accuracy to allow for precise modeling of flood boundaries and flood water depths. BOR personnel continued research to determine the feasibility of using high-resolution Space Imaging Corporation. IKONOS satellite imagery to classify land use and land cover for potentially flooded areas, thus providing better estimates of loss of life and property.

BOR staff used commercial Earth Search Sciences Inc. Probe 1 hyperspectral and IKONOS imagery to map the extent of the invasive plant species purple loosestrife at Winchester Wasteway, Washington, to monitor biological control efforts at that location. BOR and USGS personnel also collected ground spectral data of another invasive plant, leafy spurge, in Theodore Roosevelt National Park, North Dakota, in preparation for detailed large-scale mapping using Airborne Visible Infrared Imaging Spectrometer (AVIRIS), Earth Observing-1 Hyperion, IKONOS, and Compact Airborne Spectrographic Imager (CASI) data. BOR continued to use Landsat Thematic Mapper (TM), Indian Remote Sensing Satellite multispectral and panchromatic imagery, as well as USGS digital orthophoto quarterquads, to map agricultural crops in the Colorado River basin. Scientists used irrigation status and crop type data with crop water use coefficients and locally varying climate data to calculate agricultural consumptive water use.

The Minerals Management Service used GPS to assist in determining baseline points used to delineate offshore boundaries in the U.S. Virgin Islands. Accurate boundaries were needed to support Territorial Submerged Lands jurisdictions as well as a proposed national monument for protection of coral reefs around St. Thomas and St. Croix.

The Bureau of Indian Affairs (BIA) used remote sensing and GPS to support BIA and tribal initiatives to map land use, inventory natural resources, and conduct environmental assessments. Scientists used digital orthophotography, National Aerial Photography Program (NAPP) aerial photography, National Elevation Dataset (NED) data, and Digital Raster Graphics (DRG) as backdrops to model potential flood inundation zones caused by the failure of BIA-managed dams. BIA used these datasets with GPS and digital cameras to map irrigation structure condition on irrigated agricultural lands within BIA irrigation districts on Indian reservations in the Western United States. The BIA also expanded the applications of both civilian and military (encrypted) GPS receivers in natural resource planning, inventory, and mapping.

The Bureau of Land Management (BLM) used remotely sensed data from satellites and aircraft sensors, and GPS technology, to support 47 Bureauwide land-use planning programs during FY 2000. These technologies were used in conjunction with Geographic Information Systems (GIS) to address increased energy and mineral demands, competing resource demands from urban growth, and other changing resource conditions on the public lands. Scientists continued to use data from traditional and digital aerial cameras and multispectral and hyperspectral sensors with GIS technology to support inventory, assessment, modeling, and monitoring efforts associated with wildlife habitat, wilderness, recreation, rangeland, timber, fire, minerals, and hazardous materials.

The USGS and BLM used Landsat-7, RADARSAT, and European Remote Sensing Satellite (ERS)-2 synthetic aperture radar (SAR) images to investigate glacier dynamics at Bering Glacier, Alaska. The potential failure of the ice dam that impounds water in Berg Lake threatens to inundate large areas of Native American lands that are important wildlife habitat, used for subsistence hunting, popular for numerous recreational uses, and contain mineral resources that may soon be developed. Hence, lives as well as economic development are at risk from this unpredictable hazard.

The USGS, the French Space Agency (CNES), and NASA developed a dynamic algorithm to determine snow depth from passive microwave observations obtained by the Special Sensor Microwave Imager (SSM/I) on the Defense Meteorological Satellite. USGS and NASA planned to use the new algorithm to improve measurements of global snowpack. USGS and CNES also developed a new technique to map snow depth using radar altimeter observations from the ERS-2 satellite that is based on attenuation of the radar pulse by the snow pack.

The USGS also worked with scientists at the University of Washington to improve snow-melt runoff forecasts using SSM/I passive microwave observations. Investigators continued to develop techniques to combine hydrology models with a microwave snow-pack scattering model to determine the distribution of snow water equivalent for test basins in the Upper Rio Grande River, Colorado, and the upper Salmon River, Idaho. This technique has yielded greatly improved snow-water equivalent estimates when compared to conventional microwave techniques based solely on the satellite observations.

The year 2000 wildland fire season was quite active in the United States; almost 80,000 fires burned some 6,940,000 acres. The USGS EROS Data Center responded by providing spatial technologies and research experience to support wildfire management. Landsat-7 data acquired before and after the Jasper Fire in the Black Hills National Forest of South Dakota illustrated the change in green biomass caused by the fire, and demonstrated the capability for mapping the fire perimeter and the severity of burn. The Black Hills National Forest staff and the governor of South Dakota used these data to make a rapid assessment of the Jasper Fire. National Forest staff also used the data to map fire severity and model tree mortality. The NPS determined that these products could be of value as the tool for the national yearly mapping of the extent of wild land fires.

The BLM, BIA, and U.S. Forest Service (USFS) continued to work with the USGS to validate the utility of the Fire Potential Index (FPI), a fire ignition predictive tool developed by USGS and USFS scientists. The FPI characterizes relative fire potential for forests, rangelands, and grasslands both regionally and locally, using NOAA AVHRR multispectral satellite data with information from vegetation maps and daily weather information to generate 1-km resolution fire potential maps. The FPI is updated daily to reflect changing weather conditions and is posted by the USFS and the Alaskan Fire Service on their Web sites. Fire management staffs in Alaska, Arizona, California, Oregon, Montana, Nevada, and Wyoming continued to use the FPI in their daily decisionmaking process to supplement traditional information sources for establishing priorities for prevention activities to reduce the risk of wildland fire ignition and spread, and for allocating suppression forces to improve the probability that initial attack will control fires occurring in areas of high concern. Scientists tested the FPI in Argentina, Chile, Mexico, and Venezuela with the support of the Pan American Institute for Geography and History. The Joint Research Center for Remote Sensing in Ispra, Italy, worked with the USGS to test and implement the FPI for all of Europe.

The regional component of the interagency Multi-Resolution Land Characterization Project (MRLC) was completed in FY 2000 with release of the National Land Cover Data (NLCD) set. These data were derived from Landsat TM data acquired in the early 1990's and shows the distribution of 21 categories of land cover across the conterminous 48 United States. The NPS became a member of the MRLC consortium this year, joining USGS, EPA, NASA, NOAA, and other agencies. In FY 2000, researchers began work on NLCD 2001, which will cover all 50 United States and Puerto Rico using current data.

The USGS carried out a study of ground-water flooding in the Puget Sound Basin, Washington, using RADARSAT SAR data. Ground-water flooding occurs in the complex glacial geologic framework of the region when the water table rises above low-lying land surfaces as a result of above-average precipitation. This flooding lasts for several weeks until the water table lowers. Groundwater flooded areas were identified by comparing SAR images from dry periods with images from wet periods.

USGS developed a field spectral radiometer for rapid, frequent remote monitoring of turbidity in the Colorado River in the Grand Canyon. The instrument measured the brightness and color of river water every 30 minutes from August 1999 to September 2000. The measurements were highly correlated to turbidity and total suspended sediment concentration measured from water samples collected during part of this time period, thus confirming the value of the method. Because of access restrictions within national parks and the high cost of monitoring remote areas such as the Grand Canyon, this system offers frequent, noninvasive remote monitoring of such areas. Near real-time monitoring is possible if the measurements are telecommunicated directly to an office for recording and analysis.

USGS scientists used Interferometric Synthetic Aperture Radar (InSAR) data from the ERS-1 and ERS-2 satellites to detect an uplift of several centimeters that occurred during the first half of 1993 in the San Bernardino groundwater basin of Southern California. This uplift correlates with unusually high runoff from the surrounding mountains and increased groundwater levels in nearby wells. The deformation of the land surface is used to identify the location of faults that restrict groundwater flow, map the location of recharge, and suggest the actual distribution of fine-grained aquifer materials. The results demonstrated that naturally occurring runoff and resultant recharge can be used with InSAR deformation mapping to help define the structure and important hydrogeologic features of a groundwater basin. This approach may be particularly useful to investigate remote areas having limited ground-based hydrogeologic data.

The USGS used digitized aerial photographs and airborne digital Scanning Hydrographic Operational Airborne LIDAR Survey (SHOALS) laser bathymetry data to map coral reef environments on the Hawaiian island of Molokai. The laser bathymetry and aerial photography images show information to a depth of approximately 35 and 20 meters, respectively. Researchers used digitized aerial photographs collected in September 1993 and January 2000 to detect changes in the amount of sea grass and sand cover on the inner and fore reef areas.

The USGS cooperated with NOAA and the United Kingdom Royal Aircraft Establishment National Remote Sensing Council to produce a 1:5,000,000-scale map of the Antarctic continent using NOAA Advanced Very High Resolution Radiometer (AVHRR) satellite data. The USGS also printed six image maps at 1:250,000-scale around Ross Island using Landsat Multispectral Scanner (MSS) data. Using Landsat data, the USGS also produced satellite image maps of South Florida and the Chesapeake Bay watershed. Numerous agencies involved in environmental restoration programs used these products.

In FY 2000, the USGS Volcano Disaster Assistance Program (VDAP) responded to the eruptions at Guagua Pichincha and Tungurahua volcanoes in Ecuador. For the first time, VDAP personnel combined classified reconnaissance data of the volcanoes acquired through the National Civil Applications Program with field-based and aerial observations of eruption features to assess the nature and magnitude of danger to people and property in the area. This project represented a new collaboration between the USGS Volcano Hazards Program and NCAP personnel.

In cooperation with university research groups and the National Science Foundation, the USGS assisted in the expansion of the network of continuously operating permanent GPS stations to measure crustal deformation in tectonically active areas in the western United States, Alaska, Hawaii, and the South Victoria land region of the Transantarctic Mountains (near McMurdo, Antarctica). Data continued to be transmitted to analysis centers for processing and analysis to produce highly accurate estimates for horizontal and vertical changes in Earth's crust. The study area in Antarctica involves measuring crustal rebound resulting from changes in ice sheet mass balance. These measurements may contribute information for investigations of global sea-level changes.

The USGS cooperated with universities in Southern California to establish a large array of GPS receivers to make continuous measurements between stations that bridge known faults. Immediately following a major earthquake, new dual-frequency geodetic receivers are deployed on stations in the affected region to measure postearthquake rebound. Using advanced GPS data processing software and coordinated data, baseline vectors are determined to a few millimeters in each component. In FY 2000, technicians upgraded GPS networks at Mt. St. Helens in Washington and at Augustine Volcano in Cook Inlet, Alaska, to better monitor deformation at those hazardous volcanoes.

GPS use continued to expand to meet a wide range of USGS water resources applications. Researchers performed high-accuracy GPS surveys to prepare highly accurate digital elevation models of levees along the Mississippi and Missouri Rivers in areas that were flooded during 1993. Researchers continued to use this information to modify flood plain management practices to reduce damage from major floods in the future. High-accuracy differential GPS surveys provided elevation data at the few centimeter (cm) level for surface water flow modeling in the South Florida Ecosystem Restoration Initiative where extremely low relief requires elevation accuracies of at least 15 cm to be achieved over wide areas. Traditional differential leveling methods could not meet this requirement because it is much too expensive and time-consuming. In Puerto Rico, the public benefitted from use of GPS surveying techniques to help manage water resources. Researchers used GPS measurements to accurately map reservoir depth and reveal that the storage capacity of the Lago Dos Bocas reservoir had been reduced by over 40 percent due to sedimentation during the last 52 years.

USGS scientists regularly used GPS technology in a variety of projects in the Great Lakes region in FY 2000. Scientists used GPS receivers and aerial photographs to determine sample locations, provide geographic reference for GIS data sets and assist in navigation during wetland restoration projects on FWS National Wildlife Refuges. GPS technology supported side-scan sonar surveys conducted in several Great Lakes and habitat mapping projects in the Detroit River to locate sample sites and provide geographic reference for biological data. Researchers used GPS to guide sampling procedures and simplify navigation in open water for studies of larval fish habitat preference in Lake Erie. GPS was also used as part of native clam research in several national parks in Michigan.

USGS developed a GPS database of accurate locations of 16,000 bridges for the State of Pennsylvania. This engineering application will benefit public safety through assessment of the condition of bridges that are located on rivers with unstable channels and high scour potential where countermeasures are necessary to protect bridges from possible damage.

FEDERAL COMMUNICATIONS COMMISSION

FCC

All FCC accomplishments in space during FY 2000 were related to communications and Earth observation satellites. The FCC formulates rules to facilitate and regulate the U.S. domestic satellite industry and the licensing of all stations and satellite launches. Internationally, the FCC continued to coordinate satellite placement with other countries. FCC's specific accomplishments are outlined for FY 2000.

In the area of satellite authorizations and launches, the FCC authorized a number of launches of communications satellites. On August 8, 2000, the FCC authorized licensing of the entire Intelsat constellation upon Intelsat's privatization. Upon its privatization, Intelsat will be a U.S. licensee with 17 satellites in orbit and authorizations for 10 additional launches. The FCC authorized E-SAT to launch and operate six nonvoice, Nongeostationary orbit (NGSO) mobile satellites in low-Earth orbit. On June 28, 2000, E-SAT successfully launched its first satellite, and on August 17, 2000, the satellite was brought into operation. The FCC also authorized Space Imaging, Inc., to launch and operate two satellites in low-Earth orbit to provide Earth exploration satellite services. On December 15, 1999, Space Imaging successfully brought into operation its first satellite. On October 18, 1999, Globalstar launched four satellites in NGSO orbit. On each of two more occasions, it also launched four satellites on November 22, 1999, and on February 8, 2000. This brought the Globalstar constellation up to 28 satellites in orbit with 24 operational and 4 spares.

On December 4, 1999, ORBCOMM launched 7 satellites into NGSO orbit, which brought the ORBCOMM constellation up to 35 satellites in orbit. On November 30, 1999, the FCC granted SatCom Systems, Inc., a U.S. company, and TMI Communications and Company, L.P., a Canadian company, authority to operate mobile Earth terminals to provide mobile satellite service in the United States via a Canadian-licensed satellite, MSAT-1. Sirius Satellite Radio launched two NGSO Digital Audio Radio Service (DARS) satellites during FY 2000. The launches, authorized by a special temporary authority issued on December 20, 1999, took place on July 1, 2000, and September 5, 2000. During FY 2000, there were also seven C/Ku-band satellite launches: Loral TELSTAR-12 on October 19, 1999; PanAmSat PAS-9 on July 28, 2000; Galaxy XR on January 24, 2000; Galaxy IVR on April 18, 2000; Galaxy XI on December 21, 1999; GE Americom GE-7 on September 14, 2000; and GE-4 on November 13, 1999.

During FY 2000, the FCC was also active in international satellite coordination. On July 27, 2000, the United States and Mexico signed an agreement on the implementation and operation of the Satellite Digital Audio Radio Service. Both countries may now implement DARS systems in the 2310–2360 MHz band. In October 1999, December 1999, February 2000, July 2000, and August 2000 the FCC held satellite network coordination meetings with the Administrations of the United Kingdom, Brazil, Canada, India, and Malaysia, respectively.

In December 1999, U.S. and French negotiators finalized a coordination agreement on behalf of EUTELSAT for certain satellites. Similarly, in February and April 2000, INTELSAT negotiators finalized coordination agreements for certain satellites.

Department of Agriculture

USDA

USDA research and operational programs used remotely sensed data and related technologies to monitor, assess, and administer agricultural, rangeland, and forestry resources. The Agriculture Research Service (ARS) enhanced remote-sensing knowledge and developed productive applications at research facilities located throughout the United States. At the ARS Jornada Experimental Range, the ARS Hydrology and Remote Sensing Laboratory (HRSL) collected laser-scanning data and visible, thermal infrared, and video imagery to infer surface temperature, albedo, vegetation indices, roughness, and other land surface characteristics. These parameters were used as inputs for land-surface models, coupled with atmospheric models to determine heat and water balance for the area. With the launch of NASA's Earth Observing System (EOS)-AM1 satellite, the HRSL has flown multispectral thermal infrared sensors over the Jornada Experimental Range to estimate surface emissivity and temperature for selected EOS-AM1 overpasses. ARS used these data to estimate the surface sensible heat flux. Thermal infrared radiation data from ASTER were used to map surface fluxes at the El Reno Grazinglands sites. The remote-sensing fluxes were in good agreement with ground measurements. Aircraft flights with a digital multispectral camera collected multi-angle reflectance, an intrinsic surface characteristic needed for radiometric correction of optical remote-sensing data, for accurate estimates of shortwave albedo and for improved cover-type classification.

Research coordinated by a HRSL scientist demonstrated the feasibility of large-scale soil moisture detection using airborne and space microwave platforms. With these advances in the theory and the planned launches of new microwave remote-sensing satellites, it is feasible to implement a global observing soil moisture system. Research is focused on developing and implementing these tools through large-scale field experimentation in the United States and Asia. Although soil moisture is a critical variable for climate and agriculture, measuring soil moisture over continental scales has been hindered by a lack of appropriate instrumentation.

Scientists at the HRSL combined NOAA's Advanced Very High Resolution Radiometer (AVHRR) satellite data with field-level measurements of ecosystem carbon dioxide exchange from other ARS locations to estimate carbon sequestration in rangelands of the Western United States at 1 kilometer resolution. Historic Landsat MSS and Landsat 7 Extended Thematic Mapper data were used to validate estimates of carbon sequestration at 30 to 100 meters resolution.

A simple operational approach has been developed at the HRSL for relating evapotranspiration (the amount of water evaporated from soil and transpired by plants) to satellite observations of surface temperature, vegetative cover and type, and measurements of near-surface wind speed and air temperature from the synoptic weather network. This scheme reduces both the errors associated with satellite observations and defining weather data at large scales, and thus, it has potential in providing regional scale assessment of evapotranspiration. This information will greatly enhance techniques for estimating crop yield and for assessing vegetation stress on a regional basis, ultimately improving agricultural management decisions.

The HRSL used airborne and satellite imagery for delineating consistent patterns of crop growth within fields for developing within-field management zones for precision farming. Scientists merged the use of crop growth models with remote-sensing data to quantify the amount of production in the growth patterns and used geostatistical techniques to improve airborne scanner image analysis to map within-field crop foliage density.

Scientists at the HRSL evaluated the application of MODIS to develop a crop yield map for the soybean and corn crop in McLean County, Illinois, in cooperation with the Illinois State Statistical Office and the Research and Development Division of National Agricultural Statistics Service (NASS) in Fairfax, Virginia. The Illinois State Water Survey cooperated in acquiring ground data.

Using remote-sensing and geospatial technologies, the HRSL evaluated the economic and environmental impact of three farming systems on surface and subsurface water quality. Subsurface flow patterns were mapped with groundpenetrating radar and linked to crop yields and remotely sensed images. A new spectral method was developed to assess chlorophyll content of plant canopies that indicates crop fertilizer needs. These assessments of spatial and temporal variability of crops will benefit farmers by providing a watershed-scale demonstration site where crop yields, profitability, and environmental impact can be compared under identical hydro-geological setting and climatic conditions.

The ARS Soil and Water Research Unit at Lincoln, Nebraska, used multispectral and hyperspectral data to evaluate crop vegetation indices in terms of chlorophyll meter readings and for prediction of yield for irrigated corn. Using combinations of individual reflectance bands, the most appropriate band combinations at each growth stage were determined for making relative crop yield maps.

At Weslaco, Texas, the ARS Integrated Farming and Natural Resources Unit used color-infrared aerial photography to successfully detect the invasive alien aquatic weed, giant salvinia, in Texas waterways. These data were used by Texas Parks and Wildlife Department personnel involved in controlling this aquatic weed. Airborne multispectral and hyperspectral images and yield monitor data were collected from several fields owned by Rio Farms, Inc., of Monte Alto, Texas, and used by Rio Farms to make farm management decisions. Multispectral digital imagery was used successfully to detect and assess foot rot infection in south Texas citrus orchards.

At the ARS National Soil Tilth Laboratory in Ames, Iowa, comparisons with plant tissue testing, leaf chlorophyll readings, broadband reflectance with ground-based instruments, and airborne sensors showed that detection of the nitrogen status early in the season is possible when canopy observations are combined with meteorological models for predicting the expected nitrogen use. Observations made during the grain-filling period related well to yield and showed where nitrogen was not a contributing factor to yield variation across the field. Remote sensing of the soil and crop provided a spatial representation of the agronomic variation across varying soils. Scientists used ground-based, narrow-band sensors to develop spectral libraries for corn, soybean, and wheat. Scientists used the information collected from this system to determine growth rates, light interception, biomass, and lead chlorophyll content across a range of soils and management practices.

At the ARS J. Phil Campbell, Sr., Natural Resource Conservation Center in Watkinsville, Georgia, researchers used Landsat satellite imagery to classify land use in the Upper Oconee Watershed of Georgia into 10 types. Land use within selected subwatersheds will be related to observations of water quality. These studies focused on portions of the Upper Oconee Watershed receiving Federal funding in the Environmental Quality Improvement Program (EQIP). These remote-sensing data are used to determine the efficacy of the EQIP program within the context of the predominant land use.

The ARS Plant Science and Water Conservation Research Laboratory, in Stillwater, Oklahoma, used commercially available high-spatial resolution multispectral imagery to determine reflectance characteristics of pest insect infested wheat. These data were used with spatial interpolation techniques to create maps of spatially varying pest density, and the spatial pattern metrics were used to develop a "spatial signature" for greenbug infestations in wheat fields from the processed imagery so that greenbug infested fields can be quickly, accurately, and inexpensively identified.

Scientists at the ARS Genetics and Precision Agriculture (GAPA) Research Unit at Mississippi State University, Mississippi, combined high-resolution, multispectral imagery and improved insect scouting methods to create a georeferenced pest density map on nearly 1,100 acres of cotton on Perthshire Farm in the Mississippi Delta. These maps were loaded into a ground sprayer to dispense pesticides and/or growth regulator chemicals (PIX) only where needed with the use of a variable rate controller. Several spatially variable prescriptions (Maps) were made throughout the growing season, pointing out the success of this cooperative, insect management effort between ARS, ITD Spectral Visions, GPS, Inc., Perthshire Farm, and farm consultants. GAPA scientists also collaborated with Mississippi State University scientists to identify spectrally narrow crop reflectance wavebands sensitive to nitrogen, potassium, and water deficit in upland cotton. Researchers developed algorithms for detecting crop nutrient and water stress conditions from hyperspectral or multispectral airborne platforms. In cooperation with Natural Resources Conservation Service (NRCS) scientists, GAPA scientists delineated soil management zones in a 400-acre, irrigated cotton field. By applying different fertilizer nitrogen prescriptions based on simulated yields from the ARS Cotton Model, they confirmed that natural soil boundaries are better than an arbitrary rectangular grid system when a decision support system is used to optimize soil nitrogen applications.

At the ARS Wind Erosion and Water Conservation Research Unit in Lubbock, Texas, irrigation timing, based on remotely measuring temperature of crop canopies was successfully demonstrated under field conditions. The correlation between canopy temperature and leaf water potential of corn and cotton was studied after irrigation rates were either increased or decreased. Significant changes were detected in canopy temperature and leaf water potential of cotton, but only in leaf water potential of corn. The absence of a measured canopy temperature response in corn suggests that a modification in the procedure for remotely monitoring corn temperature is needed to increase its sensitivity to the water status of corn to optimize irrigation management. The response of five vegetation indices was compared with the development of Leaf Area Index (LAI) and Fractional Vegetative Area (FVA) and compared with their impact on canopy Photosynthetically Active Radiation (PAR) absorption. The vegetation indices varied more linearly with FVA than LAI, and FVA is more influential in PAR absorption, thus linearity in FVA may be a more relevant criteria in choosing an index design to monitor crop productivity.

At the ARS Western Integrated Cropping Systems Research Unit in Shafter, California, aerial imagery was acquired of cotton and other crops using a multispectral digital camera to detect and characterize pests in cotton, including spider mites and aphids; for measurements of water stress using a thermal camera; midseason yield estimation; and development of remote sensing for targeted soil sampling for salinity management. Spectral signatures for mites and other stressors of cotton were developed using multispectral remote-sensing technologies, both on the ground and from aircraft. Researchers at the ARS Water Management Research Unit in Ft. Collins, Colorado, used ground-based, remote-sensing techniques (multispectral sensors mounted on a high-clearance tractor) to assess the plant Nitrogen status in irrigated corn for in-season nitrogen management. A previously developed Nitrogen Reflectance Index (NRI), calculated from canopy reflectance data acquired in the green and near-infrared portions of the electromagnetic spectrum from a nadir view (0°) and an oblique view (75°), was compared to measured plant nitrogen. The NRI was not representative of plant nitrogen at the sixth leaf growth stage (V6) for either view angle because of the soil background influence on canopy reflectance. However, the oblique view NRI was a good predictor of plant nitrogen at V9 and V12, as was the nadir view NRI at V12. The nadir view NRI was not as sensitive as the oblique view NRI at the V9 growth stage because soil was still visible through the canopy. Consequently, the nadir view NRI provides a conservative estimate of plant nitrogen prior to complete canopy cover.

The ARS Rangeland Resources Research Unit in Cheyenne, Wyoming, and BLM used an ultralight airplane to obtain Very-Large Scale Aerial (VLSA) 70-mm color photographs from 20 feet above ground to evaluate range condition. This effort demonstrated the practicality of using this type of aircraft to rapidly acquire a statistically adequate number of VLSA images (samples) over extensive rangeland areas. The imagery is being tested as a means for measuring ground cover and the leaf area of dominant functional plant types. The results are used to monitor rangeland health and for estimating CO_2 fluxes and carbon cycling.

The ARS National Sedimentation Laboratory in Oxford, Mississippi, has worked on projects that used the Next Generation Weather Radar, the Surface Radiation Network (SURFRAD), and the Soil Climate Analysis Network as part of the Global Energy and Water Cycle Experiment and its continental component based on the Mississippi River. Researchers used these data to model the variations of the global hydrological regime, its impact on atmospheric and surface dynamics, and variations in regional hydrological processes and water resources and their response to changes in the environment, such as the increase in greenhouse gases.

The ARS Southeast Watershed Research Laboratory in Tifton, Georgia, is working with scientists from the ARS Hydrology and Remote Sensing Laboratory, Georgia Institute of Technology, and University of South Carolina to perfect methods to estimate soil-water conditions at the land surface using remote sensing techniques. Past research has indicated the applicability of such a technique for sparsely vegetated landscapes. However, because of the difficulty associated with closed canopies in heavily vegetated landscapes, less work has been done in areas with dense vegetation. Initial studies conducted in July 2000 indicated that techniques can be developed for landscapes with dense canopies.

ARS scientists at the U.S. Water Conservation Laboratory (USWCL) in Phoenix, Arizona, refined methods to integrate remotely sensed information with computer models that predict crop growth, based on weather and soil conditions to help meet the information needs for precision farming. Remotely sensed data provide information on plant conditions at fine spatial resolution at select times during the season for improving the crop model predictions.

In cooperation with agricultural engineers at the University of Arizona, USWCL scientists developed a system (AgIIS) of visible, near infrared, and thermal sensors mounted on a cart that travels the length of a linear move irrigation system collecting measurements at 1-meter intervals. Researchers processed the data to generate an image that was used to detect crop and water stress. A Canopy Chlorophyll Content Index (CCCI) developed from multispectral reflectance data, obtained while using the AgIIS sensor in a cotton experiment, has now been modified for use in wheat. As chlorophyll content is a good indicator of fertilizer needs, the CCCI may find use in assessing midseason fertilizer requirements of wheat and in predicting grain quality. Scientists at the ARS South Central Agricultural Research Laboratory in Lane, Oklahoma, and at the Horticultural Research and Development Centre in Saint-Jean-sur-Richelieu, Quebec, Canada, provided quality assessment observations and evaluated the potential to integrate the remotely sensed data with models to predict crop quality.

Scientists at the ARS Northwest Irrigation and Soils Research Laboratory in Kimberly, Idaho, in cooperation with Utah State University made remote-sensing measurements with an aircraft to develop reflectance-based, evapotranspiration (ET) crop coefficients for irrigated bean, sugar beet, and potato. High resolution, airborne multispectral digital imagery were used to develop vegetation indices related to the spatial and temporal variation in crop growth and biophysical parameters obtained in field measurements. Ground-based measurements obtained for a field of beans verified the reflectance-based ET crop coefficients developed from the remotely sensed data. Airborne or multispectral satellite imagery can be used to develop spatially and temporally variable ET crop coefficients useable for precision irrigation scheduling with potential also for assessing aggregate irrigation water requirements and yield for mixed cropping patterns in large irrigated tracts.

The ARS Northwest Watershed Research Center (NWRC) in Boise, Idaho, used synthetic aperture radar to map the extent of frozen soil in rugged topography. Ground data on soil water content, snow depth, and soil freezing were collected in conjunction with overpasses of the RADARSAT platform. Summer scenes were acquired to obtain imagery during dry, unfrozen conditions to be used as a reference. Data are currently being analyzed to determine the optimal approach to differentiating freezing effects from those due to topography, vegetation, and surface roughness.

NWRC scientists conducted an analysis of Landsat and SPOT imagery to determine the relationship between satellite-derived vegetation indices and the soil water regime and found a good correlation between the vegetation index or Soil Adjusted Vegetation Index (SAVI) and the seasonal water stress, relative to evaporative demand in semiarid rangelands.

Invasion of cheatgrass, an exotic annual grass, into rangelands throughout the Intermountain West has dramatically altered the natural fire regime, thus impacting public safety, plant community integrity, and rangeland hydrology. NWRC scientists developed analysis tools to map fuel types, quantify fuel biomass and moisture, and assess fire severity in the Snake River Birds of Prey National Conservation Area near Boise, Idaho, using Landsat imagery. These tools will be useful to land management agencies for assessing fire hazards, planning fuels reduction treatments, predicting fire behavior, and evaluating postfire rehabilitation needs on rangelands.

NWRC scientists evaluated remote sensing to assess stream shading as a surrogate to direct stream temperature measurement. If good relationships exist between remotely sensed stream shading values and stream temperature, land managers could use these remotely sensed data to evaluate stream temperature variability for extensive and dynamic rangeland stream systems.

Scientists at the ARS Southwest Watershed Research Center (SWRC) in Tucson, Arizona, developed a spatially explicit hydro-ecological model calibrated with satellite images to produce daily estimates of regional plant growth, evaporation, and soil moisture. Over a 10-year period, this model simulated daily plant and root growth and rangeland health in the ARS Walnut Gulch Experimental Watershed with accuracies that were three times better than conventional products without satellite images. This breakthrough provided spatially distributed information about vegetation and soil conditions for day-to-day grassland management and for long-term evaluation of the effects of climate change and drought.

SWRC scientists cooperated with NASA and Michigan State University to develop a remote-sensing method to estimate biomass of senescent grasses. This information will be used with rangeland managers to make biomass information into usable data products, and finally, assess the potential for such information to be provided on an ongoing basis as a commercial product.

SWRC scientists worked with the Environmental Protection Agency to develop a PC-based GIS hydrologic tool to relate landscape patterns to watershed condition across multiple scales for applications across a wide range of conditions and geographies. This PC-based tool was applied to three watersheds of different sizes and climatic characteristics, ranging from the semiarid ecosystem in the ARS Walnut Gulch Experimental Watershed and San Pedro River Basin in Arizona to the humid Cannonsville watershed in New York.

Scientists at the ARS Grazinglands Research Laboratory (GRL) in El Reno, Oklahoma, combined remotely sensed near-surface estimates of soil water content with meteorological, vegetation, and soils data to produce estimates of total root zone soil water content at watershed scales. Scientists at GRL cooperated with scientists at the HRSL in the calibration and validation of satellite microwave sensors to provide a regional soil water content product. Scientists at the GRL also worked with scientists at the ARS Sub-Tropical Animal Research Station in Brooksville to detect forage quality using hand-held hyperspectral remote sensing.

The ARS Application and Production Technology Research Unit in Stoneville, Mississippi, used an aircraft system with a digital video camera and a GPS interface so images could be associated with ground position images to map weed populations from altitudes of 70 to 1,500 feet. Scientists analyzed images to distinguish weeds from the surrounding crops earlier in the season, when weed management plans need to be defined

Researchers at the ARS Southern Regional Research Center in New Orleans, Louisiana, designed submersed sensor arrays for monitoring harmful algal species. A prototype of this sensor was installed in the St. John's River as part of collaborative research efforts with regional, State, and Federal research groups to monitor algal species in the river. Scientists at the ARS Catfish Genetics Research Unit in Stoneville, Mississippi, installed automated oxygen sensors for monitoring oxygen levels in catfish ponds. This sensor system controls aeration equipment to maintain desired oxygen levels for catfish growth.

The Foreign Agricultural Service's (FAS) satellite remote-sensing program remained a critical element in USDA's analysis of global agricultural production and crop conditions by providing timely, accurate, and unbiased estimates of global agriculture area, yield, and production. Satellite-derived early warnings of unusual crop conditions and production enabled more rapid, objective, and precise determinations of global supply conditions necessary for commodity price discovery. FAS used a full private-Government partnership program that contracts over 90 percent of its imagery from the commercial space industry and partners within other government agencies (NASA, NOAA, USGS) to ensure that FAS requirements are defined for mission planning and research. FAS continued to strengthen its abilities to extract the most from acquired data by sharing over 900 satellite scenes with partner USDA agencies. Over the past year, the FAS remote-sensing program provided global crop condition assessments in support of trade policy and food aid decisions made by USDA policymakers. These included crop assessments on China, the Korean Peninsula, Indonesia, Eastern Europe, North Africa, the countries of the former Soviet Union, India, the horn of Africa, and Mexico.

The Farm Service Agency (FSA) fielded reegineered business processes combining the use of digital orthophotography, GIS, GPS, and satellite imagery to replace the use of hardcopy aerial photography from the National Aerial Photography Program (NAPP) and aerial 35mm slides. Over 200 counties will be empowered with GIS technology by the end of 2000. FSA, through the Farm Service Agency-Foreign Agricultural Service Center for Remote Sensing, fielded compressed Landsat and AVHRR imagery to several State offices for disaster monitoring and compliance testing. FSA tested the use of the Space Imaging IKONOS imagery for use in digital compliance programs. FSA currently acquires aerial 35mm slides over much of the continental United States one to three times per year. The IKONOS imagery is being evaluated as one of many possible digital replacements. FSA continues to cost share with FAS analysis of imagery over the United States, receiving timely reports on U.S. crop conditions from FAS. These imagery-based reports, combined with weather data, crop model results, and GIS products, made possible the development of accurate and timely projections and comprehensive evaluations of crop disaster situations. FSA continues to be a partner in NAPP but has been unable to partner in National Digital Orthophoto Program (NDOP) activities due to a lack of funds.

The National Agricultural Statistics Service (NASS) used remote-sensing data to construct area frames for statistical sampling, estimate crop area, create crop-specific land-cover data layers for GIS, and assess crop conditions. For area frame construction, NASS combined digital Landsat and SPOT data with USGS digital line-graph data, enabling the user to assign each piece of land in a State to a category, based on the percentage of cultivation or other variables. NASS implemented a new remote-sensing-based area frame and sample for Pennsylvania and North Carolina. The remote-sensing acreage estimation project analyzed Landsat data from the 1999 crop season in Arkansas, Illinois, Mississippi, New Mexico, and North Dakota to produce crop acreage estimates for major crops at State and county levels, and a crop-specific categorization in the form of a digital mosaic of TM scenes distributed to users on a CD-ROM. For the 2000 crop season, NASS headquarters and several NASS field offices continued partnership agreements with State organizations to decentralize the Landsat processing and analysis tasks and expanded into Indiana and Iowa. Data for 2000 acreage estimation analysis were collected in Arkansas, Illinois, Indiana, Iowa, Mississippi, New Mexico, and North Dakota. Vegetation condition images, based on AVHRR data, were used with conventional survey data to assess crop conditions. The 2000 drought conditions in Nebraska and South Dakota, southern Texas, and the southeastern States were followed closely with these data.

The Natural Resources Conservation Service (NRCS) continued its cooperative partnership with Federal, State, and local agencies in developing 1-meter digital orthoimagery coverage of the Nation through NDOP and NAPP. By year's end, approximately 2,500 counties were completed with digital orthoimagery coverage. NRCS delivered digital orthoimagery to its county field service centers for their use in a desktop GIS in place of using paper copies of aerial photographs. NRCS continued to advance the use of GPS at the county field offices, and at the end of the fiscal year, there were more than 1,000 GPS receivers in use.

NATIONAL SCIENCE FOUNDATION

NSF

After extensive data analysis, an international team of cosmologists led by Andrew Lange of the California Institute of Technolgoy and Paolo de Bernadis of the University of Rome released the first results from the BOOMERanG (Balloon Observations Of Millimetric Extragalactic Radiation and Geomagnetics) Antarctic long-duration balloon flight that took place during FY 1999. The measurements provide the first truly convincing observational evidence that is consistent with the leading "inflationary" theories of creation.

"Cosmic shear" is defined as slight distortions in the images of distant galaxies caused by large intervening structures of primarily dark matter. During FY 2000, J. Anthony Tyson and his colleagues detected a statistical signal of cosmic shear for the first time, using wide-field images with the NSF Cerro Tololo Inter-American Observatory 4-meter telescope. This initial detection was based upon measurements of the images of about 50,000 galaxies. These measurements provide a powerful tool to determine fundamental cosmological parameters related to the distribution of mass in the universe and test the foundations of cosmology.

John Dickey of the University of Minnesota is midway through an NSF-sponsored 4-year project to carry out a survey of radio emission in the inner Milky Way using radio-wavelength telescopes in Australia. The survey is producing maps of the density and velocity distribution of interstellar hydrogen gas. These maps trace out the violent motions of the interstellar medium associated with supernova remnants and stellar winds. The first survey results have revealed several very large-scale structures, including an immense shell or bubble more than 1,500 light years in diameter. This supershell, located in the outer galaxy, at about 33,000 light years from the Galactic center, is the largest and most empty supershell yet discovered in the Milky Way.

Alyssa Goodman of Harvard University has produced important results in another NSF-sponsored project that offers quantitative new measures of how material in the interstellar medium is distributed. She has been developing and applying new methods for analyzing both numerical simulations and observed data sets. With these new, discriminating statistical techniques, she and collaborators have shown that simulations without magnetic fields and/or self-gravity cannot match the behavior exhibited by real observations. Only simulations of magnetized, self-gravitating turbulence are able to approach matching the behavior of the real star-forming interstellar medium. Self-gravity means that one has to include the effects of the gravitational field of the material in the interstellar medium upon itself. That is, each molecule and grain in the interstellar medium has a gravitational field that interacts on every other molecule and grain in the medium. The total effect cannot be ignored if one wishes to obtain results that agree with real observations.

Among the most active areas of research and discovery in astronomy today are investigations into the birth and the death of stars and their planetary systems. Searches for extrasolar planets have become increasingly productive recently, and samples have grown from a few curiosities to data sets whose properties and characteristics can be analyzed for insight into common formation processes. Several groups have been extremely active and productive in the search for extrasolar planetary systems. Using high-precision radial velocity measurements of candidate stars, investigators have been monitoring the presence of planets by regular changes in velocity, as the star and planet revolve around a common center of gravity. Common center of gravity means that if one were to place oneself above the plane of the orbit of the planet around the star, and traced the path that the planet made, one would find that both the planet and the star appear to orbit a common point, known as the "center of gravity."

NSF-sponsored researchers Paul Butler of the Carnegie Institute of Washington; Geoffrey Marcy of the University of California, Berkeley; and Steve Vogt of the University of California, Santa Cruz and collaborators have found 30 of 44 known extrasolar planets. Their most recent work includes the first optical detection of a planet as it passed in front of its host star and the discovery of the first multiple planet system.

Observations show that flattened disks of gas and dust are common around young stars. Several of the stars known to have giant gas planets also have disks, believed to be the remnants of the nebulae from which the planets formed. Peter Bodenheimer and collaborators at the University of California, Santa Cruz, have been performing numerical simulations of the interactions between protoplanets and disks. They find that once a planet grows to about Jupiter's mass, a gap is created in the disk. If two giant planets form, each one opens up a gap. Ultimately, the inner planet is driven outward slightly, and the outer one tends to be driven inward. These models are beginning to provide a theoretical basis for understanding the unusual properties of the extrasolar planets, such as their close proximity to their stars, and their high orbital eccentricities.

Fragmentation of molecular cloud cores, during their self-gravitational collapse to form stars, is the leading explanation for the origin of binary and multiple protostars. Molecular cloud cores appear to be supported against collapse in large part by magnetic fields. However, most protostellar fragmentation calculations have either ignored the effects of magnetic fields or found that in the presence of frozen-in magnetic fields, fragmentation is prohibited.

Alan Boss of the Carnegie Institute of Washington and collaborators have computed the first three-dimensional calculations that show magnetic tension also helps in avoiding a central density singularity during protostellar collapse. The net effect is to enhance fragmentation of collapsing magnetic cloud cores into multiple protostar systems.

During the approximately 15-billion-year lifetime of our Milky Way galaxy, several billion supernova explosions have progressively enriched it with the oxygen that we breathe, the iron in our blood cells, the calcium in our bones, and the silicon in the soil at our feet. Supernova explosions, with a peak luminosity as high as an entire galaxy of stars, trigger the births of new stars, are the source of the energetic cosmic-rays that irradiate us on Earth, and collectively may have helped shape the earliest galaxies. In addition, supernova have recently been used to measure the geometry of the universe and implicated as a potential source of gamma-ray bursts.

Modeling supernova has proven problematic: most models collapse, but do not explode. What material is initially ejected when the supernova detonates tends to fall back onto the stellar core. Adam Burrows of the University of Arizona and collaborators have developed a time-dependent, spherically symmetric code for modeling supernova explosions and have applied it to the problem of supernova in binary star systems. Explosions of massive stars in binary systems and the velocity "kicks" that the component stars receive are believed to be the origin of some of the high velocities seen in pulsars.

Because of its direct impact on terrestrial life, understanding how the Sun works has a very high scientific priority. NSF-sponsored researchers Douglas Braun of the Solar Physics Research Corporation and Charles Lindsey of Northwest Research Associates obtained the first images of an active region on the far side of the Sun using seismic holography techniques. Active regions are the centers of energetic phenomena such as solar flares and coronal mass ejections whose occasional bursts of radiation interfere with telecommunications and power transmissions on Earth and can pose significant hazards to astronauts and spacecraft.

William Merline and colleagues at the Southwest Research Institute have used ground-based adaptive optics to search for satellites orbiting asteroids. The team has discovered a satellite around the asteroid 45 Eugenia. The main asteroid's diameter is close to 215 km, and the Moon's size is estimated to be 13 km in diameter. The Moon is 285 times fainter than the main asteroid and is very close to the main asteroid (just over 5 asteroid diameters away).

Jens Gundlach and Stephen Merkowitz of the University of Washington have made an important new determination of one of the fundamental constants of nature, the gravitational constant. Their value for the gravitational constant is a hundred times more precise than the previously accepted value.

Detailed model studies for thermonuclear explosions on the surface of an accreting neutron star have been performed by the research groups of Hendrik Schatz of Michigan Statue University, Michael Wiescher of the University of Notre Dame, and Lars Bildsten of the Universtiy of California, Santa Barbara. The results defined for the first time the endpoint for the process that drives the thermonuclear explosion and sets new limits on the resulting abundance distribution in the crust of the neutron star.

During large magnetic storms, the electric fields and particle populations, which typically occur at high latitudes in the auroral region, move toward the equator, and their effects can be observed over the continental United States. Intense convection electric fields cause the plasma in the ionosphere to move at high speeds, which can cause density variations in the ionosphere that can disrupt transionospheric communication and navigation signals. John Foster of the Massachuessetts Institute of Technology, using the Millstone Hill incoherent scatter radar near Boston, observed such a disturbance during the magnetic storm of October 15, 1999. Scientists have been using these detailed radar and optical observations to test quantitatively their understanding about the relationship between these various atmospheric phenomena. By connecting ionospheric phenomena to magnetospheric processes, scientists will better understand the coupled space weather environment and will be able to improve forecasts of magnetic storms and the resulting effects on technological systems.

DEPARTMENT OF STATE

DoS

The DoS continued its efforts to coordinate international agreements and arrangements for cooperation on the International Space Station (ISS). During FY 2000, DoS made preparations for the first meeting of the partners to the ISS Intergovernmental Agreement (IGA). Originally scheduled for fall 2000, it ultimately took place in Berlin in December 2000. At the meeting, delegations expressed great satisfaction with the significant progress that has been made in assembling the ISS on orbit. The successful launch of the Expedition One crew marked the beginning of a permanent human presence onboard the ISS. With the recent successful missions, the ISS has now initiated integrated operations, allowing initial research onboard the ISS. This progress demonstrates that the ISS management structure is functioning on the basis of genuine partnership, as envisioned in the IGA.

During FY 2000, the DoS led U.S. Government participation in the United Nations' Committee on the Peaceful Uses of Outer Space (COPUOS). The Committee was formed in 1958 and is the only standing body of the United Nations to consider international cooperation in the exploration of outer space. Over the past year, the Committee undertook important work in areas such as 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 states and equitable access to geostationary orbit.

The DoS continued to lead an interagency effort to promote the U.S. GPS as a worldwide standard for satellite-based navigation and to protect the spectrum in which GPS operates. Diplomatic efforts included visits by U.S. experts to more than than a dozen foreign capitals for discussions on GPS-related issues. These efforts directly contributed to the successful achievements of U.S. objectives at the World Radiocommunication Conference (WRC). Most significantly, the WRC defeated Resolution 220 (a proposal to share the spectrum used by GPS L1 with mobile satellite systems) and approved a new allocation of spectrum for additional GPS signals which are a part of the modernization of GPS capabilities. The DoS also led the preparation of a draft framework agreement between the United States and the European Community on satellite navigation systems. This draft was provided to the European Commission and the European Union member states in October 2000.

DEPARTMENT OF ENERGY

DoE

During FY 2000, DoE worked on a demonstration of technologies to clean up dense, nonaqueous phase liquid solvents at Launch Complex 34, Cape Canaveral, Florida. At the end of the fiscal year, the demonstration had removed 5,000 kilograms (kg) of solvents at a cost of $5.1 million, of which DoE has funded $3.1 million. DoE developed these technologies, and the test data will benefit DoE sites in terms of cost and performance data. Agencies who are cofunding this demonstration of technologies include the U.S. Air Force, U.S. Navy, Environmental Protection Agency, and three private companies.

DoE continued to support NASA's space exploration program by maintaining the program and facility infrastructure for providing radioisotope power sources and heater units and developing new, advanced power systems covering a range of power levels required to meet more stringent power system requirements for future missions. DoE personnel initiated safety analyses to support potential use of radioisotope heater units on the Mars 2003 mission and radioisotope power systems on the Europa Orbiter mission. DoE competitively contracted with several potential system contractors to develop a conceptual design of a radioisotope Stirling power system, which adds heat through a wall to an expanding gas at high temperature to perform work. One of these contractors will be selected to proceed with the development and demonstration of the radioisotope Stirling power system for potential use on the Europa Orbiter, Solar Probe, and Mars 2007 missions. Finally, a bench-scale demonstration was completed of a process to recover Plutonium-238 scrap for reuse as an energy source for future NASA missions.

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, Massachusetts, to form the Harvard-Smithsonian Center for Astrophysics (CfA), where over 300 scientists are engaged in a broad program of research in astronomy, astrophysics, and science education. The Smithsonian Institution also continued to contribute to the National Air and Space Museum (NASM) in Washington, DC, through its research and education activities.

SAO has had a lead role in operating the NASA Chandra X-ray Observatory, which completed its first year of observations in FY 2000 with a series of widely reported results and discoveries. Chandra studied the presence of compact x-ray stars in supernova remnants, the galactic center x-ray source, the disk and jets in the Crab Nebula, and obtained deep images that resolve the x-ray background into faint sources. Chandra also found superbubbles of very hot gas within colliding galaxies; discovered that even small, failed stars emit x-ray flares; found x-rays coming from a comet; and opened a new field of research by discovering medium-sized black holes.

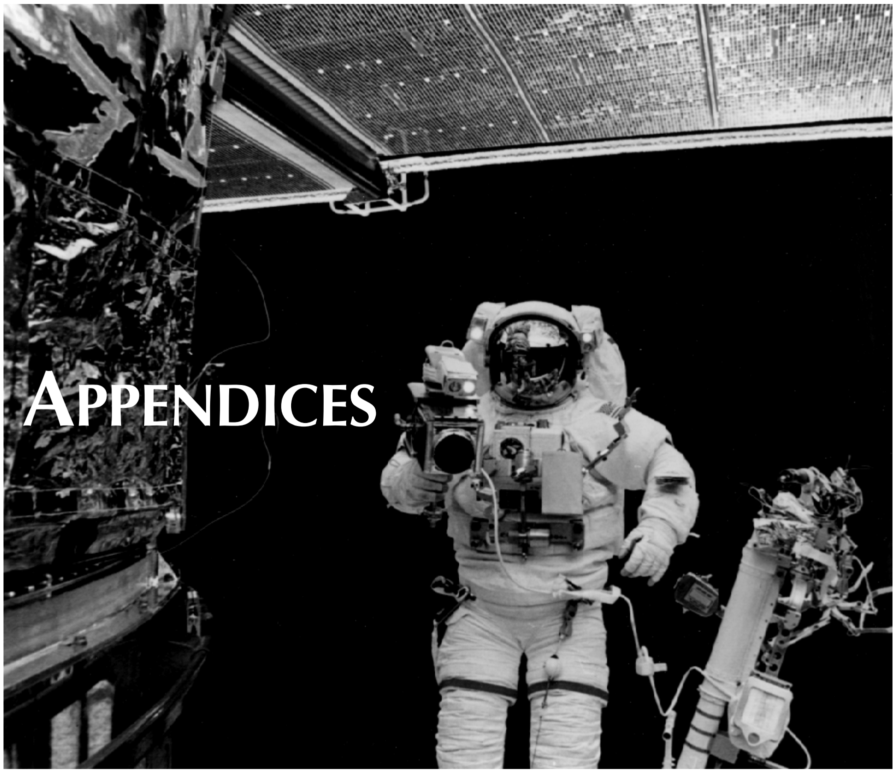
SAO is also the leader of another NASA satellite, the Submillimeter Wave Astronomy Satellite (SWAS) mission, a space telescope that studies the chemistry and dynamics of the interstellar gas clouds in the Milky Way galaxy. SWAS discovered that water, a key component for life, is prevalent throughout space, and found that a substantial amount of water is present in the Martian atmosphere, but, surprisingly, SWAS has been unable to find any molecular oxygen in space. Another SAO program called “The Milky Way in Molecular Clouds: A New

Complete CO Survey," this fiscal year completed a 20-year radio astronomy effort and released an image of the entire galaxy with unprecedented detail and clarity.

In FY 2000 SAO astronomers and their colleagues discovered two new moons of Jupiter (numbers 17 and 18) and a new moon of Saturn (number 22). Solar scientists at SAO used the Transition Region and Coronal Explorer (TRACE) spacecraft to watch the Sun as its activity climbed to a peak during the maximum of its 12-year solar cycle; they also used the Solar and Heliospheric Observatory (SOHO) spacecraft to study the Sun. New models of the solar activity based on these observations promise to help predict storms of charged space particles. SAO scientists this year discovered several new planets around other, nearby stars, including one Jupiter-sized planet, and achieved the first detection of a new planet by observing it pass in front of the face of its star. Scientists also detected a class of objects, intermediate in size, between stars and planets called "brown dwarfs," in the Orion nebula. Some very newly formed stars were observed in the process of collapsing, and others were found to have disks or rings of material around them, with compositions resembling that of our own solar system at the time of its formation. SAO scientists continued to be leaders in the field of cosmology and the structure of the universe, especially through the incredible, recent discovery that the universe may be accelerating its expansion due to a repulsive force to gravity. Scientists also developed another new technique for calibrating the distances to galaxies during FY 2000.

The Science Education Department (SED) at CfA continued to host teachers from across the United States at sessions designed to train them in the use of the Department's many curriculum programs for grades 3-12. SED activities included the "MicroObservatory Program," which enables classrooms to control small telescopes located around the world, plan observations, take data, and share their results with other schools. SED produced several new television and video shows this year, while staff throughout SAO continued their active involvement with schools. The 7 public Web sites at SAO received about 80 million hits during the year.

The Center for Earth and Planetary Studies (CEPS) at NASM continued to conduct an active research program in planetary and terrestrial geology and geophysics using remote-sensing data from Earth-orbiting satellites and manned and unmanned space missions. The scope of research activities includes work on Mercury, Venus, the Moon, and Mars, and corresponding field studies in terrestrial analog regions. CEPS staff studied a variety of geophysical processes, such as volcanism, floods, cratering, tectonics, and sand movement. Many of the terrestrial studies also address topics of current concern for global climate change. As a NASA Regional Planetary Image Facility, CEPS houses an extensive collection of images of the planets and their satellites. CEPS continued to have curatorial responsibility for two museum exhibit galleries. The "Exploring the Planets" gallery highlights the planets and their satellites and explores what we have learned about our solar system from interplanetary spacecraft. Planning is actively underway for a new "Exploring the Planets" gallery. The "Looking at Earth" gallery illustrates the ways in which aerial photography and satellite images are used to obtain a better understanding of the Earth. Staff participated in the development and presentation of public programs, including teacher workshops, special events, and outreach activities in the community. CEPS staff also continued to be responsible for developing and maintaining the NASM Web site, including innovative online exhibit materials, interactive educational programs, research highlights, and virtual tours of museum galleries.



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 *(through September 30, 2000)*	23 [f]	0	0	0
TOTAL	1,475	153	94	15

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.

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 *(through September 30, 2000)*	21	27				3			7		
TOTAL	1,197	3,625	10	8	54	61	1	1	125	11	3

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.

Successful Launches to Orbit on U.S. Launch Vehicles
October 1, 1999–September 30, 2000

Launch Date Spacecraft Name COSPAR Designation Launch Vehicle	Mission Objectives	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
Oct. 7, 1999 Navstar 46 (USA 145) 55A Delta II	Global Positioning System (GPS) navigation satellite	21,164 km 20,097 km 736.2 min 53.1°	
Nov. 23, 1999 UFO 10 63A Atlas IIA	UHF Follow on 10 is a military communications satellite	Geosynchronous	
Dec. 4, 1999 Orbcomm A-G 65A-G *Pegasus XL	Communications satellite	834 km 830 km 101.5 min 45°	
Dec. 12, 1999 DMSP F15 (USA 147) 67A Titan	Quasi-military satellite	851 km 837 km 101.8 min 98.9°	Uses visible, infrared, and microwave imagers to monitor weather.
Dec. 18, 1999 Terra 68A Atlas IIAS	Weather Satellite	685 km 654 km 98.1 min 98.2°	Joint spacecraft with Japan and Canada.
Dec. 20, 1999 STS-103 69A Space Shuttle	Hubble Space Telescope servicing mission	609 km 563 km 96.4 min 28.5°	
Dec. 21, 1999 Kompsat 70A *Taurus	Experimental remote sensing satellite	710 km 688 km 98.8 min 98.3°	South Korean spacecraft.
Dec. 21, 1999 ACRIMSAT 70B Taurus	Solar science satellite	727 km 683 km 99 min 98.3°	Carries active cavity radiometer irradiance monitor instrument.
Jan. 21, 2000 DSCS 3 (USA 148) 1A Atlas II	Military communications satellite	Geosynchronous	Defense Satellite Communications System 3.
Jan. 27, 2000 JAWSAT 4A Minuteman	Military minisatellite	773 km 773 km 100.4 min 100.2°	Joint air force Academy-Weber state university SATellite launched OCS, OPAL FALCONSAT, and ASUSAT microsatellite.

APPENDIX B

(Continued)

Successful Launches to Orbit on U.S. Launch Vehicles

October 1, 1999–September 30, 2000

Launch Date Spacecraft Name COSPAR Designation Launch Vehicle	Mission Objectives	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
Jan. 27, 2000 OCS 4B Minuteman	Military microsatellite	773 km 773 km 100.4 min 100.2°	Optical Calibration Sphere
Jan. 27, 2000 OPAL 4C Minuteman	Military microsatellite	773 km 773 km 100.4 min 100.2°	Orbiting Picosatellite Automated Launcher
Jan. 27, 2000 FALCONSAT 4D Minuteman	Military microsatellite	773 km 773 km 100.4 min 100.2°	
Jan. 27, 2000 ASUSAT 4E Minuteman	Military microsatellite	773 km 773 km 100.4 min 100.2°	Arizona State University SATellite
Jan. 27, 2000 Picosats 4-8 4H-M Minuteman	Engineering student experimental satellites	805 km 750 km 100.4 min 100.2°	Tethered picosatellites were launched by OPAL.
Feb. 3, 2000 Hispasat 7A *Atlas IIAS	Communications satellite	Geosynchronous	Spanish spacecraft.
Feb. 8, 2000 Globalstar A-D 8A-D *Delta II	Communications satellites	930 km 914 km 103.5 min 52° min	Final members of Globalstar fleet, now totaling 52 members including 4 reserves.
Feb. 11, 2000 STS-99 10A Space Shuttle	Earth mapping mission	242 km 224 km 89.2 min 57°	Joint NASA-NIMA (National Imagery and Mapping Agency) mission to produce a 3-D map of 70% of global terrain.
Mar. 12, 2000 MTI 14A Taurus	Quasi-military reconnaissance satellite	614 km 577 km 96.6 min 97.4°	Multi-spectral Thermal Imager

APPENDIX B

(Continued)

Successful Launches to Orbit on U.S. Launch Vehicles
October 1, 1999–September 30, 2000

Launch Date Spacecraft Name COSPAR Designation Launch Vehicle	Mission Objectives	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
Mar. 25, 2000 IMAGE 17A Delta II	Magnetospheric science satellite	45,995 km 993 km 856 min 89.9°	Imager for Magnetopause-to-Aurora Global Exploration
May 3, 2000 GOES 11 22A Atlas IIA/Centaur	Weather satellite	Geosynchronous	
May 8, 2000 DSP 20 (USA 149) 24A Titan IVB	Military reconnaissance satellite	Geosynchronous	
May 11, 2000 Navstar 51 (USA 150) 25A Delta II	GPS navigation satellite	20,200 km 20,200 km 712 min 55°	
May 19, 2000 STS-101 27A Space Shuttle	Repair and upgrade International Space Station (ISS)	320 km 320 km 91 min 51.6°	
May 25, 2000 Eutelsat W4 28A *Atlas IIIA	Communications satellite	Geosynchronous	European spacecraft.
June 7, 2000 TSX 5 30A *Pegasus XL	Military satellite	1,704 km 404 km 106 min 69°	Tri-service eXperiments 5 satellite is designed to monitor other spacecraft and aircraft.
June 30, 2000 TDRS 8 34A Atlas IIA	Tracking and Data Relay Satellite	Geosynchronous	
July 14, 2000 Echostar 6 38A *Atlas IIAS	Communications satellite	Geosynchronous	
July 16, 2000 Navstar 48 (USA 151) 40A Delta II	Navigational satellite	20,456 km 167 km 358 min 39°	

APPENDIX B

(Continued)

Successful Launches to Orbit on U.S. Launch Vehicles

October 1, 1998–September 30, 1999

Launch Date Spacecraft Name COSPAR Designation Launch Vehicle	Mission Objectives	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
July 19, 2000 Mightysat 2.1 42A Minotaur	Experimental technology military satellite	Orbital parameters unknown	
Aug. 17, 2000 USA 152 47A Titan IVB	Military-intelligence satellite	Orbital parameters unknown	Joint military-National Reconnaissance Office radar imaging mission.
Aug. 23, 2000 DM-F3 48A *Delta III	Dummy satellite to test launch capability of new Delta III vehicle	20,634 km 192 km 361 min 27.6°	
Sept. 8, 2000 STS-106 53A Space Shuttle	Resupply and repair mission to the ISS	386 km 375 km 92.2 min 51.6°	
Sept. 21, 2000 NOAA 16 55A Titan II	Weather satellite	850 km 843 km 102.1 min 98.8°	

* Commercial launch licensed as such by the Federal Aviation Administration. More launch data are available at *http://ast.faa.gov/launch/history.cfm*.

APPENDIX C

U.S. and Russian Human Space Flights

1961–September 30, 2000

Spacecraft	Launch Date	Crew	Flight Time (days:hrs: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 hrs.
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 hrs.
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 duration 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	Sep. 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. Aldrin, Jr.	3:22:35	Longest EVA to date (Aldrin, 5 hrs.).
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, 2000

Spacecraft	Launch Date	Crew	Flight Time (days:hrs: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. 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,
Soyuz 7	Oct. 12, 1969	A. V. Filipchenko Viktor N. Gorbatko Vladislav N. Volkov	4:22:41	including welding and Earth and celestial observation.
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 inflight EVA of 38 min., 12 sec. 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	Sep. 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, 2000

Spacecraft	Launch Date	Crew	Flight Time (days:hrs: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 and 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.
Anomaly (Soyuz 18A)	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	Sep. 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 days, 10 hrs.
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 days, 22 hrs., 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 days, 14 hrs., 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 days, 20 hrs., 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 days, 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, 2000

Spacecraft	Launch Date	Crew	Flight Time (days:hrs: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 days, 20 hrs., 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 days, 20 hrs., 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 days, 20 hrs., 42 min. Pham was first Vietnamese to orbit.
Soyuz 38	Sep. 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 days. 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 crew members. 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.

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U.S. and Russian Human Space Flights

1961–September 30, 2000

Spacecraft	Launch Date	Crew	Flight Time (days:hrs: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 woman 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 crew members, one of whom was West German; first non-U.S. astronaut to fly in U.S. space program (Merbold).
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 days. 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 female EVA.
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 crew members, including first flight of two U.S. women and one Canadian (Garneau).

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U.S. and Russian Human Space Flights

1961–September 30, 2000

Spacecraft	Launch Date	Crew	Flight Time (days:hrs: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	Sep. 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, 2000

Spacecraft	Launch Date	Crew	Flight Time (days:hrs: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 (FRG) Wubbo J. Ockels (ESA)	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 long-distance stay in space record of 326 days.
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, 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; Aleksandrov first Bulgarian in space. Crew returned Jun. 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)	Sep. 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 Sergey 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-day mission 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, 2000

Spacecraft	Launch Date	Crew	Flight Time (days:hrs: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	Thirtieth STS flight. Dedicated DoD mission.
Soyuz TM-8	Sep. 5, 1989	Aleksandr Viktorenko Aleksandr Serebrov	166:6	Docked with *Mir* space station. Crew of Viktorenko and Serebrov returned in Soyuz TM-8, 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	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.

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U.S. and Russian Human Space Flights

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Spacecraft	Launch Date	Crew	Flight Time (days:hrs: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	175:01:52	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 on board *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)	Sep. 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

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Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Soyuz TM-13	Oct. 2, 1991	Aleksandr Volkov Toktar Aubakirov (Kazakh Republic) Franz Viehboeck (Austria)	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 (ESA)	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 (Germany)	145:15:11	First manned CIS space mission. Docked with *Mir* space station Mar. 19. The TM-13 capsule with Flade, Aleksandr Volkov, and Sergei Krikalev returned to Earth Mar. 25. Krikalev had been in space 313 days. 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 (France)	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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Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Space Shuttle *Atlantis* (STS-46)	Jul. 31, 1992	Loren J. Shriver Andrew M. Allen Claude Nicollier (ESA) Marsha S. Ivins Jeffrey A. Hoffman Franklin R. Chang-Díaz Franco Malerba (Italy)	7:23:16	Forty-ninth STS flight. Deployed Tethered Satellite System-1 and Eureca 1.
Space Shuttle *Endeavour* (STS-47)	Sep. 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 ten 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 (Germany) Hans W. Schlegel (Germany)	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 in orbit since August 1992.

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Spacecraft	Launch Date	Crew	Flight Time (days:hrs: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)	Sep. 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 testbed 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	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 of the Hubble Space Telescope.
Soyuz TM-18	Jan. 8, 1994	Viktor Afanasyev Yuri Usachev Valery Polyakov	182:0:27	Docked with *Mir* space station 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 (Russia)	8:7:9	Sixtieth STS flight. Carried the Wake Shield Facility to generate new semi-conductor 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 the Earth and 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 July 3. Both Malenchenko and Musabayev returned to Earth with the Soyuz TM-19 spacecraft, landing in Kazakhstan on Nov. 4 together 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.

APPENDIX C

(Continued)

U.S. and Russian Human Space Flights

1961–September 30, 2000

Spacecraft	Launch Date	Crew	Flight Time (days:hrs: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 (Japan)	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)	Sep. 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)	Sep. 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 (ESA)	*	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 (ESA) 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 (Russia)	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 International Space Station. (Shuttle flew close by to *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.

APPENDIX C

(Continued)

U.S. and Russian Human Space Flights
1961–September 30, 2000

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Soyuz TM-21	Mar. 14, 1995	Vladimir Dezhurov Gennadi Strekalov Norman Thagard (U.S.)	*	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 one hundredth 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	Sep. 3, 1995	Yuri Gidzenko Sergei Avdeev Thomas Reiter (ESA)	*	Soyuz TM-21 returned to Earth on Sep. 11, 1995, with Mir 19 crew (Anatoliy Solovyev and Nikolay Budarin).
Space Shuttle *Endeavour* (STS-69)	Sep. 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 (CSA) Jerry L. Ross William S. McArthur, Jr.	8:4:31	Seventy-third STS flight. Docked with M*ir* 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 (Japan) 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).

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U.S. and Russian Human Space Flights

1961–September 30, 2000

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Space Shuttle *Columbia* (STS-75)	Feb. 22, 1996	Andrew M. Allen Scott J. Horowitz Jeffrey A. Hoffman Maurizio Cheli (ESA) Claude Nicollier (ESA) Franklin R. Chang-Díaz Umberto Guidoni (ESA)	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 (CSA)	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 (CSA) Robert B. Thirsk (ESA)	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 (ESA) Valery Korzun Alexander Kaleri	*	Soyuz TM-23 returned to Earth on Sep. 2, 1996, with Claudie Andre-Deshays, Yuri Onufrienko, and Yuri Usachev.
Space Shuttle *Atlantis* (STS-79)	Sep. 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*.

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U.S. and Russian Human Space Flights

1961–September 30, 2000

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Soyuz TM-25	Feb. 10, 1997	Vasily Tsibliev Aleksandr Lazutkin Reinhold Ewald	*	Soyuz TM-24 returned to Earth on March 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)	Sep. 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, 2000

Spacecraft	Launch Date	Crew	Flight Time (days:hrs: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 February 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* 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 (ESA) Chiaki Mukai (NASDA) 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 (RSA)	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 (ESA) Ivan Bella	*	Soyuz mission to *Mir*.

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U.S. and Russian Human Space Flights

1961–September 30, 2000

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Space Shuttle *Discovery* (STS-96)	May 27, 1999	Kent V. Rominger Rick D. Husband Daniel T. Barry Valery I. Tokarev (RSA) Ellen Ochoa Julie Payette (CSA) 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 (CNES) 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	Hubble Space Telescope Servicing Mission #3
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.

* *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 D

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	460 350[e]	—	335	1994[g]
	1. Orion 50S-XL	Solid	743.3	1.28x10.29				
	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 1,080[e]	255	1,020	Not scheduled
	0. Castor 120	Solid	1,687.7	2.34x11.86				
	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)				2.44x29.70	5,089 3,890[e]	1,842[i]	3,175	1990, Delta-7925 [1960, Delta]
	1. RS-270/A	LOX/RP-1	1,043.0 (SL)	3.05x38.1				
	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	Geosynch. Transfer Orbit	Sun-Synch. Orbit[e]	First Launch[f]
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) (5-1/2 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)		7690	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_20_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 wing span.

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, and oxidizer from the External Tank. The boosters stage first, with SSME's 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	Ag	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	31	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		21,76
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	13,197	990	102	571	60	44	207	6	26,708

* Transition Quarter

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 it 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

APPENDIX E-1B

Space Activities of the U.S. Government

BUDGET AUTHORITY IN MILLIONS OF EQUIVALENT FY 1999 DOLLARS
(adjusted for inflation)

FY	Inflation Factors	NASA Total	NASA Space[b]	DoD	Other[c]	DoE[d]	DoC	DoI	Ag	NSF[a]	DoT	Total Space
1959	4.815	1,594	1,257	2,359	164	164						3,780
1960	4.7234	2,475	2,182	2,650	203	203						5,035
1961	4.6789	4,510	4,333	3,809	318	318						8,459
1962	4.6168	8,426	8,296	5,993	919	683	235					15,208
1963	4.5603	16,750	16,536	7,068	1,172	976	196					24,776
1964	4.5071	22,986	22,608	7,207	960	946	14					30,775
1965	4.4495	23,360	22,861	7,003	1,072	1,019	53					30,937
1966	4.3748	22,640	22,159	7,389	936	818	118					30,484
1967	4.1954	20,834	20,264	6,981	894	772	122					28,139
1968	4.1487	19,030	18,379	7,974	723	602	116	0.8	4			27,075
1969	4.0008	15,967	15,291	8,054	682	472	80	0.8	4	125		24,026
1970	3.8304	14,349	13,586	6,427	540	395	31	4	4	107		20,554
1971	3.6355	12,037	11,274	5,497	589	345	98	7	4	134		17,359
1972	3.4561	11,429	10,614	4,863	461	190	107	21	7	136		15,937
1973	3.2967	11,229	10,197	5,351	486	178	132	33	7	136		16,033
1974	3.1523	9,573	8,697	5,567	498	132	189	28	9	139		14,762
1975	2.9433	9,504	8,580	5,569	464	88	188	24	6	158		14,613
1976	2.6768	9,502	8,633	5,308	451	62	193	27	11	159		14,391
TQ	2.4968	2,327	2,120	1,149	77	12	55	7	2			3,346
1977	2.4153	9,222	8,309	5,826	467	53	220	24	14	156		14,602
1978	2.3161	9,403	8,391	6,341	523	79	239	23	19	164		15,256
1979	2.1688	9,968	8,740	6,584	538	128	213	22	17	158		15,862
1980	2.012	10,543	9,416	7,742	465	80	187	24	28	145		17,623
1981	1.8526	10,223	9,248	8,944	434	76	161	22	30	145		18,627
1982	1.69	10,214	9,342	11,287	528	103	245	20	25	135		21,158
1983	1.5819	10,875	10,010	14,267	517	62	282	8	32	135		24,794
1984	1.5139	11,291	10,383	15,435	598	51	357	5	29	156		26,415
1985	1.4593	11,051	10,106	18,632	852	50	617	3	22	160		29,590
1986	1.4134	11,035	10,127	19,966	674	49	437	3	33	152		30,767
1987	1.3805	15,079	13,542	22,485	643	66	384	11	26	154	1	36,669
1988	1.3449	12,188	11,193	23,777	997	324	473	19	24	155	1	35,966
1989	1.3029	14,292	13,156	23,331	730	126	392	22	27	158	4	37,216
1990	1.2544	15,459	14,375	19,589	634	99	305	39	31	155	5	34,598
1991	1.2085	16,938	15,766	17,137	933	303	303	35	31	255	5	33,836
1992	1.1647	16,675	15,373	17,498	929	260	381	40	34	210	5	33,800
1993	1.1391	16,300	14,881	16,068	832	188	369	38	28	205	5	31,781
1994	1.1109	16,186	14,467	14,627	703	82	347	34	34	199	6	29,796
1995	1.086	15,045	13,621	11,559	824	65	382	34	35	302	7	26,004
1996	1.0635	14,766	13,367	12,245	880	49	502	38	39	245	6	26,493
1997	1.0434	14,304	12,998	12,236	824	37	467	44	41	229	6	26,057
1998	1.026	14,002	12,641	12,680	861	106	446	44	40	219	6	26,182
1999	1.013	13,831	12,621	13,375	995	106	582	60	37	203	6	26,991
2000	1	13,601	12,521	12,521	990	102	571	60	44	207	6	26,708

SOURCE: Office of Management and Budget

APPENDIX E-2

Federal Space Activities Budget

(in millions of dollars by fiscal year)

Federal Agencies	Budget Authority			Budget Outlays		
	1998 actual	**1999 actual**	**2000 est.**	**1998 actual**	**1999 actual**	**2000 est.**
NASA	12,321	12,459	12,521	12,866	12,466	12,427
Defense	12,359	13,203	13,197	12,230	12,453	12,755
Energy	103	105	102	97	103	103
Commerce	448	575	571	336	431	517
Interior	42	59	60	42	42	59
Agriculture	39	37	44	39	37	44
Transportation	6	6	6	6	6	6
NSF	213	200	207	221	216	207

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		
	1998 actual	1999 actual	2000 est.	1998 actual	1999 actual	2000 est.
NASA[a]	1,327	1,194	1,060	1,339	1,217	1,014
Defense[b]	6,256	5,532	6,460	6,354	5,913	6,099
Transportation[c]	2,146	2,271	2,201	2,528	2,369	2,243

a. Research, Development, Construction of Facilities, Research and Program Management
b. Research, Development, Testing, and Evaluation of aircraft and related equipment.
c. Federal Aviation Administration: Research, Engineering, and Development; Facilities, Engineering, and Development

SOURCE: Office of Management and Budget.

GLOSSARY AND ACRONYMS

A

ACTS	Advanced Communications Technology Satellite
ADEOS	Advanced Earth Observing Satellite
ADS-B	Automated Dependent Surveillance-Broadcast
AEAP	Atmospheric Effects of Aviation Project
AGATE	Advanced General Aviation Technology Experiment
AMOS	Air Force Maui Optical Site
ARS	Agricultural Research Service (USDA)
AST	Advanced Subsonic Technology (Program)
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ASTP	Apollo-Soyuz Test Project
ATLAS	Atmospheric Laboratory for Applications and Science
AVHRR	Advanced Very High Resolution Radiometer
AVIRIS	Airborne Visible and Infrared Imaging Spectrometer
AVOSS	Advanced Vortex Sensing System
AXAF	Advanced X-ray Astrophysics Facility (former name of Chandra X-ray Observatory)

B

BIA	Bureau of Indian Affairs (DoI)
Black hole	A completely collapsed, massive dead star whose gravitational field is so powerful that no radiation can escape from it; because of this property, its existence must be inferred rather than recorded from radiation emissions
BXA	Bureau of Export Administration (DoC)

C

CEOS	Committee on Earth Observation Satellites
CIS	Commonwealth of Independent States
CITEL	Commission on Inter-American Telecommunications
CME	Coronal Mass Ejections
CNES	Centre National d'Etudes Spatiales (France)
COPUOS	Committee on the Peaceful Uses of Outer Space (United Nations)
Corona	The outer atmosphere of the Sun, extending about a million miles above the surface
CORS	Continuously Operating Reference Station
Cosmic rays	Not forms of energy, such as x-rays or gamma rays, but particles of matter
COSPAR	Committee on Space Research
CrIS	Cross-track Infrared Sounder
CRISTA-SPAS	Cryogenic Infrared Spectrometers and Telescopes for the Atmosphere-Shuttle Pallet Satellite
CSC	Commercial Space Center
CSOC	Consolidated Space Operations Contract
CT	Computerized Tomography
CUE	Collaborative Ukrainian Experiment

D

DAAC	Distributed Active Archive Center
DARWIN	Design Assessment of Reliability With Inspection
DMSP	Defense Meteorological Satellite Program—DoD's polar-orbiting weather satellite system
DoC	Department of Commerce
DoD	Department of Defense
DoE	Department of Energy
DoI	Department of the Interior
DoS	Department of State
DoT	Department of Transportation
DSN	Deep Space Network
DSP	Defense Support Program

E

EELV	Evolved Expendable Launch Vehicle (program)
EHF	Extremely High Frequency
El Niño	A warm inshore current annually flowing south along the coast of Ecuador around the end of December and extending about every 7 to 10 years down the coast of Peru
EOS	Earth Observing System—a series of satellites, part of NASA's Earth Science Enterprise, being designed for launch at the end of the 1990's togather data on global change
EPA	Environmental Protection Agency
EPIC	Environmental Photographic Interpretation Center (EPA)
ERAST	Environmental Research Aircraft and Sensor Technology (project)
EROS	Earth Resources Observation System (USGS)
ERS	European Remote-Sensing Satellite
ESE	Earth Science Enterprise
ESA	European Space Agency
ET	External Tank
ETM+	Enhanced Thematic Mapper-Plus (Landsat instrument)
EUV	Extreme ultraviolet
EVA	Extravehicular activity

F

FAA	Federal Aviation Administration
FACE	Free Air Carbon dioxide Enrichment
FAR	Federal Acquisition Regulation
FAS	Foreign Agricultural Service (USDA)
FCC	Federal Communications Commission
FGB	Functional Cargo Block (Russian acronym)
Fly-by-light	The use of light signals to connect the pilot's control devices with the aircraft control surfaces; or the use of light (fiber optic) control connections with no mechanical backup linkages and providing the pilot direct control of aircraft motion rather than control surface position
Fly-by-wire	The use of electrical signals to connect the pilot's control devices with the aircraft control surfaces; or the use of electrical control connections

	with no mechanical backup linkages and providing the pilot direct control of aircraft motion rather than control surface position
Free flight	A concept being developed by the FAA and the aviation community in which pilots could ultimately choose their own routes, speeds, and altitudes in flight, thus improving safety, while saving fuel, time, and natural resources.
FSA	Farm Service Agency (USDA)
FSS	Fixed Satellite Service
FWS	(U.S.) Fish and Wildlife Service (DoI)
FY	Fiscal Year

G

Gamma rays	The shortest of electromagnetic radiations, emitted by some radioactive substances
GDIN	Global Disaster Information Network
Geo-stationary	Traveling around the Earth's equator at an altitude of at least 35,000 kilometers and at a speed matching that of the Earth's rotation, thereby maintaining a constant relation to points on the Earth
Geosynchronous	Geostationary
GIS	Geographic Information System
GOES	Geostationary Operational Environmental Satellite
GOIN	Global Observation Information Network
GPS	Global Positioning System

H

Heliosphere	The region of the Sun's influence, including the Sun and the inter planetary medium
HST	Hubble Space Telescope
Hypersonic	Faster than Mach 4; faster than "high speed"
Hyperspectral	An instrument capability using many very narrow spectral frequency bands (300 or more), enabling a satellite-based passive sensor to discriminate specific features or phenomena on the body being observed (such as Earth)

I

ICM	Interim Control Module
IGEB	International GPS Executive Board
IGOS	Integrated Global Observing Strategy
IGS	International GPS Service for Geodynamics
INM	Integrated Noise Model
INMARSAT	International Mobile Satellite Organization
InSAR	Interferometric Synthetic Aperture Radar
INSAT	Indian Remote Sensing Satellite
Integrated modular avionics	Aircraft-unique avionics cabinet that replace multiple black boxes with shared common equipment and generic software
INTELSAT	International Telecommunications Satellite (Organization)

Interferometry	The production and measurement of interference from two or more coherent wave trains emitted from the same source
Internet	An international computer network that began about 1970 as the NSF Net; very slowly it became a collection of more than 40,000 independently managed computer networks worldwide that have adopted common protocols to permit the exchange of electronic information
Ionosphere	That region of Earth's atmosphere so named because of the presence of ionized atoms in layers that reflect radio waves and short-wave transmissions
IPO	Integrated Program Office
ISO	International Organization for Standardization
ISS	International Space Station
ITA	International Trade Administration (DoC)
ITU	International Telecommunications Union

J

JEM	Japanese Experimental Module
JPL	Jet Propulsion Laboratory (NASA)

K

K-band	Radio frequencies in the 20-gigahertz range
Ka-band	Radio frequencies in the 30-gigahertz range
KSC	Kennedy Space Center
Ku-band	Radio frequencies in the 11–12-gigahertz range

L

Landsat	Land [remote sensing] Satellite—a series of satellites designed to collect information about Earth's natural resources
Laser	Light amplified by simulated emission of radiation—a device that produces an intense beam of light that may be strong enough to vaporize the hardest and most heat-resistant materials, first constructed in 1960
LDEF	Long-Duration Exposure Facility
LEO	Low-Earth Orbit—100 to 350 nautical miles above Earth
LH2	Liquid Hydrogen
LIDAR	Light Intersection Direction and Ranging
LOX	Liquid Oxygen
LVIS	Laser Vegetation Imaging Sensor

M

Mach	A relative number named after Austrian physicist Ernst Mach (1838–1916) and indicating speed with respect to that of sound in a given medium; in dry air at 32 degrees Fahrenheit and at sea level, for example, Mach 1=approximately 741 miles per hour (1,192 kilometers per hour)
Magnetosphere	The region of Earth's atmosphere in which ionized gas plays an important role in the atmospheric dynamics and where, consequently, the geomagnetic field also exerts an important influence;other magnetic planets, such as Jupiter, have magnetospheres that are similar in many respects to Earth's

MCC-H	Mission Control Center–Houston
MCC-M	Mission Control Center–Moscow
MCO	Mars Climate Orbiter
MHz	Megahertz
MilSatCom	Military Satellite Communications
MISR	Multiangle Imaging Spectroradiometer
MMH	Monomethyl Hydrazine
MMS	Minerals Management Service (DoI)
MODIS	Moderate Resolution Imaging Spectrometer
MPL	Mars Polar Lander
MPLM	Multi-Purpose Logistics Module

N

NAPP	National Aerial Photography Program
NAS	National Airspace System (FAA)
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency (of Japan)
NASM	National Air and Space Museum
NASS	National Agricultural Statistics Service (USDA)
NATO	North Atlantic Treaty Organization
NAWQA	National Water Quality Assessment
NCAP	National Civil Applications Program (USGS)
NDGPS	Nationwide Differential GPS
NDOP	National Digital Orthoquad Program
NESDIS	National Environmental Satellite, Data and Information Service (NOAA)
Neutron star	Any of a class of extremely dense, compact stars thought to be composed primarily of neutrons; see pulsar
NEXRAD	Next Generation Weather Radar
NGS	National Geodetic Survey
NGSO	Nongeostationary satellite
NIST	National Institute of Standards and Technology (DoC)
NOAA	National Oceanic and Atmospheric Administration (DoC); also the designation of that administration's Sun-synchronous satellites in polar orbit
Nominal	Functioning as designed
NOx	Oxides of nitrogen
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NPP	NPOESS Preparatory Project
NPS	National Park Service (DoI)
NRA	NASA Research Announcement
NRCS	National Resources Conservation Service (USDA)
NRO	National Reconnaissance Office (DoD)
NSC	National Security Council
NSF	National Science Foundation
NTIA	National Telecommunications and Information Administration (DoC)—the Federal Government's radio spectrum manager, which coordinates the use of LEO satellite networks, such as those for Landsat, Navstar GPS, the Space Shuttle, and the Television and Infrared Operational Satellite (TIROS), with other countries of the world

NWRC	Northwest Watershed Research Center (ARS)

O

ODERACS	Orbital Debris Radar Calibration Spheres
OLMSA	Office of Life and Microgravity Sciences and Applications (NASA)
OMPS	Ozone Mapping and Profiler Suite
Order of magnitude	An amount equal to 10 times a given value; thus if some quantity was 10 times as great as another quantity, it would be an order of magnitude greater; if 100 times as great, it would be larger by two orders of magnitude
ORFEUS-SPAS	Orbiting and Retrievable Far and Extreme Ultraviolet Spectrograph-Shuttle Pallet Satellite
OSMRE	Office of Surface Mining Reclamation and Enforcement (DoI)
OSS	Office of Space Science (NASA)
OSTP	Office of Science and Technology Policy

P

PAMS-STU	Passive Aerodynamically Stabilized Magnetically Damped Satellite-Satellite Test Unit
PARCS	Primary Atomic Reference Clock in Space
Pathfinder	A program that focuses on the processing, reprocessing, maintaining, archiving, and distributing existing Earth science data sets to make them more useful to researchers; NASA, NOAA, and USGS are involved in specific Pathfinder efforts
PCB	Polychlorinated biphenyl
PEACESAT	Pan-Pacific Education and Communications Experiment by Satellite
PECAD	Production Estimates and Crop Assessment Division (FAS)
Photo-grammetry	The science or art of obtaining reliable measurements by means of photography
PMA	Pressurized Mating Adapter
POES	Polar-orbiting Operational Environmental Satellite (program)
PPS	Precise Positioning Service
PRA	Probabilistic Risk Assessment
Pulsar	A pulsating radio star, which is thought to be a rapidly spinning neutron star; the latter is formed when the core of a violently exploding star, called a supernova, collapses inward and becomes compressed together; pulsars emit extremely regular pulses of radio waves

Q

Quasar	A class of rare cosmic objects of extreme luminosity and strong radio emission; many investigators attribute their high-energy generation to gas spiraling at high velocity into a massive black hole
QuikSCAT	Quick Scatterometer

R

RADARSAT	Canadian Radar Satellite
Ramjet	A jet engine with no mechanical compressor, consisting of specially shaped tubes or ducts open at both ends, along with the air necessary

	for combustion being shoved into the duct and compressed by the forward motion of the engine
RFID	Radio Frequency Identification
RLV	Reusable Launch Vehicle
RPA	Remotely Piloted Aircraft
RSA	Russian Space Agency
RSML	Remote Sensing and Modeling Laboratory (ARS)

S

SAMRSS	Shafter Airborne Multispectral Remote Sensing System
SAO	Smithsonian Astrophysical Observatory
SAR	Synthetic Aperture Radar
SBIRS	Space Based Infrared System
SBS	Satellite Business Systems
Scramjet	Supersonic-combustion ramjet
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
SLS	Spacelab Life Sciences
SMA	Safety and Mission Assurance
SNOE	Student Nitric Oxide Experiment
SOFIA	Stratospheric Observatory for Infrared Astronomy
SOHO	Solar and Heliospheric Observatory
Solar wind	A stream of particles accelerated by the heat of the solar corona (outer region of the Sun) to velocities great enough to permit them to escape from the Sun's gravitational field
SPACEHAB	Commercial module for housing Shuttle experiments
SPARTAN	Shuttle Pointed Autonomous Research Tool for Astronomy
SPOT	Satellite Pour l'Observation de la Terre (French satellite for the observation of Earth)
SRB	Solid Rocket Booster
SRM	Solid Rocket Motor
SRMU	Solid Rocket Motor Upgrade
SSBUV	Shuttle Solar Backscatter Ultraviolet
SSCC	Space Station Control Center
SSCE	Solid Surface Combustion Experiment
SSME	Space Shuttle Main Engine
SSM/I	Special Sensor Microwave Imager
SSRMS	Space Station Remote Manipulator System
SSTF	Space Station Training Facility
SSTI	Small Satellite Technology Initiative
START	Strategic Arms Reduction Treaty
STS	Space Transportation System
SWAS	Submillimeter Wave Astronomy Satellite

T

TA	Technology Administration (DoC)
TATP	Triacetone triperoxide (terrorist explosive)
TDRS	Tracking and Data Relay Satellite
TERRIERS	Tomographic Experiment using Radiative Recombinative Ionospheric

	EUV and Radio Sources
TOMS	Total Ozone Mapping Spectrometer
TOPEX	Ocean Topography Experiment
TRACE	Transition Region and Coronal Explorer
TRACON	Terminal Radar Approach Control (system)
TRMM	Tropical Rainfall Measuring Mission

U

UARS	Upper Atmosphere Research Satellite
UHF	Ultrahigh Frequency—any frequency between 300 and 3,000 megacycles per second
UNISPACE	United Nations Conference on the Exploration and Peaceful Uses of Outer Space
URET	User Request Evaluation Tool
U.S.	United States
USAID	U.S. Agency for International Development
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey (DoI)
USML	U.S. Microgravity Laboratory
USMP	U.S. Microgravity Payload
USWCL	U.S. Water Conservation Laboratory (ARS)

V

VCL	Vegetation Canopy Lidar
VHF	Very High Frequency—any radio frequency between 30 and 300 megacycles per second
VLBA	Very Large Baseline Array
VLSA	Very Large Scale Aerial

W

WAAS	Wide Area Augmentation System
Wind shear	Variation of wind speed and wind direction with respect to a horizontal or vertical plane; powerful but invisible downdrafts called microbursts focus intense amounts of vertical energy in a narrow funnel that can force an aircraft to the ground nose first if the aircraft is caught underneath
WIRE	Wide-field Infrared Explorer
WRC	World Radiocommunication Conference
WSDDM	Weather Support to Deicing Decision Making
WSF	Wake Shield Facility

X-Y-Z

X rays	Radiations of very short wavelengths, beyond the ultraviolet in the spectrum
XRSIM	X-ray simulation software