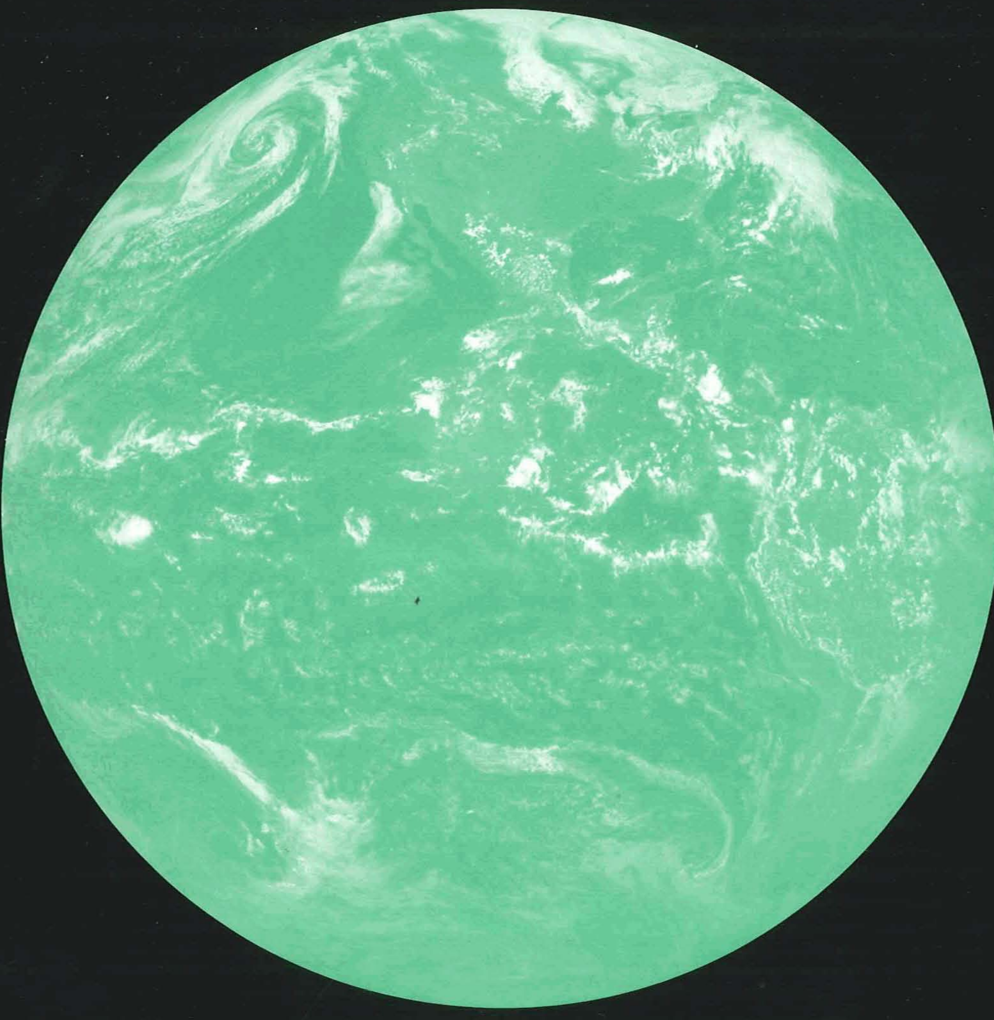
Aeronautics and Space Report of the President



Fiscal Year 1998 Activities

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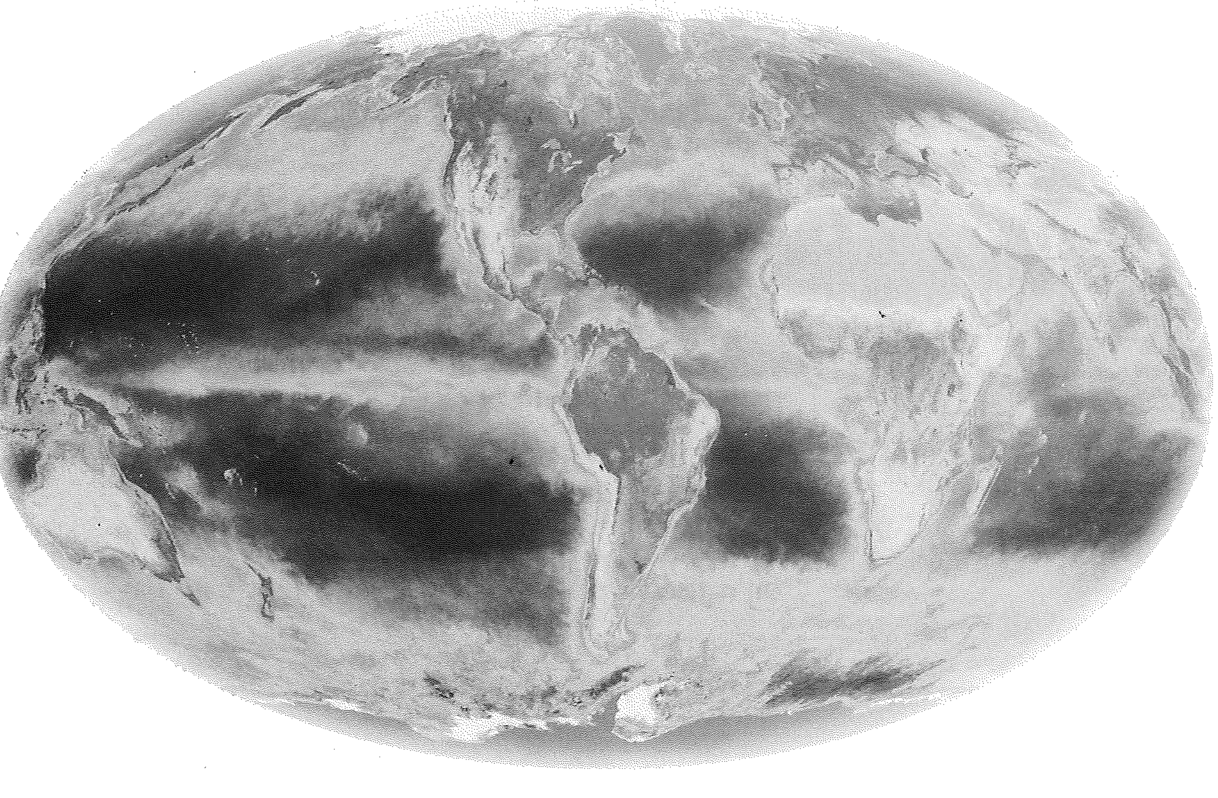
Aeronautics and Space Report of the President



Fiscal Year 1998 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 (FY) 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, 1997, through September 30, 1998.

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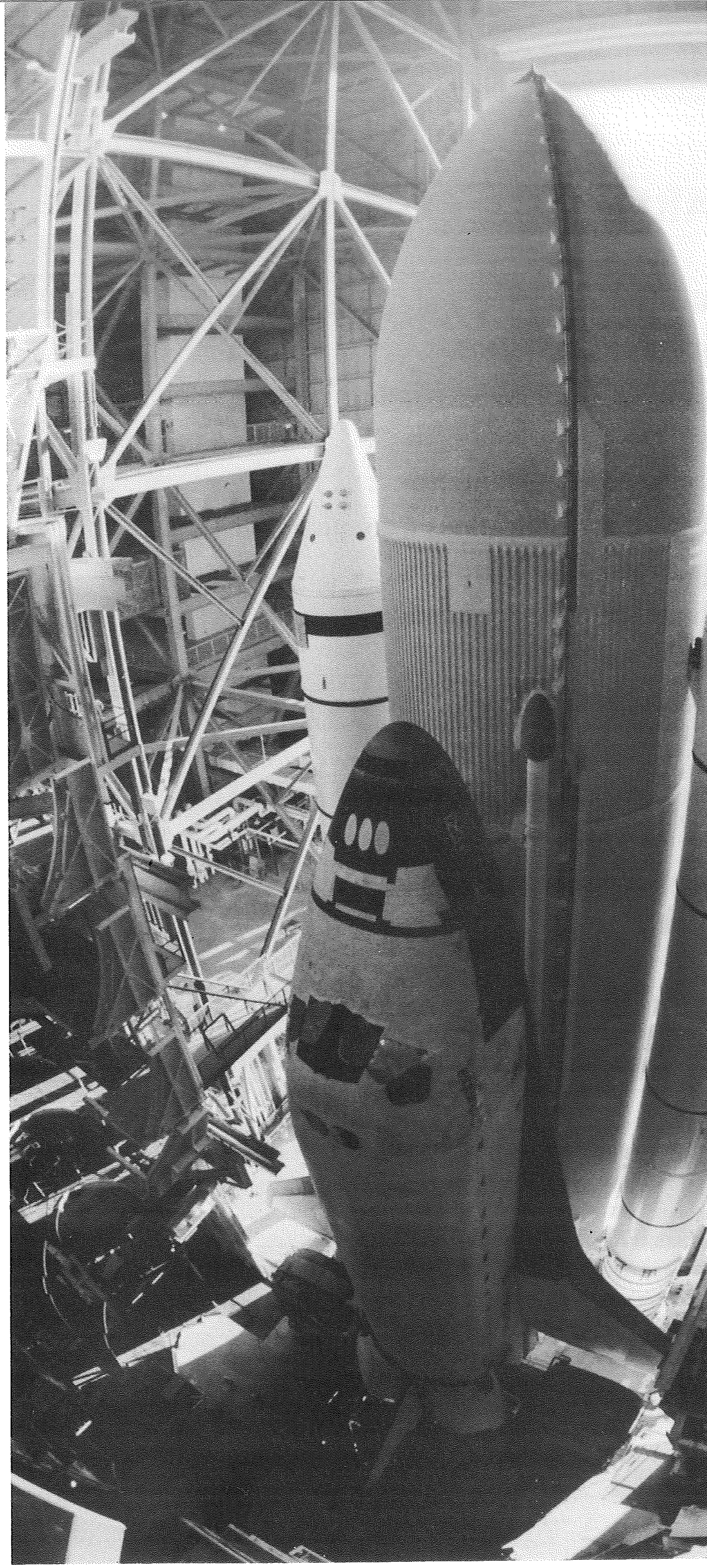


The Space Shuttle Columbia begins its rollout from the Vehicle Assembly Building for the April 1998 STS-90 mission, whose primary payload was the Neurolab experiments focusing on the effects of microgravity on the human nervous system.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA

In the area of human space flight, the Space Shuttle program continued its goal of providing safe, reliable, and affordable access to space. In FY 1998, 28 crew members spent approximately 605 crewdays in orbit, including time spent by American astronauts aboard the Russian space station *Mir*. Also in FY 1998, the Shuttle successfully completed the ninth and last of its planned rendezvous missions to *Mir*. This milestone marked the completion of Phase I of the International Space Station (ISS) program. On this same mission, the Shuttle carried into orbit the Alpha Magnetic Spectrometer (AMS) payload. The cutting-edge AMS scientific payload found and measured highly charged particles.

The Space Shuttle program continued to fly more safely, reliably, and at lower cost than at any previous time in its history. Recent restructuring activities have resulted in operations cost reductions of more than 30 percent since 1992. The consolidation of Space Shuttle contracts into a single prime contract continued on pace with the incorporation of the Solid Rocket Booster production contract into the Shuttle Flight Operations Contract in FY 1998. The Phase I upgrades, to improve Shuttle safety and performance, neared completion in FY 1998 with the first launch of the Super Light Weight Tank. The program also scheduled final testing of the

Block II Space Shuttle Main Engine (SSME) in preparation for its first flight on STS-96 in September 1999. The Block II SSME will require less maintenance between flights than previous engines and will deliver increased thrust so that, when combined with flight design changes, the Shuttle will be able to reach the altitude and inclination of the ISS orbit with as much as 17,200 pounds of additional payload. Phase II upgrades to improve supportability and combat obsolescence also progressed on schedule.

During FY 1998, NASA and the Russian Space Agency (RSA) completed joint activities on the Shuttle-*Mir* program (Phase I), ending more than 2 years of U.S. astronaut presence aboard *Mir* in orbit. With the successful completion of the Shuttle-*Mir* program, a total of 17 successful crew member exchanges between the two countries occurred, with 10 cosmonauts on the Shuttle and 7 U.S. astronauts on long-duration missions on *Mir*. As a highly valuable precursor for the successful implementation of Phase II and III of the ISS program, Phase I provided significant benefits in four major areas:

1. American and Russian experts had an opportunity to learn from each other on ways to work together on operating and maintaining a space station.
2. NASA gained a better understanding of ways to conduct long-duration science in advance of planned research on the ISS.
3. U.S. and Russian hardware, systems, and scientific aims have become closely integrated.
4. ISS risks were reduced through lessons learned and a better understanding of joint operations, the spacecraft environment, rendezvous and docking, on-orbit repair, spacewalks, and hardware exchange.

Also on the ISS program, the Russian-built first element, *Zarya* (which is Russian for "sunrise"), was delivered to the launch site in Baikonur. The second major element, *Unity* (Node 1), along with two Pressurized Mating Adapters, all built by the United States, underwent final checkout and inspection at the Kennedy Space Center. Several other key elements, including the Z-1 Truss, a third Pressurized Mating Adapter, and the Integrated Electronics Assembly, were also delivered to Kennedy in preparation for a mid-1999 launch. At the end of FY 1998, NASA had completed 75 percent of its development activity, and its international partners had also made considerable progress. Although funding shortfalls in Russia continued to present challenges, RSA's work on the development of the Service Module continued. To address Russian government funding shortfalls, NASA continued to implement its contingency plans, established in 1997, and planned to proceed with the launch of its first two elements in late 1998.

In terms of robotic space flight, there were 29 successful U.S. Expendable Launch Vehicle launches in FY 1998. Of those, 3 were NASA-managed missions, 2 were NASA-funded/Federal Aviation Administration (FAA)-licensed missions, 8 were Department of Defense (DoD)–managed missions, and 16 were FAA-licensed commercial launches. There were two launch vehicle failures—a U.S. Air Force-managed Titan IV-A and a commercially licensed Delta III. NASA collaborated with the U.S. Air Force, Lockheed Martin Aeronautics, and Boeing in the failure investigations, corrective action, and return-to-flight process.

In June 1998, the STS-91 crew and the Russian Mir-25 crew pose for the traditional joint inflight Shuttle-*Mir* portrait in the Core Module of the Russian space station. Left to right are cosmonaut Valery Ryumin (who flew as a mission specialist on *Discovery*), mission specialist Wendy Lawrence, Shuttle commander Charles Precourt, Andrew Thomas (who spent more than 4 months on *Mir*), *Mir* commander Talgat Musabayev, mission specialist Janet Kavandi, Shuttle pilot Dominic Gorie, cosmonaut Nikolai Budarin, and payload commander Franklin Chang-Díaz. This was the last docking of the Shuttle-*Mir* program.

In the area of space communications, NASA's space and ground networks successfully supported all NASA flight missions and numerous commercial, foreign, and other Federal Government agency missions. Mission Control and Data Systems provided the operation of 15 on-orbit science missions, including launch and mission support for the Tropical Rainfall Measuring Mission (TRMM) and the Transition Region and Coronal Explorer (TRACE). In FY 1998, NASA awarded a consolidated space operations contract to outsource NASA's space operations under a single contract. The contractor, Lockheed Martin, will manage all of NASA's data collection, telemetry, and communications operations supporting NASA's Earth-orbiting satellites, planetary exploration, and human space flight activities.

NASA continued to work with DoD and other agencies to develop a national architecture for satellite operations and to provide the radio spectrum allocations crucial to U.S. Government flight missions. NASA personnel also made significant improvements to NASA's mission control and data systems as well as ground networks, which contributed to several successful launches and significantly reduced operations staff for several orbiting missions. Internationally, NASA collaborated with colleagues from Japan, the European Space Agency (ESA), Germany, and France to foster the cooperative and reimbursable use of communications networks.

NASA's Office of Life and Microgravity Sciences and Applications (OLMSA) supported a total of 850 ongoing noncommercial investigations during FY 1998. Commercial investment in space products and service development took significant steps forward, as demonstrated by an increase from $35 million to $48 million of industry-leveraged resources. Also, 28 new industry partners joined the Commercial Space Centers, and OLMSA researchers received 11 commercial patents.

Findings in the life and microgravity sciences ranged from fundamental information on human physiology to basic results in combustion science. For example, Dr. Kenneth Baldwin published research that has clarified the role of nerve connections and the thyroid gland in the development of muscle. Dr. Gerald Faeth's research in combustion science suggested the existence of a "soot paradigm," which may supply improved methods for controlling soot processes in applications such as aircraft propulsion systems, diesel engines, and furnaces. Based on protein crystal growth in space, NASA's Dr. Alex MacPherson established a new benchmark in the study of viruses by publishing a structure of the satellite tobacco mosaic virus at far greater resolution than had ever been published before.

OLMSA's premier mission of FY 1998 was the flight of the Neurolab mission, which addressed both basic neuroscience questions and applied studies related to the astronauts' responses to space flight. Among the many "firsts" on this mission were three experiments that used state-of-the-art technology to record nerve activity in human and nonhuman subjects.

Also flown in FY 1998 was the fourth U.S. Microgravity Payload (USMP-4) mission. OLMSA researchers used this mission to conduct a series of experiments in physics and materials science. The initial results included validation of theories of physical behavior on a quantum mechanical scale when matter is confined to only two dimensions during the Confined Helium Experiment. The mission also allowed researchers to measure the growth speed and crystal size of a material that serves as a model for industrially useful metals.

In FY 1998, the Phase 1 NASA-*Mir* research program included seven biomedical experiments. These evaluated the effects of space flight on sleep patterns, vestibular and immune function, the risk of developing kidney stones, changes in bone mineral density, changes in muscle mass and strength, cardiovascular system function, and interactions among crew members and ground support.

FY 1998 was another auspicious year for NASA's Space Science Enterprise. It began with the successful launch of the Cassini/Huygens mission to Saturn on October 15, 1997. The Galileo and Mars Surveyor spacecraft made new discoveries in our solar system, such as ancient riverbeds on Mars, a possible icy subsurface ocean on Jupiter's moon, Europa, and volcanic fireworks on Io, another Jovian moon. In addition, for the first time in 25 years, NASA was once again studying the Moon with the Lunar Prospector mission.

Other space science missions yielded fascinating data as well. The Solar and Heliospheric Observatory discovered that solar flares produce seismic waves in the Sun's interior that closely resemble those created by earthquakes on our planet. The TRACE mission revealed how magnetic fields control the structure of the Sun's corona and produce arch-like structures filled with million-degree gas.

On August 27, 1998, a group of scientists led by NASA observed an intense wave of gamma rays emanating from a catastrophic magnetic flare on a mysterious star 20,000 light years away. The waves from this "magnetar" struck Earth's atmosphere, and their impact has begun providing important clues about some of the most unusual stars in the universe.

The Hubble Space Telescope continued its impressive performance, revealing the first optical glimpse at what is possibly a planet outside our solar system—one that apparently has been ejected into deep space by its parent stars. Located 450 light years away in the sky (the deepest Hubble image thus far) within a star-forming region in the constellation Taurus, the object seems to lie at the end of a strange filament of light. This suggests that it may have been flung away from the vicinity of a newly forming pair of binary stars.

For the Earth Science Enterprise (formally Mission to Planet Earth), FY 1998 was a year of great accomplishment. TRMM was launched successfully in November 1997 and exceeded expectations by providing unprecedented insights into rainfall cloud systems in the tropics and subtropics. TRMM's all-weather, sea-surface temperature data from September 1998 indicated a possibly waning La Niña event, a cooling phase of El Niño. In August 1998, TRMM provided spectacular images of Hurricane Bonnie over the Atlantic Ocean by capturing towering clouds extending up to 59,000 feet above the hurricane's eye. Earth scientists believe that the scientific understandings resulting from this mission will revolutionize knowledge of how storms and hurricanes form and dissipate. Earth scientists also completed an experiment off the coast of Florida, the Convection and Moisture Experiment, to measure the hurricane's structure, environment, and changes in intensity. This effort coincided with the occurrence of Hurricanes Bonnie, Danielle, Earl, and Georges.

The Earth Science Enterprise also created the new Applications, Commercial, and Education Division. This new organization reflects an increased emphasis on partnerships between the commercial remote-sensing industry and the NASA-sponsored science research community. NASA's Earth Science Enterprise also began a planning process to enhance international and interagency partnerships for the follow-on Earth Observing System (EOS) missions. NASA also made significant progress in planning the next generation of instruments and spacecraft for future Earth Science Enterprise missions.

During FY 1998, NASA's Aero-Space Technology Enterprise (formerly called the Aeronautics and Space Transportation Technology Enterprise) continued its work in the "Three Pillars for Success" initiative—Global Civil Aviation, Revolutionary Technology Leaps, and Access to Space. Within these pillars, NASA defined 10 long-range technology goals. These goals address the Nation's critical aerospace needs, which include productivity, the protection of the environment, low-cost access to space, and most notably aviation safety.

Within the Aviation Safety program, NASA tested the airborne Light Intersection Direction and Ranging (LIDAR), which demonstrated the capability of precisely detecting the air turbulence level 1 kilometer ahead of the airplane. This provides sufficient time for the crew to avoid rough air or to prepare for an appropriate evasive action. NASA researchers conducted flight tests to improve our understanding of aircraft tailplane icing and developed a new, environmentally safe anti-icing fluid that is so environmentally safe that it has been referred to as "food grade."

The Aeronautics Base Research and Technology program continued its successful list of accomplishments. The Pathfinder Plus solar-powered remotely piloted vehicle was flown to a world-record altitude of greater then 80,000 feet. In a cooperative project with the Russian Central Institute of Aviation Motors, NASA achieved the first extended supersonic combustion in flight, using a scramjet flown to Mach 6.6. NASA researchers also flight-tested two types of advanced electric control-surface actuators on the F-18 Systems Research Aircraft.

In the High Speed Research program, NASA successfully completed a series of flight tests of a Russian Tu-144 supersonic transport to validate critical engineering prediction capabilities and learn about supersonic transport design practices and operational characteristics. NASA researchers obtained aerodynamic, aerothermodynamic, and heat-transfer data at speeds in excess of Mach 2 to validate computational fluid dynamic and heat transfer codes. Other experiments measured the effectiveness of techniques to reduce cabin noise, pilot handling qualities, and slender wing ground effects.

The Advanced Subsonic Technology program made several important accomplishments. In terms of reducing commercial transport emissions, advanced combustor concepts demonstrated a 50-percent reduction in nitrous oxide (NO_x) in flame tube tests, and these showed promise for achieving the program's 70-percent NO_x reduction goal. NASA researchers also participated in a joint international field campaign to probe the North Atlantic flight corridor to study the chemical, radiative, and dynamic interactions between Earth's background atmosphere and aircraft exhaust.

Research in noise-reduction technology progressed as well. Active noise-control tests in a high-fidelity engine simulator indicated that it is technically feasible to reduce fan tones by as much as 10 decibels. NASA aeronautics researchers also developed concepts that indicate great promise in significantly reducing flap edge airframe noise. In developing ways to lessen the noise impact on passengers, researchers conducted flight tests that demonstrate an optimized active control system to reduce the interior noise of propellers on commuter aircraft.

During FY 1998, the Space Transportation Technology program achieved several major milestones. The X-33 flight demonstrator successfully completed its Critical Design Review, verifying the feasibility of the integrated design prior to major hardware construction and integration. The dual-lobe liquid oxygen tank, the first major X-33 flight component, was delivered to the X-33 final assembly area in Palmdale, California. Workers also broke ground for the X-33 launch site.

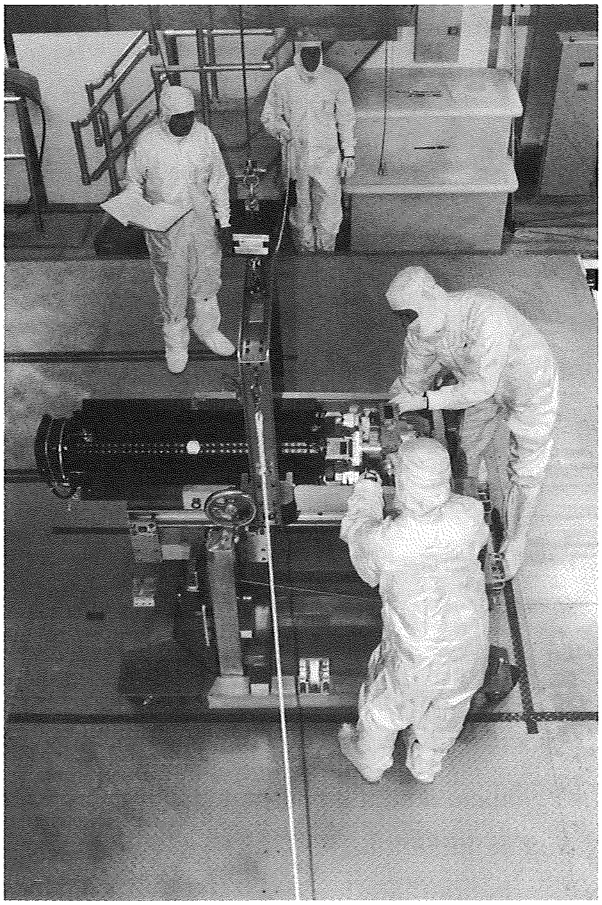
The X-34 program also completed many key milestones in FY 1998. The program completed the first flight wing, the test fuselage, the qualification testing on the liquid oxygen tanks, and the delivery of the first tank. Technicians also completed the development of the generator component and the injector development testing, while work on the Fastrac engine continued on pace. Finally, the propulsion test article and Fastrac engine assembly were delivered to NASA's Stennis Space Center for testing.

In the area of international relations, the most significant new agreements were those associated with the ISS. In January 1998, the United States, Russia, Japan, 10 nations of Europe, and Canada signed the Intergovernmental Agreement for the ISS. In parallel, NASA memoranda of understanding (MOU) were signed with the Canadian Space Agency, ESA, RSA, and the government of Japan, outlining additional details of the cooperation. In October 1997, another related agreement was signed between NASA and the Brazilian Space Agency, which makes Brazil a participant in the program. Other agreements signed during this period provide for cooperation in aeronautics, space science, Earth science, and life and microgravity sciences.

NASA actively participated in many international aerospace forums. These included various coordination mechanisms for strategic planning in life and microgravity sciences, space science, Martian exploration, orbital debris research and observations, and Earth observation programs. In addition, NASA led the U.S. delegation to the Scientific and Technical Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) and supported the Legal Subcommittee and full COPUOS meetings. A major focus for COPUOS was the planning for Unispace III, a United Nations conference on space, held in July 1999 in Vienna, Austria. NASA was actively involved in drafting background papers and report material, as well as in planning for various technical sessions.

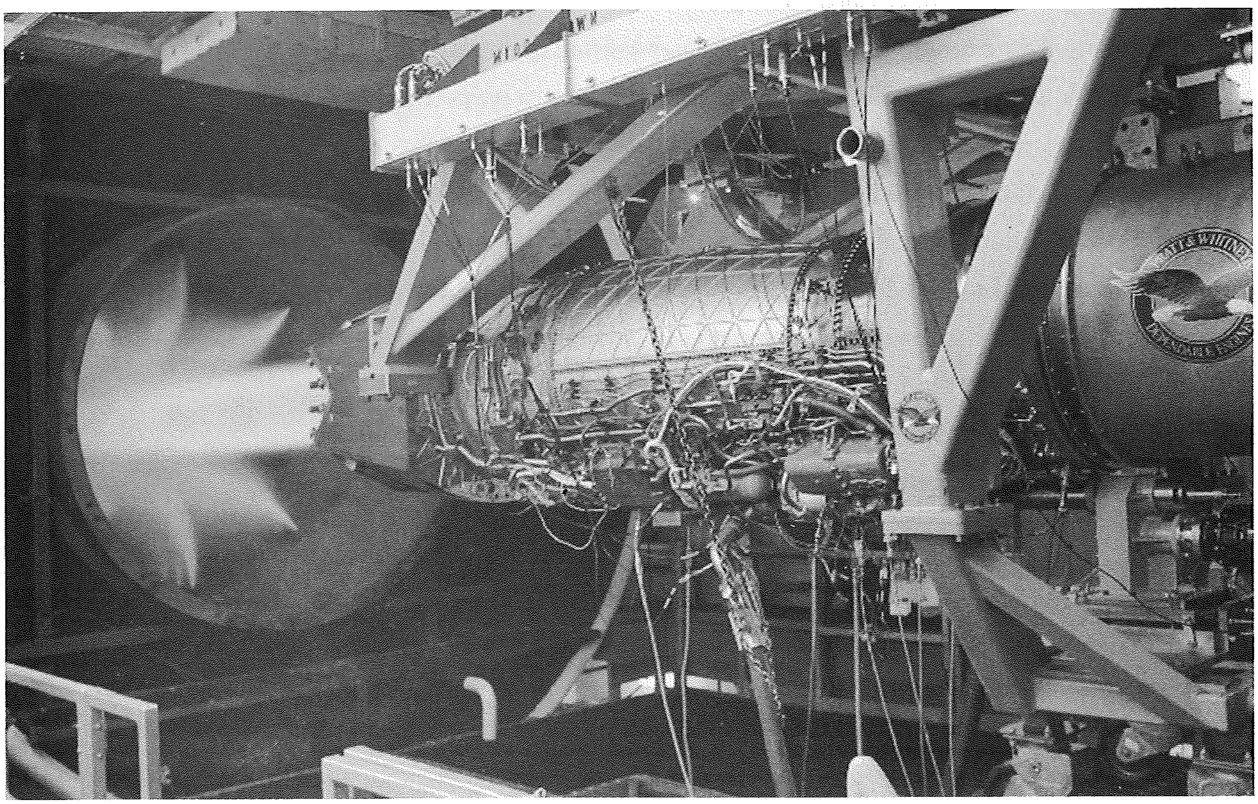
Several significant international projects achieved the major milestone of launch in late 1997. The Cassini mission to Saturn—with the orbiter provided by NASA, the Huygens Probe provided by ESA, and the communications system provided by the Italian Space Agency—was launched in October 1997. The U.S.-Japanese TRMM was launched in November 1997 and has returned substantial data during its highly successful operations. Virtually all Space Shuttle missions during this period included crew members from other nations, foreign payloads, or both. The Shuttle-*Mir* cooperation between NASA and RSA was brought to a successful close in June 1998. In support of NASA's research programs, numerous aircraft campaigns were conducted around the world for space and Earth science observations.

Overall, safety remained one of NASA's fundamental or core operating values. In support of this value during FY 1998, NASA implemented a multifaceted approach to measure and improve the health, stability, and capability of its safety processes. By combining customer agreements, annual planning, and process and performance assessment into a unified effort, NASA strengthened safety insight. Independent assessments, conducted by NASA safety and mission assurance experts, provided valuable input for



This shows workers installing three radioisotope thermoelectric generators on the Cassini spacecraft at Cape Canaveral Air Station's Launch Complex 40. Cassini was successfully launched on October 25, 1997; its target is Saturn. NASA provided the orbiter, ESA contributed the Huygens Probe, and the Italian Space Agency delivered the communications system.

several NASA programs, including the Space Shuttle, the ISS, the Super Light Weight Tank, the X-33 and X-34, Cassini, the Chandra X-ray Observatory (formerly the Advanced X-ray Astrophysics Facility), and the Stratospheric Observatory for Infrared Astronomy. NASA extrapolated valuable safety and mission assurance information from the Shuttle-*Mir* program and incorporated these lessons into the ISS. NASA has fortified its risk management implementation through policy, training, and tools. NASA safety personnel developed the Quantitative Risk Assessment System, a new software tool for advanced computer-assisted quantitative or probabilistic risk assessment. This software, generic enough to support any NASA program, already began supporting decisionmaking on Space Shuttle safety-enhancing upgrades. During FY 1998, three NASA Centers (Johnson Space Center, Kennedy Space Center, and Marshall Space Flight Center) were certified to ISO 9001 as part of NASA's continuing effort to implement this quality management standard. In addition, the Langley Research Center became the first Federal installation to receive "Star" certification under the Occupational Safety and Health Administration's Voluntary Protection Program.



This XTE66/SE "CAESAR" engine is operating on a test stand.

Department of Defense

DoD

DoD focused on three areas of aeronautics research and development in FY 1998. The first demonstrated technologies that offer the best potential for increasing the capability and affordability of future aircraft and missile systems, such as the Joint Strike Fighter and Joint Transport Rotorcraft. The second area enhanced emerging aircraft systems, such as the F-22, F-18 E/F, and V-22, to reduce program risk. The third area extended the service life for the full spectrum of currently fielded systems. Specific aeronautics technology highlights for FY 1998 included transonic wind tunnel validation of an advanced compact inlet system, which offers the potential for a 35-percent reduction in inlet weight and volume for a typical fighter aircraft inlet. Another highlight was the evaluation of bonded repair techniques on a full-scale fatigue test article, which demonstrated the capability to arrest fatigue cracks on metallic aircraft structures. A third highlight was the evaluation of an advanced rotorcraft airfoil concept, which demonstrated stall-free operation in a dynamic stall environment. Modelers also developed a low-speed data base for tailless fighter aircraft to improve modeling accuracy and reduce development time and cost, as well as the Control Designer's Unified Interface software package for optimizing helicopter control system laws.

In aircraft propulsion, the joint DoD-NASA-industry Integrated High Performance Turbine Engine Technology program successfully completed the testing of Pratt & Whitney's turbofan/turbojet core engine demonstrator, which indicated a significant increase in engine thrust-to-weight ratio. The program also successfully completed component and engine structure assessment research with core engine testing, which verified component durability in an experimental engine relevant to a broad spectrum of applications, including the Joint Strike Fighter and F-22. In aircraft power, DoD personnel successfully transferred technologies demonstrated under the More Electric Aircraft initiative—including an engine external starter/generator, an auxiliary power starter/generator, an electric actuator controller, and electric power distribution technologies—to the Joint Strike Fighter program.

During FY 1998, DoD's evolving space capabilities to provide communications, surveillance, reconnaissance, navigation, and weather data continued to support U.S. national security objectives. In terms of direct support to military operations, DoD's space systems played a crucial role as a force multiplier everywhere U.S. forces were deployed, particularly in Bosnia.

In FY 1998, the Assistant Secretary of Defense for Command, Control, Communications and Intelligence became responsible for space management functions. The Secretary of Defense disbanded the Office of the Deputy Under Secretary of Defense for Space, and its functions were transferred to the new Office of the Deputy Assistant Secretary of Defense for Command, Control, Communications, Intelligence, Surveillance, Reconnaissance, and Space Systems.

During FY 1998, several milestones were accomplished in the Military Satellite Communications (MilSatCom) area. The Global Broadcast Satellite Service (GBS) system was awarded, and a GBS payload was successfully launched. A UHF Follow-On satellite, a Defense Satellite Communications System spacecraft, and a Polar Adjunct program payload were successfully launched. Also, Milstar II began its initial operational test and evaluation.

In terms of surveillance and warning capability, the Space Based Infrared System (SBIRS) made significant progress during the past year.

Technicians began the manufacturing development of the high-altitude component of SBIRS, proceeding on schedule for deployment during FY 2002. DoD managers updated mission requirements for SBIRS in FY 1998, and the low-altitude element underwent a program review in preparation for the start of program definition. Two flight demonstrators, designed to test new technologies for the low component, have made significant progress toward their scheduled launch in FY 2000, with one of the demonstrators beginning sensor and bus assembly and integration.

In FY 1998, DoD led an interagency Global Positioning System (GPS) modernization effort to document the evolving needs of all GPS users and identify effective modifications to the system to satisfy those needs well into the next century. As part of this effort, DoD personnel performed a significant amount of analysis to satisfy the requirement for a second GPS signal for civil use.

In the area of meteorology, DoD's ongoing interagency and international cooperative efforts made great strides during FY 1998. A milestone toward the convergence of U.S. civil and military polar-orbiting weather satellites was reached during FY 1998 when the command and control of both military and civil weather satellites were consolidated.

During FY 1998, DoD continued to work on the Evolved Expendable Launch Vehicle (EELV) program to develop a national launch capability that satisfies Government requirements and reduces the cost of a space launch by at least 25 percent. In November 1997, DoD approved a revision to the EELV acquisition strategy, which included awarding launch services instead of purchasing launch vehicles and operations. In June 1998, DoD released a request for proposal (RFP) that reflected this strategy. A month later, the two contractors submitted proposals for engineering and manufacturing development, as well as for the provision of initial launch services from FY 2002 to FY 2006.

The National Reconnaissance Office (NRO) continued to contribute substantially to the expanding flow of vital information to the warfighter, its national customers, and a growing set of "nontraditional" users, such as civil, environmental, and diplomatic customers. The NRO began work on one such program, Eagle Vision II, a mobile commercial imagery satellite ground receiving and processing system. During FY 1998, the NRO also joined with the Defense Advanced Research Projects Agency and the Air Force in the Discoverer II program, an initiative to prove the feasibility of using a space-based radar for moving target indication. Finally, the NRO issued two RFP's on the Future Imagery Architecture to officially begin the acquisition process.

The NRO continued to work with its mission partners—the National Security Agency, the National Imagery and Mapping Agency, the Central Measurement and Signature Intelligence Office, the U.S. Space Command, the Defense Intelligence Agency, and the Central Intelligence Agency—to ensure support for intelligence analysis, policy enforcement, and military operations. To also ensure improved organizational communication, requirements analysis, and architecture review, the NRO established both a Systems-of-Systems Architect and the Air Force-NRO Integration Program Group. In addition, the NRO assigned personnel to the newly formed National Security Space Architect's Office.

Federal Aviation Administration

FAA

The FAA continued a dynamic research and development program in support of its mission to ensure the safe and efficient use of the Nation's airspace, to foster civil aeronautics and air commerce in the United States and abroad, and to support the requirement of national defense. To achieve these goals, during FY 1998, the FAA continued to acquire new automation systems for the National Airspace System (NAS). The agency installed display system replacements at 12 air route traffic control centers, bringing the total installed to date up to 16 of the eventual 21 that will be installed. The FAA also installed nine voice switching and control system backup systems at en route centers that will be used for training purposes. At the end of FY 1998, the FAA had installed 10 of 22 of these systems. Installation of the host and oceanic computer system replacement began with 11 systems delivered to en route centers, the FAA Academy, and the William J. Hughes Technical Center. The agency upgraded the existing terminal automation system software and hardware at 21 terminal radar-approach control facilities nationwide. These upgrades established a common hardware and software baseline, providing new maintenance efficiencies for the agency. Work also continued on a new standard terminal automation replacement system that will provide a platform for future automation enhancements to meet the increased traffic demands.

The FAA made substantial progress in two programs that aid controllers in reducing incidents and accidents that are attributable to runway incursions. The first, the Airport Surface Detection Equipment Model 3 (ASDE-3), provides radar surveillance of aircraft and airport service vehicles at high activity airports. The second, the Airport Movement Area Safety System (AMASS), visually and aurally prompts tower controllers to respond to situations that potentially compromise safety. The agency commissioned ASDE-3 systems at Memphis, Dallas/Fort Worth, and Dulles International Airports, bringing the total number commissioned to 30 out of 40 systems. The agency also commissioned 15 Mode S, Monopulse Secondary Surveillance Radars, bringing the total to 130 systems of 148 commissioned. These systems provide highly accurate aircraft identification and altitude information to air traffic controllers. In addition, the FAA awarded a contract to the Raytheon Corporation for up to 127 Air Traffic Control Beacon Interrogator replacement systems, which will replace 30-year-old, secondary-surveillance beacon systems.

In cooperation with NASA and industry, the FAA's Aeronautical Data Link Program continued research and development on next-generation data link applications. As part of that effort, a Government-industry consortium, the FAA-sponsored Flight Management System-Air Traffic Management Next Generation, developed a "Required Functional Capabilities Document," outlining the required flight operations (air and ground), air traffic management, communications, and navigation and surveillance capabilities. The FAA and NASA sponsored a study to compare aircraft fuel consumption during flight management system–derived flight paths and air traffic management–derived flight paths to validate the concept of flight profile negotiation via data link. The FAA and NASA also jointly sponsored and authored a test plan to use data from revenue aircraft to validate the benefits of incorporating user information into air traffic automation functionality.

The FAA made continued progress toward the implementation of the Wide Area Augmentation System (WAAS), which will provide the availability, integration, and accuracy for GPS to be used for precision civilian navigation. During the fiscal year, the FAA completed the installation of 25 reference and 2 master land-based stations necessary for the WAAS to achieve initial operating capability in the summer of 1999. A partnership of the FAA, NASA, DoD, and the aviation industry made substantial progress in moving the NAS toward free flight—a concept that could ultimately allow pilots to choose their own routes, speeds, and altitudes during flight. This free flight concept could improve safety, save time and fuel, and be a more efficient use of airspace and our natural environment. Efforts toward a Global Navigation Satellite System continued to produce results. Cooperative agreements with Canada, Mexico, Iceland, and Chile, as well as cooperation with Europe and the Far East, represented measurable progress toward seamless worldwide coverage.

The FAA's en route automated radar terminal system became fully operational at all offshore facilities during the fiscal year. The FAA reduced the vertical separation standards from 2,000 to 1,000 feet over North Atlantic airspace and implemented the new standards at the New York oceanic center, allowing for the addition of two north-south routes to the North Atlantic airspace. Ground-to-ground data link communications via the air traffic services interfacility communications system also became operational between Oakland, California, and Japan and between Anchorage, Alaska, and the Russian Far East. This enabled a more efficient transfer of aircraft navigation information and provided more timely position and performance data to controllers.

The FAA commissioned its 350th automated surface observing system to automate weather observation gathering and dissemination during the fiscal year. The FAA unconditionally certified the Weather and Radar Processor (WARP) program, which is the first program to receive such certification. WARP is a system that receives and processes real-time weather data from multiple sources and produces displays of weather information for multiple users to support the en route environment. The Integrated Terminal Weather System (ITWS) program was installed as a prototype at New York's LaGuardia Airport and completed its preliminary design review. This is an automated weather system that provides near-term

(0 to 30 minutes) prediction of significant terminal area weather, integrating data from radars, sensors, and automated aircraft reports. The FAA's Runway Incursion Reduction Program and NASA's Terminal Area Productivity Program completed the data analysis and final report on the joint demonstration of the Low Visibility Landing and Surface Operations project at Atlanta Hartsfield International Airport. The demonstration allowed the FAA to integrate several operational and research and development surveillance systems to provide real-time seamless coverage, conflict alerts, identification, and information sharing of targets on the airport surface. The FAA continued to improve wind shear detection capability by commissioning nine Terminal Doppler Weather Radars. At the end of FY 1998, this improved capability was available at 38 major airports.

The FAA and NASA jointly sponsored the development of a prototype for a worldwide aircraft noise impact model. In April 1998, at the fourth meeting of the International Civil Aviation Organization's Committee on Aviation Environmental Protection, the FAA successfully promoted the inclusion of further model development into the current work program with the commitment of continued FAA and NASA support.

The FAA continued its advanced research activities in a number of critical aviation safety areas, including structural integrity, nondestructive inspection, and crashworthiness. For example, in conjunction with the U.S. Air Force, the FAA has developed a new user-friendly software tool, Repair Assessment Procedure and Integrated Design (RAPID), that is capable of static strength and damage tolerance analysis of fuselage skin repairs. The FAA began deploying the Safety Performance Analysis System, a web-based automated risk-based analytical tool, to all aviation safety inspectors. As of September 1998, more than 2,000 aviation safety inspectors had received training and been granted access to the system. In April 1998, the FAA made RAPID 2.1 software and supporting documentation available to the public through the World Wide Web. In September 1998, the FAA teamed with NASA and DoD to sponsor the Second Joint Conference on Aging Aircraft.

The FAA teamed with Boeing to construct and operate the Airport Pavement Test Facility, which will be used to explore and validate new pavement design, construction methods, and paving materials. Researchers conducted a successful evaluation of the prototype Advanced Taxiway Guidance System during FY 1998. They collected data from subject pilots that clearly indicated that the implementation of such a system would enhance airport safety by reducing the chances of incorrect turns and/or runway incursions, particularly in night and/or low-visibility operations. During the fiscal year, the FAA ordered the retrofit of approximately 3,000 airliners in the U.S. fleet with cargo compartment fire-detection and suppression systems because of demonstrated hazards of aerosol cans in passenger luggage during a cargo fire and the effectiveness of halon extinguishing agent in preventing aerosol can explosions. The FAA also reestablished a flight loads data collection program for large transport airplanes.

The FAA continued to lead the Nation in research and development activities to prevent explosives, weapons, and other threat materials from being introduced on aircraft. During FY 1998, to detect weapons in checked luggage, the FAA worked with its industry partners to support the certification of an upgraded InVision explosives detection system, the CTX 5500DS, and develop a Prototype 3 View X-Ray System and an advanced quadruple resonance research prototype. To enhance checkpoint security operations, the agency worked in partnership with the aviation community to complete laboratory evaluations of 6 trace detection systems, leading to the deployment of more than 350 machines at domestic airport checkpoints. To optimize and standardize security system operator performance, the agency deployed computer-based training and screener selection tests to 18 of the 19 major domestic airports and deployed threat image projection equipment to the Atlanta, Detroit, and Seattle airports for data collection and evaluation. Researchers also are working with international partners to examine potential development of trace detection techniques for cargo and to establish interagency cooperation for conducting baseline evaluations of cargo inspection systems. In addition, researchers validated wide-body aircraft vulnerability estimates by explosives testing, certified an LD3 hardened container, and, with Boeing, conducted aircraft vulnerability validation with explosive tests on a pressurized L-1011 airframe.

During FY 1998, the FAA continued an ongoing effort to develop reliable, valid, and sensitive human-performance metrics and baselines to support system-performance tests and evaluation during acquisition. These measures are essential to evaluate changes in system hardware, software, and procedures. Researchers at the Civil Aeromedical Institute, from the U.S. Air Force, and from Japan continued their assessments of the effects of bright lights as a potential fatigue countermeasure for air traffic control personnel working midnight shifts. Human factors specialists continued to explore several display concepts designed to improve the quality of information available to the busy air traffic controller.

Human factors specialists also continued work to enhance the performance of pilots and aircraft maintenance technicians by developing techniques that will allow the airlines to assess pilots in a more standardized way, target deficiencies, and provide needed training. The FAA worked on developing advanced data collection and analysis systems to allow air carriers and FAA oversight offices to monitor the effectiveness of pilot training systems. For aircraft maintenance technicians, new computer-based training programs provided concentrated instruction on concepts such as human error and teamwork. Human factors researchers also participated in a joint FAA–National Institute of Occupational Safety and Health 5-year study of airline cabin air quality. Areas of concentration included the potential routes of transmission of disease from an infected individual to other airline passengers in the same cabin, the reproductive health problems of flight attendants, and the health consequences of repeated exposure to higher levels of cosmic radiation at various altitudes.

During the fiscal year, FAA's Associate Administrator for Commercial Space Transportation monitored a new record of 22 FAA-licensed commercial space launches—more than 50 percent higher than the previous year—and issued two new launch site operator licenses for new sites in Virginia and Alaska, doubling the number of such commercially or State-operated launch sites. The FAA issued nine license amendments, including four renewals. The FAA briefly suspended one license in an enforcement action to correct a potentially dangerous situation and completed 27 compliance inspections relating to commercial launches. The Office of Commercial Space Transportation compiled and published its annual low-Earth orbit (LEO) commercial satellite market projection and collaborated with its Commercial Space Transportation Advisory Committee to produce its geostationary Earth orbit market projection.

The FAA also published in the *Federal Register* the final rule relating to financial responsibility requirements for licensed launch activities and continued work on a proposed final rule updating commercial space transportation licensing regulations relating to launches from Federal launch sites. It also undertook a major new initiative to develop a concept of operations to integrate the needs of space transportation into the NAS. The Office of Commercial Space Transportation, Air Traffic Control, the FAA's Office of General Counsel, and the U.S. Air Force agreed to work together to provide an organizational framework to facilitate the development of an integrated Space and Air Traffic Management System. By the end of FY 1998, the agency had completed a draft "Commercial Space Transportation NAS 2005 Concept" document for internal coordination.

Department of Commerce

DoC

The Department of Commerce (DoC) is responsible for promoting U.S. commercial interests in both domestic and international markets. During FY 1998, the National Oceanic and Atmospheric Administration (NOAA), the Office of Air and Space Commercialization (OASC), the International Trade Administration (ITA), the National Telecommunications and Information Agency (NTIA), and the National Institute of Standards and Technology (NIST) engaged in a wide variety of space-related activities to ensure U.S. economic growth, development, and competitiveness in the global marketplace.

NOAA successfully launched NOAA-K (15), the first of its new series of polar-orbiting satellites, on May 13, 1998. NOAA-15 is the first in a series of five satellites with improved imaging and sounding capabilities that will operate over the next 12 years and will collect meteorological and environmental data and transmit information to users around the world. On May 29, 1998, as part of the convergence of the U.S. polar satellites under the National Polar-orbiting Operational Environmental Satellite System (NPOESS), NOAA assumed operational responsibility for the Defense Meteorological Satellite Program (DMSP) from the U.S. Air Force. With respect to the Geostationary Operational Environmental Satellite (GOES) program, NOAA took operational responsibility of the GOES-10 satellite, which had been launched in 1997, and placed it into an onorbit storage mode for use as an "onorbit spare" satellite, should one of the two operational satellites (GOES-8 or GOES-9) fail. In April 1998, when GOES-9 (GOES West) started to experience anomalies, NOAA personnel brought GOES-10 back into onorbit operational mode to provide meteorological coverage with minimal impact to the Nation's weather forecasting. NOAA personnel continued to conduct both the polar satellites—those of DMSP and the Polar-orbiting Operational Environmental Satellite (POES) program—and GOES program operations from the Suitland, Maryland, satellite control center.

NOAA's National Environmental Satellite, Data, and Information Services (NESDIS) continued its involvement in the Landsat Program Management group, comprised of NESDIS, NASA, and the U.S. Geological Survey (USGS). NOAA, NASA, and the USGS cohosted the 27th Landsat Ground Station Operations Working Group in May 1998, as well as conducted a Special Technical Session on Landsat 7 operations. NESDIS continued negotiations with 18 international ground stations interested in signing Landsat 7 MOU's to receive data directly from the spacecraft. NESDIS continued to work with the 11 international ground stations that are currently part of the Landsat 4/5 program.

At NOAA's NESDIS, research and data centers made significant progress toward utilizing the World Wide Web as a means to meet national and global customer data demands. The three data centers—the National Climatic Data Center, the National Geophysical Data Center, and the National Oceanographic Data Center—surpassed prior records for fulfilling data requests from the public and the research community. NESDIS personnel continued to develop new products for public and Government use. National Climatic Data Center personnel participated in a number of global climate change studies in which long-term data revealed significant anomalies in global land-surface temperature. The National Geophysical Data Center continued its geophysical and paleo-environmental work, as well as applications of the DMSP data to develop global nighttime lights and global fire products.

The Washington, D.C., Volcanic Ash Advisory Center (VAAC) within NOAA began operations in November 1997. One purpose of the VAAC is to provide to the aviation and volcanology community virtually real-time analysis of satellite products to support volcanic ash eruptions. In addition to providing operational messages about other eruptions in its area of responsibility, the VAAC provided more than 435 advisory messages for the Soufriere Hills volcano in Montserrat, West Indies. This VAAC is the largest of nine worldwide and is operated under the auspices of the World Meteorological Organization and the International Civil Aviation Organization. NESDIS provided operational satellite-derived fire support for wildfires in Indonesia, Mexico, Central America, and Brazil at the request of the U.S. Agency for International Development, the Department of State, the U.S. Department of Agriculture (USDA) Forest Service, and the governments of Mexico and Brazil. NESDIS personnel also provided satellite-derived products to support fire-suppression activities to local fire-fighting units in southern Florida.

In the area of commercial licensing, NESDIS published a Notice of Proposed Rulemaking on private remote-sensing regulations in November 1997 and held a public meeting to solicit comments on the proposed regulations in April 1998. NESDIS issued its first Synthetic Aperture Radar (SAR) license, issued two license amendments, and approved six international agreements. In response to statutory requirements on the commercial imagery of Israel, NESDIS worked with an interagency group to develop and publish the 2-meter imaging limitation.

During FY 1998, the Administrators of NOAA and NASA signed a basic agreement on behalf of the two agencies concerning collaborative programs. This was an umbrella agreement covering 12 MOU's, some of which also involved international partners. In addition, the NOAA and NASA Administrators signed an MOU with the secretary of the Indian Department of Space for science cooperation in the areas of Earth and atmospheric sciences. The Indian MOU will provide for real-time exchange of Indian geostationary satellite data (from INSAT) within the context of cooperative activities in the Earth and atmospheric sciences.

Also in the international arena, NOAA completed amendments to the Argos MOU Amendment with France's Centre Nationale d'Etudes Spatiales (CNES) to cover instruments on the future NOAA-N' (N prime) satellite. NESDIS participated in a number of bilateral activities with the Canadian Space Agency for Radarsat I/II, the National Space Development Agency (NASDA) of Japan for the Advanced Land Observing Satellite and Advanced Earth Observing Satellite II systems. Negotiators made significant progress on the proposed Integrated Joint Polar Systems with the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) for instruments on future polar satellites as part of the NPOESS program.

NESDIS also participated in many activities associated with the Committee on Earth Observation Satellites (CEOS) at the plenary, working group, and project levels. NESDIS chaired the Disaster Management Support Project in connection with CEOS and the Integrated Global Observing Strategy and held a number of meetings in Europe, Asia, and the United States aimed at gathering information from space agencies and disaster/emergency managers about their current use of satellite data and their requirements.

Also at DoC, OASC continued efforts to foster an economic and policy environment that promotes the global preeminence of the U.S. commercial space industry. OASC served as an advocate for the U.S. commercial satellite imaging industry during high-level interagency meetings on U.S. remote-sensing policy regarding Canada, Greece, Israel, Italy, Japan, Korea, Russia, and Spain. The office also worked in coordination with other DoC bureaus to serve U.S. commercial interests in the areas of GPS and launch services.

As a member of the Interagency GPS Executive Board (IGEB), DoC contributed significantly to major U.S. decisions affecting the future of GPS. NOAA, OASC, and the NTIA participated in the decisionmaking processes that led to and stemmed from the March 1998 commitment to add new civilian capabilities to GPS, as announced by Vice President Al Gore. In particular, NOAA and OASC cochaired an interagency working group established by the IGEB to develop a strategy for funding GPS as a national priority. NOAA also led the collection and documentation of civilian requirements for GPS modernization. With respect to GPS radio spectrum, NTIA played an essential role in conducting technical studies, supporting both the GPS modernization effort and the U.S. position at the World Radio Conference. DoC officials also served on U.S. delegations that met with Japan and the European Union to negotiate agreements intended to establish GPS as a worldwide standard. The consultations with Japan culminated in a joint statement on GPS cooperation signed by President Bill Clinton and Japanese Prime Minister Keizo Obuchi in September 1998.

OASC and ITA represented the interests of U.S. launch and satellite industries during annual consultations with China, Russia, and the Ukraine on commercial space launch services. In October 1997, DoC participated in the negotiation and signing of an amendment to the U.S.-China agreement covering price guidelines for launches to LEO.

ITA's Office of Aerospace also participated in discussions with the European Union concerning government support for the development of new civil aircraft programs. ITA, in concert with other agencies, undertook efforts to advance U.S. trade interests regarding regulatory measures in Europe that could restrict U.S. exports. ITA also participated in discussions with Russia and the Ukraine to encourage them to sign the GATT Agreement on Trade in Civil Aircraft as a part of their World Trade Organization (WTO) accession. In the Asia-Pacific Economic Cooperation (APEC) forum, ITA sought to advance a proposal aimed at eliminating aircraft tariffs imposed by APEC members. ITA served on a U.S. delegation that met with Russia to discuss the implementation of tariff waivers on civil aircraft. ITA also supported efforts of the U.S.-China Joint Committee on Commerce and Trade to expand intergovernmental cooperation and trade in civil aviation and airports.

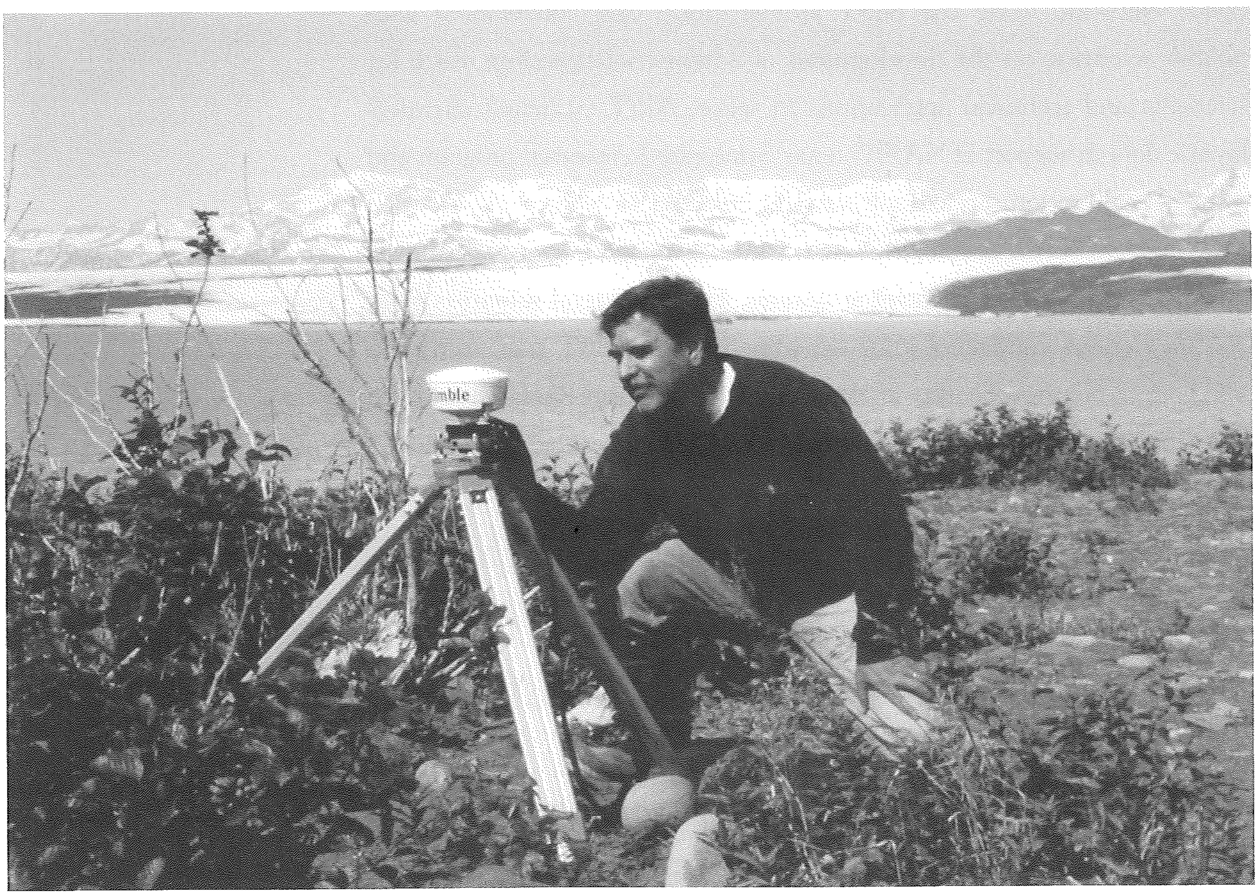
To promote the export of U.S. aerospace products, ITA sponsored Aerospace Product Literature Centers at major international aerospace exhibitions and air shows in Berlin, Chile, China, Dubai, Kuala Lumpur, South Africa, Singapore, and the United Kingdom. Trade leads generated through this literature center concept numbered more than 7,500. ITA also supported U.S. firms in international aerospace competitions, including those for helicopters, commercial transport aircraft, and space launch vehicles.

ITA's Office of Telecommunications continued its work to support U.S. access to satellite markets overseas through a variety of bilateral and multilateral initiatives. Under the WTO Agreement on Basic Telecommunications Services, the Office of Telecommunications supported the U.S. Trade Representative's office in monitoring several aspects of the agreement, including provisions relating to market access for satellite service providers. ITA supported the inclusion of certain satellite products in the Information Technology Agreement II, with the goal of reducing tariffs and facilitating increased trade. ITA sought to increase market access for U.S. companies through its support for the U.S.-Argentina Satellite Services Agreement, which was signed in June 1998. ITA also endeavored to open Japan's direct-to-home satellite services market for U.S. companies through the U.S.-Japan Enhanced Initiative on Deregulation and Competition Policy. Also with regard to Japan, ITA monitored compliance with the 1990 U.S.-Japan Satellite Procurement Agreement.

ITA developed updated market data and projections on the sales of satellite services and equipment, space transportation services, and other space-related goods and services for inclusion in the *1999 U.S. Industry and Trade Outlook*. ITA also released a major study of market trends and growth in the commercial GPS industry.

As the lead advisory agency for Federal Government telecommunications issues, NTIA undertook a number of policy initiatives regarding satellites and other space-based communications systems. Specifically, NTIA provided policy guidance on the restructuring of the International Telecommunications Satellite (INTELSAT) Organization and the International Mobile Satellite (INMARSAT) Organization. NTIA continued to manage the Federal Government's use of the radio spectrum, including assignments for NASA, DoD, NOAA, and other Government satellite programs. NTIA worked closely with other U.S. regulatory authorities and commercial satellite users at the ITU World Radio Conference to secure spectrum allocations for satellite systems in frequency bands above 15 gigahertz (GHz).

NIST performed a wide variety of metrology-related research in support of aeronautics and space activities during FY 1998. NIST scientists and engineers worked in collaboration with their counterparts in eight NASA Centers on more than 50 projects. NIST supplied the Jet Propulsion Laboratory (JPL) with time and frequency reference services for the Deep Space Network, using the NIST atomic clock, and collaborated with NASA scientists on the development of a laser-cooled cesium clock for scientific and technical applications in space. NIST evaluated chemical kinetic data in support of NASA's upper atmospheric research program and provided calibration services for NASA's EOS. NIST worked closely with NASA scientists on developing space telescope imaging spectrograph and spectral and photometric imaging systems. Finally, several scientists from NASA Centers conducted joint experiments with NIST staff, using the NIST Cold Neutron Facility at the Center for Neutron Research and the NIST Synchrotron Ultraviolet Radiation Facility.



Ed Harne of BLM at joint BLM/USGS Bering Glacier Field Camp (photo by Bruce Keating, BLM).

Department of the Interior

DoI

The Department of the Interior (DoI) continued to depend on the DoD Navstar GPS Precise Positioning Service (PPS) for real-time positioning in wildland areas that are out of reach of traditional differential GPS methods. DoI user growth for GPS exceeded training capacity; the USGS facilitated five 2-day training sessions for DoI in FY 1998, and more GPS training courses were scheduled for FY 1999. DoI GPS coordinators continued to identify DoI requirements for specifications of future military handheld GPS receivers, such as the Special Operations Lightweight GPS Receiver and the Defense Advanced GPS Receiver.

The Office of Surface Mining (OSM) used GPS technology to locate surface resources to determine their premining status and condition and to confirm that reclamation efforts have adequately restored these resources. On active mines, inspection staff used GPS to determine reclaimed acreage and to locate features that require regular inspection. On abandoned mine lands, Office of Surface Mining staff used GPS to quickly assess the disturbed areas and features to facilitate the preparation of reclamation plans and contracts. In addition, Bureau of Reclamation personnel often used GPS for such applications as locating sampling sites to study geologic features, vegetation, and water quality, mapping infrastructure locations, and mapping environmental features such as wetland boundaries.

The USGS Volcano Hazards Program expanded its volcano-monitoring network at Long Valley, California, by installing additional GPS sensors during FY 1998. The expansion of this GPS network was set to continue over the next 2 years, resulting in a modern instrument array capable of continuous, real-time detection of ground deformation associated with potential volcanic activity in this seismically active area.

USGS scientists used a 63-station GPS network to measure the distribution of subsurface bedrock deformation across the western United States through surveys conducted in 1992, 1996, and 1998. Subsurface bedrock deformation was determined to be quite variable across the region and is influenced by patterns of fault networks and plate tectonic processes. Maximum deformation of 6.0 ± 1.6 millimeters per year occurred near the Sierra Nevada Mountain range, reflecting a concentration of deformation adjacent to the rigid Sierra Nevada and Colorado Plateau blocks.

The Bureau of Indian Affairs extensively used Landsat and Satellite Pour l'Observation de la Terre (SPOT) satellite imagery, digital orthophotography, National Aerial Photography Program (NAPP) and other aerial photography, and GPS-derived data to generate image maps, inventory natural resources, conduct environmental assessments, and support other Geographic Information System (GIS) analyses.

Remotely sensed data derived from satellites and aircraft sensors and GPS technology continued to play an important role in efforts by the Bureau of Land Management (BLM) to sustain the health, diversity, and productivity of the public lands. The data provided critical information to resource specialists in the field for use in their inventory, assessment, modeling, and monitoring efforts. BLM has significantly increased the use of GPS and GIS technology to implement the Automated Lands and Minerals Record System Modernization program. As a result, many BLM offices were able to perform complex spatial data analysis at the field office level.

The Bureau of Reclamation used remotely sensed data in support of a number of water resource management projects. The bureau derived crop acreage from Landsat Thematic Mapper (TM), SPOT high-resolution visible, Indian Remote Sensing Satellite (INSAT) panchromatic, and Radarsat data as inputs to consumptive water use models for the Colorado and Yakima River basins in the western United States. Scientists mapped in-channel and flooded bottomland habitat in the Yakima basin, using large-scale aerial photography, and mapped surface temperatures in the Yakima River, using airborne scanner imagery. Reclamation scientists also used medium- to large-scale aerial photography to support a number of resource mapping projects at selected Federal lands throughout the western United States. NASA acquired Airborne Visible and Infrared Imaging Spectrometer (AVIRIS) hyperspectral imagery of the Owyhee River basin in eastern Oregon for the Bureau of Reclamation to use in support of surface geology and water quality mapping projects.

The National Park Service used Landsat and SPOT data, along with conventional aerial photography, to map and monitor land cover, vegetation, and other specific features in many National Parks, from Alaska to Florida.

The USGS EROS Data Center continued to work with NASA and NOAA to prepare the facilities to receive, process, and deliver data from the Landsat 7 satellite, which is planned for launch in 1999. The Landsat 7 Processing and Image Assessment Systems became operational in 1998. On September 17, 1998, the new Landsat 7 antenna successfully acquired the first Landsat image that the EROS Data Center had ever acquired directly from a Landsat satellite—a TM image of the Black Hills of South Dakota.

The Multi-Resolution Land Characterization project—a joint activity of the USGS, the Environmental Protection Agency (EPA), NASA, NOAA, and other agencies—released medium-resolution land-cover data derived from Landsat data for the States of Alabama, Florida, Georgia, Kentucky, Mississippi, and Tennessee. Scientists successfully tested an accuracy assessment methodology in Federal Region 2 (States in the Chesapeake Bay watershed) and applied the methodology in New York and New Jersey. The USGS also continued to build the Alaska Multi-Resolution Land Characterization data base. This data base contains land-cover maps derived from Landsat Multispectral Scanner, Landsat TM, and SPOT satellite data, dating back to 1980.

The USGS worked with the USDA Forest Service to incorporate satellite-derived fire fuels information into the Forest Service's Fire Potential Index (FPI) model. Technicians installed the enhanced model at nine national study sites where fire managers began using it in daily local fire hazard briefings. Forest Service fire managers at the national level used the FPI to allocate funding to the field for the 1998 fire management and suppression season. The model is also being applied internationally; fire managers, suppression experts, modelers, and geospatial analysts from Argentina, Chile, Mexico, Spain, and the United States met in Argentina to complete fire fuels maps for these countries that will be used to calculate the FPI for 1992 through 1997.

The USGS National Civil Applications Program (NCAP) provided secure facilities for Federal civil agencies to acquire and process classified satellite data for applications such as land and resource management, global change research, environmental monitoring, and disaster detection and mitigation. In addition, NCAP supported a national wildland fire detection and global volcano monitoring network, maintained and preserved a global library of classified remotely sensed data, and trained civil users. In FY 1998, NCAP staff began testing the prototype Hazards Support System, which will provide warnings of wildland fire outbreaks in the United States and monitor volcanic eruptions worldwide. They also began developing and testing the Global Fiducials Library, which provides the scientific community with digital classified satellite data collected at selected worldwide sites for long-term environmental monitoring.

The USGS Alaska Volcano Observatory began using a variety of real-time and archival satellite data and computer modeling techniques to monitor and analyze volcanic activity in the North Pacific region. During FY 1998, the observatory provided information about airborne volcanic ash from several volcanic events to the National Weather Service, the FAA, and the U.S. Air Force to assist in weather forecasting and air traffic control.

USGS scientists demonstrated that satellite Interferometric Synthetic Aperture Radar (InSAR) is uniquely suited to monitoring year-to-year deformation of the entire 3,000-square-kilometer Yellowstone

Caldera that underlies Yellowstone National Park. Sequential interferograms indicated that subsidence within the caldera migrated from northeast to southwest, from one resurgent dome to the other, between 1992 and 1995. Subsidence of the caldera ceased in 1995–96, but it began again in 1996–97. These patterns of subsidence are matched well by other measures of the migration of hydrothermal and magmatic fluid throughout the entire caldera floor at a depth of approximately 8 kilometers.

USGS scientists used a variety of remote-sensing and spatial analysis tools for environmental analysis and modeling in Everglades National Park and surrounding areas. Airborne, ground, and borehole geophysical methods were used to map saltwater intrusion and develop three-dimensional water quality models. Scientists used more than 1,500 satellite images to derive a time series of water turbidity conditions in Florida Bay since 1985. Scientists used these images to determine turbidity and light availability for seagrass and to assess conditions in the bay and adjacent areas prior to the time when extensive monitoring programs began in 1991. An analysis of the imagery indicated that 200 square kilometers of dense Everglades seagrass meadows were lost between 1987 and 1997.

The USGS Astrogeology Program continued to make major contributions to Martian exploration. With the successful completion of operations of the Mars Pathfinder spacecraft, USGS scientists turned their attention to the creation of special digital images, image mosaics, and topical science issues on the characteristics of the rocks, soils, and terrain at the landing site. The USGS was also involved in both the Mars Orbital Camera and the Thermal Emission Spectrometer teams of NASA's Mars Global Surveyor mission, assisting with observations and analyses to guide the spacecraft through its critical aerobraking phases as it settled into low Martian orbit.

In addition, USGS investigators played a major role in shaping the design of NASA's new and highly aggressive Mars Exploration Strategy. This plan includes two spacecraft launched to Mars every 2 years for the next 10 years, culminating in the return of Martian surface samples in about a decade and the exploration of the planet by humans approximately a decade later.

FEDERAL COMMUNICATIONS COMMISSION

FCC

The Federal Communications Commission (FCC) has continued to be involved in making rules to facilitate and regulate the U.S. domestic satellite industry and the licensing of all ground stations and satellite launches. Internationally, the FCC continued to coordinate satellite placement with other countries.

In terms of station licensing, the FCC streamlined the existing application process by introducing the electronic filing of ground- and space-based transmitter and receiver applications. The electronic filing of ground-based applications has enabled the FCC to process applications four times faster than the former, manual mechanism. In FY 1998, the FCC processed more than 10,000 ground-based applications.

In the area of satellite launches, the FCC licensed a number of launches during FY 1998. In January 1998, the FCC authorized COMSAT to participate in the launch, positioning, and onorbit testing of the INMARSAT-3 (F-5) satellite. This satellite will serve as a spare in orbit. In February 1998, the FCC authorized COMSAT to participate in the launch and onorbit testing of the INTELSAT VIII-A (F-6) (INTELSAT 806) satellite, which was launched that month and began commercial service in May 1998. The FCC authorized the Columbia Communications Corporation in

March 1998 to acquire and operate an operational C-band satellite from INTELSAT (Columbia-515, formerly INTELSAT 515). Columbia began commercial operation of this satellite the next month. In April 1998, the FCC granted permission to EchoStar to launch a Direct Broadcast Service (DBS) satellite (EchoStar 4), which was launched in May 1998 but, because of technical difficulties, was located in a different orbital location than originally planned. In June 1998, the FCC authorized COMSAT to participate in the launch and testing in orbit of the INTELSAT VIII-A (F-5) (INTELSAT 805) satellite, which later began providing international telecommunications services to the Asia-Pacific region. The FCC authorized PanAmSat in September 1998 to launch and operate a Fixed Satellite Service (FSS) satellite (PAS-21).

In addition, the FCC authorized Orbital Communications Corporation to launch and operate 12 satellites, increasing its total LEO constellation from 36 to 48 satellites. In accordance with its FCC license, Iridium launched the remainder of its LEO satellites (34 were launched in the previous fiscal year) and began testing. The FCC also licensed five so-called "little" LEO systems ("little" refers to the fact that they operate at frequencies lower than 1 GHz). These systems will provide nonvoice mobile satellite service throughout the world.

During FY 1998, the FCC held a number of meetings with its counterpart agencies in foreign governments to facilitate international satellite communications. In particular, the U.S. and Argentine governments agreed on orbital locations for a U.S.-licensed satellite and an Argentine-licensed satellite to serve North America. The agreement was instrumental in facilitating hemispheric services licensed by both countries and in promoting competition in the market for satellite services. FCC officials also held two meetings with their Brazilian counterparts as part of an ongoing effort to coordinate U.S. and Brazilian satellites.

The United States reached an agreement with Canada to allow the use of a common satellite platform for provision of L-band multispectral services to Canada and the United States. Canadian and U.S. officials also reached an agreement on the operation of U.S. Digital Audio Radio Service

(DARS) in the S-band. The agreement will provide for U.S. satellite DARS systems to operate interference-free with Canadian terrestrial systems.

The U.S. and Indian administrations met to discuss coordinating the PanAmSat satellite systems with Indian satellite networks and to complete the coordination of satellite networks. Japanese and U.S. officials reached coordination agreements on six of eight commercial satellite systems and established working methods to complete the remaining satellite coordinations. Russian and U.S. officials met to coordinate a wide range of satellite networks. They reached coordination agreements and established methods to coordinate other systems in the C-, Ku-, and Ka-bands.

Officials from the United States and the United Kingdom met to discuss coordination between various U.S. and British satellite networks in the Ku- and Ka-bands. The agenda focused primarily on coordination among the U.K. Pacific Centuries Group operator and nine separate U.S.-licensed operators in the Ka-band. Officials also coordinated information exchanges between a large number of U.S.-licensed satellites and British satellites. Both administrations agreed that further exchange of information and coordination may take place directly between satellite operators.

Finally, the United States reached a coordinated agreement with INTELSAT on behalf of Columbia Communications Corporation, a U.S. satellite licensee. Under the agreement, which resolved a long-standing dispute, Columbia is now operating its own satellite, the Columbia-515, which INTELSAT sold to Columbia, and INTELSAT is operating its INTELSAT 806. A coordination agreement has also been reached for the Columbia-515 and INTELSAT's neighboring satellites.

DEPARTMENT OF AGRICULTURE

USDA

USDA's research and operational programs made use of remotely sensed data and related technologies to benefit agriculture and forestry. This section of the report highlights USDA agencies that advanced remote-sensing knowledge, developed improved applications, and used imagery and technology to produce more accurate and timely products and services.

The Agriculture Research Service (ARS) enhanced remote-sensing knowledge and developed productive applications of the technology at research facilities located throughout the United States. At Weslaco, Texas, the ARS Integrated Farming and Natural Resources Unit collected data over the Southern Great Plains to determine the relationship between soil moisture and regional climate conditions and the variability of soil moisture over space and time. At the Jornada Experimental Range, the ARS Hydrology Laboratory collected laser profiler data and visible, thermal infrared and video imagery to infer surface temperature, albedo, vegetation indices, roughness, and other land-surface characteristics. At ARS laboratories in Ames, Iowa, Lincoln, Nebraska, and Lubbock, Texas, scientists quantified relationships among plant populations, nitrogen stress, water stress, and remotely sensed information. In Iowa, for example, ARS determined when in the growing season weeds can be differentiated from economic crops, such as corn and soybeans, and how variations in soil patterns are related to observed patterns in crops. In Phoenix, Arizona, the ARS U.S. Water Consèrvation Laboratory cooperated with NASA's Stennis Space Center to develop products and applications using data from multispectral airborne sensors to manage crops and soils.

Using remote-sensing technology, the ARS Remote Sensing and Modeling Laboratory (RSML) and the Hydrology Laboratory initiated a long-term experiment to evaluate the economic and environmental impact of four alternative farming practices on surface and subsurface water quality. Working with the National Agricultural Statistics Service (NASS), RSML assessed crop yields at regional scales, using models and remote-sensing data. Researchers succeeded in assessing spring wheat yields in North Dakota in just 1 month following crop maturity, compared to the usual 4 months. This increased speed and improved spatial accuracy are very important to program managers because of the potential for assessing foreign crops. RSML also developed a method for using multispectral fluorescence imaging to conduct nondestructive evaluations of crop physiological status. Likewise, RSML used fluorescent sensing to detect ozone damage, ultraviolet radiation damage to vegetation, and the effect of increased carbon dioxide. RSML research demonstrated that remote sensing can accurately assess tropospheric environmental problems.

The satellite remote-sensing program of the Foreign Agricultural Service (FAS) remained a critical element in USDA's analysis of global agricultural production and crop conditions by providing timely, accurate, and unbiased estimates of global area, yield, and production. Satellite-derived early warning of unusual crop conditions and production anomalies enabled more rapid and precise determinations of global supply conditions. FAS used NOAA, Advanced Very High Resolution Radiometer (AVHRR), Landsat, and French SPOT imagery, crop models, weather data, attaché reports, field travel, and ancillary data to forecast foreign grain, oilseed, and cotton production. FAS remote sensing supported Department of State (DoS) assessments of food needs in Indonesia, North Korea, and the former Soviet Union. Also, FAS prepared detailed analyses of the El Niño event, the record Argentine soybean crop, the bumper wheat crop in Australia, the bumper soybean crop in Brazil, flooding in China and North Korea, and drought in Mexico and Indonesia.

The Farm Service Agency (FSA) continued to share with FAS the cost of analyzing imagery of the United States. Timely analysis of U.S. crop conditions, 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 continued to be a partner in NAPP and the National Digital Orthoquad Program (NDOP). FSA started to field reengineered business processes that combine the use of digital orthophotography, GIS, GPS, and satellite imagery to replace the use of hardcopy NAPP aerial photography and 35-millimeter slides.

The USDA Forest Service and Stephen F. Austin University hosted the Seventh Forest Service Remote Sensing Applications Conference, in Nassau Bay, Texas. The conference, focusing on "Natural Resources Management Using Remote Sensing and GIS," attracted a wide range of representatives from Federal and State government, the private sector, and academia, and it resulted in more than 35 published papers. Besides using remotely sensed data to manage 191 million acres of land in the National Forest System, the Forest Service supported many international projects by providing remotely sensed data and expertise. These projects included pre-fire planning in Brazil, fire suppression support in Mexico, and fire recovery work in Indonesia. All three countries received fire mapping support, for which remotely sensed data were essential in providing timely and accurate information.

NASS used remote-sensing data to construct area frames for statistical sampling, to estimate crop area, to create crop-specific land-cover data layers for GIS, and to 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 new remote-sensing-based area frames and samples for Texas and Puerto Rico for the survey and census of agriculture coverage measures.

The remote-sensing acreage estimation project analyzed Landsat data of the 1997 crop season in Arkansas, North Dakota, and South Dakota and then collected 1998 crop season data for the same three States. End-of-season TM analysis produced crop acreage estimates for major crops at State and county levels, as well as a crop-specific categorization in the form of a digital mosaic of TM scenes distributed to users on a CD–ROM. Vegetation condition images based on AVHRR data were used with conventional survey data to assess crop conditions.

The Natural Resources Conservation Service (NRCS) continued its partnership with Federal, State, and local agencies in sharing costs to develop 1-meter digital ortho-imagery coverage through NDOP. By year's end, 76 percent of the Nation's digital ortho-imagery was either complete or in progress. Federal-State cooperative agreements for statewide ortho-imagery were started in Indiana, Kentucky, Louisiana, Maryland, Missouri, Ohio, Texas, and West Virginia. Indiana was the first project of this magnitude to use airborne GPS horizontal ground control acquired concurrently with new aerial imagery. The NRCS increased the use of remote sensing to collect natural resource data for its National Resources Inventory Program by contracting for low-level high-resolution imagery over 6,000 sampling sites across the Nation during the growing season.

National Science Foundation

NSF

Projects sponsored by the National Science Foundation (NSF) continued to contribute new knowledge about the origins, composition, and dynamics of the universe and Earth's near-space environment. NSF-sponsored scientists have discovered many new outer solar system objects as a result of ongoing optical surveys. For example, scientists now believe that the region beyond the orbit of Neptune is home to hundreds of thousands of minor planets and perhaps billions of comet-like objects. Astronomers have begun to develop a picture of the relationship between these objects and the formation of planets, the origin of comets, and the existence of dust disks around stars.

In addition, NSF-sponsored scientists began monitoring a previously unremarkable binary star that suddenly began emitting x-rays and radio waves. Scientists believe that one of the pair is either a black hole or a neutron star—both very compact objects. Astronomers theorize that, in such systems, the neutron star or black hole is drawing material away from its companion star and that the material is formed into a rotating disk around the compact companion. The x-rays, they believe, come from superheated material in this "accretion disk" and are ejected at right angles to the plane of the disk. Because scientists do not fully understand the relevant physical processes, astronomers are eager to gain as much new information as possible whenever one of these systems is discovered.

Scientists have discovered a way to study so-called "dark matter"—matter we cannot see because it does not give off any radiation. Astronomers have known for several years that a small galaxy is orbiting our home galaxy, the Milky Way. New calculations indicate that the small galaxy orbits the Milky Way in less than 1 billion years and that it has completed 10 orbits. Amazingly, the strong gravitational forces of the Milky Way have not destroyed the small galaxy as would have been expected. This indicates that the small galaxy contains far more mass than indicated by its number of stars, thus signaling the presence of a significant amount of dark matter. Astronomers think that at least 90 percent of the matter in the universe is dark and hope to clarify the nature of this dark matter.

Radio telescope studies of the fiery afterglow of a gamma ray burst have provided astronomers with the best clues yet about the origins of these tremendous cosmic cataclysms since their discovery more than 30 years ago. Observations with NSF's Very Large Array radio telescope confirm that a blast seen to occur on March 29, 1998, had its origin in a star-forming region of a distant galaxy. There are two leading theories for the causes of gamma ray bursts. According to one theory, the blasts occur when a pair of superdense neutron stars collide. The second is that a single, very massive star explodes in a "hypernova," more powerful than a supernova, at the end of its normal life. Observations favor this second hypothesis.

Astronomers have found evidence for the most powerful magnetic field ever seen in the universe. They have observed a long-sought, short-lived "afterglow" of subatomic particles ejected from a magnetar—a neutron star with a magnetic field billions of times stronger than any on Earth and 100 times stronger than any previously known in the universe. The afterglow is believed to be the aftermath of a massive starquake on the neutron star's surface.

NSF-sponsored researchers at Hughes STX Company developed a method for the early warning of solar events using interplanetary radio bursts observed remotely by both the Ulysses and Wind spacecraft. These emissions are generated when coronal mass ejections create shocks in the interplanetary medium. The investigators have been successful in using the timing of these radio emissions to estimate the arrival time of the shocks on Earth.

Scientists at Science Applications International Corporation in San Diego developed a comprehensive, three-dimensional, magnetohydrodynamic model to use remote observations of the Sun to predict the state of the solar wind at Earth's orbit. Researchers have already used the model to determine the coronal magnetic field and heliospheric current sheet structure during the period from February 1997 to March 1998. Scientists also have used the model to simulate the triggering of a coronal mass ejection, including its appearance as seen by a space-based coronagraph.

Scientists from Cornell University used a sensitive all-sky imaging camera to study the behavior of structured airglow layers in the thermosphere over Puerto Rico. These elongated structures are believed to be a result of enhanced geomagnetic activity. Their behavior is consistent with plasma irregularities commonly seen near the magnetic equator, but scientists do not yet completely understand the connection between the two phenomena.

Researchers at SRI International and the University of Alaska's Geophysical Institute in Fairbanks discovered new evidence for a theory explaining the presence of thin sporadic layers of sodium in Earth's upper atmosphere. Scientists believe that these sporadic layers, distinct from the better understood layer of neutral sodium atoms found between 80 and 100 kilometers altitude, are a byproduct of meteors vaporizing when entering the atmosphere. Using data from the NSF-supported incoherent scatter radar and sodium LIDAR, the investigators demonstrated that thin ion layers are pushed downward to a region in which chemical catalysts recombine the ionized sodium, leaving behind a thin layer of neutral sodium.

NSF-funded scientists at the High Altitude Observatory of the National Center for Atmospheric Research continued to develop instruments to assist in studying solar irradiance—energy flux in the plane of Earth's orbit. Solar irradiance and total solar luminosity vary over time scales from days to years. Not only do astronomers not know the physical mechanisms that cause these changes in the Sun's brightness, but astronomers cannot even identify which of the components of the Sun's visible outer photosphere are responsible for the solar energy flux variations that have been detected by satellite experiments. In response to mounting documentation that terrestrial climate is correlated with such changes in the Sun, NSF researchers have developed a long-range plan and experiment to address how and why the Sun's irradiance changes.

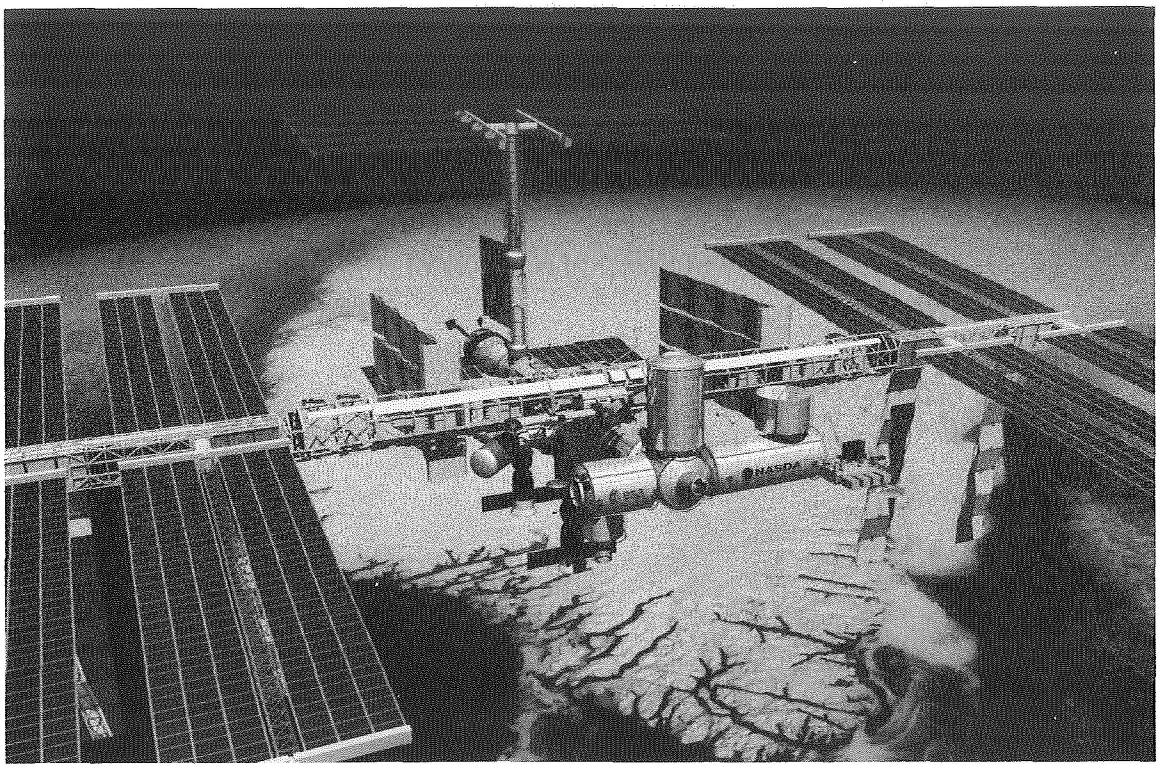
Department of State

DoS

After months of negotiations, the United States, Europe, Russia, Canada, and Japan successfully reached an Intergovernmental Agreement for the ISS. The signing ceremony took place on January 29, 1998, at DoS in Washington, D.C., and drew considerable press coverage.

On September 22, 1998, President Clinton and Japanese Prime Minister Obuchi signed the U.S.-Japan joint statement on GPS, pledging that the United States and Japan would work together to promote broad and effective use of GPS. The joint statement was the result of 2 years of discussions between the two governments on issues related to expanding civilian use of GPS. Cooperation between the United States and Japan—the world's two largest producers of GPS user equipment—is expected to promote international acceptance of GPS for civilian applications and help create a stable international playing field so that U.S. industry can take full advantage of a rapidly growing multibillion dollar market. International negotiations on GPS remained a high priority at DoS, with ongoing negotiations with Europe and Russia, as well as with Japan.

DoS continued to promote foreign policy and national security interests as the interagency lead in considering exports of U.S.-origin commercial remote-sensing systems. DoS controls the export of all U.S.



The International Space Station (ISS) presents the opportunity for several nations to work together toward a singular goal.

Munitions List items, including remote-sensing satellites and Earth stations under the Arms Export Control Act.

In FY 1998, DoS concluded a bilateral Technical Safeguard Agreement (TSA) with the Ukraine and began discussions toward a bilateral TSA with Russia and a trilateral TSA with Russia and Kazakhstan. These agreements are designed to protect U.S. satellite and missile technology and allow U.S. industry to launch satellites from foreign locations.

In addition, DoS served as the lead agency for U.S. delegations to meetings of the INTELSAT and INMARSAT member countries, successfully gaining agreement to privatize INMARSAT and restructure INTELSAT. It also provided policy guidance to COMSAT, the U.S. signatory to the organizations. DoS officials also promoted access to overseas markets for commercial satellite companies, including negotiating a landmark bilateral satellite services agreement with Argentina, and worked to resolve complex problems of orbit and spectrum availability.

Department of Energy

DoE

The Department of Energy's (DoE) Sandia National Laboratory, in cooperation with NIST, developed the portable Josephson Voltage Standard. This new compact, fully automated calibration system for direct current reference standards and digital voltmeters has proved useful to NASA, and technicians may eventually adapt this portable concept for space applications. NASA began using one portable Josephson Voltage Standard among all its Centers, saving the cost of $150,000 per laboratory system at each Center.

DoE and NASA collaborated on the Alpha Magnetic Spectrometer (AMS) experiment, which flew on a Space Shuttle mission during FY 1998. The AMS collaboration was the first time such a detector has been put in orbit, and it measured antimatter and dark matter in space.

Los Alamos National Laboratory, which is operated by the University of California for DoE, recently completed testing a space instrument designed to provide a better understanding of the compositions of comets and asteroids and delivered the instrument for eventual integration with the NASA spacecraft. The first spectrometer combines two spectrometers into one package and is known as the Plasma Experiment for Planetary Exploration. This experiment package can analyze the composition of many types of cosmic matter and can also determine whether a nuclear or chemical explosion took place in the upper atmosphere or in space.

Los Alamos National Laboratory scientists received a grant from NASA to use laboratory space instrument design and manufacturing expertise to test critical components of an instrument for possible use on a future mission to Jupiter's moon, Europa. Simultaneously, three researchers from Los Alamos worked as part of a 17-member international team to determine for NASA the technical requirements for an instrument to study that moon's icy surface. The team began studying many criteria, including how to distinguish the various radar reflection signals returned by rocks, cracks in the ice, salty and nonsalty ice, and other conditions on the Europa's surface.

DoE's Oak Ridge National Laboratory continued to serve as one of NASA's nine Distributed Active Archive Centers as part of NASA's EOSDIS, a key component of the U.S. Global Change Research Program. Finally, DoE's Lawrence Berkeley National Laboratory continued to support NASA's research on radiation levels in space and their effects on the human body.

Smithsonian Institution

Headquartered in Cambridge, Massachusetts, the Smithsonian Astrophysical Observatory (SAO) is joined with the Harvard College Observatory to form the Harvard-Smithsonian Center for Astrophysics (CfA), where more than 300 scientists are engaged in a broad program of research in astronomy, astrophysics, Earth and space sciences, and science education. The Smithsonian Institution also continued to support national aerospace activities through research and education activities at the National Air and Space Museum in Washington, D.C.

Peering halfway across the universe to analyze light from exploded stars that died long ago, SAO astronomers and their Harvard colleagues have inferred that the cosmos will expand forever. Using the Hubble Space Telescope, these scientists have found that there is too little matter in the universe to halt its expansion. As a result, the universe should continue to balloon outward infinitely.

A team of astronomers, including scientists at SAO, discovered a disk of gas and dust around a nearby star that may be forming—or may have already formed—planets. The protoplanetary disk, about three times the diameter of Pluto's orbit around the Sun, surrounds a star roughly 220 light-years from Earth. The discovery was made with a NASA-funded instrument on a telescope in Chile at about the same time as an independent discovery was made by a second team using NASA's Infrared Telescope Facility in Hawaii.

Researchers from the CfA and the University of Arizona used the Hubble Space Telescope to study approximately two dozen examples of "gravitational lensing" in a project dubbed "CASTLeS" (which stands for the CfA-Arizona Space Telescope Lens Survey). Gravitational lensing is a phenomenon predicted by Einstein's Theory of General Relativity in which light rays emanating from a distant background object (such as a quasar) are bent by the gravitational field of a foreground object (such as a massive black hole or galaxy), thus distorting the appearance of the background object. The results will be used to learn more about the properties of distant galaxies and to determine the Hubble Constant—that is, the rate at which the universe is expanding. To illustrate gravitational lensing in a more familiar setting, the team started with a digitized photograph of the Smithsonian's Castle and then used computer software originally written for analyzing astronomical gravitational lenses to distort the image as if a black hole with the mass of the planet Saturn lay between the viewer and the Castle.

Arms Control and Disarmament Agency

ACDA

During FY 1998, the Arms Control and Disarmament Agency (ACDA) continued to support missile nonproliferation efforts and worked to prevent the acquisition of offensive ballistic missile programs by other countries. ACDA personnel also worked on Strategic Arms Reduction Treaty (START) issues related to the use of excess ballistic missiles for space launch purposes.

ACDA continued to work in strengthening and expanding the scope of the 32-nation Missile Technology Control Regime (MTCR), which is intended to limit the risks of proliferation of weapons of mass destruction (that is, nuclear, chemical, and biological weapons) by controlling transfers that could make a contribution to delivery systems (other than piloted aircraft) for such weapons. During FY 1998, ACDA supported the inclusion of three new members to the MTCR. Poland, the Czech Republic, and the Ukraine were accepted at the MTCR meeting in May 1998 and officially participated at the October 1998 plenary in Budapest, Hungary. ACDA continued to participate in discussions focused on reformatting the MTCR Equipment and Technology Annex to make it more useful and effective. ACDA supported the implementation of U.S. sanctions against India and Pakistan because of their recent activities in this area.

ACDA worked on the development of U.S. policy related to the use of U.S. ballistic missiles made excess under the START I and START II treaties. The United States intends to retain such missiles for U.S. Government use or eliminate them. ACDA has encouraged other governments with excess ballistic missiles to adopt a similar policy. In addition, the START I parties exchanged policy statements not to construct silo launchers of intercontinental ballistic missiles at space launch facilities located outside their national territories.

ACDA continued to be an active member of several interagency committees concerned with missile-related issues. At the policy level, these include various committees chaired by the National Security Council, such as the Interagency Working Group on Nonproliferation and Export Controls and the Interagency Working Group on Arms Control.

ACDA participated in the Missile Trade Analysis Group, which reviews intelligence related to international transfers of missile-related items, and in the Missile Technology Export Control Group, which reviews export license applications subject to missile proliferation controls. ACDA actively supported the efforts of the United Nations Special Commission on Iraq to destroy or remove from Iraq any materials, equipment, and facilities related to missiles with a range greater than 150 kilometers. ACDA also participated in the Weapons and Space Systems Intelligence Committee to ensure that U.S. policy initiatives were based on accurate intelligence assessments.

Environmental Protection Agency

EPA

EPA continued to apply remotely sensed imagery, tools, and technologies to a wide range of environmental applications in FY 1998. EPA's Environmental Photographic Interpretation Center (EPIC) utilized current and historical aerial photography to research and identify past and current hazardous waste and other environmental problems. In FY 1998, EPIC produced hundreds of aerial photographic products on hazardous sites around the country. Scientists at EPIC used AVIRIS data sets to identify and evaluate polychlorinated biphenyl (PCB)–contaminated soils at a Superfund site in Massachusetts and hazardous wastes from a munitions activity at Yorktown, Virginia.

EPA scientists also used imaging spectroscopy to research water quality issues in the Chesapeake Bay and to characterize the environmental impacts from mining operations in the western United States. EPA and NASA scientists jointly researched the utilization of the NASA-JPL topographic SAR and aerial photography with softcopy photogrammetry for Digital Elevation Model construction.

Internationally, EPA personnel participated on an environmental task force that completed a remote-sensing GIS data base for the Priobskoye area of the Russian Arctic. EPA analysts used the data base to provide ecological risk assessment information on oil and gas exploration in the region.

In FY 1998, Government and university scientists, including NASA, the USGS, and EPA, participated in the EPA Advanced Measurement Initiative external grants program by preparing proposals to evaluate a variety of remote-sensing technologies and their application to EPA needs. EPA awarded funding to five proposals:

- Application of the SeaWiFS for Coastal Monitoring of Harmful Algal Blooms
- Field Test of Buoy-Stationed Oil Spill Remote Sensing for Potable Water Sources
- Remote Assessment of the Location and Quality of Mine Drainage Using Spectral Reflectance
- Remote Sensing Technology to Support Toxics Release Inventory
- Validation of Aerosol and Optical Parameters from the Multi-Angle Imaging Spectrometer on NASA's AM1 Satellite with Ground Measurements from Interagency Monitoring of Protected Visual Environments and the Clean Air Status and Trends Network

U.S. Information Agency

USIA

During FY 1998, the U.S. Information Agency (USIA) provided regular coverage of NASA-related events in its news services, the print-based Washington File, the Voice of America's news broadcasts, and WORLDNET Television's Newsfile. Other feature stories and thematic programs, often presented in local languages, carried accounts of NASA and related topics, to all regions of the world. For example, WORLDNET Television's Newsfile series carried a total of 43 NASA-related stories during the last fiscal year, with topics ranging from the *Mir* spacewalk to updates on the Mars Pathfinder project.

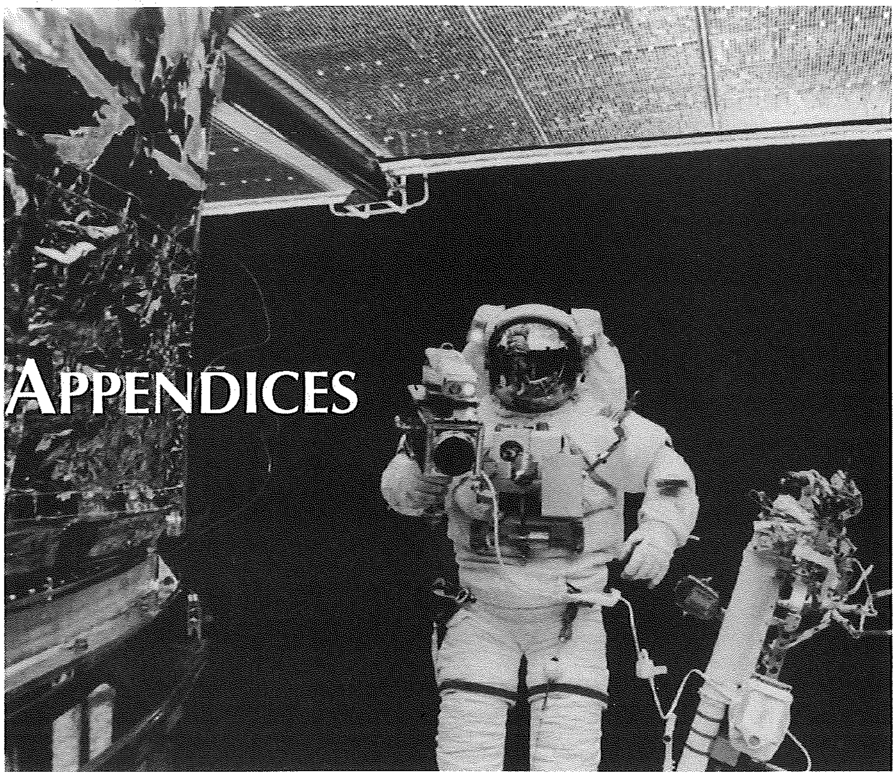
NASA officials and astronauts routinely make themselves available for USIA programs. NASA Administrator Daniel Goldin participated in U.S. Information Service (USIS)—as USIA is known abroad—programs in Germany, France, and Italy, in which he highlighted cooperation with each of those countries. He discussed the ISS, continued cooperation with the Russians, and NASA's vision for the 21st century.

One program offered a USIS Singapore-arranged interview with astronaut Guy Gardner for the local television network. Another program had USIS Italy-arranged coverage on Italian television of a visit by all seven of the STS-84 astronauts as they worked with Italian public and private partners on a project to support space education in Italy. The day after the astronauts arrived, the Italian government announced its approval of an expanded multibillion-dollar 5-year program of research and development in space exploration, which will make the Italian Space Agency one of NASA's leading international partners. A WORLDNET "Window on America" segment featured a Ukrainian astronaut in training for an upcoming Space Shuttle mission.

In FY 1998, the WORLDNET service broadcast nine interactive dialogs, among them a call-in program in Spanish, in which callers from around Latin America were able to speak with two Spanish-speaking NASA officials on NASA's future projects. A program titled "Space Exploration and Technology Transfer" in English and Arabic featured Robert Dotts, Assistant Director of the Technology Transfer and Commercialization Office at the Johnson Space Center, for viewers throughout the Middle East.

USIS San José hosted an important WORLDNET interactive dialog with Costa Rica's national hero, astronaut Franklin Chang-Díaz, during his sixth mission in space. Costa Rican-born Chang-Díaz maintains strong ties to his native country and spends a good part of each year conducting environmental and tropical disease research at an internationally renowned center in Costa Rica. In June 1998, USIS San José linked Chang-Díaz in space aboard the Space Shuttle *Discovery* with the remote research center in Costa Rica and also with Costa Rican President Miguel Rodriguez, then in New York for a United Nations meeting.

USIA also continued to make information on NASA activities available on its World Wide Web sites. These sites maintain links to NASA's home page and its daily space photograph.



APPENDICES

APPENDIX A-1

U.S. Government Spacecraft Record

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

Calendar Year	Earth Orbit[a] Success	Earth Orbit[a] Failure	Earth Escape[a] Success	Earth Escape[a] 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 *(through September 30, 1998)*	7	0	0	0
TOTAL	1,401	149	90	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.

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 *(through September 30, 1998)*	23	19			2	5			6		
TOTAL	1,143	2,563	10	8	54	53	1	1	103	10	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, 1997–September 30, 1998

Launch Date Spacecraft Name COSPAR Designation Launch Vehicle	Mission Objectives	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
Oct. 5, 1997 EchoStar 3 59A Atlas IIAS*	Communications satellite	Geosynchronous	
Oct. 15, 1997 Cassini 61A Titan IVB	Interplanetary spacecraft to orbit Saturn		
Oct. 22, 1997 STEP-4 63A Pegasus XL	Military satellite	495 km 429 km 1 hour 34 minutes 44.9°	Space Test Experimental Program 4
Oct. 24, 1997 USA 133 64A Atlas IIA	Military satellite	Orbital parameters unavailable	
Oct. 25, 1997 DSCS 3 65A Atlas IIA	Military satellite	Orbital parameters unavailable	Defense Satellite Communications System 3
Nov. 6, 1997 Navstar 38 (USA 135) 67A Delta II	GPS satellite	20,644 km 19,923 km 12 hours 2 minutes 54.9°	
Nov. 7, 1997 USA 136 68A Titan IVA	Military satellite	Orbital parameters unavailable	
Nov. 8, 1997 Iridium 38–41, 43 69A–E Delta II*	Communications satellite	650 km 635 km 1 hour 37 minutes 86.6°	
Nov. 19, 1997 Space Shuttle *Columbia* (STS-87) 73A Space Shuttle	Carry out EVA's as training for ISS spacewalks	286 km 280 km 1 hour 30 minutes 28.4°	Payloads included USMP-4, SPARTAN 201-04 free- flyer, CUE in space biology, and several other "hitchhiker" payloads.
Nov. 21, 1997 SPARTAN 201-04 73B Space Shuttle	Reusable solar observatory	Orbital parameters similar to those of STS-87	Recaptured manually by spacewalking astronauts

APPENDIX B

(Continued)

Successful Launches to Orbit on U.S. Launch Vehicles

October 1, 1997–September 30, 1998

Launch Date Spacecraft Name COSPAR Designation Launch Vehicle	Mission Objectives	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
Dec. 8, 1997 Galaxy 8 78A Atlas IIAS*	Communications satellite	Geosynchronous	
Dec. 20, 1997 Iridium 45–49 82A–E Delta II*	Communications satellites	642 km 633 km 1 hour 37 minutes 86.6°	
Dec. 23, 1997 Orbcomm FM 84A–H Pegasus*	Relay GPS signals	834 km 824 km 1 hour 41 minutes 45°	
Jan. 6, 1998 Lunar Prospector 1A Delta II*	Lunar orbiter		
Jan. 9, 1998 Skynet-4D 2A Delta II*	British military communications satellite	Geosynchronous	
Jan. 22, 1998 Space Shuttle *Endeavour* (STS-89) 3A Space Shuttle	Eighth Shuttle docking mission to *Mir*	385 km 379 km 1 hour 32 minutes 51.7°	Andrew Thomas replaced David Wolf on *Mir*. Shuttle payloads included SPACEHAB double module of science experiments.
Jan. 29, 1998 Capricorn (USA 137) 5A Atlas IIA	Military photo/radar imaging satellite	Initial apogee and perigee of 38,400 km and 320 km, respectively	NRO satellite
Feb. 10, 1998 Geosat Follow-On 7A Taurus*	Military Earth science satellite	878 km 775 km 1 hour 41 minutes 108°	
Feb. 10, 1998 Orbcomm FM-3, FM-4 7B, 7C Taurus*	Communications satellite	878 km 784 km 1 hour 41 minutes 108°	
Feb. 10, 1998 Celestis 2 7D Taurus*	Funeral ashes disposal	Disintegrated with launch vehicle upon atmospheric reentry	

APPENDIX B

(Continued)

Successful Launches to Orbit on U.S. Launch Vehicles

October 1, 1997–September 30, 1998

Launch Date Spacecraft Name COSPAR Designation Launch Vehicle	Mission Objectives	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
Feb. 14, 1998 Globalstar L-1, L-2, U-1, U-2 8A–D Delta II*	Communications satellite	1,258 km 1,245 km 1 hour 52 minutes 52°	
Feb. 18, 1998 Iridium 50, 52–54, 56 10A–E Delta II*	Communications satellites	643 km 625 km 1 hour 37 minutes 86.5°	
Feb. 25, 1998 SNOE 12A Pegasus XL*	Student science satellite	580 km 535 km 1 hour 36 minutes 97.7°	Student Nitric Oxide Explorer
Feb. 27, 1998 INTELSAT 806 14A Atlas IIAS*	International consortium's communications satellite	Geosynchronous	
Mar. 16, 1997 UHF F/O F8 (USA 137) 126A Atlas IIAS*	Military communications satellite	Geosynchronous	
Mar. 29, 1998 Iridium 55, 57–60 19A–E Delta II*	Communications satellites	635 km 620 km 1 hour 37 minutes 86°	
Apr. 1, 1998 TRACE 20A Pegasus XL	Solar physics science satellite	644 km 597 km 1 hour 37 minutes 97.8°	Transition Region and Coronal Explorer
Apr. 17, 1998 Space Shuttle *Columbia* (STS-90) 22A Space Shuttle	Carry Neurolab module for microgravity research in the human nervous system	286 km 257 km 1 hour 30 minutes 39°	Secondary goals included measurement of Shuttle vibration forces, demonstration of the bioreactor system for cell growth, and three Get Away Special payloads.
Apr. 24, 1998 Globalstar 5–8 23A–D Delta II*	International consortium's communications satellites	1,253 km 1,236 km 1 hour 51 minutes 52°	

APPENDIX B

(Continued)

Successful Launches to Orbit on U.S. Launch Vehicles
October 1, 1997–September 30, 1998

Launch Date Spacecraft Name COSPAR Designation Launch Vehicle	Mission Objectives	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
May 9, 1998 USA 139 29A Titan IVB	Military reconnaissance satellite	Orbital parameters unavailable	NRO satellite
May 13, 1998 NOAA 15 (NOAA-K) 30A Titan II	Weather satellite	824 km 808 km 1 hour 41 minutes 98.7°	Replacement for decommissioned NOAA 12 satellite
May 17, 1998 Iridium 70, 72–75 32A–E Delta II*	Communications satellites	670 km 665 km 1 hour 38 minutes	Completed constellation of 66 operational and 6 reserve satellites
June 2, 1997 Space Shuttle *Discovery* (STS-91) 34A	Last of nine docking missions with *Mir*	330 km 326 km 1 hour 31 minutes 51.7°	Mission brought home Andrew Thomas. Payloads included DoE's Alpha Magnetic Spectrometer (AME) to study high-energy particles from deep space, four Get Away Specials, and two Space Experiment Modules.
June 10, 1998 Thor 3 35A Delta II*	Norwegian communications satellite	Geosynchronous	
June 18, 1998 INTELSAT 805 37A Atlas IIAS*	International consortium's communications satellite	Geosynchronous	
Aug. 2, 1998 Orbcomm FM-13–20 46A–H Pegasus XL*	Communications satellite	826 km 816 km 1 hour 41 minutes 45°	
Sep. 8, 1998 Iridium 77, 79–82 51A–E Delta II*	Communications satellites	540 km 520 km 1 hour 35 minutes 86°	Replacements for dysfunctional members of the fleet
Sep. 23, 1998 Orbcomm FM-21–27 53A–H Pegasus XL*	Communications satellites	830 km 820 km 1 hour 41 minutes 45°	

* Commercial launch licensed as such by the Federal Aviation Administration.

APPENDIX C

U.S. and Russian Human Space Flights
1961–September 30, 1998

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

APPENDIX C

(Continued)

U.S. and Russian Human Space Flights

1961–September 30, 1998

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. Kubasovf	4:22:42	Soyuz 6, 7, and 8 operated as a group flight without actually docking. Each conducted certain experiments, including welding and Earth and celestial observation.
Soyuz 7	Oct. 12, 1969	A. V. Filipchenko Viktor N. Gorbatko Vladislav N. Volkov	4:22:41	
Soyuz 8	Oct. 13, 1969	Vladimir A. Shatalov Aleksey S. Yeliseyev	4:22:50	
Apollo 12	Nov. 14, 1969	Charles Conrad, Jr. Richard F. Gordon, Jr. Alan L. Bean	10:4:36	Second human lunar landing explored surface of Moon and retrieved parts of Surveyor 3 spacecraft, which landed in Ocean of Storms on Apr. 19, 1967.
Apollo 13	Apr. 11, 1970	James A. Lovell, Jr. Fred W. Haise, Jr. John L. Swigert, Jr.	5:22:55	Mission aborted; explosion in service module. Ship circled Moon, with crew using Lunar Module as "lifeboat" until just before reentry.
Soyuz 9	June 1, 1970	Andriyan G. Nikolayev Vitaliy I. Sevastyanov	17:16:59	Longest human space flight to date.
Apollo 14	Jan. 31, 1971	Alan B. Shepard, Jr. Stuart A. Roosa Edgar D. Mitchell	9:0:2	Third human lunar landing. Mission demonstrated pinpoint landing capability and continued human exploration.
Soyuz 10	Apr. 22, 1971	Vladimir A. Shatalov Aleksey S. Yeliseyev Nikolay N. Rukavishnikov	1:23:46	Docked with Salyut 1, but crew did not board space station launched Apr. 19. Crew recovered Apr. 24, 1971.
Soyuz 11	June 6, 1971	Georgiy T. Dobrovolskiy Vladislav N. Volkov Viktor I. Patsayev	23:18:22	Docked with Salyut 1, and Soyuz 11 crew occupied space station for 22 days. Crew perished in final phase of Soyuz 11 capsule recovery on June 30, 1971.
Apollo 15	July 26, 1971	David R. Scott Alfred M. Worden James B. Irwin	12:7:12	Fourth human lunar landing and first Apollo "J" series mission, which carried Lunar Roving Vehicle. Worden's 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, 1998

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, 1998

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	8:4:49	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.

APPENDIX C

(Continued)

U.S. and Russian Human Space Flights

1961–September 30, 1998

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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(Continued)

U.S. and Russian Human Space Flights
1961–September 30, 1998

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.

Appendix C

(Continued)

U.S. and Russian Human Space Flights

1961–September 30, 1998

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. 27, 1985	Brewster H. Shaw Bryan D. O'Connor Mary L. Cleave Sherwood C. Spring Jerry L. Ross Rudolfo Neri Vela Charles D. Walker	6:22:54	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 Roger 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.

APPENDIX C

(Continued)

U.S. and Russian Human Space Flights

1961–September 30, 1998

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. 23, 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.

APPENDIX C
(Continued)

U.S. and Russian Human Space Flights
1961–September 30, 1998

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	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

1961–September 30, 1998

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)	8:1:12	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	9:0:10	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	8:16:17	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	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 Jul. 29. Tognini returned to Earth in TM-14 capsule with Aleksandr Viktorenko and Aleksandr Kaleri. Solovyov and Avdeyev spent over six months in the *Mir* orbital complex and returned to Earth in the descent vehicle of the TM-15 spacecraft on Feb. 1, 1993.

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U.S. and Russian Human Space Flights

1961–September 30, 1998

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 Eureka-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	6:23:39	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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U.S. and Russian Human Space Flights

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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 body in the first of two ESA missions to *Mir* to prepare for the International Space Station.

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U.S. and Russian Human Space Flights

1961–September 30, 1998

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.

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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-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 *Mir* space station as part of International Space Station (ISS) Phase I efforts.
Space Shuttle *Endeavour* (STS-72)	Jan. 11, 1996	Brian Duffy Brent W. Jett, Jr. Leroy Chiao Winston E. Scott Koichi Wakata (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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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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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, 1998

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.

* *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.

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_2O_4 = Nitrogen Tetroxide

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

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

d. Inclination of 28.5° except where indicated.

e. Polar launch from Vandenberg AFB, CA.

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

g. First launch was a failure

h. Diameter dimension represents vehicle wing span.

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	DoC	DoI	USDA	NSF[a]	DoT	EPA[d]	Total Space
1959	331	261	490	34	34							785
1960	524	462	561	43	43				0.1			1,066
1961	964	926	814	69	68				1			1,809
1962	1,825	1,797	1,298	200	148	51			1			3,295
1963	3,673	3,626	1,550	259	214	43			2			5,435
1964	5,100	5,016	1,599	216	210	3			3			6,831
1965	5,250	5,138	1,574	244	229	12			3			6,956
1966	5,175	5,065	1,689	217	187	27			3			6,971
1967	4,966	4,830	1,664	216	184	29			3			6,710
1968	4,587	4,430	1,922	177	145	28	0.2	1	3			6,529
1969	3,991	3,822	2,013	141	118	20	0.2	1	2			5,976
1970	3,746	3,547	1,678	115	103	8	1	1	2			5,340
1971	3,311	3,101	1,512	127	95	27	2	1	2			4,740
1972	3,307	3,071	1,407	97	55	31	6	2	3			4,575
1973	3,406	3,093	1,623	109	54	40	10	2	3			4,825
1974	3,037	2,759	1,766	116	42	60	9	3	2			4,641
1975	3,229	2,915	1,892	106	30	64	8	2	2			4,913
1976	3,550	3,225	1,983	111	23	72	10	4	2			5,319
TQ*	932	849	460	32	5	22	3	1	1			1,341
1977	3,818	3,440	2,412	131	22	91	10	6	2			5,983
1978	4,060	3,623	2,738	157	34	103	10	8	2			6,518
1979	4,596	4,030	3,036	177	59	98	10	8	2			7,243
1980	5,240	4,680	3,848	233	40	93	12	14	74			8,761
1981	5,518	4,992	4,828	233	41	87	12	16	77			10,053
1982	6,044	5,528	6,679	311	61	145	12	15	78			12,518
1983	6,875	6,328	9,019	325	39	178	5	20	83			15,672
1984	7,458	6,858	10,195	392	34	236	3	19	100			17,445
1985	7,573	6,925	12,768	580	34	423	2	15	106			20,273
1986	7,807	7,165	14,126	473	35	309	2	23	104			21,764
1987	10,923	9,809	16,287	462	48	278	8	19	108	1		26,558
1988	9,062	8,322	17,679	737	241	352	14	18	111	1		26,738
1989	10,969	10,097	17,906	560	97	301	17	21	116	3	5	28,563
1990	12,324	11,460	15,616	512	79	243	31	25	125	4	5	27,588
1991	14,016	13,046	14,181	697	251	251	29	26	131	4	5	27,924
1992	14,317	13,199	15,023	769	223	327	34	29	145	4	7	28,991
1993	14,310	13,064	14,106	698	165	324	33	25	139	4	8	27,868
1994	14,570	13,022	13,166	601	74	312	31	31	140	5	8	26,789
1995	13,854	12,543	10,644	629	60	352	31	32	141	6	7	23,816
1996	13,884	12,569	11,514	750	46	472	36	37	147	6	6	24,833
1997	13,709	12,457	11,727	727	35	448	42	39	152	6	6	24,912
1998	13,648	12,321	12,359	768	63	456	43	42	152	6	6	25,448

* 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*.

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.

d. EPA has recalculated its aeronautics and space expenditures since 1989, making them significantly higher than reported in previous years.

SOURCE: Office of Management and Budget

APPENDIX E-1B

Space Activities of the U.S. Government

BUDGET AUTHORITY IN MILLIONS OF EQUIVALENT FY 1998 DOLLARS
(adjusted for inflation)

FY	Inflation Factors	NASA Total	NASA Space	DoD	Other	DoE	DoC	DoI	USDA	NSF	DoT	EPA	Total Space
1959	4.8506	1,606	1,266	2,377	165	165							3,808
1960	4.7579	2,493	2,198	2,669	205	205				0.5			5,072
1961	4.7149	4,545	4,366	3,838	325	321				5			8,529
1962	4.6469	8,481	8,350	6,032	929	688	237			5			15,311
1963	4.5942	16,875	16,659	7,121	1,190	983	198			9			24,970
1964	4.5409	23,159	22,777	7,261	981	954	14			14			31,019
1965	4.4796	23,518	23,016	7,051	1,093	1,026	54			13			31,160
1966	4.4057	22,800	22,315	7,441	956	824	119			13			30,712
1967	4.3070	21,388	20,803	7,167	930	792	125			13			28,900
1968	4.1756	19,154	18,498	8,026	740	605	117	0.8	4	13			27,263
1969	4.0223	16,053	15,373	8,097	568	475	80	0.8	4	8			24,038
1970	3.8525	14,431	13,665	6,464	443	397	31	4	4	8			20,572
1971	3.6594	12,116	11,348	5,533	465	348	99	7	4	7			17,346
1972	3.4803	11,510	10,688	4,897	338	191	108	21	7	10			15,923
1973	3.3220	11,315	10,275	5,392	362	179	133	33	7	10			16,029
1974	3.1821	9,664	8,779	5,620	369	134	191	29	10	6			14,768
1975	2.9674	9,582	8,650	5,614	315	89	190	24	6	6			14,579
1976	2.6904	9,551	8,677	5,335	299	62	194	27	11	5			14,310
TQ	2.5092	2,339	2,130	1,154	80	13	55	8	3	3			3,365
1977	2.4307	9,280	8,362	5,863	318	53	221	24	15	5			14,543
1978	2.3318	9,467	8,448	6,385	366	79	240	23	19	5			15,199
1979	2.1783	10,012	8,779	6,613	386	129	213	22	17	4			15,778
1980	2.0119	10,542	9,416	7,742	469	80	187	24	28	149			17,626
1981	1.8476	10,195	9,223	8,920	430	76	161	22	30	142			18,574
1982	1.6819	10,166	9,298	11,234	523	103	244	20	25	131			21,054
1983	1.5709	10,800	9,941	14,168	511	61	280	8	31	130			24,620
1984	1.5016	11,199	10,298	15,309	589	51	354	5	29	150			26,195
1985	1.4513	10,990	10,050	18,530	842	49	614	3	22	154			29,422
1986	1.4029	10,953	10,052	19,818	664	49	434	3	32	146			30,533
1987	1.3641	14,900	13,381	22,217	630	65	379	11	26	147	1		36,228
1988	1.3258	12,014	11,033	23,439	977	320	467	19	24	147	1		35,449
1989	1.2813	14,055	12,937	22,943	718	124	386	22	27	149	4	6	36,598
1990	1.2293	15,150	14,088	19,197	629	97	299	38	31	154	5	6	33,914
1991	1.1803	16,544	15,399	16,738	823	296	296	34	31	155	5	6	32,960
1992	1.1317	16,203	14,938	17,002	870	252	370	38	33	164	5	8	32,810
1993	1.1026	15,779	14,405	15,554	770	182	357	36	28	153	4	9	30,728
1994	1.0766	15,686	14,020	14,175	647	80	336	33	33	151	5	9	28,841
1995	1.0513	14,565	13,187	11,190	661	63	370	33	34	148	6	7	25,038
1996	1.0311	14,316	12,960	11,872	773	47	487	37	38	152	6	6	25,605
1997	1.0120	13,874	12,607	11,868	737	35	453	43	39	154	6	6	25,211
1998	1.0000	13,648	12,321	12,359	768	63	456	43	42	152	6	6	25,448

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		
	1996 actual	1997 actual	1998 est.	1996 actual	1997 actual	1998 est.
NASA	12,569	12,457	12,321	12,694	13,055	12,866
Defense	11,514	11,727	12,359	11,353	11,959	12,230
Energy	46	35	63	46	37	60
Commerce	472	448	456	354	336	342
Interior	36	42	43	36	42	43
Agriculture	37	39	42	37	39	42
Transportation	6	6	6	6	6	6
EPA	6	6	6	7	6	6
NSF	147	151	152	142	146	147
TOTAL	24,833	24,911	25,448	24,675	25,626	25,832

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		
	1996 actual	1997 actual	1998 est.	1996 actual	1997 actual	1998 est.
NASA[a]	1,315	1,252	1,327	1,187	1,302	1,339
Defense[b]	6,792	6,323	6,184	6,974	6,600	6,318
Transportation[c]	2,052	2,146	2,099	2,676	2,528	2,429
TOTAL	10,159	9,721	9,610	10,837	10,430	10,086

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

A

ACDA Arms Control and Disarmament Agency
ACTS Advanced Communications Technology Satellite
AMASS Airport Movement Area Safety System
AMOS Air Force Maui Optical Site
AMS Alpha Magnetic Spectrometer
APEC Asia-Pacific Economic Cooperation
ARS Agricultural Research Service (USDA)
ASDE Air Surface Detection Equipment (Model)
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

B

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
BLM Bureau of Land Management (DoI)

C

CASTLeS CfA-Arizona Space Telescope Lens Survey
CEOS Committee on Earth Observation Satellites
CfA Center for Astrophysics (Harvard-Smithsonian)
CIS Commonwealth of Independent States
CNES Centre Nationale 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
Cosmic rays Not forms of energy, such as x-rays or gamma rays, but particles of matter

COSPAR Committee on Space Research
CRISTA-SPAS Cryogenic Infrared Spectrometers and Telescopes for the Atmosphere-Shuttle Pallet Satellite
CUE Collaborative Ukrainian Experiment

D

DARS Digital Audio Radio Service
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
DSP Defense Support Program

E

EELV Evolved Expendable Launch Vehicle
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 to gather data on global change
EOSDIS Earth Observing System Data and Information System
EPA Environmental Protection Agency
EPIC Environmental Photographic Interpretation Center (EPA)
EROS Earth Resources Observation System (USGS)
ESA European Space Agency
ET External Tank
EUMETSAT European Organisation for the Exploitation of Meteorological Satellites
EVA Extravehicular activity

F

FAA Federal Aviation Administration
FAS Foreign Agricultural Service (USDA)
FCC Federal Communications Commission
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
FPI Fire Potential Index
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
FY Fiscal year

G

Gamma rays The shortest of electromagnetic radiations, emitted by some radioactive substances
GBS Global Broadcast Satellite Service
Geostationary 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
GHz Gigahertz
GIS Geographic Information System
GOES Geostationary Operational Environmental Satellite
GPS Global Positioning System

H

Heliosphere The region of the Sun's influence, including the Sun and the interplanetary 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

IGEB International GPS Executive Board
INMARSAT International Mobile (formerly Maritime) Satellite Organization
InSAR Interferometric Synthetic Aperture Radar
INSAT Indian Remote Sensing Satellite
Integrated modular avionics Aircraft-unique avionics cabinet that replaces 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
ISS International Space Station
ITA International Trade Administration

J

JPL Jet Propulsion Laboratory (NASA)

K

K-band Radio frequencies in the 20-GHz range
Ka-band Radio frequencies in the 30-GHz range
Ku-band Radio frequencies in the 11–12-GHz 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
LIDAR Light Intersection Direction and Ranging

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
MilSatCom Military Satellite Communications
MOU Memorandum of Understanding
MTCR Missile Technology Control Regime

N

NAPP National Aerial Photography Program
NAS National Airspace System (FAA)
NASA National Aeronautics and Space Administration
NASDA National Space Development Agency (of Japan)
NASS National Agricultural Statistics Service (USDA)
NCAP National Civil Applications Program (USGS)
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
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
NO_x Nitrous oxide
NPOESS National Polar-orbiting Operational Environmental Satellite System
NRCS National Resources Conservation Service (USDA)
NRO National Reconnaissance Office
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

O

OASC Office of Air and Space Commercialization (DoC)

OAST Office of Aeronautics and Space Technology (former NASA office)

ODERACS Orbital Debris Radar Calibration Spheres

OLMSA Office of Life and Microgravity Sciences and Applications (NASA)

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

OSS Office of Space Science (NASA)

OSTA Office of Space and Terrestrial Applications (former NASA office)

P

PAMS-STU Passive Aerodynamically Stabilized Magnetically Damped Satellite-Satellite Test Unit

Pathfinder A program that focuses on the processing, reprocessing, maintenance, archiving, and distribution of 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

Photogrammetry The science or art of obtaining reliable measurements by means of photography

POES Polar-orbiting Operational Environmental Satellite (program)

PPS Precise Positioning Service

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

R

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

RAPID Repair Assessment Procedure and integrated Design (software)

Radarsat Canadian radar satellite

RSA Russian Space Agency

RSML Remote Sensing and Modeling Laboratory (ARS)

S

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
SNOE Student Nitric Oxide Experiment
SOFIA Stratospheric Observatory for Infrared Astronomy
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
SSCE Solid Surface Combustion Experiment
SSME Space Shuttle Main Engine
SSTI Small Satellite Technology Initiative
START Strategic Arms Reduction Treaty
STS Space Transportation System

T

TDRS Tracking and Data Relay Satellite
TM Thematic Mapper (Landsat instrument)
TRACE Transition Region and Coronal Explorer
TRMM Tropical Rainfall Measuring Mission
TSA Technical Safeguard Agreement

U

UARS Upper Atmosphere Research Satellite
UHF Ultrahigh Frequency—any frequency between 300 and 3,000 megacycles per second
U.S. United States
USDA U.S. Department of Agriculture
USGS U.S. Geological Survey (DoI)
USIA U.S. Information Agency
USIS U.S. Information Service (USIA abroad)
USML U.S. Microgravity Laboratory
USMP U.S. Microgravity Payload
USSR Union of Soviet Socialist Republics (former)

V

VAAC Volcanic Ash Advisory Center
VHF Very High Frequency—any radio frequency between 30 and 300 megacycles per second

W

WAAS Wide Area Augmentation System
WARP Weather and Radar Processor (program)
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
WSF Wake Shield Facility
WTO World Trade Organization

X-Y-Z

X-rays Radiations of very short wavelengths, beyond the ultraviolet in the spectrum

National
Aeronautics and
Space
Administration