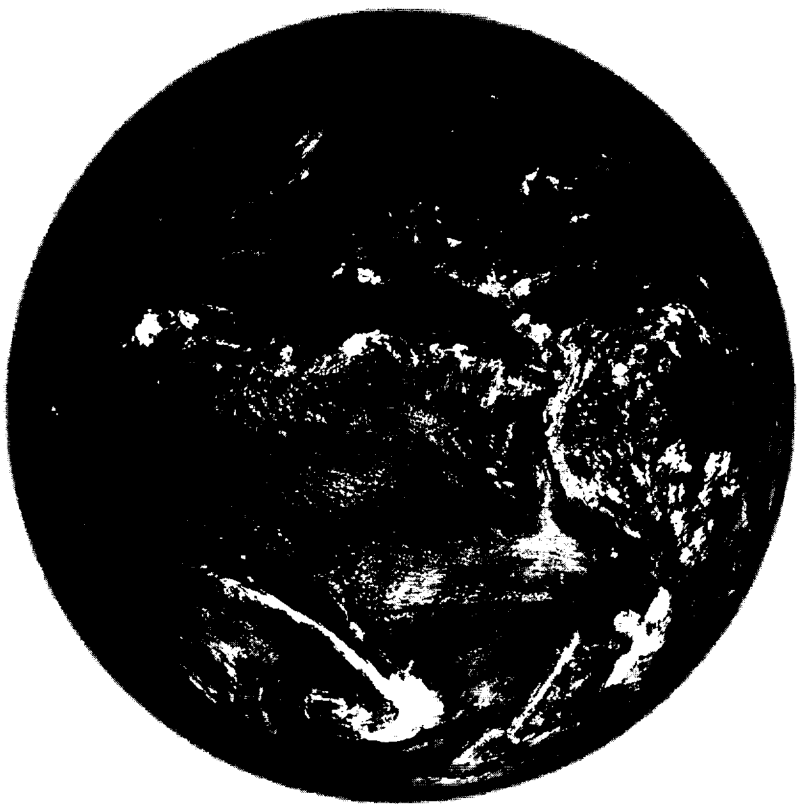
Aeronautics and Space Report of the President



Fiscal Year 1996 Activities

National Aeronautics and Space Administration

Washington, DC 20546

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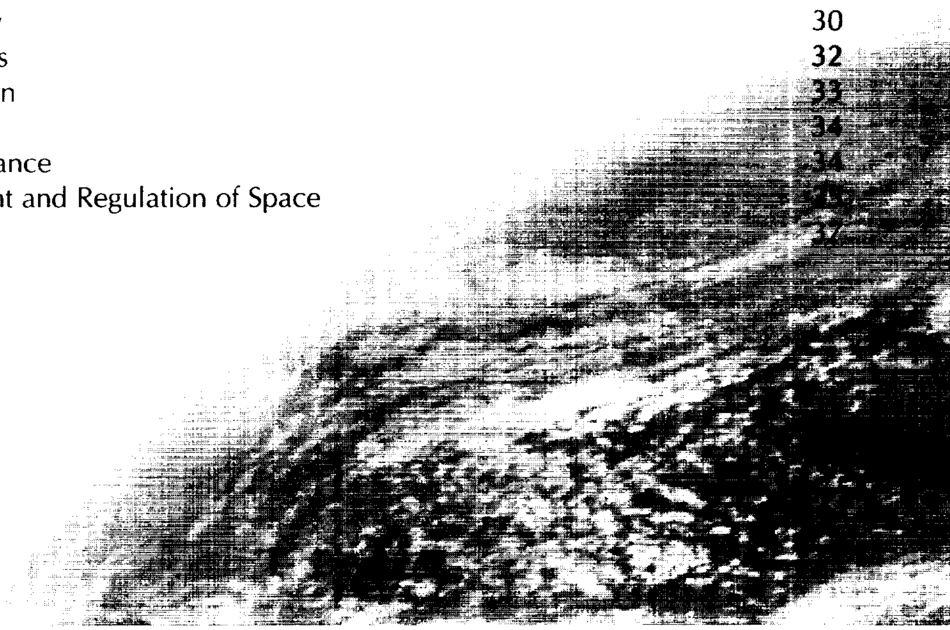
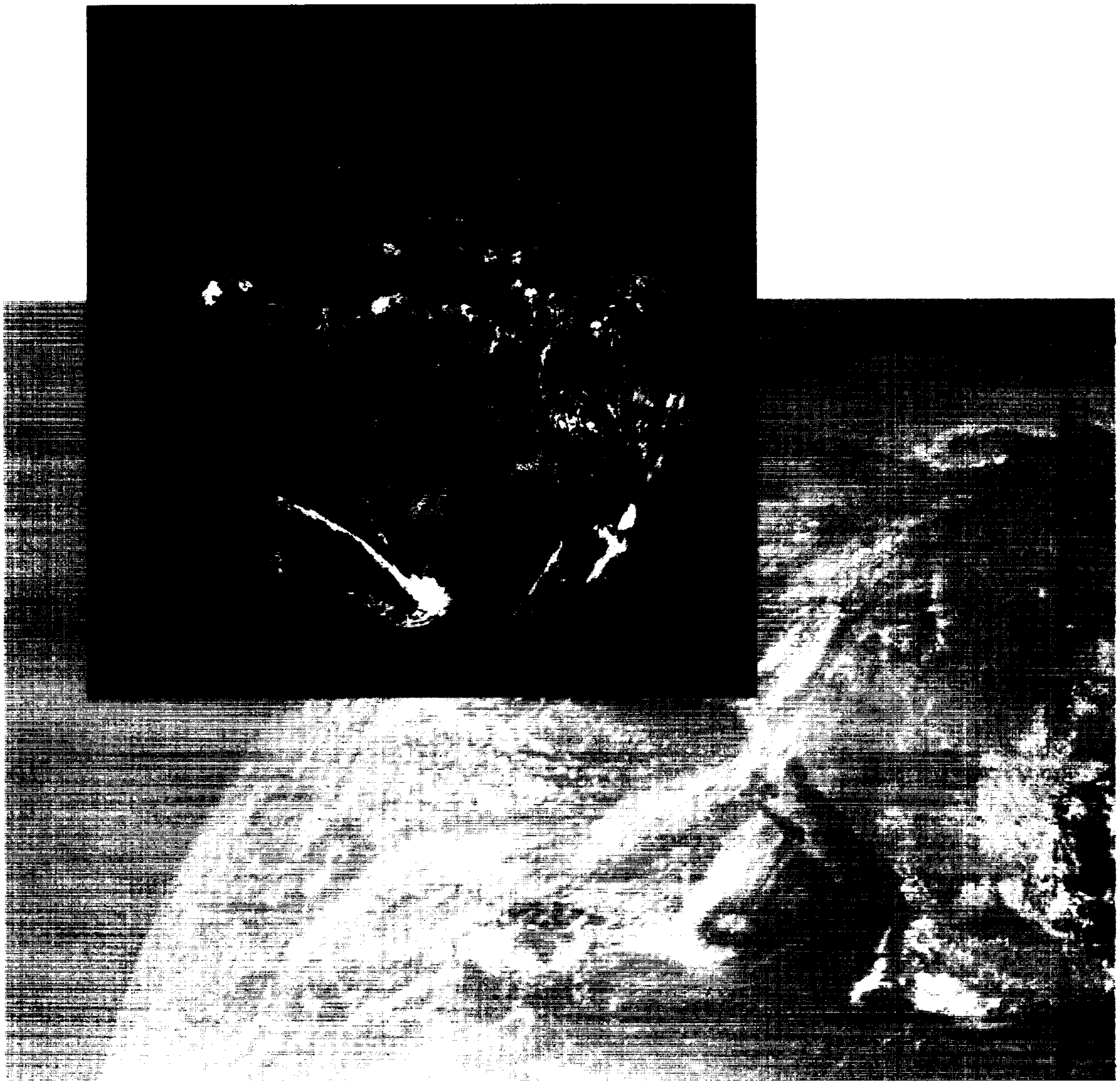
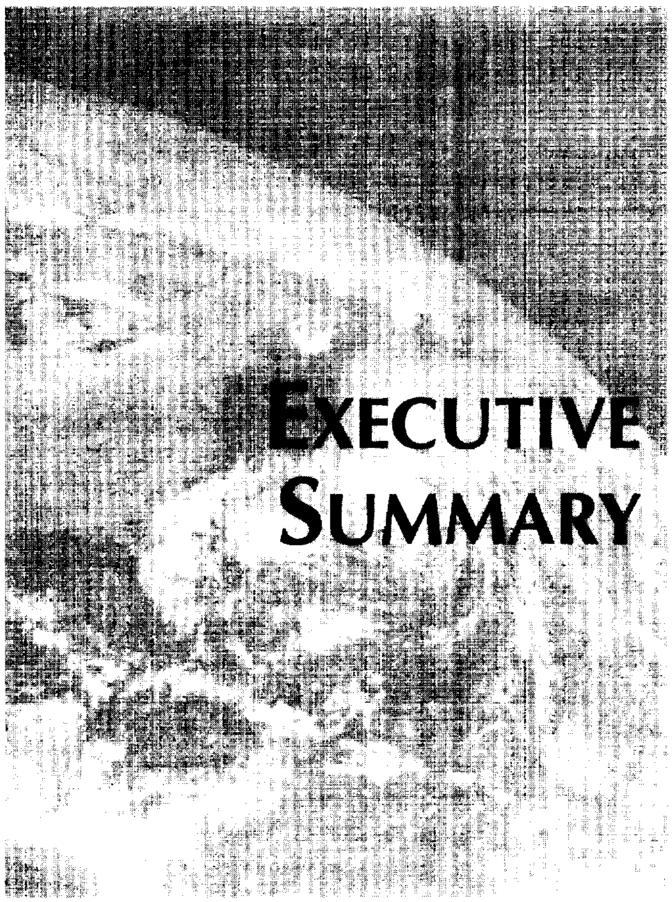




This photo of Earth was processed by NOAA's National Environmental Satellite, Data, and Information Service.

EXECUTIVE SUMMARY



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, 1995, through September 30, 1996.

A wide variety of aeronautics and space developments took place during FY 1996. The National Aeronautics and Space Administration (NASA) successfully completed eight Space Shuttle flights. Shuttle orbiters made three successful sorties with the Russian space station *Mir* in preparation for building and permanently inhabiting the International Space Station (ISS). Astronaut Shannon Lucid set records for the longest space flight for a woman and for an American by staying in space for 188 days.

NASA successfully launched seven Expendable Launch Vehicles (ELV), while the Department of Defense (DoD) successfully conducted nine ELV launches during the fiscal year. These launches included satellites to study astrophysics and space physics, track the Earth's global change patterns, and support military communications. In addition, there were 13 commercial launches that the Federal Aviation Administration (FAA), part of the Department of Transportation, licensed and monitored.

On the Reusable Launch Vehicle (RLV) program, Vice President Albert A. Gore, Jr., announced that Lockheed Martin Corporation had been selected to design, fabricate, and flight-test the X-33 vehicle. NASA hoped to develop new kinds of launch technologies that will enable significantly more affordable and reliable access to space.

In aeronautics, NASA, the FAA, and DoD developed technologies to increase safety, reduce negative environmental impacts, and assist U.S. industry in becoming more competitive in the world market. Air traffic control activities focused on various automation systems to increase flight safety and enhance the efficient use of airspace.

In space science, researchers at NASA's Johnson Space Center examined a small meteorite believed to have come from Mars, which offered exciting evidence that it may have once contained small, primitive forms of life. Additionally, the Galileo spacecraft detected possible signs of water on Jupiter's moon Europa, a finding with potentially great implications for extraterrestrial life. In astrophysics, the Hubble Space Telescope (HST) gave astronomers their first detailed look at Pluto's surface and provided important clues to the universe's age.

Earth scientists continued to study the complex interactions of physical forces that influence our weather and environment. Agencies such as the Environmental Protection Agency (EPA), as well as the Departments of Agriculture and the Interior, used remote-sensing technologies to better understand terrestrial changes.

Microgravity researchers conducted research and scientific investigations on the Space Shuttle, on the Russian *Mir* space station, and through an array of ground-based and suborbital facilities. Much of this research was to prepare for the long-duration stays of humans on the ISS.

Close international partnerships, particularly with Russia, occurred on the Shuttle-*Mir* docking missions and on the ISS program. The United States and Japan increased their cooperation on the Mission to Planet Earth (MTPE) program. NASA also cooperated with nontraditional partners in South America and Asia.

During FY 1996, the Federal Government released two significant interagency space policy documents that are included in this report's appendix section. The first is the Global Positioning System (GPS) Policy, and the second is the National Space Policy.

National Aeronautics and Space Administration

During FY 1996, NASA had eight Space Shuttle launches, with its crews conducting a variety of experiments and deploying several payloads. Specifically, Shuttle crews deployed the third U.S. Microgravity Payload, the second U.S. Microgravity Laboratory, the commercial SPACEHAB module, the SPARTAN-207 astronomical platform, and the Life and Microgravity Sciences Spacelab. A Shuttle crew also retrieved the previously launched Japanese Space Flyer Unit. Shuttle orbiters made three successful sorties with the Russian *Mir* space station in preparation for building and permanently inhabiting the ISS. *Columbia* set a Shuttle record by staying aloft for almost 17 days on STS-78. Astronaut Shannon Lucid also set records for longest space flight for a woman and for an American by staying in space for 188 days. Shuttle managers made significant strides in using environmentally friendly technologies to service the Shuttle.

For the third consecutive year, the ISS program remained within budgetary guidelines and on schedule for first element launch in November 1997. NASA completed work on more than 132,000 pounds of hardware and implemented new procedures to handle any technical concerns. In April 1996, the Russian Priorda module was launched to *Mir*, enabling U.S. researchers to conduct numerous long-duration experiments before the ISS begins operating.

NASA successfully launched seven ELV's during FY 1996. Technicians upgraded the Atlas IIAS launch vehicle to accommodate the large Earth Observing System (EOS) AM-1 spacecraft and also outfitted the Delta II with new avionics. Engineers designed telemetry upgrades for the Atlas Centaur and Titan Centaur vehicles. After several failures in previous years, the Pegasus XL successfully launched three times in FY 1996.

On the RLV program, Vice President Gore announced that Lockheed Martin Corporation had been selected to design, fabricate, and flight-test the X-33 vehicle. After canceling the original X-34 cooperative agreement, NASA awarded a restructured contract to Orbital Sciences Corporation. NASA terminated the Clipper Graham (formerly the DC-XA) project after the test vehicle was destroyed in a landing accident.

In space science, researchers and the general public became excited by the possible discovery of ancient life on Mars. A group of researchers, led by Dr. David McKay at the Johnson Space Center, examined a small meteorite believed to have come from Mars, and they found evidence that it may have once contained small, primitive forms of life. Additionally, the Galileo spacecraft detected possible signs of water on Jupiter's moon Europa, a finding with potentially great implications for extraterrestrial life, and revealed a wealth of information about Jupiter's atmosphere and large moons. In astrophysics, the HST continued to produce dramatic images of the solar system and universe. Specifically, the HST provided astronomers their first detailed look at Pluto's surface and provided important clues to the universe's age. The Compton Gamma Ray Observatory continued its investigation of mysterious gamma rays, which, according to project scientists, originate from molecular clouds in our Milky Way galaxy. Similarly, the Rossi X-ray Timing Explorer provided valuable new information on neutron stars and black holes. In space physics, the Solar and Heliospheric Observatory provided a large amount of useful data on the Sun's outer atmosphere and its interior. Additionally, the Polar satellite produced valuable results about the solar wind.

FY 1996 was a productive year for NASA's MTPE program, which seeks to expand and publicly disseminate scientific knowledge of the Earth's system. Data from a joint U.S.-French satellite challenged a fundamental oceanographic theory about the speed of large-scale ocean waves and provided definitive information on the principal tidal components of the world's oceans. A scientific paper based in large part on ozone data from NASA satellites found that solar ultraviolet radiation reaching the Earth's surface has increased over large regions of the planet during the past 15 years, as the amount of total ozone in the atmosphere has decreased. A joint U.S.-Canadian research campaign revealed that the air above the northern forests was much drier than expected, leading to adjustments in the models used by forecasters to predict the weather. Maps produced from a NASA airborne sensor cut costs and helped speed the cleanup of hazardous waste at a Superfund site in Colorado. NASA launched the Canadian RADARSAT spacecraft, opening new avenues of radar exploration of the Antarctic ice sheet and other surface features. In addition, NASA and the Defense Mapping Agency signed an agreement for a Shuttle radar mission to produce the most accurate and complete topographic map of the Earth's surface ever assembled. Space radar data also helped scientists in China locate and study two generations of the Great Wall of China buried under the sand for centuries.

In FY 1996, NASA's Office of Life and Microgravity Sciences and Applications conducted research and scientific investigations on the Space Shuttle, on the Russian *Mir* space station, and through an array of ground-based and suborbital facilities. The office conducted a successful 30-day closed regenerative life support system test, during which atmosphere and water were recovered and recycled for a crew of four test subjects. Researchers using space-grown protein crystals designed a drug that effectively stops the spread of the flu virus within the body and published the highest resolution structure of insulin to date. Record-breaking stays on the Russian *Mir* space station by American astronauts Norman Thagard and Shannon Lucid led to numerous important findings, including observations on the course of bone loss in low gravity and surprising results on the radiation environment in low-Earth orbit. Researchers at the NASA/National Institutes of Health Center for Three-Dimensional Tissue Culture produced the first in-vitro tissue system that permits the study of HIV inside human lymphoid tissue. Dr. John Lipa published results in *Physical Review Letters;* these results confirm a Nobel prize-winning theory that describes conditions under which matter will change between different states, such as from liquid to gas.

NASA's Aeronautical Research program continued to pioneer the development, transfer, application, and commercialization of high-payoff aeronautical technologies in FY 1996. The research remained applicable to the development of safe, superior, and environmentally compatible civil and military aircraft. NASA program managers coordinated their efforts with U.S. customers to ensure that both NASA and the private sector efficiently utilized national investments in aeronautical research and technology. Researchers supported the development of new-generation subsonic aircraft and a safe, highly productive global air transportation system. Innovations in information science led to significant advances in the design, manufacture, and testing of aircraft, including the utilization of virtual wind tunnels. In the past year, researchers made advances in establishing an economically feasible, environmentally friendly high-speed civil transport. Significant progress also occurred in demonstrating technologies for air-breathing hypersonic flight. In FY 1996, NASA continued to hone its many tools used in aeronautical research, including high-performance computing techniques and critical national facilities.

In the area of space communications, NASA networks provided support for numerous NASA flight missions, including eight Shuttle missions, in FY 1996. NASA established several bilateral panels with international partners to promote cost-effective ways to share resources. A team with representatives from NASA, DoD, and the National Oceanic and Atmospheric Administration (NOAA) looked at ways to increase cooperation on satellite telemetry and tracking. NASA made its Tracking and Data Relay Satellite (TDRS) system available to other agencies for launch vehicle telemetry service and to a commercial broadcaster under a revenue-sharing arrangement for telecommunications services, including the 1996 Summer Olympics in Atlanta. Technicians also made significant improvements to NASA's ground networks, as well as mission control and data systems.

Internationally, NASA and Russian Space Agency officials reached agreement on a memorandum of understanding to define mutual roles and responsibilities on the ISS program at the seventh meeting of the U.S.-Russia Commission on Economic and Technological Cooperation, known more widely as the Gore-Chernomyrdin Commission. Together with NOAA, NASA hosted a meeting at which space agencies and international organizations discussed strategies for assuring long-term global observations of the Earth. The MTPE program benefited from increased international cooperation, particularly with Japan. During FY 1996, NASA cooperation with nontraditional partners flourished, with Administration officials signing new cooperative agreements in Argentina and Brazil and NASA Administrator Daniel S. Goldin meeting with civilian space officials from Chile, India, Korea, and Israel.

In the area of safety and mission assurance, NASA safely completed eight Space Shuttle flights and six expendable spacecraft launches in FY 1996. At the same time, NASA managers reduced safety and mission assurance costs for Shuttle ground processing through improved data collection techniques. To oversee the safety of human space flight, NASA formed a safety assurance board for its Human Exploration and Development of Space (HEDS) Enterprise. To comply with international norms, NASA adopted International Organization for Standardization (ISO)-9000 as its standard for quality management. NASA safety specialists also set standards for orbital debris damage risk reduction, as well as oxygen and hydrogen safety.

During FY 1996, NASA updated its new Strategic Plan. New in this plan are NASA's Roadmaps for its Strategic Enterprises, the "Centers of Excellence" approach, the identification of NASA's crosscutting processes, and the strategies the agency will use to revolutionize itself. In addition, NASA completed its new *Strategic Management Handbook*, which describes the ways in which NASA combined its strategic planning, Zero-Base Review, and new Program Management System to create a fully integrated management process. Throughout the Government, NASA was recognized as a model in successful strategic management. At the behest of the Office of Management and Budget and the Office of Personnel Management, NASA developed a video on strategic planning called "Charting a Course for the Future," which portrays NASA's successful strategic planning process and summarizes its Strategic Plan. The Office of Personal Management distributed the video to all Federal agencies to assist them in developing their own strategic plans and in more clearly communicating their visions, missions, and goals to the American people.

Department of Defense

DoD conducted nine ELV launches during FY 1996. The Air Force's heavy-lift Titan IV has become the workhorse of DoD's launch vehicles, with five successful launches in FY 1996. In the medium- and light-lift categories, DoD successfully launched three Delta II ELV's and two Pegasus/Pegasus XL ELV's, respectively. The Air Force also supported NASA Space Shuttle and ELV launches from Cape Canaveral Air Station in Florida. To implement its part of the National Space Transportation Policy, DoD has initiated an Evolved ELV (EELV) program to replace the current medium- and heavy-lift launch systems. DoD continued to support the NASA-led RLV program through cooperative technology development.

In terms of surveillance capabilities, the Air Force's Defense Support Program continued to provide front-line warning of missile attack to the National Command Authorities, and the program also has become valuable to other world leaders. As a follow-on to the Defense Support Program, DoD proceeded with the development of a new constellation of infrared detection satellites to aid in missile warning, missile defense, and technical intelligence. The Naval Research Laboratory and the National Reconnaissance Office sponsored the Tether Physics and Survivability experiment for research in gravity-gradient dynamics and the survivability of tethered systems in low-Earth orbit. Launched by a commercial operator in May 1996, the Air Force's Miniature Sensor Technology Integration-3 satellite is to gather data to determine whether tracking theater ballistic missiles in the coast phase against a warm Earth background is feasible. In April 1996, the Ballistic Missile Defense Organization launched its Midcourse Space Experiment, the first space system demonstration to characterize ballistic missile signatures during the "midcourse" flight phase between booster burnout and missile reentry.

In the area of military communications, space systems played a critical role as a force multiplier everywhere DoD deployed U.S. forces, such as Bosnia, Korea, Europe, the Asian-Pacific rim, and the United States. To increase communications support to forces in Bosnia, DoD personnel repositioned several Defense Satellite Communications System satellites.

In December 1995 the Secretary of Defense and the Director of Central Intelligence signed the charter for the Joint Space Management Board (JSMB). The JSMB's functions include reviewing and approving tradeoffs among requirements, programs, and resources; reviewing and approving defense and intelligence space policies, architectures, and program plans for consistency and budget recommendations; integrating defense and intelligence space architectures; and making recommendations to the Secretary of Defense and Director of Central Intelligence on issues that affect national security space activities. After an August 1996 briefing by the DoD Space Architect, the board approved the architecture and transition plans for the military satellite communications (MILSATCOM) system. The JSMB also created a National Security Space Review team to conduct a comprehensive planning review of all space activities of the intelligence community and DoD. The JSMB is cochaired by the Under Secretary of Defense for Acquisition and Technology and the Deputy Director of Central Intelligence.

Under the overall direction of the Deputy Under Secretary of Defense (Space), DoD officials created the National Security Space Master Plan task force in March 1996. The specific purpose of this group is to develop a long-range plan and guidelines for national security space activities.

In support of the Administration's Global Positioning System (GPS) policy, DoD continued to work closely with civil agencies to enhance the GPS contribution to U.S. and allied civil and commercial users while guarding against a breach in U.S. national security. With regard to the latter concern, DoD continued to perform analytical studies and testing on GPS signal protection against potential enemies on the battlefield. Recognizing this balance, in March 1996, the Administration approved a comprehensive national policy on the future management and use of GPS. In it, the Administration announced the Government's intention to discontinue the use of Selective Availability, which provides for increased accuracy only to authorized users, within a decade. DoD proposed to Congress a plan for the effective maintenance of GPS services, as well as the acquisition of the next block of GPS satellites to sustain the constellation beyond the year 2000.

The Aeronautics and Astronautics Coordinating Board, a body composed of senior managers from DoD and NASA who coordinate their agencies' activities, completed a major initiative to increase cooperation between the two organizations. Integrated Product Teams studied the following areas: Technology and Laboratories; Space Launch Activities; Satellite Telemetry; Tracking and Commanding; Base/Center Support and Services; Major Facilities; Interagency Agreements; and Personnel Exchange. The teams completed their work, and the two agencies began to implement their recommendations.

Federal Aviation Administration

As part of the Department of Transportation (DoT), 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. The FAA embarked on an effort to modernize the air traffic control system in an economically feasible manner, with minimal disruption to users. As part of that effort, the FAA released the initial version of its new National Airspace System (NAS) Architecture, a comprehensive blueprint for the NAS infrastructure over the next 20 years.

The Display System Replacement (DSR) program to modernize equipment used at Air Route Traffic Control Centers (ARTCC's) proceeded on schedule. During FY 1996, the DSR program completed hardware and software design and development, accomplished product integration, fulfilled the initial requirements for DSR console testing, and completed its production readiness review. Work on the interim system, the Display Channel Complex Rehost, which will provide a modern and reliable display channel system at five ARTCC's, proceeded significantly ahead of schedule.

Work on the Satellite Navigation program also continued on track. During the fiscal year, the FAA fielded the National Satellite Test Bed, which is a research and development program that mitigates risks for systems such as the Wide Area Augmentation System (WAAS). The WAAS program, developed to serve all phases of flight from en route through precision approach, is the key program in FAA's plan to move to a satellite-based navigation system. In May 1996, the agency signed a contract with Hughes Aircraft Corporation for WAAS development.

During FY 1996, the FAA continued developing integrated terminal weather systems to provide short-range forecast and warning notices to pilots and air traffic controllers. The FAA commissioned 13 more terminal Doppler weather radar systems. In addition, the agency enhanced a low-level wind-shear alert system at seven major airports and made the decision to proceed with full-scale development activities on another program, the airport surveillance radar weather systems processor. That system will provide for the timely detection of hazardous wind shear in the terminal approach and departure areas. Under the wake vortex program, the FAA and NASA participated on a Government-industry team to address aircraft classification and air separation standards. The FAA expanded its international coordination efforts to include the United Kingdom, France, and Germany in the analysis of aircraft separation data relevant to wake vortices.

In the area of airliner safety, the FAA continued its research efforts on civil aviation structural integrity, flight loads, and corrosion. FAA engineers made significant progress in decreasing the flammability of new interior insulation materials and passenger blankets. During the fiscal year, the FAA also successfully tested an aircraft arrestor bed.

The FAA's efforts to improve human performance in the national airspace system through its research and development program had numerous successes during the fiscal year. In July 1996, the FAA began operational tests of an automated performance measuring system for analyzing, processing, and managing digital flight-recorded data. The test allowed the FAA to evaluate the system's capability to extrapolate and analyze a continuous stream of aircraft data and translate it into information that will help detect and correct safety problems before accidents happen. The FAA also deployed and began evaluating the systematic air traffic operations research initiative, a research tool designed to support assessments of air traffic control operations at four en route centers.

During the fiscal year, DoT's Office of Commercial Space Transportation joined the FAA. Also during FY 1996, the FAA's Associate Administrator for Commercial Space Transportation (AST) granted licenses for 13 commercial space launches. In connection with the amended Commercial Space Launch Act, the Office of Commercial Space Transportation processed 11 maximum probable loss determinations, based on the actual risks associated with proposed launch activities during the fiscal year. The office also continued a program to encourage and facilitate the development of voluntary industry and international standards for launch safety.

A major priority for the Office of Commercial Space Transportation during FY 1996 was to update and "reinvent" its existing regulations. The AST participated in several interagency efforts on space policy led by the White House Office of Science and Technology Policy, including the National Space Policy and Spaceport Guidelines initiatives. The office supported the U.S. Trade Representative's office in its negotiations for a new space launch trade agreement between the United States and Ukraine, as well as a delegation led by the U.S. Trade Representative's office that negotiated several significant amendments to the space launch trade agreement between the United States and Russia.

In the area of launch vehicle technology, the AST provided technical assistance and policy analysis as a member of DoD's Source Selection Advisory Board for the EELV program. Similarly, the AST's staff provided technical and analytical support to NASA-led RLV technology programs. The Office of Commercial Space Transportation contributed significantly to the interagency effort to develop policy on space orbital debris for the U.S. delegation to the United Nations Committee on Peaceful Uses of Outer Space (COPUOS). To support pending and anticipated applications for licenses to launch large constellations of communications satellites in low-Earth orbit, AST personnel researched collision risk and the effects of service disruptions caused by collisions.

Department of Commerce

Within the Department of Commerce (DoC), NOAA was active in many space activities. In atmospheric studies, NOAA participated in and led numerous interagency and international studies on topics such as weather prediction, ozone depletion, and trace gases. In the oceanographic area, NOAA involvement in projects such as TOPEX/Poseidon, CoastWatch, and RADARSAT led to increased knowledge of ocean color, temperature, circulation patterns, and shore erosion. NOAA scientists also conducted significant research on terrestrial studies topics, such as land use/land cover, vegetation density, and population and energy consumption in urban centers.

DoC's Office of Air and Space Commercialization (OASC) ensured that U.S. commercial space interests were represented in the formulation of space-related Government policies and agreements. OASC personnel contributed to the Administration's National Space Policy and GPS Policy. Internationally, OASC participated in negotiations with the government of Ukraine on a bilateral launch agreement, with the government of Japan regarding GPS policies, and with the government of China regarding the pricing of satellite launch services. Also in FY 1996, OASC participated in the preparation of guidelines for licensing commercial space launch sites (spaceports), DoD's Source Selection Advisory Council for the EELV program, the X-33 RLV selection panel, and the National Spacelift Requirements process.

The International Trade Administration's Office of Aerospace also contributed to a commercial space launch agreement with Ukraine, as well as consultations for similar agreements with Russia and China. The office participated in discussions with the European Union under a 1992 agreement on trade in large civil aircraft, and with the World Trade Organization's General Agreement on Tariffs and Trade (GATT) Aircraft Committee. The Office of Aerospace encouraged as many countries as possible to sign the GATT Agreement on Trade in Civil Aircraft as part of the World Trade Organization's accession process. To promote the export of U.S. aerospace products, office staff led an executive trade mission to Turkey and Egypt and sponsored nine "Aerospace Product Literature Centers" at major international aerospace exhibitions and air shows. Together with International Trade Administration's Advocacy Center, the Office of Aerospace helped organize U.S. Government advocacy for several international aerospace competitions, including helicopters, commercial transport aircraft, and space launch vehicles.

As the lead advisory agency for Federal Government telecommunications issues, the National Telecommunications and Information Administration (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 Organization (INTELSAT) and the International Mobile Satellite Organization (INMARSAT). While the Federal Communications Commission continued to regulate the electromagnetic spectrum for commercial users, NTIA managed the Federal Government's use of the spectrum and helped to clear unexpected regulatory hurdles. NTIA engineers were instrumental in developing a national plan to augment the navigation signals of GPS for the benefit of a wide variety of civilian and commercial users.

The National Institute of Standards and Technology performed a wide variety of research in support of aeronautics and space activities during FY 1996. The institute received funding from NASA Headquarters and six NASA centers for 63 projects, totaling $4 million in research and development activities in FY 1996.

Department of Energy

In FY 1996, the Department of Energy (DoE) continued its work in the fabrication and testing of three general purpose heat source radioisotope thermoelectric generators (GPHS-RTG's) and 157 lightweight radioisotope heater units (LWRHU) for NASA's Cassini mission to Saturn. DoE provided three LWRHU's to NASA for the upcoming launch of the Mars Pathfinder spacecraft. For NASA's Pluto Express mission, DoE continued studies of advanced converter technologies to provide high-efficiency, lightweight power sources.

DoE's Sandia and Los Alamos National Laboratories continued to provide nuclear explosion sensors for integration onto DoD's GPS and Defense Support Program spacecraft. FY 1996 marked the launch of the 60th payload in this series, which was initiated by the Vela satellites in the 1960's. DoE personnel also provided expertise to NASA on power and propulsion options for exploration of the Moon, Mars, and other planets.

Department of the Interior

The Department of the Interior (DoI) applied GPS technology and remote sensing from satellites and aircraft to a variety of operational and research programs in FY 1996. DoI continued to cooperate with DoD to use the Navstar GPS Precise Positioning Service (PPS). DoI established a centralized facility in Denver to maintain and encrypt approximately 400 precision lightweight GPS receivers that have been purchased by DoI bureaus since 1995. DoI used GPS technology for a wide range of mapping, inventory, monitoring, and research activities in FY 1996.

The Bureau of Indian Affairs continued to use Landsat and Satellite Pour l'Observation de la Terre (SPOT) data and GPS for resource mapping, image mapping, environmental assessments, inventories, and other related Geographic Information System (GIS) support activities. Bureau of Land Management resource specialists continued to use remotely sensed data and GPS to provide critical information for its inventory, assessment, modeling, and monitoring programs. During FY 1996, the Bureau of Reclamation used remotely sensed data to support a number of water resource management projects, including modeling consumptive water use for rivers in the western United States, estimating snow precipitation rates from the next-generation weather radar Doppler radar system, and mapping river bottom habitats for endangered fish.

The National Biological Service used Landsat, SPOT, and Advanced Very High Resolution Radiometer (AVHRR) data for mapping and research, such as the Gap Analysis Program, land cover and change detection mapping, the assessment of damage from Hurricane Andrew, the analysis of waterfowl habitats, and the analysis of surface snow characteristics. The U.S. Fish and Wildlife Service increased its use of Landsat data for creating baseline habitat maps in several diverse locations and used this information to determine the suitability of the area for endangered species. In Alaska, the National Park Service used remotely sensed data for land cover mapping and the documentation of glacial changes.

The U.S. Geological Survey (USGS) Earth Resources Observation System (EROS) Data Center completed a major expansion in FY 1996, providing additional space for the center's support of NASA's EOS Data Information System (EOSDIS) program and the Landsat-7 Data Handling Facility. The center has collected, processed, and archived more than 75,000 daily AVHRR observations since the beginning of the Global Land 1-kilometer AVHRR Pathfinder project (1972), in cooperation with NASA, NOAA, and several international partners. Center staff began to develop a baseline global land cover data set from the project's 18-month time series of cloud-free vegetation index composites. The Multi-Resolution Land Characterization project (a joint activity of USGS, EPA, NASA, NOAA, and other agencies) released several data sets covering regional and continental areas. The USGS EROS Data Center acquired more than 800,000 recently declassified intelligence photographs and made them available to the public for the cost of reproduction.

In FY 1996, USGS personnel actively participated with their NASA colleagues in mission planning and data analysis for several planetary exploration missions:

the Galileo mission around Jupiter, the NASA Mars Global Surveyor and Mars Pathfinder missions, and the Cassini mission to Saturn. USGS investigators also worked with NASA personnel at the Jet Propulsion Laboratory on the upcoming New Millennium program that is to demonstrate and validate advanced technologies for use in the next generation of spacecraft missions.

Department of Agriculture

The Agricultural Research Service used remote sensing to develop improved techniques for measuring crop residue cover, classify spring wheat regions, measure land cover features, determine soil salinity, and improve farm management practices and crop assessment work. The Foreign Agricultural Service used remote-sensing data to perform global crop condition assessments and production analyses for grains, oilseeds, and cotton. Working closely with the Foreign Agricultural Service, the Farm Service Agency acquired and tested the usability of high-resolution Russian imagery to augment aerial photography coverage.

The Forest Service used satellite imagery to coordinate firefighting, produce maps, and manage more than 191 million acres of land in the National Forest System. The National Agricultural Statistics Service used remote-sensing data to stratify land for area-based statistical samples, estimate planted crop area, create crop-specific, land cover data layers for GIS's, and assess crop conditions.

The Natural Resources Conservation Service shared costs with State and Federal agencies to acquire aerial photography through the National Aerial Photography Program and to develop digital orthoimagery through the National Digital Orthophoto Program. In addition, the National Resources Conservation Service cooperated with DoD to use the Navstar GPS PPS and assisted other Department of Agriculture and Federal agencies by purchasing and encrypting PPS receivers.

Federal Communications Commission

During FY 1996, the Federal Communications Commission (FCC) coordinated and registered several launches of spacecraft for INTELSAT, a consortium of more than 130 countries that own and operate the world's most extensive global communications satellite system. The FCC also authorized launches of global communications satellites by PanAmSat, the first private company to provide global satellite services. In addition, the FCC authorized Comsat's participation in the construction and launch of five INMARSAT-3 spacecraft and authorized the construction, launch, and operation of numerous fixed-satellite service satellites during FY 1996. Finally, in January 1996, the FCC released a regulation allowing all U.S. licensed satellites to provide U.S. domestic service and international service.

Environmental Protection Agency

EPA applied remotely sensed imagery, tools, and technologies to a wide range of environmental applications in FY 1996. EPA's Environmental Photographic Interpretation Center (EPIC) continued to utilize aerial photography to research hazardous waste and other environmental problems. In partnership with DoD, NASA, DoE, and DoI, EPA managed a study of advanced remote-sensing techniques to detect wetlands under forest cover and also applied multiresolution land characterization data to a variety of environmental change detection problems, such as water impacts, urbanization, and wetland losses. EPA scientists also conducted research utilizing data from the North American Landscape Characterization data base to determine vegetation changes from 1970 to 1990.

During FY 1996, EPA's Office of Water participated in the intelligence community's Government Applications Task Force, which Congress created to demonstrate civilian environmental applications of advanced remote-sensing technology. Internationally, EPA personnel participated on an environmental task force that began developing a remote-sensing GIS data base for the Priobskoye area of the Russian Arctic.

National Science Foundation

Scientists, supported by the National Science Foundation (NSF) or using NSF-sponsored facilities, made a number of advances in astronomy and space physics during FY 1996. NSF-supported scientists developed new software that interpreted variations in star light to identify several planets orbiting around other stars similar to our Sun. Another team of scientists focused cameras on more than 9 million stars in a search for information about massive compact halo objects, which seem to comprise roughly half of the dark matter in the halo of the Milky Way galaxy. A third international team of investigators used the NSF-sponsored Cerro Tolelo Inter-American Observatory in Chile and other ground-based telescopes to identify the most distant population of normal galaxies ever found.

In another project, an international team using the Cerro Tolelo observatory discovered 18 supernovas in galaxies ranging from 4 million to 7 million light-years away. Some of these exploding stars destroyed themselves before our own solar system formed. By analyzing the shift in colors associated with these observations, scientists have begun to test competing theories regarding rates of expansion of the universe in an effort to determine whether the universe will continue indefinite expansion or whether the expansion ultimately will reverse itself.

Researchers also made advances at NSF-sponsored facilities in polar regions. The Center for Astrophysical Research in Antarctica completed its third full winter of operations at the South Pole. The center's telescopes made more than 100,000 observations of neutral carbon and carbon monoxide in the Milky Way and other galaxies, while another experiment resulted in a fully sampled map of the cosmic microwave background radiation in a significant patch of the sky. Elsewhere in Antarctica, five automatic geophysical observatories, previously deployed by NSF, continued to operate, gathering data on a range of variables without an attendant.

On the other side of the globe, experimentation continued at the Early Polar Cap Observatory (EPCO), a prototype facility exploring the feasibility for establishing a state-of-the-art polar cap observatory at Resolute Bay in Canada near the north magnetic pole. Initial research at EPCO included the development of a new technique for directly observing the signatures of gravity waves and tides in mesospheric neutral winds.

NSF continued to support a proof-of-concept project called GPS-MET, which uses a low-Earth-orbiting satellite launched in 1995 to measure how signals from GPS satellites bend as they pass at oblique angles through various layers of the Earth's atmosphere. By analyzing these signals, scientists improved their capabilities for estimating ionospheric electron density, atmospheric density, pressure, temperature, and moisture profiles in the atmosphere.

Demonstrating that research and education can be integrated, Naomi Bates, a recent high school graduate from Franklin, West Virginia, used a telescope at NSF's National Radio Astronomy Observatory to conduct a research project that measured the rotation of our galaxy. She also completed plans to use a larger telescope to detect high-velocity gases in other galaxies. Because of the excellence of her research, Naomi Bates received numerous awards.

Smithsonian Institution

The Smithsonian Institution contributed to the national space program through the research of staff scientists at the Smithsonian Astrophysical Observatory (SAO) in Cambridge, Massachusetts, and at the Center for Planetary Studies and Laboratory for Astrophysics, based at the National Air and Space Museum in Washington, D.C. The SAO-designed Ultraviolet Coronagraph Spectrometer instrument aboard the NASA-European Space Agency international Solar and Heliospheric Observatory satellite produced the first images of the Sun's extended corona. SAO was selected to operate the Flight Operations Control Center for the upcoming Advanced X-ray Astrophysics Facility spacecraft. Special devices for creating images of astronomical objects emitting infrared radiation, developed in part by SAO and collaborators for flight aboard the proposed Space Infrared Telescope Facility mission, won industry recognition for their contribution to this technology. An SAO astronomer, using the HST, made the first direct image of the surface of a star, the stellar behemoth Betelgeuse, other than the Sun. At the Smithsonian's Center for Planetary Studies, researchers used Shuttle Imaging Radar (SIR-C) data to identify areas for detailed field investigations in Egypt.

Department of State

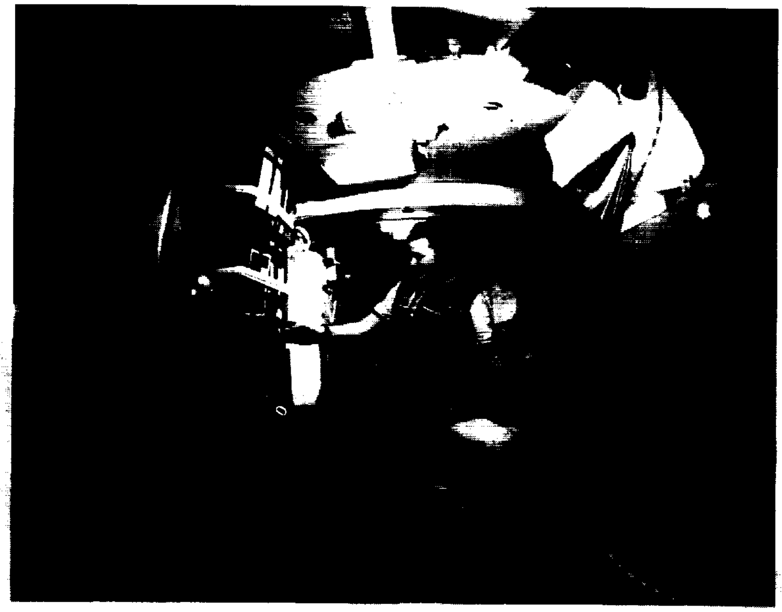
The Department of State (DoS) continued negotiations with Russia on the ISS and began international discussions on the use of GPS with Japan. In addition, DoS served as the lead agency for U.S. delegations to meetings of the INTELSAT and INMARSAT member countries and provided relevant policy guidance to Comsat, the U.S. signatory organization. DoS played an active role in interagency discussions to develop U.S. positions on INTELSAT and INMARSAT restructuring and to promote them internationally. DoS officials also promoted access to overseas markets for commercial satellite companies and worked to resolve complex problems of orbit and spectrum availability.

Arms Control and Disarmament Agency

During FY 1996, the Arms Control and Disarmament Agency (ACDA) worked to strengthen and expand the scope of the 28-member Missile Technology Control Regime (MTCR), which is intended to prevent the proliferation of missiles, space launch vehicles, and other unmanned aerial vehicles capable of delivering weapons of mass destruction. ACDA participated in new MTCR discussions of missile proliferation from a regional perspective. ACDA also worked on the U.S.-sponsored MTCR export control seminar on transshipment, attended by both MTCR members and nonmembers who are key transshipment countries. ACDA advised other Government agencies, such as DoC, DoD, and DoS, on policies relating to space launch joint ventures and worked to ensure the consistent implementation of U.S. export control policies. ACDA supported missile nonproliferation efforts and focused intensely on offensive ballistic missile programs covered by the MTCR and worked to prevent the acquisition of such weapons by other countries, particularly in south Asia and the Korean peninsula. ACDA also supported the vigorous implementation of sanctions legislation, specifically against entities in North Korea and Iran. ACDA continued to work on Strategic Arms Reductions Treaty (START) issues related to the conversion of excess ballistic missiles to space launch vehicles. Finally, ACDA actively supported the efforts of the United Nations Special Commission on Iraq to destroy or remove from Iraq materials, equipment, and facilities related to missiles with a range greater than 150 kilometers.

U.S. Information Agency

As part of its mission to inform foreign publics of American achievements, the U.S. Information Agency (USIA) acquainted worldwide audiences with NASA activities through regular reporting of Space Shuttle flights in the daily *Washington File* and on Voice of America news broadcasts. Voice of America also held a live broadcast with astronauts during an Atlantis-*Mir* linkup. The Worldnet television service brought live interviews with astronauts in space to audiences in Africa and Latin America. For every Shuttle docking with the space station *Mir*, USIA officers in Moscow sent media advisories to American journalists in Moscow and organized their access to the Star City facility. Worldnet's Newsfile series carried more than 100 stories featuring NASA activities during the year. Many of these received widespread placement on television stations around the world. USIA also continued to distribute independently produced video programs about NASA's work, such as "Exploring the World Beyond" and "Lift-off to Learning."



Shannon Lucid in the Spektr module of the Mir *space station. She set records for an American astronaut and for a woman by staying in space for more than 6 months.*

Space Launch Activities

Space Shuttle Missions

During FY 1996, NASA successfully completed eight Space Shuttle missions. Launch of the first mission, Space Transportation System (STS)-73, occurred shortly after the beginning of the year. This flight was followed by STS-74, -72, -75, -76, -77, -78, and -79. For the human space flight program, the year was particularly remarkable in that three of the eight Shuttle missions involved highly successful linkups with the Russian space station *Mir* as part of the ISS program's Phase I, which encompasses a total of nine Shuttle-*Mir* docking missions.

Launched on October 20, 1995, the orbiter *Columbia*, on its 18th flight, spent nearly 16 days in space. The mission, the 72nd of the Shuttle program, carried a crew of seven, including two females. The second U.S. Microgravity Laboratory (USML-2) was the primary payload. USML-2 is a Spacelab equipped for science and technology experiments from the U.S. Government, universities, and industry in areas such as fluid physics, materials science, biotechnology, combustion science, and commercial space processing technologies. During the flight, students at four sites around the country interacted with the crew, discussing and comparing onboard microgravity experiments with similar ground-based experiments. After a highly successful mission, STS-73 landed at Kennedy Space Center (KSC) on November 5, 1995.

The next mission, STS-74, was launched only a week later, on November 12. *Atlantis*, on its 15th flight, performed the second of the nine planned Shuttle-*Mir* docking missions of ISS Phase I. The payload included a Russian-built docking module, two new solar arrays, and various supplies. After attaching the docking module to *Mir's* Kristal module with Canada's Remote Manipulator System and linking the Shuttle's airlock to it, the *Atlantis* crew of five, including Canadian Chris Hadfield, was welcomed by the three station occupants—Yuri Gidzenko, Sergei Avdeyev, and Thomas Reiter, a German. Thus, for the first time in history, representatives of four nations were together in space. During 3 days of joint operation, the crews transferred the U.S. biomedical and microgravity science samples and data collected by the *Mir*-18, *Mir*-19, and *Mir*-20 resident crews from the station to the Shuttle, along with fresh supplies from *Atlantis* to *Mir*. On November 18, the Shuttle undocked, leaving the docking module attached to *Mir* for future linkups. *Atlantis* landed at KSC on November 20, 1995.

On the next mission, STS-72, launched by the Shuttle *Endeavour* on its 10th flight with a six-member crew, including a Japanese astronaut, and retrieved the Japanese satellite Space Flyer Unit, which had been launched by a Japanese H-2 rocket in March 1995. On January 14, 1996, the crew released the Office of Aeronautics and Space Technology Flyer, a free-flying platform carrying four autonomous experiments. Two days later, the satellite was brought back onboard. Also on January 14, two of the flight crew performed a 6-hour spacewalk (extravehicular activity or EVA) to evaluate a new portable work platform and to build spacewalking experience for ISS assembly. Two astronauts performed a second EVA of almost 7 hours on January 17 for further testing of spacesuit modifications and ISS assembly tools and techniques. *Endeavour* returned to KSC on January 20, 1996.

The following mission, STS-75, was launched on February 22, 1996. *Columbia*, on its 19th flight, carried three international members among its seven-member crew—two from Italy and one from Switzerland. On February 25, the crew began to deploy the Tethered Satellite System (TSS), a joint project between NASA and the Italian Space Agency. TSS was a reflight from STS-46 in July 1992. About 5 hours after deployment, however, the 12.5-mile-long TSS cable snapped near the Shuttle's cargo bay, and the satellite was lost in higher orbit (it burned up in the atmosphere on March 19, 1996). Later evaluations by a failure review board indicated that the most probable cause was arcing from the electrically charged tether to the deployment mechanism because of a small defect in the tether's insulation sheath. Activities onboard STS-75 then focused on the operation of the third U.S. Microgravity Payload (USMP-3). Onboard conditions and work progress were so favorable that mission controllers extended *Columbia*'s stay in space for an extra day; it returned to KSC on March 9, 1996.

For the third linkup with *Mir* in ISS Phase I, STS-76 lifted off only 2 weeks later, on March 22, 1996. *Atlantis* carried a crew of six with the commercial SPACEHAB module on its first flight. After the docking and hatch opening on March 23, the two crews of eight conducted joint operations and transferred 5,000 pounds of supplies and water to *Mir*. The first spacewalk by U.S. astronauts with a Shuttle attached to *Mir* took place on March 27, mounting four experiments to its outside for assessing its environment; this EVA lasted approximately 6 hours. After concluding science and technology experiments in SPACEHAB, *Atlantis* undocked on March 28, leaving astronaut Shannon Lucid aboard *Mir* with the two cosmonauts Yuri Onufrienko and Yuri Usachev. Lucid, in space for the fifth time, was the first U.S. crewmember to be ferried to *Mir* by Shuttle transport. After a successful mission, *Atlantis* returned to Edwards Air Force Base, California, on March 31.

On the 77th Shuttle mission, STS-77, *Endeavour* lifted off on May 19, 1996, with six persons. The payload included the commercial SPACEHAB module on its second flight, with nearly 3,000 pounds of experiments and support equipment, an Inflatable Antenna Experiment (IAE) on the free-flying Shuttle Pointed Autonomous Research Tool for Astronomy (SPARTAN)-207 platform and a suite of four technology experiments called Technology Experiments for Advancing Missions. The crew released SPARTAN on May 20, and the 50-foot-diameter IAE inflated on its 92-foot-long struts—the most complex and precise inflatable space structure ever and the largest since the Echo II satellite in 1964. Later, it separated from SPARTAN and burned up in the atmosphere on May 22, 1996. Astronauts retrieved the satellite on May 21 and then conducted further experiments, including observations of the behavior of and rendezvous with the Passive Aerodynamically Stabilized Magnetically Damped Satellite Test Unit (PAMS-STU). Having set a new record of four rendezvous maneuvers with two satellites, *Endeavour* returned to KSC on May 29 after successfully completing its 10-day mission.

STS-78 set a new Shuttle duration record of almost 17 days by flying from June 20 to July 7, 1996. *Columbia*'s main payload, the Life and Microgravity Sciences Spacelab, was equipped to study fluid physics, materials science, biotechnology, human and animal physiology, and plant biology in microgravity. The mission involved dozens of scientists and research institutes with principal investigators from Belgium, Canada, France, Germany, Italy, Switzerland, Spain, Sweden, the United Kingdom, and the United States. The seven-member crew included French and Canadian payload specialists. After a very successful mission, the final approach and touchdown phase could be seen for the first time by television audiences on the ground via a camera with the pilot's point of view.

STS-79 provided a successful conclusion to FY 1996 with the docking of *Atlantis* to *Mir*. Launched on September 16, 1996, it was the third flight to carry a commercial SPACEHAB in its cargo bay and the first featuring the two-segment version of the module. Docking occurred on September 18. The mission's main purposes were the exchange of astronaut Shannon Lucid on *Mir* with astronaut John Blaha for a 4-month stay; hauling 4,600 pounds of supplies, including food, clothing, experimental supplies, and spare equipment to Mir; and returning 2,200 pounds of Russian, European Space Agency (ESA), and U.S. science samples and hardware to Earth. The flight, which drew worldwide attention because of Dr. Lucid's accomplishments, also marked the first transfer of powered scientific apparatus to *Mir*, as five different experiments were turned off on the Shuttle and rapidly transferred to the station. When *Atlantis* landed at KSC on September 26, 1996, a new era of permanent space occupancy by U.S. astronauts had begun, and Shannon Lucid became the holder of the new world record for longest space flight for a female and for an American astronaut (188 days).

Expendable Launch Vehicles

NASA conducted seven successful launches aboard ELV's in FY 1996. The Canadian-built RADARSAT spacecraft was launched aboard a Delta II rocket into a polar orbit on November 4, 1995. RADARSAT did not use the full capability of the Delta rocket, which enabled NASA to fly a student undergraduate's research fellowship satellite as a secondary payload. On December 2, 1995, ESA's Solar and Heliospheric Observatory (SOHO) was launched on an interplanetary trajectory by an Atlas-Centaur IIAS rocket. The NASA Rossi X-ray Timing Explorer (RXTE) was launched on December 30, 1995, aboard a Delta II from the Florida launch site. NASA's February 17, 1996, launch of the Near Earth Asteroid Rendezvous (NEAR) spacecraft aboard a Delta II from Florida was followed 7 days later by the launch of the NASA Polar spacecraft. Polar also was launched on a Delta II rocket, but from the California launch site. Two NASA payloads that had been grounded by the resolution of two previous Pegasus XL launch failures, the Total Ozone Mapping Spectrometer (TOMS) and the Fast Auroral Snapshot Explorer (FAST), were launched successfully on July 2, 1996, and August 21, 1996, respectively.

The Pegasus XL rocket, which was deployed from a commercially owned L1011 aircraft, completed its return to flight after two previous launch failures. NASA, the United States Air Force (USAF), and Orbital Sciences Corporation established a series of failure anomaly and accident investigation boards, which reviewed the entire Pegasus XL program and hardware and jointly agreed to a corrective action plan. The Pegasus XL demonstrated its first successful flight with the deployment of the Space Test Program Radiation Experiment II into orbit on March 9, 1996.

Also, in March 1996, NASA signed the Med-Lite launch services contract with McDonnell Douglas Corporation, which is to provide lower cost launches for NASA's Discovery, Mars Orbiters/Landers, and Explorers missions. NASA managers planned to award launch services contracts to support smaller missions in FY 1997.

NASA funded and oversaw the upgrade of the Atlas IIAS launch vehicle in structural capability to accommodate NASA's Earth Observing System (EOS) AM-1 spacecraft. The EOS AM launch vehicle was strengthened to carry payloads up to 11,000 pounds, the payload nose fairing was lengthened by 3 feet to accommodate the 22-foot-long spacecraft, and a new payload separation system was developed for the mission. The upgrade of the Atlas IIAS vehicle will benefit future missions planned by the USAF, which shared in the cost of the structural modifications with NASA, as well as commercial ELV customers.

The Delta II completed a major avionics upgrade in FY 1996. RXTE, launched in December 1995, was the first spacecraft to use the new system.

NASA's Lewis Research Center (LeRC) released a request for proposals in FY 1996 for designing and developing a digital telepak to replace the older telepaks on the Atlas Centaur launch vehicle. Once the digital telepak is fully qualified, tracking specialists will use it to acquire high-frequency data in a format compatible with the Tracking and Data Relay Satellite System (TDRSS) and will eliminate the need for costly airborne sensors used to gather down-range telemetry data. NASA planners designed the new telemetry system to support the EOS-AM 1 mission. NASA and the USAF shared the cost of this project.

NASA LeRC also began working with the USAF to integrate a new, higher powered TDRSS telemetry transmitter into the Titan Centaur for the upcoming Cassini mission. When completed, the new design should allow most future Titan Centaur missions to use TDRSS and save nearly $1 million per mission. Additionally, NASA personnel worked with their colleagues at McDonnell Douglas and Orbital Sciences Corporation to develop a similar strategy to integrate TDRSS onto the Delta and Pegasus launch vehicles.

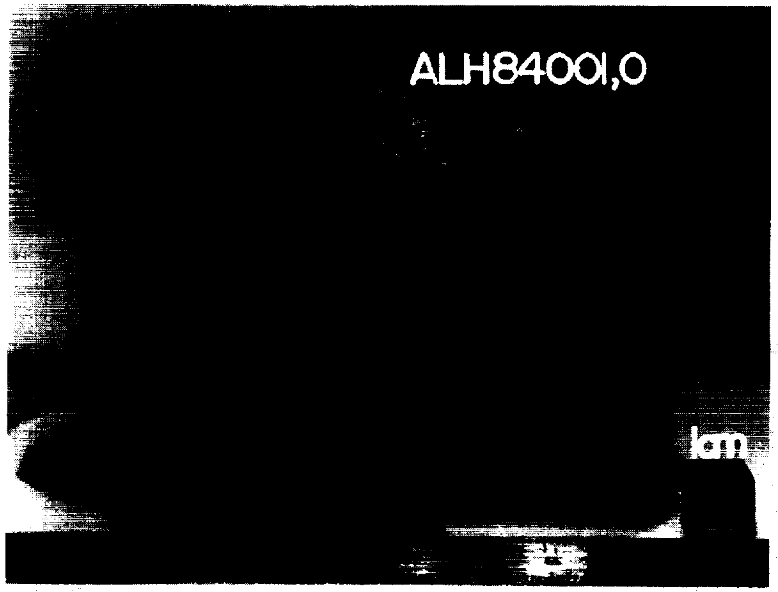
At DoD, the military conducted nine ELV launches during FY 1996. The USAF's heavy-lift Titan IV has become the workhorse of DoD's launch vehicles, with five successful launches in FY 1996. In the medium- and light-lift categories, DoD successfully launched three Delta II ELV's and one Pegasus XL ELV, respectively.

The Air Force also supported eight NASA Space Shuttle and eight nonmilitary ELV launches from Cape Canaveral Air Station, Florida. Additionally, the Air Force's Western Range at Vandenberg Air Force Base, California, supported seven operational test flights of intercontinental ballistic missiles.

DoD's Titan and Delta launch vehicles both made unprecedented quick turnarounds. The successful qualification of the new stage II nozzle for the Titan IV averted a potential grounding of the fleet. To sustain its medium-lift capability, DoD personnel established the Atlas Reliability Enhancement Program to increase the reliability of the Centaur upper stage that delivers DoD satellites to geostationary orbit.

To implement its part of the National Space Transportation Policy, DoD has initiated an Evolved ELV (EELV) program to replace current medium- and heavy-lift launch systems. By using innovative methods, program managers hope to allow U.S. industry a greater leadership role in free market access to space.

In FY 1996, the U.S. commercial launch industry conducted 13 launches licensed by the FAA. Eleven orbital launches and one suborbital launch went successfully. The one failure was the maiden flight of the Conestoga launch vehicle with the NASA-sponsored Multiple Experiment to Earth Orbit and Return (METEOR) payload aboard. In total, there were 30 ELV launches during FY 1996.



This potato-sized rock is actually believed to be a meteorite from Mars that once contained microscopic life. The meteorite, ALH84001, was found in the Allen Hills region of Antarctica in 1984.

SPACE SCIENCE

Astronomy and Space Physics

During the second full year of Hubble Space Telescope (HST) operations since the successful Shuttle servicing mission, astronomers from around the world studied the nearest objects in the solar system, the birth of young stars across our galaxy, and the furthest depths of the cosmos. The HST continued to be one of the most heavily used observatories in history, with an estimated 65 percent of U.S. astronomers using this Great Observatory.

Astronomers thrilled people with their stunning HST images of a stellar nursery in the Eagle Nebula. The images of embryonic stars emerging from vast columns of dark, interstellar matter appeared on television and in magazines throughout the world. This opened a new chapter in the mysteries of star formation.

Additionally, an astronomer from the Smithsonian Astrophysical Observatory (SAO) used the HST to make the first direct image of the surface of a star other than the Sun. This scientist observed the stellar behemoth Betelgeuse and, in the process, revealed the presence of a huge, hot, and mysterious bright spot on its face.

The HST's superb optics also allowed astronomers to study surface features of Pluto for the first time since the planet was discovered. Scientists have speculated that this distant planet was made up of a mixture of ice and rock, but the HST's images show a surface with significant bright and dark regions. Pluto has emerged as an interesting object in its own right with almost as much brightness variation across its surface as the Earth.

At the other extreme of the cosmos, the HST produced the most detailed images of extraordinarily distant galaxies yet obtained. Dubbed the "Hubble Deep Field," the light from the galaxies in the image have been traveling to the Earth for billions of years, perhaps from a time when the universe was only 10 percent of its present age. The structure of these young galaxies was discernible only because of the HST's optical quality. This allowed astronomers to study the early appearance of spiral and elliptical galaxies, as well as collisions between them, which may have determined the subsequent appearance of these vast stellar systems as the universe aged. One of the most exciting results is what may be very young "building blocks" of larger galaxies. Astronomers have speculated for years on the formation mechanisms of giant galaxies. Were they formed via the gravitational contraction of enormous gas clouds in the early universe? Or were they instead built up via the coalescence of smaller "baby galaxies"? The results from the HST have suggested the latter, but the Deep Field holds more information in the continuing study of the universe.

Astronomers also used the HST to narrow the range of allowable values for the age of the universe. For decades, scientists have carefully been estimating how fast galaxies are moving apart as the universe expands. With an accurate estimate of the distances to galaxies, astronomers can estimate the universe's "expansion rate," the length of time the universe has taken to reach its current size. HST observations allowed for the precise determination of the luminosities of a certain class of star in galaxies, which permit the best estimates of distance. In this manner, HST observations have narrowed the age of the universe to between 9 to 12 billion years. Astronomers have planned further observations to narrow this estimation even more precisely.

With the discovery of the most distant supernovas ever observed, an international scientific team sponsored by National Science Foundation (NSF) may be on the verge of learning the ultimate fate of our universe. These scientists discovered 18 supernovas by the brilliant light of their self-destruction and found 11 of them, including several of the most distant known stars, at the end of November 1995 within a 48-hour period. The team found the supernovas in galaxies ranging from 4 billion to 7 billion light-years away. This means that the furthest of these explosions took place billions of years before our own solar system was formed, halfway back to the beginning of the universe.

The scientists made these discoveries as part of the NSF-sponsored Supernova Cosmology Project. The goal of the project is to measure the universe's "deceleration," the rate at which the known continual expansion of the universe is declining. At stake is an understanding of the way the universe will end. Having begun expanding with the big bang, will the universe continue to expand forever, becoming ever more cold and empty? Or will the expansion of the universe slow to a halt, reverse itself, and eventually contract to a fiery dense finale—a big crunch? The experiment to explore these questions only recently became possible, because it depends on the advances in light detectors and computers and in the Internet, which ties together the most important ingredients—astronomers using the newest and largest telescopes around the world. Scientists sighted all of the recent supernovas on NSF's Cerro Tololo Inter-American Observatory telescope in Chile.

An international team of scientists concluded that massive compact halo objects may comprise approximately 50 percent of the dark matter in the halo of the Milky Way galaxy and that the objects likely are "white dwarfs," or burned-out stars. The team is associated with Lawrence Livermore National Laboratory and the NSF-sponsored Center for Particle Astrophysics.

A group of astronomers using NSF's Cerro Tololo Inter-American Observatory and other ground-based telescopes identified the most distant population of normal galaxies yet found. Using a new technique designed to isolate large numbers of extremely distant, young galaxies, the scientists discovered what are likely the progenitors of the bright spiral and elliptical galaxies that are seen today. They observed the galaxies at a time very soon after they first formed, roughly 10 billion years ago. These objects indicate that galaxies were already forming in large numbers at an epoch when the universe was only 10 to 20 percent of its current age.

A recent discovery by NSF-supported scientists settled an astronomical controversy by indicating that certain bright galaxies had in fact formed quite early in the universe's history and that it is now quite straightforward to observe them. Astronomers have long had difficulty finding young galaxies born just after the big bang for several reasons, including their extreme distances, which makes them exceptionally faint as seen from Earth. In addition, astronomers did not know exactly how these early galaxies would appear.

Following the initial discovery of planets around stars similar to the Sun in FY 1995, NSF-supported researchers Geoffrey Marcy and Paul Butler of San Francisco State University and the University of California at Berkeley, respectively, discovered several large planets orbiting other stars. These findings make it clear that planets around other stars are not isolated curiosities. Because they are so much dimmer than the stars they orbit, these planets cannot be seen directly; therefore, their presence must be deduced by indirect means. Marcy and Butler measured Doppler shifts in a star's light to detect a wobble in the star's motion caused by the pull of a planet's gravity. They have developed special software that gives them unprecedented precision in the analysis of the data that would indicate the characteristic signature of an orbiting planet.

NASA's Compton Gamma Ray Observatory (CGRO) continued a variety of observations of gamma rays, the most energetic form of radiation. Gamma ray bursts appear randomly around the sky and last from a few milliseconds to tens of seconds, yet contain an incredible amount of energy. By the end of FY 1996, CGRO had detected 1,600 gamma ray bursts. CGRO also has mapped the universe at the highest energies, including the first detailed map of the Milky Way galaxy and the first cosmic map of radioactive aluminum. The CGRO team found that cosmic rays are galactic in origin and discovered a unique high-energy source that simultaneously exhibits regular pulsations and outbursts.

The Rossi X-ray Timing Explorer (RXTE), launched by NASA in December 1995, has provided invaluable information on the variations of x rays from neutron stars and black holes, the bizarre end products of stars. The time scale of the variations studied was very short, and RXTE is the first satellite designed to capture them. Data from RXTE and CGRO have provided physicists with key insights into the nature of matter inside neutron stars.

The Center for Astrophysical Research in Antarctica (CARA), one of NSF's Science and Technology Centers, completed its third full winter of operations at the Amundsen-Scott South Pole Station in 1995. CARA's Antarctic Submillimeter Telescope and Remote Observatory (AST/RO) produced more than 100,000 spectra of neutral carbon and carbon monoxide in molecular clouds in the Milky Way and other galaxies. AST/RO is a joint project of SAO and Boston University. The South Pole is the only developed site where the water vapor content of the atmosphere is low enough to make regular neutral carbon observations useful.

Another CARA experiment, Cosmic Background Radiation Anisotropy (COBRA), has produced a fully sampled map of a significant patch of the sky at two wavelengths after four summers of operation. At fiscal year's end, the COBRA team was in a position to help test several competing models of the early universe.

CARA researchers continued their efforts to characterize the atmospheric conditions, especially in the near- and mid-infrared portions of the spectrum. The South Pole Infrared Explorer (SPIREX) has now established that the sky is 20 to 50 times darker at the South Pole than at an observatory such as Mauna Kea in Hawaii, but other experiments have shown that there are "seeing" problems at the South Pole. "Seeing" is an astronomical term for the twinkling of star light caused by small motions of the image from atmospheric turbulence. Thus, for the observation of small objects such as stars, Mauna Kea may be the best place, but for extended observations of large objects such as galaxies, the South Pole may be better because of the darker sky there. Several collaborative efforts with other groups, including NASA's Goddard Space Flight Center, continued at the South Pole.

NSF operated five automatic geophysical observatories (AGO's) during FY 1996, leaving only one more AGO to be deployed. The AGO's provide heat, power, and data storage that enable a suite of remote-sensing instruments to operate for a year without an attendant. All five AGO's operated through most of the winter, returning state-of-health and meteorological data via the Argos satellite system. When all six AGO's are finally in the field and working in conjunction with a few manned stations, they will provide uninterrupted and overlapping observations of the very high magnetic latitude ionosphere with a number of instruments, ranging from visible imagers to direct current magnetometers. Because of the distribution of land masses, it is not possible to make these observations in the Northern Hemisphere. Following the lead of NSF, the British and Japanese Antarctic Programs are developing their own AGO's, which will provide additional data in the lower latitude auroral zone. The AGO network complements the International Solar-Terrestrial Physics Program (ISTP), especially NASA's Polar satellite.

During FY 1996, NASA and NSF researchers launched two large long-duration balloon payloads from McMurdo Station in Antarctica. One of these, the Japanese American Cosmic-ray Emulsion Chamber Experiment (JACEE), collected data on the composition of energetic cosmic rays. The other, which was funded by NSF, NASA, and the USAF, produced images of the Sun to elucidate the processes that cause solar flares. Both payloads successfully circumnavigated Antarctica and were parachuted to the surface, but only JACEE has been recovered, leaving the solar telescope to be returned during the austral summer of 1996–97.

SAO was selected to operate the Flight Operations Control Center for the Advanced X-ray Astrophysics Facility (AXAF) satellite, scheduled for launch in 1998. Together with the previously awarded contract to operate the AXAF Science Center, SAO is to be responsible for most aspects of the space observatory's mission after launch, including planning observations, analyzing results, and archiving data for the world's scientific community.

Special devices for creating images of astronomical objects emitting infrared radiation, developed in part by SAO and collaborators for flight aboard the proposed Space Infrared Telescope Facility mission, won industry recognition for their contribution to this technology. These multipixel focal-plane arrays produced several outstanding and important high-resolution images, ranging from the bright Comet Hyakutake to the "hot spot" on Jupiter where the Galileo spacecraft entered the planet's atmosphere.

Naomi Bates, a recent high school graduate from Franklin, West Virginia, has been working for the last 4 years on research projects that used the telescopes at NSF's National Radio Astronomy Observatory in Green Bank, West Virginia. During FY 1996, Ms. Bates presented the results of a research project that measured the rotation of our galaxy with the 40-foot telescope using neutral hydrogen atom spectroscopy. She also refined plans for a new project that will allow her to spend part of each week doing research at Green Bank using the 140-foot telescope to detect high-velocity gases in other galaxies. Ms. Bates' research was recognized through a diverse array of prestigious awards. She became a finalist in the Westinghouse Science Talent Search, received eight awards at the International Science and Engineering Fair, and also won an expense-paid trip to attend the Nobel Prize festivities in Stockholm.

In space physics, measurements from the NASA-ESA Solar and Heliospheric Observatory (SOHO) may have provided the key to a long-standing puzzle—how is the Sun's outer atmosphere, the corona, heated to temperatures more than 100 times that of the visible surface? The SAO-designed Ultraviolet Coronagraph Spectrometer instrument aboard SOHO produced the first images of the Sun's extended outer corona. These data suggested a mechanism that heats ions according to their mass. The unexpectedly high ion temperatures also seem to explain how the solar wind (coronal gas that flows away from the Sun at supersonic speeds) is accelerated to velocities of 800 kilometers per second.

Additional data from SOHO revealed unexpected activity on the Sun and the best views yet of the sources of strange, chaotic "plume" structures that extend from the solar poles to the corona. SOHO was specifically designed to observe the Sun during a supposedly "quiet" period of its solar cycle. To the surprise and excitement of SOHO's scientific investigators, SOHO ultraviolet data indicated that there is continuous motion and activity everywhere on the Sun. Disturbances occurred even within so-called "coronal holes" (areas of particularly low density, low temperature, and open magnetic field lines in the corona), where scientists least expected such disturbances.

In FY 1996, NSF-sponsored solar researchers also observed the Sun during its period of quiescence, the "solar minimum." Solar physicists took advantage of this quiet period to ascertain how the Sun is preparing itself for its next cycle of activity, which should peak around the year 2000. For example, scientists at Stanford University discovered "hot spots" on the Sun, which last as long as several solar cycles. These seem to be preferred sites for the emergence of large sunspot groups, as well as for major solar flares and coronal mass ejections.

Measurements from the joint NASA-ESA Ulysses mission found a surprisingly small increase in the amount of helium-3 since the formation of the solar system, allowing a more precise estimate of the amount of dark matter in the universe. The exact nature of dark matter remained one of the most intriguing mysteries in astronomy. Although scientists do not know what it is, their best estimates indicate that most of the universe—perhaps as much as 90 percent—is composed of dark matter. Dark matter may be "ordinary" matter, such as planets and burned-out stars too dim to detect, or perhaps exotic objects, such as black holes or as-yet undetected particles that pervade the universe.

The Earth-orbiting Polar spacecraft obtained spectacular movies of the auroral regions in the Earth's polar regions. Ultraviolet and x-ray images depicted the development of auroral structures caused by solar and geomagnetic activity. The Polar spacecraft detected the outflow of low-energy plasma from the ionosphere into space and has shown how the ionosphere can be a source of ionized particles making up the magnetosphere. The Geotail spacecraft has detected these atmospheric particles beyond the orbit of the Moon, in the "tail" direction or in the direction opposite the Sun where the solar wind sweeps the Earth's magnetic field to large distances from Earth. The Polar spacecraft also has discovered 20 key energetic particles above the North and South Poles, which seem to be solar wind particles that are accelerated by interactions between the solar wind and the Earth's magnetic field.

In efforts to forecast space weather, NSF-supported space scientists have begun the development of the Geospace General Circulation Model to explore the global dynamics of the magnetosphere in response to various solar wind inputs. This model is unique in its ability to model both large- and small-scale magnetospheric processes, eventually leading to a predictive capability that can be used to produce reliable space weather forecasts.

Pioneer 10 and Voyagers 1 and 2, by fiscal year's end at 66, 64, and 45 astronomical units, respectively, reached the outer frontier of the solar system. Their measurements of energized interstellar gas indicated that the heliospheric shock, in which the solar wind outflow encounters the interstellar medium, is between about 80 and 90 astronomical units.

Solar System Exploration

A group of American researchers, led by Dr. David McKay of NASA's Johnson Space Center, examined a 2-kilogram meteorite believed to have originated from Mars and found evidence that it once contained primitive forms of life. The meteorite, known as ALH84001, was found in the Allan Hills ice field of Antarctica in 1984. ALH84001 is believed to have left the Martian surface 16 million years ago from a comet or asteroid impact, and it arrived on Antarctica 13,000 years ago. The meteorite displays small spheres or globules of carbonate material that seem to have biological origin. An abundant number of polycylic aromatic hydrocarbons are associated with these globules, and the isotopic composition of oxygen in the meteorite is characteristic of Mars. This was the first reduced carbon ever discovered in a meteorite from Mars, indicating that mineralization was an effective means for preserving organic material on the planet. The report by Dr. McKay and his colleagues stimulated enormous interest, and much scientific work has gotten under way to follow up on this discovery.

The NASA Galileo probe successfully entered the atmosphere of Jupiter on December 7, 1995. The entry was the most difficult ever attempted in terms of heat and deceleration loads. The probe and all its scientific instruments functioned successfully and returned data on composition, clouds, thermal structure, winds, energy balance, lightning, and inner radiation belts. This was the first time that scientists directly sampled the atmosphere of an outer planet. German scientists were highly involved in Galileo's numerous scientific investigations of the Jovian atmosphere's physical state and chemical composition.

In June 1996, the Galileo spacecraft obtained its first remote-sensing measurements within the Jovian system. Galileo imaged and measured spectroscopically Jupiter's atmosphere and the surfaces of its four largest moons (Ganymede, Callisto, Io, and Europa). The Galileo spacecraft also made radio, plasma wave, and magnetic field measurements in the Jovian magnetosphere. Observations by the Galileo plasma wave receiver revealed that Ganymede is the source of narrow-band electromagnetic radio waves, making this satellite the first in the solar system to have non-thermal radio emissions. In addition, the HST provided images of Jupiter's ultraviolet aurora that complemented Galileo's ultraviolet, field, and particle measurements.

The USGS was heavily involved in data analyses for the Galileo mission in orbit around Jupiter. USGS scientists provided assistance on the use of the Near-Infrared Mapping Spectrometer to recognize and map minerals on Jupiter's four largest moons, including active eruptions on the moon Io. USGS personnel also participated on the Solid-State Imaging Team, which did the detailed sequence planning of Galileo operations. Galileo program personnel began detailed mapping of Jupiter's four largest moons.

In August 1996, Galileo images of Europa provided tantalizing clues that liquid water may have existed, or even may currently exist, beneath this moon's icy crust. The results were an important first step toward determining whether Europa could support any form of life.

The appearance of Comet Hyakutake (C/1996 B2) in early 1996 provided a unique opportunity for astronomers to observe the closest and brightest comet to appear in the last 400 years. Scientists made many new discoveries using both ground-based telescopes and spacecraft. New discoveries included the detection of x-ray emissions from the comet, as well as the presence of ethane, methyl cyanide, and acetylene. These scientists also imaged the comet's nucleus at radio and infrared wavelengths. Taken together, these observations should enable astronomers to better understand the nature and origin of comets.

Scientists also obtained radar echoes from seven near-Earth objects (NEO's) between January and June 1996. These observations, made with NASA telescopes at Goldstone, California, allowed for a precise measurement of the NEO's positions to be made. Efforts continued by NASA-supported astronomers to find NEO's. A "Spacewatch" survey conducted by personnel at the University of Arizona continued to scan the sky for near-Earth asteroids with a charge-coupled device camera system mounted on a 0.9-meter telescope. A Jet Propulsion Laboratory and USAF system known as Near-Earth Asteroid Tracking became fully operational in FY 1996. This system already has detected nearly 6,000 potential objects. Over half of these were new objects, including comet C/1996 E1, five near-Earth asteroids, and several comets and asteroids that cross Mars' orbital path. In addition, scientists discovered the unusual asteroid 1996 PW and determined that it has the most eccentric orbit of any known asteroid.

The Near Earth Asteroid Rendezvous (NEAR) spacecraft was successfully launched on February 17, 1996, on its 3-year journey to rendezvous with asteroid (433) Eros. NEAR is to pass the asteroid (253) Mathilde in June 1997 on its way to Eros.

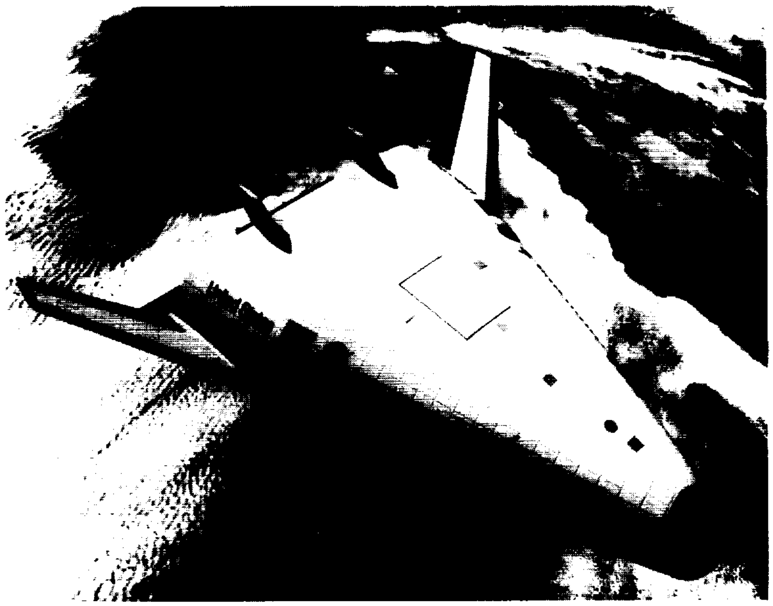
USGS scientists have been involved in many phases of the NASA Mars Global Surveyor mission, such as the Mars Orbital Camera and the Thermal Emission Spectrometer instruments. Having completed detailed mapping of Mars, using data from earlier spacecraft missions, USGS expected to be involved in developing cartographic products from the Mars Global Surveyor data.

USGS also has been involved in developing instruments for the NASA Mars Pathfinder mission, which was launched in December 1996. It is expected to operate at least 30 Martian days, collecting surface information. Several USGS scientists and technicians assisted the Pathfinder project in developing a plan for producing large digital mosaics and extracting digital-terrain models of the landing site.

USGS personnel also helped develop the Cassini mission to Saturn. USGS participated on the Imaging Science, Visual Infrared Mapping Spectrometer, Titan Radar, and Interdisciplinary Science teams.

Meanwhile, personnel at the USGS Flagstaff field center built a small observatory dedicated to photometric observations of the Moon. This work is to supply accurate lunar spectral radiance images to NASA for calibrating Earth-orbiting imaging systems.

USGS investigators also worked with NASA personnel at the Jet Propulsion Laboratory on the New Millennium spacecraft program. The first New Millennium flight is to carry an imaging ultraviolet/visible/near-infrared integrated camera-spectrometer to an asteroid and to a comet. A consortium headed by a USGS scientist developed the original concept for this very lightweight and low-power innovative instrument, the Miniature Integrated Camera Spectrometer.



A computer-generated image of the X-33. Lockheed Martin Skunk Works was chosen to lead an industry team to build and flight-test this subscale technology demonstrator.

SPACE FLIGHT AND TECHNOLOGY

Life and Microgravity Sciences

On October 20, 1995, NASA launched the second U.S. Microgravity Laboratory (USML-2), a 16-day Spacelab mission dedicated to microgravity research. Building on scientific foundations laid by previous Space Shuttle missions, USML-2 investigators pursued 22 investigations in fluid physics, combustion science, materials science, and biotechnology. Each investigation used the unique, low-gravity environment of Earth orbit to conduct experiments that are impossible to conduct on the Earth because of the influence of gravity.

Launched on June 20, 1996, the Life and Microgravity Spacelab (LMS) completed a highly successful 17-day mission that set a record for the longest Space Shuttle flight. The LMS mission used the pressurized Spacelab module, carried in *Columbia*'s payload bay, to conduct 41 investigations with participation from 10 countries. Science investigations included experiments in fluid physics, materials science, biotechnology, human and animal physiology, and plant biology. Researchers designed their life sciences investigations to provide information on changes in muscles and bones during space flight, on sleep rhythms, and on the functioning of the human nervous system. The mission included remote operations conducted by scientists at five different sites in Belgium, Italy, France, and the United States. The international crew successfully completed all experiments. NASA cut preparation time and mission management costs in half for LMS when compared to previous Spacelab missions.

The third U.S. Microgravity Payload (USMP-3) was a remotely controlled set of physics and materials sciences experiments that flew into orbit in the payload bay of the Space Shuttle *Columbia* on February 22, 1996. The mission lasted approximately 13 days. Researchers on the ground used remote control to conduct three investigations in microgravity materials science and one investigation in microgravity physics. The flight crew conducted small science and technology experiments in combustion science, using a new middeck glovebox, which allows crew members to manipulate experiments directly without exposing the Shuttle's atmosphere to possible contamination from the experiments.

In addition to the investigations conducted during dedicated Shuttle missions, NASA's Office of Life and Microgravity Sciences and Applications used opportunities aboard other Shuttle missions and sounding rockets to conduct experiments. In January 1996, for example, NASA launched the third in a series of collaborative payloads with the National Institutes of Health (NIH), using the Shuttle middeck. This series has focused on developmental biology by studying the effects of microgravity on gestation and early development in rats. The most recent experiment studied the effects of microgravity on the rat family (lactating dam and nursing pups) in a specially designed habitat. This experiment successfully demonstrated a hardware concept in preparation for the Neurolab Life Sciences Spacelab mission scheduled for 1998. Three groups of rat families were flown in three animal enclosure modules.

In April 1996, NASA and NIH flew the seventh middeck payload in a series of collaborative research investigations focusing on cellular and molecular biology. This payload studied the effects of microgravity on muscle cells maintained in culture in space.

On STS-77, BioServe Space Technologies and the Wisconsin Center for Space Automation and Robotics developed and flew a plant chamber that was totally enclosed and environmentally controlled. The chamber functioned successfully in microgravity, and the plants thrived. In addition to demonstrating this new technology, the mission contributed to scientists' understanding of the way environmental factors influence plant growth.

The last of three sounding rocket tests of the Spread Across Liquids experiment was successfully launched at White Sands Missile Range on February 23, 1996. The experiment was an investigation of the flame-spread characteristics across a deep pool of combustible liquid in a microgravity environment. The experimental hardware performed flawlessly. The results showed that microgravity has a profound effect on the flame spread across liquids, with important implications for future space missions.

Also flying on a sounding rocket was the Diffuse and Radiative Transport in Fires Experiment, which was conducted on June 20, 1996. Researchers investigated flame initiation, fire spread, and post-spread, steady-state combustion of a solid fuel. Scientists viewed these experiments as important both for fire safety on orbit and as fundamental research on the nature of combustion.

As part of NASA's Human Test Initiative, a 30-day chamber test with a crew of four was completed on July 12, 1996. This was the second in a series of four regenerative life-support technology demonstration tests with humans. During the test, the atmosphere and water were recovered with prototype physicochemical regenerative life-support systems and reused by the crew. More than 6,500 pounds of water were recovered from more than 6,840 pounds of waste water, consisting of shower water, hand wash water, flush water, urine, laundry water, and humidity condensation. Most of the carbon dioxide removed from the chamber atmosphere was combined with hydrogen to form water, which was then converted to oxygen for reuse.

Protein crystal researchers took advantage of the *Mir* space station to conduct the longest period of protein crystal growth in space, with the placement of samples on *Mir* in June 1995 and their return to the Earth in November 1995. Experiments on *Mir* led to a discovery that may allow thousands of protein crystal samples to be grown on a single Space Shuttle mission. Protein crystals grown on orbit already have supported drug development efforts by major pharmaceutical companies.

Record-breaking stays on the Russian *Mir* space station by American astronauts Norman Thagard and Shannon Lucid led to numerous important findings. Bone loss in the hip and lower spine progressed at a rate of 1.2 percent per month and did not lessen over time. Researchers observed that the benefits of exercise were specific to muscles targeted and identified certain muscles as important for specific countermeasures.

An analysis of the radiation dosimetry data from *Mir* indicated that the absorbed radiation dose was higher than predicted, but still only about 20 percent of the allowed annual dose. There are two sources of concern for radiation on orbit: galactic (cosmic) radiation and trapped radiation from the Earth's magnetic field and the Van Allen radiation belts. Scientists reduced the uncertainties in predicting the galactic cosmic radiation environment from approximately 50 to 10 percent by applying a new set of mathematical models.

John Hart of the University of Colorado used the low gravity of space to create a physical model of the

Earth's atmosphere. His device substituted a liquid for the atmosphere and electrostatic forces for gravity. He observed pattern formation in the liquid, which may help to refine future mathematical models of the Earth's atmosphere and climate. Dr. Simon Ostrach of Case Western Reserve University found and characterized a type of fluid motion, driven by the thermodynamic properties of gas-liquid interfaces, that plays an important role in material processing in space and on the Earth. These experiments have provided the scientific community with the first conclusive evidence of transition from steady to oscillatory flows, a transition that can have major consequences for crystal growth and other processing technologies.

John Lipa of Stanford University analyzed scientific results from the highly successful Lambda Point Experiment flown aboard the Space Shuttle in FY 1995. In February 1996, the journal *Physical Review Letters* published his results. The Lambda Point Experiment confirmed the validity of a Nobel Prize-winning theory describing the conditions under which matter will change between different states, such as from liquid to gas. This theory constituted one of the greatest achievements of theoretical physics of the past 30 years and has very broad applications. This theory is important to scientists seeking to develop better models for the ways water seeps through soil, frost-heaving occurs in arctic climates, and turbulent weather systems evolve.

On STS-77, flown in May 1996, Paragon Vision Sciences successfully processed 56 polymer samples on its third space flight. Paragon researchers used microgravity to develop enhanced polymers for manufacturing rigid, gas-permeable contact lenses. They began verifying that polymers formed in microgravity exhibit greater uniformity and durability of material, increased oxygen permeability for improved comfort to contact lens wearers, and improved manufacturing properties.

Scientists at NASA's Center for Macromolecular Crystallography (CMC) at the University of Alabama in Birmingham isolated the neuraminidase protein and used its space flight opportunities to grow high-quality crystals to determine its structure. These scientists used that knowledge to design a drug to inhibit the function of this enzyme and, thereby, effectively stop the spread of flu within the body. Researchers tested this drug in culture and in animals and found that it specifically blocks every known strain of the flu virus. The CMC began work to configure the drug so that it is even more effective in order to minimize the effective dosage and any possible undesirable side effects. The CMC expected to have a drug within 1 to 2 years that can be used in human clinical trials and has teamed with BioCryst Pharmaceuticals on this project.

Using space-grown protein crystals, NASA life sciences researchers published the highest resolution structure for insulin to date. By studying the structure and function of insulin, scientists hoped to produce improved drugs for diabetics.

Dr. Robert Cheng and Dr. Larry Kostiuk, combustion science researchers under contract to NASA at the Lawrence Berkeley National Laboratory, developed a device that significantly reduced pollution from natural gas burners such as residential heating furnaces and hot water heaters. Cheng and Kostiuk fitted the device into an off-the-shelf home heating furnace and were able to reduce nitrogen oxide emissions by a factor of 10, while slightly increasing efficiency. The device can be readily sized to industrial scales. In May 1996, Cheng and Kostiuk received a U.S. patent for their work.

A cooperative effort between NASA and the National Institute of Child Health and Human Development to exploit NASA's bioreactor technology has produced some encouraging results. In FY 1996, researchers at the NASA/NIH Center for Three-Dimensional Tissue Culture produced the first in-vitro tissue system that permits the study of HIV pathogenesis inside human lymphoid tissue. At year's end, there were 15 ongoing projects at the center addressing a spectrum of biomedical research issues that NIH identified as potentially benefiting from the NASA tissue culture technology.

Dr. David J. Larson of the State University of New York at Stony Brook reported that cadmium zinc telluride (CdZnTe) crystals grown from the melt in the Crystal Growth Furnace on the first and second USML missions, flown in October 1992 and October 1995 respectively, were far superior to crystals grown in the best Earth-based laboratories. Larson found that dislocation densities, a particular kind of defect important in determining the electronic properties of the crystals, were 50 times lower than the best commercially available crystals and 10 times lower than the best crystals grown in research laboratories. Dr. Larson used space flight to verify his mathematical models for semiconductor crystal growth, which researchers can now apply to improve crystal fabrication on the Earth. CdZnTe is a commercially significant member of the family of semiconductors that are used in the fabrication of high-tech infrared cameras and detectors, as well as other radiation detectors, for numerous commercial, industrial, and Earth observation applications.

Dr. Martin Glicksman of the Rensselaer Polytechnic Institute continued his study of the dynamics of dendrite formation with the second flight of the Isothermal Dendritic Growth Experiment on the USMP-3 mission in February 1996. Dendritic growth is a phenomenon occurring in virtually every industrially important solidification process and is primarily responsible for determining the ultimate properties of metals and alloys as they solidify. Such properties include hardness, toughness, and corrosion resistance. Dr. Glicksman used his dendritic growth data from space to test competing theories of solidification.

A 3-year collaborative effort by NASA, industry, and university researchers resulted in the development of an instrument that can produce the world's most intense source of x rays from commercial generators. Researchers at NASA used the newly developed x-ray instrument to determine the atomic structure of important proteins that are the targets for drug design. Researchers hoped that this new x-ray technology will significantly accelerate the ability of researchers to gather the information necessary to design entire families of highly effective disease-fighting drugs.

NASA and the National Eye Institute began developing a prototype laser light-scattering instrument for the early detection of cataracts. Originally developed for microgravity research, the instrument has proven valuable for measuring the size distribution of a protein in the eye that is related to the early developmental stages of cataracts. The instrument is about the size of a pencil and works by shining a laser into the eye and analyzing the pattern of light scatter that results. The American Academy of Ophthalmology selected NASA's instrument as one of the technologies that will change ophthalmic and medical care into the 21st century.

Space Shuttle Technology

In 1992, NASA established the NASA Operational Environment Team to coordinate the search for technologies to replace environmentally offensive materials and processes. In addition, the Shuttle program has established the Shuttle Replacement Technology Team to carefully examine the specific environmental challenges that are unique to Shuttle elements. These groups have been highly successful in identifying and replacing the offending materials. NASA and the affected Shuttle prime contractors continued to replace ozone-depleting chemicals (ODC's) and hazardous air pollutants in Space Shuttle manufacturing operations. Results of a NASA-wide survey indicated that ODC usage has decreased drastically throughout NASA's operations. NASA reduced its consumption of ODC's from approximately 3 million pounds in 1990 to 1.7 million pounds in 1994, and this favorable trend has continued through 1996.

A cooperative research and development effort between NASA and Lockheed Martin has resulted in a usage reduction of trichloroethylene (TCE). TCE is a hazardous air pollutant that technicians traditionally used in large quantities during the cleaning and verification of the Shuttle's External Tank. Historically, technicians needed 10,000 gallons of TCE to clean each flight tank. At the end of FY 1996, they used only 5 gallons of TCE per tank.

Engineers are continuing to develop plans and have begun some of the Shuttle fleet and facility upgrades that will provide safe and cost-effective operations well into the 21st century. The strategy for the upgrades will be a four-phase approach: safety and performance enhancement, systems reliability, advanced technology upgrades, and cost reductions. Phase I addresses safety and performance enhancement upgrades that are currently approved and under way, such as the fuel pump for the main engines and the super lightweight external tank.

Space Shuttle Main Engine project managers successfully delivered the last three Block I engines in FY 1996. Project managers and engineers then turned their collective attention to the development activities required to implement a Block II engine. The Block II consists of the Block I safety and reliability improvements (a new phase II powerhead, a single coil heat exchanger, and an alternate high-pressure oxidizer turbopump), as well as an alternate high-pressure fuel turbopump and a large throat main combustion chamber. During FY 1996, managers emphasized the development testing of the new Block II components. This testing resulted in a total of 23,061 test seconds on the alternate high-pressure fuel pump. As a result of these tests, engineers identified design deficiencies in the turbine section of the pump and completed design fixes for these deficiencies. At the end of FY 1996, technicians delivered the first test pump to NASA's Stennis Space Center to resume testing.

A new "environmentally friendly" spray on insulation was flown on the Solid Rocket Booster for the first time in FY 1996. This NASA-developed material, which protects the booster structure from aerodynamic heating during flight, is much easier to process and nearly eliminates the use of ODC's during mixing and spraying. The private sector has sought out this technology for diverse applications such as roof coatings and roadway repair.

The booster assembly contract underwent a major restructuring during FY 1996. The existing contract, slated to expire in early 1997, was extended through FY 1999 and modified to include significant performance incentives and cost reductions. As part of this restructuring, the contractor, USBI Company, began consolidating its workforce to NASA's Kennedy Space Center from several locations across the southeastern United States.

Engineers made significant progress during FY 1996 in the design and certification of the new super lightweight external fuel tank. Project personnel scheduled the first launch of the redesigned tank for late in calendar year 1997. The super lightweight tank is constructed of aluminum lithium, which is a lighter, stronger material than the metal alloy currently used in the production of the Shuttle's external tank. NASA was the first to use this new alloy in a major development program. NASA's Marshall Space Flight Center and its contractors worked jointly to develop this alloy for the special applications required in the design of the super lightweight tank. The new external tank is the same size as the current one but is 7,500 pounds lighter. This lighter weight means that programs will benefit from the Shuttle's ability to carry an additional 7,500 pounds of payload per flight.

A major component of the super lightweight tank verification program, the Aluminum Lithium Test Article, successfully completed all its certification tests on September 5, 1996. Engineers designed the tests to prove the tank's ability to withstand loads greater than flight certification requirements. The successful tests represented a significant milestone for both the Shuttle and ISS programs. The lighter fuel tank will improve the Shuttle's capability to carry cargo to the high-inclination 51.6-degree orbit where the ISS is to be built.

With the production of this alloy and the development of manufacturing processes to machine, form, and weld the material, engineers and technicians significantly advanced the aluminum lithium metals technology associated with the super lightweight tank. Designers may use this information for future designs of weight-critical space vehicles.

In the area of Space Shuttle systems integration, the Day-of-Launch I-Load Update, Version 2 (DOLILU II) system was used for all FY 1996 launches. The DOLILU II system updates the flight trajectory to account for actual winds and atmospheric conditions on launch day. The system has eliminated significant amounts of flight-to-flight trajectory design and assessment activities and has increased system flexibility to adapt to mission requirement and launch date changes. FY 1996 accomplishments also included analyses of structural loads and aerodynamic heating; resolution of inflight anomalies, waivers, and changes; and software development and testing for the control of each mission.

In support of the ISS mission requirements, NASA continued to develop and schedule Shuttle performance enhancements. Engineers developed systems integration plans to ensure the orderly implementation of the enhancements into the Space Shuttle program. Engineers and technicians also developed plans for the phased implementation of the flight software performance enhancements, to provide flight data verification on the efficacy of the enhancements prior to their use on the launch of the first ISS assembly flight.

On the Multifunction Electronic Display System, technicians began work to replace the current Shuttle cockpit displays with an integrated liquid crystal display system. The objectives are to improve safety, reduce weight and power consumption, and reduce the aging and obsolescence problems currently being experienced.

The first test flight of GPS on STS-79 was a success. The need for the GPS on the Shuttle is driven by DoD's phaseout of the Tactical Air Navigation System. The GPS project is a two-phased approach to reduce program cost, improve abort landing site availability, improve reliability, and save weight and power.

DoS supported the Shuttle program by providing direct telecommunications links to U.S. embassies in countries with emergency landing facilities. This system became operational with the flight of STS-74 in November 1995.

Reusable Launch Vehicles

NASA continued the RLV technology development and demonstration program in FY 1996 in response to the National Space Transportation Policy of 1994. DoD worked with NASA on this program in such areas as flight testing, operations, and composite structures. NASA has structured the RLV program differently from previous similar programs, with new relationships between the U.S. Government and industry, a faster program pace, and a streamlined management structure.

In FY 1996, technicians successfully upgraded the DC-X (Delta Clipper–Experimental), which the Air Force had previously transferred to NASA, into the DC-XA (Delta Clipper–Experimental Advanced). Program personnel accomplished this in 11 months by integrating several advanced technologies, such as composite materials, into a vehicle designed to test the feasibility of a vertical landing liquid oxygen and hydrogen rocket operated with the same simplicity as conventional aircraft. The DC-XA, renamed the Clipper Graham in honor of Lieutenant General David Graham, completed four flight tests in the spring and summer of 1996, including a set of tests with only 25 hours between flights. Project personnel met all their goals, including demonstrating operability with small ground and flight crews of a vehicle incorporating advanced technologies. NASA terminated the project after the vehicle was destroyed in a landing accident unrelated to the demonstration of its advanced technologies.

NASA's partners revoked the original X-34 cooperative agreement after concluding that the program did not justify the level of their planned investment. Program managers released a NASA Research Announcement (NRA) on March 27, 1996, calling for a much smaller X-34 technology demonstrator filling the gap between the subsonic Clipper Graham in the summer of 1996 and the Mach 15 X-33 in the spring of 1999. NASA managers identified new goals, including Mach 8 velocity, first flight in the third quarter of calendar year 1998, 25 flights in 1 year, less than $500,000 average per flight cost, autonomous landing, subsonic flight through rain, and landing in 20-knot crosswinds. NASA awarded a contract to Orbital Sciences Corporation on August 28, 1996, based on an air-launched concept incorporating many advanced technologies, including composite primary and secondary airframe structures, composite fuel tank, advanced thermal protection system and materials, low-cost avionics including differential GPS, integrated vehicle health monitoring, and a flush air data system.

NASA issued a Cooperative Agreement Notice (CAN) on April 1, 1996, for the design, fabrication, and flight test of the suborbital X-33 vehicle. NASA, with the assistance of DoD, DoC, and DoT, evaluated the three competing industry proposals using a fast-track process. Setting a new procurement standard, the industry teams submitted their proposals in CD–ROM format, and the evaluation process, involving 100 experts from across Government as well as outside consultants, was carried out in an electronic, totally paperless manner. A final nonadvocate review of the X-33 program was conducted in May and the results presented to the NASA Program Management Council in June. NASA's Administrator, Daniel S. Goldin, certified that the criteria for moving into the next phase of the X-33 program had all been satisfied. On July 2, 1996, Vice President Albert A. Gore, Jr., announced that Lockheed Martin had been selected as the X-33 industry team. Their concept is a vertical-takeoff, horizontal-landing lifting body that features a linear aerospike engine, metallic thermal-protection system, a composite primary structure and fuel tank, and many other advanced technologies.

RLV program managers have committed themselves to developing new operations and component technologies, as well as to producing an industry-Government relationship that will revolutionize the space launch industry worldwide. If successful, the RLV program will deliver "leapfrog" technology that will permit the

United States to regain worldwide leadership in low-cost space launch operations.

In accordance with the National Space Transportation Policy, DoD continued to support the NASA-led RLV development and technology demonstration program through cooperative and synergistic technology development. This has been primarily funded through congressional additions to the Air Force budget request.

The FAA's Office of Commercial Space Transportation participated on the source evaluation board and the nonadvocate review team of NASA's X-33 reusable vehicle program, with particular interest in the economic feasibility of a commercial follow-on to the X-33 vehicle and in the licensing of a such a vehicle. The FAA also provided input to the source selection official on the X-33. Toward the end of the fiscal year, the FAA received the first launch license application from Kistler Aerospace Corporation for initial flights of an RLV. The proposed test operations would take place at DoE's Nevada Test Site.

International Space Station

For the third consecutive year, the ISS program remained within budgetary guidelines and on schedule for the first element launch in November 1997. ISS made significant progress in many technical areas. Technicians began qualification and development testing on a major scale and also completed the fabrication of several flight components. Program personnel delivered software and coordinated the timely delivery of components and modules to the Kennedy Space Center for processing and integration with the Space Shuttle.

Three successful Shuttle-*Mir* space missions in FY 1996 highlighted Phase I of the program, the joint U.S.-Russian effort to expand cooperation in human space flight. The successful integration of two major space programs—separated not only by language differences, but by differences in hardware design, operational procedures, and philosophy, as well as differences in engineering and developmental approaches—has continued on track.

As part of Phase I preparations for ISS, Dr. Shannon Lucid conducted a record-breaking stay aboard *Mir* during FY 1996. On March 22, 1996, Dr. Lucid was launched to *Mir* aboard the Shuttle *Atlantis*, and she returned aboard *Atlantis* 188 days later on September 26, 1996, setting records for the longest stay in space for an American astronaut and for a woman. Dr. Lucid also was the first astronaut delivered to *Mir* on a Space Shuttle, and the mission that retrieved her was the first Shuttle mission to change out crews on the *Mir*.

During her stay on *Mir*, Dr. Lucid and the two cosmonaut crewmembers conducted a wide range of research using both U.S. and Russian hardware. They conducted and participated in studies on human physiology, behavior and performance, and advanced life support. They also worked to characterize the air and microgravity environment aboard *Mir* and to gain insights into the research environment that will be provided by ISS. On April 23, 1996, the Russian Space Agency launched Priroda, a Russian-developed and U.S.-outfitted laboratory module, to the *Mir* space station. The module was equipped with more than 1,000 kilograms of equipment for Dr. Lucid's use and joined the Spektr module already on orbit. Astronaut John Blaha replaced Dr. Lucid on *Mir* and continued more than 100 life and microgravity sciences investigations.

As FY 1996 closed, less than 1 year remained until hardware for the first assembly flight of ISS needed to be shipped to KSC. Technicians structurally completed Node 1, the mating adapters, and stowage rack hardware before beginning to outfit and test this equipment. After the installation of the strengthening struts, the node passed pressure test requirements in August 1996.

NASA passed the 45-percent completion mark of scheduled work in FY 1996, having built more than 132,000 pounds of hardware in the process. NASA implemented new processes to respond to technical concerns arising through an ongoing series of internal and external independent reviews.

Regarding international activities, negotiators agreed to significant changes in the historic U.S. and Russian cooperative space plans at the Joint Commission on Economic and Technological Cooperation (commonly referred to as the Gore-Chernomyrdin Commission) in July 1996. Key elements of the revised plan call for two additional Phase I flights to *Mir* and helping the Russians overcome a *Mir* logistics shortfall in 1998. ISS officials agreed to launch the Russian Solar

Power Platform, which performs critical power and control functions, aboard the Space Shuttle, reducing the number of Russian launches required for assembly and increasing overall launch confidence.

Energy

In FY 1996, DoE continued its work in the fabrication of three general purpose heat source radioisotope thermoelectric generators (GPHS-RTG's) and 157 lightweight radioisotope heater units (LWRHU's) required for NASA's Cassini mission to Saturn. RTG's directly convert heat from the decay of the radioisotope Plutonium-238 (Pu-238) into electricity without any moving parts. They have been employed successfully on more than 20 spacecraft of long-duration missions. Technicians completed the assembly of the heat source for each of the Cassini spacecraft RTG's and installed the heat sources into the thermoelectric converters. The prime system contractor completed fabrication and acceptance testing of the second and third thermoelectric converters. In FY 1996, technicians also developed a new RTG transportation system for shipping the Cassini RTG's. Workers also finished fabricating the 157 LWRHU's and then stored them, pending final shipment to KSC. Finally, DoE continued to support NASA in developing environmental documentation and performing safety testing for the safety analysis reports required for the Cassini launch approval process.

DoE delivered three LWRHU's to KSC for the Mars Pathfinder spacecraft, which was launched in December 1996. Technicians took the LWRHU's from spares remaining from NASA's Galileo mission. In FY 1996, DoE completed a final safety review on the LWRHU's for the Mars Pathfinder mission.

For NASA's Pluto Express mission, DoE continued its studies of advanced converter technologies to provide high efficiency and lightweight power sources. DoE personnel continued technology development work to investigate and demonstrate the viability of advanced power converters using thermophotovoltaic, alkaline metal, and Stirling engine technologies in FY 1996.

Safety and Mission Assurance

In FY 1996, NASA safely and successfully completed eight Space Shuttle flights and six spacecraft launches. NASA certified for use an automated Space Shuttle orbiter window defect analyzer that will reduce costs and improve inspection confidence. In addition, NASA reduced safety and mission assurance (S&MA) costs for Space Shuttle ground processing through new and improved data collection techniques. Through the ISS independent assessment process, NASA developed an independent critical risk assessment matrix. NASA also conducted probabilistic risk assessment studies for the Soyuz Crew Escape Vehicle and ISS, field center S&MA self-assessments, several hazardous facility assessments, the Mars Pathfinder Safety Evaluation Report, and an independent assessment of initial program risk management processes for the X-33.

NASA formed a safety assurance board in June 1996 for the Human Exploration and Development of Space (HEDS) Enterprise. The Associate Administrator for Safety and Mission Assurance leads this group, which consists of top-level S&MA managers from the HEDS field centers and the Shuttle and ISS programs. The HEDS Assurance Board began meeting monthly to help resolve safety concerns on human space flight missions, with emphasis on the transition to the consolidated space flight operations contract.

In FY 1996, NASA set standards for orbital debris damage risk reduction, as well as oxygen and hydrogen safety. NASA also completed a joint test program with the Japanese National Space Development Agency (NASDA) on liquid oxygen and hydrogen explosion safety distances. NASA adopted International Organization for Standardization (ISO)-9000 as its standard for quality management, developed plans for ISO-9000 implementation, and provided training to relevant personnel. NASA developed and piloted training courses for certified quality engineer, certified reliability engineer, and certified quality technician. To capitalize on the economy of computer-based training, NASA developed 19 computer-based courses in S&MA disciplines, including nondestructive evaluation, contractor oversight, and performance-based contracting.

NASA continued to improve the effectiveness and efficiency of its mission assurance practices and tools.

Specifically, engineers tailored product and mission assurance requirements for the Mars Pathfinder and Mars Rover programs, and they successfully implemented risk management approaches early in the life cycle for the New Millennium program, Deep Space 1. In addition, NASA completed an integrated, multicenter mission assurance program for the Office of Aeronautics' High Speed Research program and initiated activities to develop a quality assurance program for the Advanced Subsonics Technology program. NASA's Flight Performance program provided spacecraft projects with on-orbit flight performance results correlated against the design, development, and mission assurance process to serve as guidance for future projects. Additional advances made by NASA to improve mission assurance capabilities included nondestructive evaluation techniques for screening advanced turbopump silicon nitride ball bearings, composite pressure vessel certification and acceptance testing, and composite debond detection. Also, NASA instituted a pooled process for calibrating equipment at all its field centers and provided a user-friendly "lessons learned" data base via the World Wide Web.

Staff at NASA's Independent Verification and Validation Facility in Fairmont, West Virginia, conducted software assurance activities for the Cassini, ISS, and Shuttle programs. They developed and piloted a formal methods approach that verified complete software assurance requirements for Cassini; baselined a quantitative software methods and measurements guidebook for the Shuttle and the Space Operations Management Office; and applied software domain reuse principles to wind tunnel control systems. NASA's software assurance experts produced a software safety guidebook and continued to develop approaches for the assurance of complex software systems.

Commercial Development and Regulation of Space

In FY 1996, DoT's Office of Commercial Space Transportation became part of the FAA. The new FAA Associate Administrator for Commercial Space Transportation (AST) reorganized this office to accomplish its mission more efficiently. The most notable changes were the establishment of a Chief of Regulations position and the reorganization of the two divisions, the Space Systems Development Division and the Licensing and Safety Division.

U.S. launch operators conducted 13 licensed commercial launches during the fiscal year, one more than during the previous year and more than in any year since commercial launching began in this country in 1989. The FAA, which now has responsibility for overseeing this industry, particularly with regard to safety, licensed all of these launches. Also during FY 1996, the FAA issued four new launch licenses and four amendments to existing licenses. In support of these and other active licenses, the agency conducted 11 maximum probable loss analyses in support of financial responsibility determinations required by statute.

In its role as the regulator of commercial launch facilities, the FAA granted its first license to Space Systems International for the operation of a commercial launch site at Vandenberg Air Force Base. Additional launch site facilities are being planned or under development in Alaska, Florida, and Virginia.

In April 1996, the AST held a public meeting to discuss certification standards for new launch vehicles, financial responsibility for joint ventures, domestic and international use of commercial spaceports, and orbital debris. The AST collected comments made at the public meeting, which then formed the basis of new initiatives in financial responsibility.

The FAA followed up by releasing a significant notice of proposed rulemaking addressing financial responsibility requirements for launches from Federal ranges. This notice was published July 26, 1996, and allowed for the submission of comments by September 23, 1996. (The comment period was extended for an additional 60 days.) The FAA also performed preliminary work on two other notices dealing with licensing requirements for launches from Federal ranges and with licensing of non-Federal launch sites.

The FAA and DoD cochaired an interagency working group to develop guidelines for Federal interaction with commercial spaceports. DoC and DoS supported the efforts of this working group. In addition to giving advice on spaceports, the FAA's Commercial Space Transportation Advisory Committee provided widely used market forecasts and advice on space launch and satellite policy issues.

The office of the U.S. Trade Representative (USTR) led interagency delegations during negotiations and consultations with China, Russia, and Ukraine on their respective bilateral commercial space launch agreements. The interagency delegations consisted of representatives from DoC's Office of Air and Space Commercialization (OASC) and the International Trade Administration's Office of Aerospace (OA), in addition to the FAA/AST and DoS. A launch agreement signed between the United States and Ukraine in December 1995 will allow Ukraine, on its own and in partnership with a U.S.-led joint venture, to enter the international space launch market. Negotiators worked out quantitative limits and pricing guidelines to ease Ukraine's entry into the market. Launch prices offered by the U.S. Government must be "comparable" to those offered by market economy providers for comparable services. The agreement will allow Ukraine a minimum of 16 launches to geosynchronous Earth orbit (GEO), including 11 set aside for a U.S.-Ukrainian joint venture.

In January 1996, the United States and Russia signed an agreement amending the September 1993 Commercial Space Launch Agreement. The new agreement provides for up to 20 GEO launches, plus the potential for 4 additional launches. Terms for pricing comparability are similar to those under the Ukraine accord.

During July 1996, OASC, OA, the FAA/AST, and DoS supported USTR in the first annual consultations held under the 1995 bilateral commercial space launch trade agreement with the Chinese government. The U.S. and Chinese delegations discussed market development for commercial launch services to GEO and low-Earth orbit (LEO), the role of Chinese launch vehicles in international commercial launch service competitions, and pricing comparability factors involving LEO.

Through the U.S.-Russia Business Development Committee, part of the Gore-Chernomyrdin Commission meetings held in January 1996, DoC Ombudsman Jan Kalicki and Russian Space Agency Director General Yuri Koptev held discussions to improve business relations in the commercial space arena. Negotiators resolved a number of specific export licensing and international coordination issues.

OA participated in discussions with the European Union to ensure continued compliance with a 1992 agreement on trade in large civil aircraft. Similarly, OA personnel met with a World Trade Organization subgroup, the General Agreement on Tariffs and Trade (GATT) Aircraft Committee, to discuss international subsidies with U.S. trading partners.

OA personnel also met with their Russian and Ukrainian counterparts to encourage their countries to sign the GATT Agreement on Trade in Civil Aircraft as a part of the World Trade Organization's accession process. OA has been encouraging as many countries as possible to follow this accession plan.

OA represented DoC in the Interagency Group on International Aviation and at the White House to formulate a response to the International Civil Aviation Organization (ICAO) motion proposing a more stringent level of nitrous oxide emissions from airliners in international air service. DoC's position, supporting that of the FAA and DoT, to oppose such an increase became part of the formal U.S. position at ICAO.

In trade promotion, OA personnel led several meetings with the U.S.-Russia Business Development Committee Aerospace Subgroup to implement current understandings on import tariff waivers and to explore additional avenues of cooperation. A similarly composed U.S.-China Joint Committee on Commerce and Trade Aviation and Airport Infrastructure Sub-Group met to promote intergovernmental cooperation and expanded trade in civil aviation and airports.

OA personnel led an executive trade mission to Turkey and Egypt. Additionally, OA sponsored aerospace product literature centers at nine international aerospace exhibitions and air shows in Dubai, China, Malaysia, Singapore, India, South Africa, Germany, Indonesia, and the United Kingdom. OA worked closely with overseas posts to maximize the exposure of small and medium U.S. companies to the export market at these events.

As a result of the Administration's new GPS Policy, OASC supported DoS in consultations with the government of Japan in August 1996. The United States and Japan are the two major users of GPS. The meeting was the first in a series of consultations with the Japanese to discuss the feasibility of developing bilateral or multilateral guidelines with the provision and use of GPS services. OASC discussed the potential international GPS market and advocated the removal of potential nontariff trade barriers to maintain continuous growth in the GPS market. DoS planned to hold similar discussions with the European Community and Russia.

Surveillance

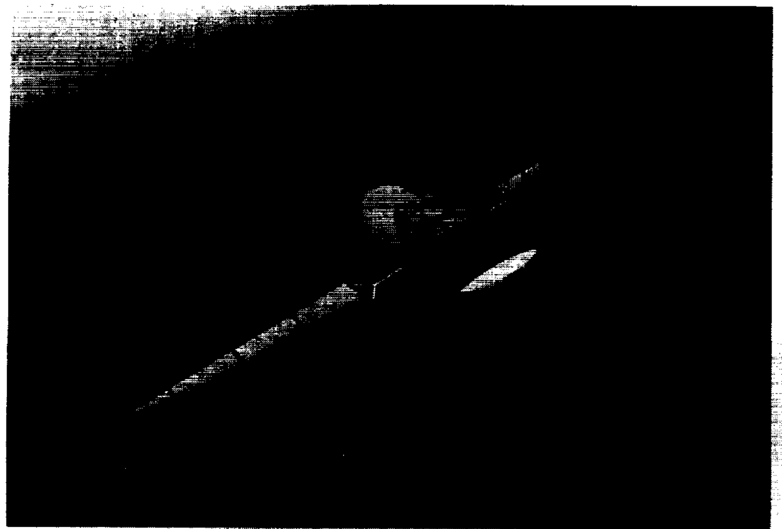
The Air Force's Defense Support Program continued to provide the front-line warning of missile attack to the National Command Authorities, but it also has grown to take on additional use for world leaders. The Theater Event System provided theater commanders with warnings of missile launches; it can be used for civil defense warning, missile engagement, and launch site attack operations. In April 1996, the United States began providing launch warnings to the governments of NATO member countries and to Japan.

DoD proceeded with the development of a new constellation of infrared detection satellites for use in GEO, LEO, and highly elliptical orbits. This program is a follow-on to the Defense Support Program and supports the missile warning, missile defense, and technical intelligence and battlespace characterization effort.

At the Naval Center for Space Technology, part of the Naval Research Laboratory (NRL), scientists and engineers designed and built the Tether Physics and Survivability (TiPS) experiment. Sponsored in part by the National Reconnaissance Office, this small satellite is intended for research in gravity-gradient dynamics to understand the way natural forces hold satellites in quiescently stable orbits. In addition, this experiment is to provide information on the survivability of tethered systems in LEO. In June 1996, DoD deployed TiPS with its small end masses connected by a 4-kilometer nonconductive braided tether. In a cooperative effort, NRL, NASA, and an international network of satellite laser ranging stations began tracking the end masses to gather this information.

The Miniature Sensor Technology Integration (MSTI) program, run by the Air Force, launched its third and most advanced satellite, MSTI-3, on May 17, 1996, from Edwards Air Force Base, California, aboard a Pegasus launch vehicle. Scientists and technicians at the Phillips Laboratory and Edwards Air Force Base integrated MSTI-3. The spacecraft carried a payload of three sensors: a medium-wave infrared camera, a short-wave infrared camera, and a visible imaging spectrometer. Its 1-year primary mission is to gather infrared data to resolve whether tracking theater ballistic missiles in the coast phase against a warm Earth background is feasible.

The Ballistic Missile Defense Organization launched its Midcourse Space Experiment (MSX) in April 1996. In August 1996, it successfully accomplished its first dedicated ballistic missile flight. MSX is the first system demonstration in space of technology to characterize ballistic missile signatures during the "midcourse" flight phase between booster burnout and missile reentry. Engineers designed MSX to gather data for future space- and ground-based missile defense systems. Specifically, they designed this first test to perform functional demonstrations and collect radiometric signature measurements of ballistic trajectory targets.



The first INMARSAT-3 communications satellite was launched on April 3, 1996.

SPACE COMMUNICATIONS

During FY 1996, NASA established bilateral interagency tracking, communications, and operations panels (ITCOP's) with other international space agencies. The ITCOP's promote the cost-effective use and exchange of NASA and other space agency assets, resources, and capabilities necessary to the success of space flight missions being carried out by either agency. This past year, NASA built on the success of the previously established ITCOP's with ESA and NASDA and established new panels with the Russian, French, and German space agencies.

In April 1996, a tri-agency team representing NASA, DoD, and NOAA completed a study chartered by the Aeronautics and Astronautics Coordinating Board to examine the potential for increased cooperation among the three agencies. One of the integrated product teams (IPT's) established under this charter addressed the subject of satellite telemetry, tracking, and commanding. Aside from recommendations to modify NOAA's Alaskan ground station for DoD compatibility and consolidate some control center activities, the IPT stressed the need for consolidation and standardization. The IPT offered several initiatives, including the joint development of a space-qualified GPS receiver, increased reliance on commercial standards, and coordinated interagency use of the radio frequency spectrum. A multi-agency architecture development team, led by the DoD Space Architect, began making use of the IPT study results, incorporating them into the broad assessment of long-term alternatives of satellite operations and control capabilities. Another IPT that dealt with space communications was the Space Launch Activities IPT. It also recommended consolidation and standardization among launch ranges and supporting stations, and it recommended increased usage of TDRSS and GPS to reduce costs. In a related development, TDRSS began providing launch support services to DoD's Titan Centaur launches.

The Space Communications Advanced Development Program accomplished several enhancements of telecommunications services. Specifically, program personnel successfully demonstrated the first two-way optical communications between a satellite in geosynchronous orbit and a ground-based terminal. This offered a significantly faster transfer of data from the spacecraft to the researcher than previous methods.

Engineers also modified spacecraft and ground systems to operate at very high frequencies to avoid interference and overcrowding in the lower bands. In addition, NASA personnel successfully demonstrated new encoding techniques, which almost doubled the error-free communications transmission rate.

Communications Satellites

On March 29, 1996, President Bill Clinton announced a comprehensive national policy on the future and management of GPS, which was designed as a dual-use system to enhance the effectiveness of U.S. and allied military forces. The growing demand from military, civil, commercial, and scientific users has generated a U.S. commercial GPS equipment and service industry that leads the world. Under the policy, the Government formed a GPS Executive Committee, chaired by the Secretaries of Defense and Transportation, to consult with Federal agencies, international entities, and U.S. industry on GPS operations.

During FY 1996, the Federal Communications Commission (FCC) coordinated and registered several launches of spacecraft for the International Telecommunications Satellite (INTELSAT) Organization, a consortium of more than 130 countries that own and operate the world's most extensive global communications satellite system. INTELSAT's attempted launch of its INTELSAT 708 failed on February 14, 1996, aboard a Long March launch vehicle in China. This was INTELSAT's first complete launch failure in 10 years. INTELSAT successfully launched its INTELSAT 707 spacecraft aboard an Ariane launch vehicle from Kourou, French Guiana, on March 14, 1996. INTELSAT also successfully launched its INTELSAT 709 spacecraft aboard an Ariane 44LP launch vehicle from Kourou on June 15, 1996. The launch of INTELSAT 709 brought INTELSAT's total on-orbit fleet to 25 satellites.

The FCC also authorized launches of global communications satellites by PanAmSat, the first private company to provide global satellite services. PanAmSat's PAS-3 satellite (designated PAS-3R by the FCC) was launched on January 12, 1996, aboard an Ariane 4 rocket and began broadcast and telecommunications services in February 1996.

The FCC authorized Comsat, the U.S. signatory to the International Mobile Satellite Organization (INMARSAT), to participate in the procurement and construction of five INMARSAT third-generation communications satellites (INMARSAT-3). These satellites will make it possible for INMARSAT to introduce smaller terminals for portable data and text messaging. INMARSAT successfully launched its first INMARSAT-3 series satellite on April 3, 1996, aboard an Atlas launch vehicle from Cape Canaveral, Florida. This satellite was deployed in the Indian Ocean region. INMARSAT successfully launched its second INMARSAT-3 series satellite on September 6, 1996, aboard a Proton rocket from Baikonur, Kazakstan. This satellite is deployed in the Atlantic Ocean region.

The FCC authorized the construction, launch, and operation of numerous fixed-satellite service satellites during FY 1996. In October 1995 and April 1996, it authorized GE American Communications, Inc., to construct, launch, and operate two replacement satellites, GE-2 and GE-4. In May 1996, the FCC adopted the 1996 Orbital Assignment Plan and authorized the construction, launch, and operation of 11 new satellites. The FCC granted authority to the AT&T Corporation to construct, launch, and operate two hybrid satellites, TELSTAR 5 and 6, and to construct a ground spare. The FCC also authorized GE Americom to construct, launch, and operate two hybrid satellites, GE-3 and GE-5. The FCC further authorized Hughes Communications Galaxy, Inc., to construct, launch, and operate the Galaxy IX and Galaxy X satellites. Hughes successfully launched its Galaxy III and Galaxy IX domestic satellites on December 14, 1995, and May 23, 1996, respectively. The FCC's expansion rule authorized new entrants in the fixed-satellite service to construct, launch, and operate up to two new satellites. The FCC granted authority to Loral Space & Communications for two new hybrid satellites, Loral 1 and 2. EchoStar Satellite Corporation received conditional authorization for two new satellites, FSS-1 and FSS-2. Orion Network Systems, Inc., entered the domestic FSS field and received conditional authority to construct, launch, and operate one new Ku-band satellite, O-F4. The FCC authorized Starsys Global Positioning Corporation to construct, launch, and operate its nonvoice, nongeostationary mobile satellite service system.

In January 1996, the FCC released a regulation allowing all U.S. licensed satellites to provide U.S. domestic service and international service. The FCC also issued a second notice of proposed rulemaking in May 1996 to consider allowing foreign satellites into the U.S. domestic market.

As the principal advisor to the President, Vice President, and the Secretary of Commerce on telecommunications issues, NTIA undertook a number of policy initiatives involving satellites and other space-based telecommunications systems during FY 1996. For example, NTIA provided policy guidance to the potential restructuring of INMARSAT and INTELSAT during the year. NTIA represented Federal users of the radio frequency spectrum in various domestic and international regulatory forums, such as those sponsored by the International Telecommunication Union and the Radio Technical Commission on Aeronautics. In particular, NTIA played a key role in implementing the results of the World Radiocommunications Conference that took place during October and November 1995. NTIA began preparations for the World Radiocommunications Conference 1997, sponsored by the International Telecommunications Union, by working with other Federal agencies and the private sector to guide the development of consistent U.S. policies on issues such as space science and mobile satellite service allocations.

As designated by Congress, the President, and the Secretary of Commerce, NTIA continued to authorize and manage all Federal use of the electromagnetic spectrum. During FY 1996, NTIA authorized 24 future Federal satellites and space systems for frequency use. NTIA continued to chair an interagency committee that reviews domestic and foreign space systems to determine the possible impact and electromagnetic compatibility with Federal telecommunications networks. Through the administration of the communications spectrum for the Government (the FCC continued to regulate the spectrum for non-Government users), NTIA prevented the interference of commercial communications systems, such as communications satellites, from weather, scientific, and national security satellites. NTIA assisted the commercial sector in coordinating with Federal users of the radio frequency spectrum so that industry could make quick use of new frequency allocations.

In the military, space forces played a critical role as a force multiplier everywhere the United States employed its forces. In Bosnia, the military deployed space support teams to advise the task force commander on the effective use of space assets in conducting a variety of peacekeeping, peace enforcement, and humanitarian missions. Space systems directly supported exercises in Korea, Europe, the Pacific, Southwest Asia, and the United States. The first small tactical terminals, providing direct weather satellite imagery at the tactical level, were fielded in Korea and Bosnia in FY 1996. The timely receipt of high-resolution weather data addressed a shortfall noted in Operation Desert Storm and has enabled field commanders to use weather data to exploit U.S. technical advantages over an adversary.

To increase communications support for forces in Bosnia, DoD personnel repositioned several Defense Satellite Communications System (DSCS) satellites, optimizing the high-capacity communications services. To replace a failed single-channel transponder on the western Atlantic DSCS satellite (B-10), DoD launched a new DSCS. Technicians then moved the B-10 over the Indian Ocean region to replace the prime satellite that had a failing transponder. The satellite replaced by B-10 in the Indian Ocean then became a reserve satellite and supported U.S. DSCS requirements in Bosnia.

DoD used communications satellite capabilities to enhance force operations and training. The launch of the second Milstar satellite (DFS-2) occurred in November 1995, with the first cross-link testing in December 1995. DFS-2 began passing operational traffic in June 1996 to support Strategic, Joint Staff, and National Command Authority users. During FY 1996, the Milstar constellation supported five aircraft carriers and portions of their battle groups.

Space Network

NASA personnel activated the sixth Tracking and Data Relay Satellite (TDRS-6) C-band package prior to the 1996 Summer Olympics. Columbia Communications Corporation utilized this resource to provide commercial services for the Olympics. Under a partnership arrangement, the expansion of the C-band network will result in additional revenues for NASA.

NASA continued to make its TDRS spacecraft available to other Government agencies and industry for testing and demonstrating various new mobile communications technologies. At NASA's Goddard Space Flight Center, specialists began developing low-power, portable transmit/receive terminals that operate with the TDRS spacecraft. NASA's space network also supported industry testing of new phased-array antenna systems for future use on aircraft and small satellites. NASA personnel also initiated the development of a compact transponder suitable for use by new, small satellites. This endeavor will provide an engineering model and a small number of flight units for use by upcoming flight projects, thereby expanding TDRS use to a new class of missions.

TDRSS assumed responsibility for covering post-Burn-1 telemetry data acquisition for required and mandatory periods of Titan IV/Centaur and Atlas II/Centaur launches. TDRSS has reduced—and in most cases replaced—support provided by the Air Force's advanced range instrumentation aircraft for major phases of Titan IV/Centaur and Atlas II/Centaur missions. Previously, up to five aircraft were needed to support a launch.

TDRSS provided support for 25 NASA flight missions, including eight Space Shuttle missions. Utilizing the TDRS remote ground terminal in Australia, technicians supported Shuttle-*Mir* crews during rendezvous and docking operations. NASA personnel began work to establish a more robust, full-service remote terminal in the TDRS zone of exclusion.

In June 1996, technicians completed the modernization of the original ground terminal in White Sands, New Mexico. The White Sands complex now has dual operational ground terminals, eliminating the ground terminal as a single point of failure in space network operations, extending the useful life of partially failed TDRS spacecraft, and reducing the life cycle costs through operating efficiencies.

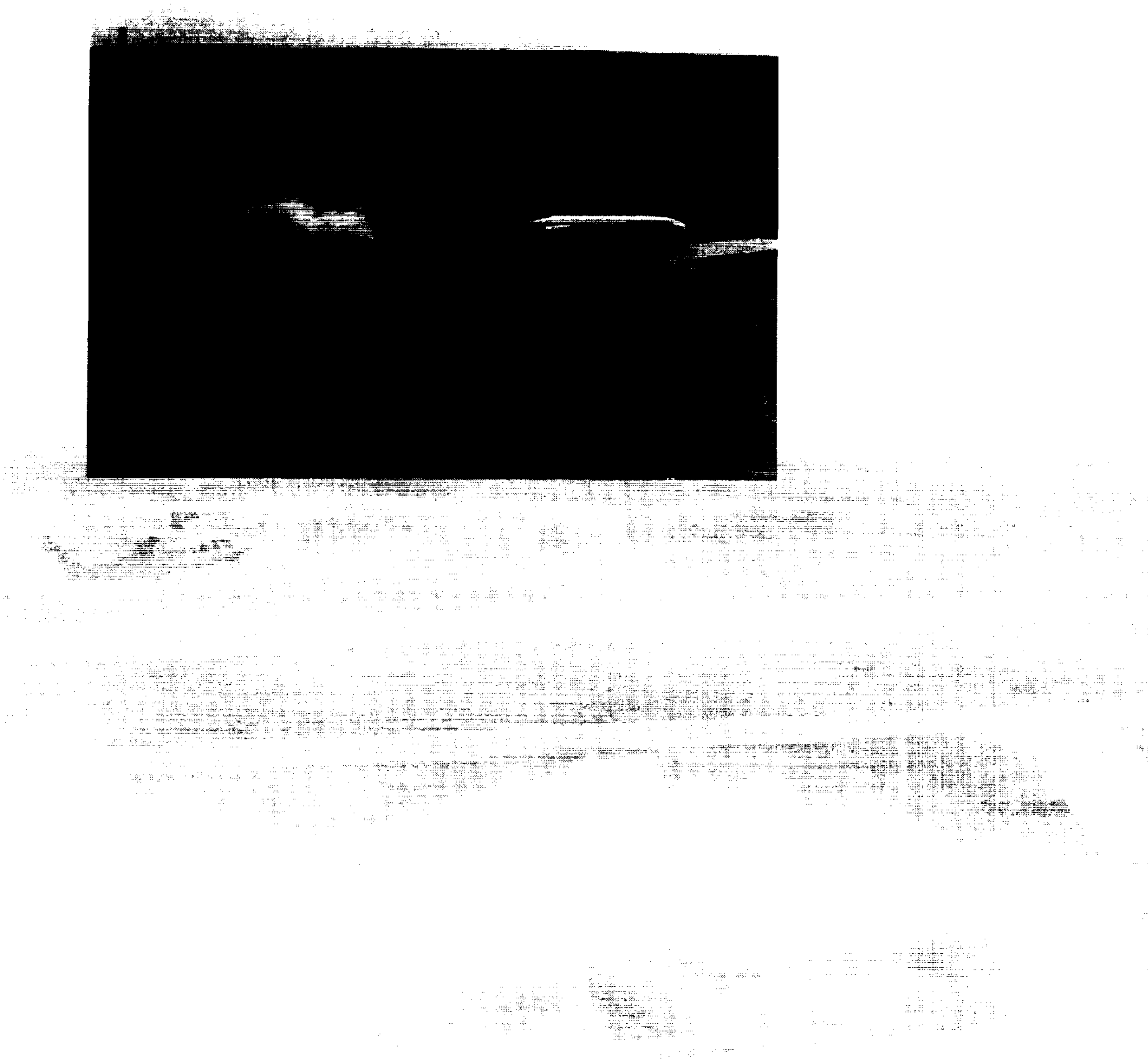
Ground Networks

NASA telecommunications specialists used ground-based facilities to provide telemetry, command, and navigation services to a number of NASA and international spacecraft, such as the Space Shuttle, Earth-orbiting spacecraft, planetary orbiters, and spacecraft on deep space missions, in addition to supporting suborbital sounding rocket and balloon flights. Accomplishments during FY 1996 included providing services to the Galileo spacecraft during its flybys of Jupiter and the Jovian moons, to the European Remote Sensing missions (ERS-1 and ERS-2), and to RADARSAT from new facilities in Antarctica, Virginia, and Alaska. Technicians also provided support to more than 75 other spacecraft missions and ELV launches, more than 1,000 aeronautical test flights, 28 sounding rocket launches, and 31 atmospheric balloon flights. NASA personnel made capacity and capability enhancements to the telecommunications facilities to ensure the fulfillment of NASA's science mission requirements, such as the electronic arraying of antennas to capture Galileo data.

NASA's development of a small, fully autonomous ground station for command and telemetry support of low-Earth-orbiting spacecraft provided a new low-cost paradigm for future LEO missions. Program personnel expected that a new microwave feed system would improve significantly the performance of the Deep Space Network (DSN) antennas, while reducing implementation and maintenance costs. This device provided the same benefit as almost doubling the size of each DSN antenna. Technicians implemented high-electron mobility transistor devices in the DSN's ground stations for use as low-noise amplifiers. These systems offer much lower implementation costs, while maintaining antenna performance in capturing very weak signals from space.

Mission Control and Data Systems

In FY 1996, five new spacecraft were launched, bringing NASA Mission Control and Data Systems' operational fleet to 15 spacecraft. Mission Control and Data Systems continued to provide the control and performance analysis of NASA's robotic Earth-orbiting spacecraft, the capture of the spacecraft data received on the ground, and the preparation of the data for scientific analysis. In FY 1996, Mission Control and Data Systems provided 45,000 hours of mission control services to the 15 on-orbit spacecraft and processed 15.5 trillion bits of received spacecraft data.



The May 1996 test of the soft ground arrestor system at the FAA's William J. Hughes Technical Center.

AERONAUTICAL ACTIVITIES

Technology Developments

NASA's Hypersonic Research program remained focused on developing the enabling technology for future aircraft and space access vehicles. In FY 1996, NASA initiated the Mach 5 to 10 Hyper-X program, which is to validate hypersonic analytical methods and wind tunnel tests with the flight of a 12-foot-long unmanned aircraft. The Hyper-X is to employ a dual-mode ramjet/scramjet hydrogen-fueled propulsion system and integrated airframe. Another key hypersonic hardware experiment was the U.S. flight test of a Russian scramjet engine designed by the Central Institute of Aviation Motors of Moscow. NASA researchers designed a flight experiment named PHYSX, which is to measure the boundary layer transition along the first stage wing of the Pegasus launch vehicle up to speeds of Mach 8. NASA, together with DoD and NSF, also funded a flight vehicle called LoFLYTE for the study of stability and control characteristics of waverider-designed aircraft.

NASA concluded its High Angle of Attack program in FY 1996. The program has focused on understanding the aerodynamics, control characteristics, and airflow phenomena associated with flight at very high angles of attack. The principal objectives of this program were the development of design data, methods, and guidelines and the associated reduction of technological risk to enable industry designers to employ new technologies that will allow future fighter aircraft to perform with much greater agility and air combat effectiveness. NASA researchers employed the full range of experimental and analytical techniques throughout the program to develop new control concepts for flight beyond the traditional angle of attack limits. As a result, the F-18 High Alpha Research Vehicle, which researchers used to flight-test these new concepts, reached a 70-degree angle of attack—far beyond the normal F-18 limits. This highly successful program concluded in September 1996 with a major technical conference in which program personnel presented important results, accomplishments, and conclusions. Industry personnel already have begun to employ the aircraft design knowledge and tools developed by NASA during the High Angle of Attack program in the development of the next generation of fighter aircraft.

In FY 1996, NASA's propulsion researchers focused on the critical technology needs that will provide improved understanding and predictive capability for propulsion components. Turbomachinery investigations concentrated on achieving improved levels of aerodynamic efficiency, improved cooling effectiveness, and enhanced operability. In order to minimize environmental impact, the smart green engine program has addressed challenging concepts such as reduced, but safe, engine operating margins. Combustor researchers aimed at reducing nitrous oxides, unburned hydrocarbons, carbon monoxide, and soot emissions. Hybrid hyperspeed propulsion systems researchers addressed critical technologies in the area of turboramjets. The high-temperature materials program focused on a multidisciplinary approach to demonstrate a small gas turbine combustor at 3,000° F with a minimally cooled liner. High-risk/high-payoff research began on the Numerical Propulsion System Simulator (NPSS). These researchers directed their efforts at improving the fundamental understanding of flow physics in inlets, nozzles, turbomachinery, and combustors. Engineers expected that the establishment of the NPSS, along with advances in single-discipline and multidisciplinary analysis, will provide faster and less expensive methods for conducting both component and engine analyses.

NASA and its industry partners continued to make progress in the High Speed Research (HSR) program. The objective of HSR is to reduce the risk of technology applications, enabling industry to develop an environmentally compatible and economically viable high-speed civil transport (HSCT) aircraft. During FY 1996, program personnel continued to develop advanced technologies essential for economic viability, reduced air and noise pollutants, weight reductions and long life in extreme temperatures, and safety and efficiency in the cockpit.

On the F-16 XL-2 program, researchers achieved all of their flight objectives in the area of supersonic laminar flow control. By achieving laminar flow over the speed range of Mach 1.7 to 2.0 and altitudes up to 55,000 feet, researchers demonstrated that wing suction at supersonic speeds can significantly reduce drag leading to HSCT gross takeoff weight. Engineers established suction requirements to maintain the laminar flow during the flights. While not incorporated in the Technology Concept Airplane baseline, the supersonic laminar flow control testing showed promise, and researchers retained it as an option should the technology be required in the future for the airplane to meet weight and range goals.

NASA personnel worked with their Russian counterparts to complete Tu-144 engine tests. The tests, conducted with the Tupolev Aircraft and Design Bureau at Zhukovsky Air Base near Moscow, measured the flow field between the inlet and the engine to provide data for validating design tools that would allow HSCT engines with a shortened inlet/engine/nacelle section to increase engine efficiency. Eight fast actuated doors (designed primarily for use as a control device for stabilizing supersonic inlets) around the periphery of the inlet acted as a source of internal airflow disturbances to provide the data necessary to validate boundary conditions used in computational fluid dynamics calculations. Researchers obtained high-quality, steady-state, and fluctuating pressure data, including measurements of the reflective characteristics of the engine face to incoming perturbations of pressure amplitude and frequency.

Recent small-scale tests on models of an HSCT engine nozzle design indicated that the design was within 2 decibels of the final noise goal and 99 percent of the final nozzle aerodynamic performance goal. This integrated noise/aerodynamic performance test was a crucial interim step in the development of HSR engine technology. Using the results of this experiment, vehicle integration results indicated a robust design space with the engine cycle and nozzle, resulting in a 3-percent reduction in vehicle weight.

Researchers tested the initial wind tunnel model of the Technology Concept Airplane, the HSR baseline configuration defined in December 1995, in the Langley Unitary Plan Wind Tunnel in July 1996. Experimental results confirmed the analytical supersonic optimized nonlinear aerodynamic design of the twist and camber of the double-delta wing. The nonlinear optimization of the total configuration will continue over the next 2 years, leading to a projected 15-percent improvement over linear optimization methods.

Researchers continued to make advances in materials and structural concepts to meet the requirements of light weight and long life in the extreme temperatures of the HSCT environment. During FY 1996, NASA managers selected both metallic and composite materials and structural concepts, moving toward the September 1998 preliminary design review of the final configurations for the large-scale technology validation tests of wing and fuselage components. Engineers and technicians at NASA's Langley Research Center scaled up the best candidate high-temperature composite material, PETI-5, from test-tube-size quantities to 1,000-pound quantities for use in element and subcomponent testing to support the preliminary design review.

Researchers at NASA's Ames, Dryden, Langley, and Lewis Research Centers made important contributions to the advanced technology of the new Boeing 777 aircraft. Boeing directly reimbursed NASA for wind tunnel testing at Langley and also built on Langley's work on reduced engine noise, mathematical procedures for computer-generated airflow images, and radial tire testing. Langley personnel also did significant research that led to the 777's advanced cockpit, digital data system, "fly-by-wire" system, and lightweight composite materials.

Also in the area of digital systems validation, the FAA and Boeing began assessing the structural coverage requirements outlined in a Radio Technical Commission on Aeronautics document, "Software Considerations in Airborne Systems and Equipment Certification." Industry indicated that some of the tests required by that document are repetitive and very expensive and do not find additional software errors over previously required verification tests. In addition, the FAA began working with industry to develop a minimum operational performance standard for an avionics computer resource. The goal of the project is to apply formal methods to the design of such an avionics resource that can provide protection between various applications with a sharing of resources.

Based on two ground-based simulation tests at the Vertical Motion Simulator at Ames Research Center and one test using the Calspan Total In Flight Simulation aircraft, NASA managers selected a baseline longitudinal control response type in July 1996. The control response type determines the long-term behavior of the airplane to pilot inputs and can affect pilot workload, actuator rate requirements, windshear penetration, pilot-induced oscillation susceptibility, and touchdown performance in landing. Researchers compared control response types in takeoff, approach, and landing tasks. Pilots from Ames, Boeing, Calspan, Langley, and McDonnell Douglas participated, completing more than 600 test runs.

The primary role of NASA's High Performance Computing and Communications (HPCC) program in the Federal HPCC program includes leading the development of applications software and algorithms for scalable parallel computing systems that will increase system performance to the sustained teraFLOPS (10^{12} floating point operations per second) level for NASA applications. NASA also continued to develop and evaluate high-performance computing, communications, and information technologies, and transferred these technologies into use for national needs. As researchers develop HPCC technologies, NASA has used these technologies to solve its "Grand Challenge" research problems. These are fundamental problems whose solutions require significant increases in computational power and are critical to meeting national needs. NASA's "Grand Challenges" include improving the design and simulation of advanced aerospace vehicles, enabling people at remote locations to communicate more effectively and share information, increasing scientists' abilities to model the Earth's climate and to forecast global environmental trends, and improving the capabilities of advanced spacecraft to explore the Earth and solar system.

The Information Infrastructure Technology and Applications (IITA) component of the HPCC program broadened the public outreach of the overall program and furthered the development of a Global Information Infrastructure (GII) by supporting research and development in education, digital library technology, and access to Earth and space science data. The IITA efforts consisted of critical information technologies and the application of these technologies to "National Challenges," in which the application of HPCC technology can provide major benefits to all Americans. IITA managers developed a technology base underlying a universally accessible GII and demonstrated substantial pilot programs. NASA's IITA K–12 effort has reached more than 650 schools in 48 states, providing teacher training; aeronautics, space, and Earth science curricula; Internet support; presentations at education conferences; and tests of low-cost networking technology in schools. IITA accomplishments during FY 1996 included the development and use of new and innovative technologies to support digital libraries, such as those being developed by NASA, the Library of Congress, and other Federal and local agencies, and the availability of new remote-sensing data bases for agricultural, urban, and disaster relief planners.

The Earth and Space Science component of HPCC completed the award of a new 384-processor Cray T3E testbed at NASA's Goddard Space Flight Center. Targeted as primary users of the testbed, nine research projects were awarded, encompassing 86 researchers at 22 U.S. universities and six Federal laboratories. Collectively, these awards are to develop improved methods of modeling changes in global climate and the Earth's surface, to simulate the evolution and dynamics of stars, to probe microgravity environments, and to process remote-sensing imagery and signals. As a broader benefit, the new computer programs and documentation are to be made available to the research community on the "National HPCC Software Exchange" via the Internet.

NASA personnel began work on the Remote Exploration and Experimentation component of HPCC in FY 1996. This component is to provide low-powered, high-performance computation capabilities onboard our Nation's spacecraft. It began conducting study contracts with industry and academia to establish the requirements, identify candidate designs and architectures, and qualify potential methodologies.

The Computational AeroSciences component of HPCC improved the design and simulation of aerospace vehicles at significantly reduced cost; developed the NPSS, whose goal is to perform 1-day-turnaround design simulations of full turbomachinery engines; developed the HSCT analysis and optimization codes to perform medium-fidelity HSCT modeling and to demonstrate accelerated aerospace design techniques; and demonstrated advanced coupling of fluid dynamics simulation and structural simulation at gigaFLOP speeds. To better address critical industry-defined needs in the area of distributed computing, NASA awarded a cooperative agreement for clustered workstation applications to an industrial/academic team led by Pratt & Whitney. This consortium has been effective in developing specialized techniques and has demonstrated the routine management of hundreds of workstations. In support of the National Research and Education Network, NASA tripled its previous capability by connecting five of its research centers through a high-speed, 155-megabits-per-second asynchronous transfer mode (ATM) network. Researchers began to use this network to explore the management of geographically dispersed supercomputers at lowered costs. FY 1996 Computational AeroSciences program accomplishments included demonstrating interoperability between independently managed networks based on ATM technology supplied by multiple vendors, demonstrating portability and scalability of software component tools to teraFLOP systems, and demonstrating multidisciplinary aeroscience applications on 10 to 50 gigaFLOP testbeds.

The Numerical Aeronautics Simulation program and facility at NASA's Ames Research Center continued its improvements during FY 1996 in support of the advanced research requirements in the aeronautics community. These requirements lead to the program's goal to provide the Nation's aerospace research and development community by the year 2000 with a high-performance, operational computing system capable of simulating an entire aerospace vehicle system within a computing time ranging from 1 to several hours. Many aerospace industry leaders have already attributed major cost savings to breakthroughs in the Numerical Aeronautics Simulation facilities, which many specialists consider to be the Nation's model for future high-performance computer centers. The Numerical Aeronautics Simulation program has led the efforts to accomplish many new visualization breakthroughs, but one of the more important accomplishments was the installation of the new Portable Batch System that permits a researcher's computer code to be transported from one high-performance computing platform to another without modification.

During FY 1996, the FAA and NASA began an assessment of the Joint Subsonic Jet Noise Reduction Research program to reduce engine noise levels of future subsonic airplanes by 3 to 5 decibels. Specifically, a new jet engine exhaust mixer system developed by NASA provided a 2- to 3-decibel reduction in effective perceived noise levels—when applied to future engine designs, this will substantially reduce jet noise near airports. The two agencies also prepared a joint assessment of current noise reduction technology for propeller-driven airplanes and rotorcraft. In the area of engine emissions, the FAA participated with NASA on the Atmospheric Effects of Aviation project to develop a scientific basis for the assessment of the impact of aircraft emissions on the environment, particularly on the ozone layer and global climate change. In FY 1996, the FAA developed a second-generation system for assessing changes in community noise exposure, due to major airspace redesign proposals.

NASA's Advanced Subsonic Technology researchers also developed a pressure-sensitive paint for use on wind tunnel models. This paint has great potential for improving the effectiveness of data obtained during wind tunnel tests and will substantially reduce the aerodynamic design cycle time and cost of aircraft wings. These researchers also made progress in reducing nitrous oxide emissions from jet engines in small-scale tests. Program personnel developed a new capability for manufacturing composite wing surfaces that can reduce the cost of wing manufacturing by 20 percent.

Throughout FY 1996, the Army Research Laboratory cooperated on many technical research projects with NASA. Highlights included power stream aerodynamics in gas turbine engines, magnetic bearing operation in future gas turbine engines, thermal barrier coatings for diesel engines, a unique gas turbine engine that reduces weight and volume, tiltrotor aircraft, advanced composites that reduce wing drag without compromising aerodynamic performance or stability, and "smart material" actuators in aircraft trim panels to control interior noise levels.

Air Traffic Control and Navigation

The FAA embarked on an effort to modernize the national airspace system in an economically feasible manner, with minimal disruption to users. As part of that effort, the FAA began the development of the system's architecture, a comprehensive blueprint to improve the system's infrastructure over the next 20 years. In February 1996, the FAA released version 1.5 of the system's architecture, covering the timeframe 1998 to 2015. The FAA received comments internally, from the aviation industry, and from the general public and worked to incorporate suggestions into the development of version 2.0

The FAA's Display System Replacement (DSR) program to modernize equipment used at the 21 Air Route Traffic Control Centers (ARTCC's) and implement modern system operations and maintenance techniques completed its hardware and software design and development in FY 1996. The DSR team successfully accomplished product integration, fulfilled the initial requirements for DSR console testing, and completed its production readiness review.

While development of the DSR was under way, the agency began acquiring an interim system, the Display Channel Complex Rehost (DCCR), which is to provide a modern and reliable display channel system at five ARTCC's. DCCR acquisition and implementation proceeded significantly ahead of schedule in FY 1996. The FAA also completed system development and delivered DCCR equipment to four of the five selected sites.

In FY 1996, a Voice Switching and Control System (VSCS) at each of 11 ARTCC's became fully operational, bringing the total to 15 sites. VSCS is a state-of-the-art digital switching system that provides air-to-ground communications between pilots of en route aircraft and controllers, as well as ground-to-ground communications between controllers and other users of the national airspace system. FAA software engineers also developed the first VSCS planned product improvement in FY 1996.

In January 1996, the RTCA (formerly the Radio Technical Commission for Aeronautics) Technical Management Committee approved the Minimum Operating Performance Standards for the Wide Area Augmentation System (WAAS). The WAAS program, developed to serve all phases of flight from en route through precision approach, is the key program in the FAA's plan to move the Nation from a ground-based to a satellite-based navigation system. The Minimum Operating Performance Standards provided the guidelines for the avionics to be used in conjunction with WAAS. In May 1996, the FAA signed a contract with Hughes Aircraft Corporation for WAAS development, replacing the initial contract the agency canceled last April.

Several years ago, the FAA initiated an effort to modernize the tools available to air traffic controllers using the Oceanic Automation System, and the FAA implemented some of these new system features during FY 1996. The first system enhancement was the telecommunications processor, which became operational during the last quarter of FY 1996, and supports flight data input and output for future applications and the functional expansion of oceanic systems. The interim situation display became operational in the last quarter of FY 1996, replacing the plan view display.

Air-to-ground communications within a single air traffic control sector became operational at Oakland in October 1995 with the implementation of the Oceanic Data Link. A multisector variant of the system became operational at the Anchorage site in April 1996. An expanded multisector Oceanic Data Link will vastly improve the speed and reliability of controller-pilot communications at three oceanic sites.

The FAA also worked to enhance air traffic services in the Gulf of Mexico airspace for en route aircraft flying at 18,000 feet and above. During FY 1996, the FAA began implementing communications enhancements and prototype development of an ocean buoy-based satellite communications system.

In response to the growth in air traffic and increased terminal area delays, the FAA initiated the development of an automated system to assist traffic management specialists and controllers in the management of terminal area traffic. This Center-terminal radar control (TRACON) Automation System (CTAS) provides automated decision support tools for the planning and controlling of arrival traffic within 200 nautical miles of the arrival airport. During the fiscal year, FAA technicians implemented prototypes of two CTAS tools, the Traffic Management Advisor and the Final Approach Spacing Tool, at the Denver and Fort Worth ARTCC's and the Dallas-Fort Worth TRACON facility.

During the fiscal year, the FAA also continued work on the Surface Movement Advisor (SMA), an automation system designed for use at high-activity airfields. SMA facilitates the sharing of information among the air traffic, airline, and airport operations communities to assist in the decisionmaking process related to the surface movement of aircraft. The FAA installed a prototype SMA system in the control tower of Atlanta's Hartsfield Airport and performed a functionality stress test on the prototype in FY 1996. In August 1996, the SMA prototype underwent functionality validation and completed a 96-hour stability test.

As the first step in modernizing the traffic flow management infrastructure, the FAA began "reengineering" traffic flow management software using commercial "off-the-shelf" products. In FY 1996, the FAA, in collaboration with NASA, focused its new traffic flow management research and development efforts on the development of collaborative decision-making tools that will enable FAA traffic flow managers to work cooperatively with airline personnel in responding to congested conditions. Additionally, the FAA provided a flight scheduling software system to nine airlines.

In FY 1996, the FAA and NASA also began studying ground operations during low visibility at 10 U.S. airports. This research for the Terminal Area Productivity program began creating computer simulation models of the ground operations and investigating the operations effects of introducing a situational awareness aid in the cockpit during ground operations.

In addition, the FAA and NASA created the Air Traffic Management Interagency Integrated Product Team (IAIPT) to formally integrate research efforts directed at enhancing the safety, efficiency, and cost-effectiveness of the national airspace system. The IAIPT solicited inputs from a broad spectrum of national airspace system stakeholders and combined these with guidance from relevant NASA and FAA advisory committees to establish technical goals and collaborative working procedures for individual research projects. During FY 1996, the IAIPT released an integrated plan for air traffic management research that defined the research scope, described the schedule and resources proposed for individual projects, and specified agency responsibilities.

In another joint FAA-NASA project, the FAA completed the first of three development efforts of the National Airspace Resource Investment Model. This model is being developed with three interrelated modeling capabilities: operational, architectural, and investment.

The FAA continued work on the Standard Terminal Automation Replacement System (STARS) during FY 1996. A joint program being undertaken by the FAA and DoD, STARS is designed to replace the Automated

Radar Terminal System (ARTS) with a modern, commercially based, fully digital system. The FAA awarded a contract for the STARS procurement in September 1996 to a team led by the Raytheon Company. Meanwhile, the FAA continued to provide upgrades and enhancements to ARTS to improve air traffic safety and equipment reliability at TRACON facilities. Significant accomplishments during FY 1996 included the implementation of the ARTS IIIE hardware and software upgrades at the Chicago, Dallas/Ft. Worth, and New York TRACON's.

During the fiscal year, the FAA also made great strides in upgrading the capability of the national airspace system by modernizing landing systems. Technicians installed more than 100 new Mark-20 instrument landing systems around the country, replacing instrument landing systems that were as much as 30 years old. The Mark-20's ensure that reliable, supportable landing systems will be in place until technicians implement the augmented GPS landing capability. Additionally, the FAA has used a service life extension program to modernize instrument landing systems that are 20 to 30 years old. At the end of the fiscal year, the factory had shipped 89 of these systems, and the FAA has outfitted more than 50 airports with the new systems.

For the 1996 Summer Olympic Games in Atlanta, the FAA joined NASA and industry in a consortium known as the Advanced General Aviation Transport Experiment (AGATE) to successfully complete Operation Heli-STAR. AGATE supplied the air and ground avionics, surveillance, and communications equipment for Heli-STAR aircraft, helicopters, and blimps operating within the Olympics' controlled airspace. AGATE also equipped the commercial aircraft that transported cargo for the Atlanta Olympic Games. These aircraft flew more than 1,400 flight-hours during the 6-week operation in which there were as many as 10 to 14 aircraft operating within a 3-mile radius at altitudes of 200 to 500 feet. Although the volume of low-altitude traffic was more than the Atlanta area had ever seen, the related "Fly Neighborly" community response system helped minimize adverse noise impacts in Atlanta neighborhoods.

Weather-Related Aeronautical Activities

During FY 1996, the FAA and NOAA awarded a contract for the development of a water vapor sensing system. United Parcel Services, Inc., agreed to equip its aircraft with the sensors and downlink the data for use in computer weather forecasting. Scientists believe that frequent observations of water vapor aloft will enable them to make significant advances in in-flight icing, ceiling, and visibility forecasts. In January 1996, local aviation officials used the findings of FAA in-flight icing research at the Aviation Weather Center in Kansas City, which issued the first forecast of freezing precipitation aloft.

In another joint project with NOAA, the FAA worked to develop a snowfall-rate system. During the fiscal year, scientists from the National Center for Atmospheric Research conducted a field experiment at Chicago's O'Hare Airport to gather data on the impact of snowfall on airport operations and airline de-icing programs.

In another area of weather data collection and reporting systems, the FAA continued to install the Automated Surface Observing System (ASOS), commissioning the 100th system in September 1996. During FY 1996, the FAA completed its purchase of 537 systems. The ASOS project is a joint effort of the FAA, the National Weather Service, and DoD to deploy automated weather observing capability at more than 800 sites throughout the United States. During the fiscal year, the FAA funded the purchase and continued development of ASOS Controller Equipment (ACE), which displays weather and airport information to tower controllers and TRACON personnel. A very reliable configuration using a low-cost automatic switchover capability resulted from these efforts. The FAA funded 10 ACE installations, in addition to the two already installed, and upgraded the ACE at Will Rogers World Airport in Oklahoma City. The ACE underwent an operational test and evaluation at Dallas/Fort Worth International Airport in the summer of 1996, resulting in only minor software modifications.

During FY 1996, the FAA continued developmental efforts of the Integrated Terminal Weather System, which provides short-range forecast and warning notices to pilots and air traffic controllers. The system's prototype operations at the Orlando, Memphis, and Dallas/Fort Worth airports continued during the year. The FAA also awarded a contract to develop a weather and radar processor to provide next-generation weather radar data for ARTCC controllers.

As part of the FAA's wake vortex program, personnel from the FAA and DoT's Volpe National Transportation Systems Center (VNTSC) began establishing a test site at New York's John F. Kennedy International Airport. FAA and VNTSC personnel installed a ground wind vortex sensing system at the Memphis airport as a part of a suite of NASA instruments at that airport that includes Lidar and meteorological sensors. Researchers used the full suite of instruments to collect wake vortex and weather-related measurements, as well as data for determining the meteorological effects on wake vortex behavior. FAA, VNTSC, NASA, and industry personnel collaborated to recommend new aircraft classification, separation standards, and operational procedures related to wake vortices. The FAA implemented new standards for aircraft classification and separation in August 1996. FAA and VNTSC personnel continued working closely with British officials in the analysis of aircraft separation data from Heathrow Airport, as well as the Chicago (O'Hare) and Toronto airports. FAA specialists also worked closely with German and French officials to increase capacity at the Frankfurt and De Gaulle Airports.

Additionally, NASA aviation and operations systems research in FY 1996 validated a wake vortex hazard computer model through key flight and wind tunnel experiments. The model has predicted terminal area capacity increases up to 12 percent with no compromise in safety.

In the area of aircraft icing, the FAA conducted a 3-day international conference in May 1996. Recommendations emanating from the conference formed the basis for an FAA in-flight icing plan that addresses both long- and short-term FAA actions to enhance aircraft safety. In cooperation with NASA, FAA engineers continued to develop techniques for recognizing susceptibility to ice-induced tailplane stalls during icing certification testing, and they initiated efforts to ascertain the susceptibility of modern airfoils to large supercooled icing droplet accretions. Also, FAA researchers continued their in-depth investigations of technologies for ground de-icing and anti-icing fluids, with an emphasis on environmentally friendly fluids. FAA engineers undertook research, development, and evaluation efforts for area-coverage, aircraft-mounted surface ice detectors for use during ground operations to ensure that all critical aircraft surfaces were clean of frozen contaminants prior to takeoff. In addition, NASA initiated the Supercooled Large Droplet icing research program to study unusual aircraft icing, such as that which contributed to the ATR-72 crash in October 1994.

During FY 1996, the FAA awarded two Direct User Access Terminal service follow-on contracts. The previous, telephone-based service provided general aviation and other FAA-authorized users with toll-free access to an FAA database for preflight weather information, as well as a flight plan processing service for filing, amending, or canceling flight plans using a personal computer. The new "off-the-shelf" system provides all of the functionality and performance of the previous service while adding several new FAA-mandatory and vendor-optional features at no cost to the user.

Also during the fiscal year, the FAA commissioned 13 additional Terminal Doppler Weather Radar Systems. This brings the number of commissioned systems to 19 out of a total of 45 that are planned for deployment at operational airports. These systems provide for the timely detection of hazardous wind shear in and near airport terminals' approach and departure corridors and report that information to pilots and controllers.

Development also continued on the Airport Surveillance Radar-Weather Systems Processor (ASR-WSP), which provides for the timely detection of hazardous wind shear in the terminal approach and departure areas. ASR-WSP performance is similar to that of a Terminal Doppler Weather Radar System. FAA specialists evaluated the system in Orlando, and it also began operating in Albuquerque. As a result of initial ASR-WSP prototype successes, the FAA made a decision to proceed with full-scale development activities.

The FAA also began enhancing the Low Level Wind Shear Alert System (LLWAS) at nine major airports. LLWAS provides real-time detection of hazardous wind and wind-shear activity in the terminal approach and departure areas. During FY 1996, the FAA deployed the

LLWAS–Network Expansion (LLWAS-NE) system to seven airports, commissioning four of the new systems prior to September 30, 1996. LLWAS-NE extends the coverage area and provides runway-oriented wind information and wind-shear detections.

Finally, the FAA continued work on the Weather Message Switching Center Replacement system, commissioning these systems in Salt Lake City and Atlanta. Such systems process and disseminate FAA and National Weather Service weather data and special notices to airspace users.

Flight Safety and Security

In the area of visual guidance, FAA specialists completed simulation studies for approach lighting systems during FY 1996. Work continued on research to find a more cost-efficient source for approach lighting. In addition, FAA specialists demonstrated the friction effects of retroreflective bead and sand additives to pavement marking material.

In FY 1996, the FAA and the Engineered Systems Company successfully tested an aircraft arrestor bed composed of cellular cement, a foam-like material that absorbs energy, at the FAA's William J. Hughes Technical Center in Atlantic City, New Jersey. During the test, the FAA's Boeing 727 aircraft taxied onto the bed at 55 knots and came to rest in 278 feet, only 16 feet beyond the math model prediction. A second partnership with the Port Authority of New York and New Jersey produced a design for an operational arrestor bed to serve John F. Kennedy International Airport.

In the area of aircraft systems fire safety, FAA engineers made progress in improving the performance of aircraft interior materials during a fire. Researchers identified a promising lightweight thermal acoustical insulation material that provided an excellent barrier against fuel fires. Also, the FAA issued a service bulletin recommending the replacement of flammable polyester blankets at the end of their service life with blankets meeting new fire test criteria.

The FAA completed the final installation of a driver's enhanced vision system for emergency vehicles at airports in August 1996. This system, used to improve emergency rescue responses under adverse weather conditions, uses infrared thermal imaging technology to see through fog, rain, sleet, and snow. The system includes GPS mapping for locating and navigating to accident sites and a radio frequency data link that allows the vehicles to receive and transmit vital messages.

The FAA continued its work to improve postcrash interior fire suppression. The FAA and the Crash Rescue Equipment Services Company developed a fully functional 55-foot arm boom with an aircraft cabin skin penetration system. In March 1996, working under a cooperative research and development agreement, the FAA Technical Center and the San Antonio Airport Authority demonstrated a full interior fire-suppression event using the vehicle's cabin skin penetration system. With the cabin interior fully on fire and with temperatures of more than 2,000 degrees in the aft end of a salvaged Boeing 707 aircraft, the cabin interior fire was quickly controlled in 30 seconds and fully suppressed in under 2 minutes with less than 600 gallons of fine mist water spray.

Under the auspices of the FAA-National Institute for Occupational Safety and Health Aircraft Cabin Exposure Assessment Study, researchers collected indoor air quality and cosmic radiation data on eight commercial flights in FY 1996. The FAA also developed a multiyear research program to address broader disease transmission issues in commercial aircraft.

During FY 1996, the FAA worked with the National Highway Traffic Safety Administration to revise the testing requirements in child restraints used on aircraft. Based on research done by its Civil Aeromedical Institute, the FAA issued revised regulations prohibiting the use of backless booster seat and harness-type child restraints on aircraft during takeoff and landing. Researchers tested prototypes of aircraft-specific child restraints being developed for airline use. Specialized crashworthiness assessments included an airbag system being developed for service in commercial airline applications. The FAA also tested a newer design of a crash dummy that more closely represents a person and features enhanced injury measurement capabilities.

In December 1995, the FAA held a meeting with industry representatives on the use of crew oxygen systems in aircraft. The meeting highlighted the lack of comfortable design and inconveniences associated with these systems' use. The FAA initiated research to identify the cause of disincentives and began investigating a solution. The FAA also began examining the strength and testing techniques for aircraft evacuation slides during FY 1996. Newly proposed test methods removed the need to place human subjects at risk of injury during a test, while resulting in a more reliable emergency slide. The FAA also continued design work to install utilities, heating, ventilation, and air conditioning equipment on a retired B-747 that is to be used for emergency passenger and crew tests.

In FY 1996, the FAA formed a partnership with the Boeing Commercial Airplane Company to build the world's first full-scale airport pavement test facility at the FAA Technical Center. The National Airport Pavement Test Facility will research pavement technologies that will accommodate the dramatic changes associated with the next generation of large aircraft. Current pavement standards work well for today's jumbo jets, but new standards will be needed to handle new designs that could weigh more than 1 million pounds. FAA personnel began developing three-dimensional models to assess accurately the life and load bearing capacities of airport pavements.

In the area of advanced materials and structural safety research, the FAA established test methods for the compression loading of composites and developed computer programs for the reliability assessment of composite aircraft structures. FAA researchers conducted a vertical drop test of a Beechcraft 1900 commuter aircraft fuselage to determine structural dynamic loads and a horizontal sled test of a narrow body (Boeing-737) fuselage section with an auxiliary fuel tank. During the fiscal year, FAA personnel continued to participate in the development of a *Composite Materials Handbook*, which is to establish goals toward the standardization of composite materials. The agency also updated the *Handbook on the Manufacture and Inspection of Composites* and Volume I of the *Fiber Composite Analysis and Design Handbook*.

Under the auspices of its aging aircraft research program, the FAA, in cooperation with NASA, sponsored a symposium in Atlanta on the continued airworthiness of aircraft structures. The two agencies also conducted technical workshops on structural integrity, corrosion, and inspection research. The FAA completed reports describing the testing of a series of large-scale flat aluminum panels with multisite damage and on two full-scale, wide-body panels. During the fiscal year, the FAA completed and distributed the initial phase of a repair design and assessment software tool. FAA personnel also conducted a video landing loads survey at the Honolulu airport and reported the analytical results from a previous survey. Work continued on developing improved safety inspection programs for critical engine components of commuter aircraft.

NASA's Advanced Subsonic Technology program developed a hand-held, eddy current probe for crack detection that has excellent capability to detect hidden cracks and corrosion beneath an aircraft's metallic skin. Airline operators began to use the device and are saving considerable cost and time as well as significantly improving aircraft safety.

The FAA specified a new inspection technique for the DC-9 wing box T-cap, where the wing joins the fuselage. This procedure reduced the time required for the mandated inspection from 800 work-hours to approximately 40 work-hours. The FAA also completed a draft advisory circular on the development of a corrosion-control program for commuter aircraft. FAA specialists continued developing and beta site testing emerging nondestructive inspection devices. In addition, FAA personnel developed a strategic plan for aviation maintenance human performance, which integrates and coordinates human factors and human performance across flight standards, aviation medicine, and aviation research. Engineers and technicians continued the field testing of a multizone ultrasonic inspection system at a titanium billet manufacturing plant. During these tests, researchers detected a titanium billet defect not found by the conventional inspection system used by industry.

As part of the FAA's propulsion systems and aviation fuels program, researchers began developing a probabilistically based damage assessment tool. The FAA also completed a computer code for determining turbine engine combustion performance when operating with mixtures of air and water and published a final report on turbine engine diagnostics. The FAA Technical Center continued working on the development of an unleaded aviation gasoline for use in the existing fleet of general aviation aircraft with piston engines. FAA personnel validated ground-based procedures for determining octane requirements for unleaded aviation fuel and initiated in-flight and ground evaluations of high-octane unleaded aviation gasoline formulas provided by industry.

The FAA continued to develop and research ways to mitigate and prevent the threat of catastrophic failure to aircraft. Researchers conducted studies and tests in flight control technologies, lightweight material barriers for high-energy rotor fragment mitigation, and aircraft loads. Grant and small business innovation research awards further expanded research in aircraft control, load technology, and rotor fragment mitigation. In FY 1996, the FAA completed small turbine engine containment tests and high-temperature containment ring tests. It also completed an analytical study of an uncontained turbine rotor fragment penetration threat to aircraft wing fuel tanks and a technology review of advanced armor concepts for turbine debris mitigation, as well as the first phase of an effort to develop an aircraft probabilistic risk assessment methodology.

In the area of aviation security technologies, the FAA certified the Invision CTX 5000SP explosive detection system after the contractor made major system hardware and software changes to the previously certified CTX 5000 to improve system performance. The airport demonstration program of the CTX 5000SP continued on track at the San Francisco, Atlanta, and Manila international airports.

The FAA also sponsored the third workshop of the International Civil Aviation Organization to discuss the screening of electronics using trace explosives detection equipment. Participants discussed the new controlled deposition process for explosives, whereby a known amount of explosives is placed on a surface to test the detection equipment. That process represented a major step forward in the development of standards for trace explosives detection equipment.

The FAA's airport security technology integration program held a workshop and then completed a report on the vulnerability analysis of 76 surveyed airports throughout the country. The workshop included the development of a test methodology for improving the vulnerability assessment capability at U.S. airports. The program also received industry concurrence on a technical report on positive passenger baggage matching, which included an assessment of the industry-wide cost and operational effects of implementing and operating domestic positive passenger baggage matching.

FAA human factors specialists worked with industry to improve the screener selection process through the testing of x-ray screening and CTX 5000 screening aptitude tests for their ability to predict on-the-job detection performance. FAA personnel developed computer-based training programs for both x-ray and CTX 5000 screeners to improve the detection of improvised (noncommercial) explosive devices.

The FAA also completed a performance-monitoring project that randomly inserts fictional threat images during screening operations. Because screeners cannot distinguish real versus fictional threat images on this program, the project provides a means to maintain vigilance and provide an accurate index of individual screener performance.

In the area of passenger profiling, the FAA began working with commercial airlines to reduce the number of domestic passengers who need special additional security treatment. The FAA awarded a grant to Northwest Airlines to upgrade its prototype automated profiling software program for system-wide implementation on reservation systems and to provide specifications supporting technology transfer to other major airline reservation systems.

Additionally, in the aircraft hardening arena, the FAA and its research partners initiated a process for acquiring blast containers for airline aircraft use. In the first of two phases of this acquisition process, the FAA evaluated six potential bids and selected two suppliers to provide 16 units.

Aviation Medicine and Human Factors

During FY 1996, the FAA continued efforts to improve human performance in the national airspace system through research and development. FAA's Civil Aeromedical Institute (CAMI) scientists supported the deployment and evaluation of the Systematic Air Traffic Operations Research Initiative research tool, designed to support assessments of air traffic control operations at four en route centers. The FAA began developing prototype air traffic control sector objective measures of workload, began collecting data to identify factors that affect team interactions and performance on a simulated air traffic control task, and completed a human factors study, using the new advanced CAMI general aviation simulator to provide recommendations for the certification of autopilot systems.

During the fiscal year, the FAA deployed the first user-tailored version of the Automated Performance Measurement System to Alaska Airlines for operational tests. This computerized system for analyzing, processing, and managing digital flight-recorded data makes aircraft flight performance data accessible and usable. The FAA also released a model pilot training program designed to enhance regional air carrier safety.

The FAA also provided human factors support to members of NASA Langley Research Center's AGATE flight systems team of Government and industry experts. The team expanded its research on the effects of shift work and fatigue on job performance to include a collaborative study with scientists from CAMI, USAF Armstrong Laboratories, and Japan to evaluate the role of "bright lights" as a potential fatigue countermeasure for personnel working the night shift. As part of a collaborative study, specialists at CAMI and the U.S. Army's Aeromedical Research Laboratory evaluated napping as another fatigue countermeasure. In addition, FAA, NASA, and DoD scientists formed a team to assess the effect of fatigue on national airspace system operators and to develop appropriate countermeasures to eliminate or mitigate adverse effects on performance. With FAA direction, a commercial firm produced a video, titled "Fatigue Busters," for use at safety seminars to help general aviation pilots recognize and address fatigue. In response to the aviation community's increased interest in discordant aircraft-pilot couplings, which has played an important role in numerous aviation accidents, NASA researchers completed a study on the safety repercussions of adverse aircraft-pilot interactions.

During this fiscal year, the FAA added three new chapters to its *Human Factors Guide for Aviation Maintenance* and provided them to airline industry maintenance managers. The FAA also sponsored several studies at Ohio State University concerning how general aviation pilots make in-flight decisions. From this research, the FAA produced a videotape to help general aviation pilots establish a set of safety criteria and to create personal safety checklists. In addition, researchers made progress in developing methods to train general aviation pilots to avoid encounters with hazardous weather.

The FAA also completed a usability study to evaluate a hand-held GPS receiver. It used the results to enhance the checklist developed for the evaluation of standalone GPS receivers.

During the fiscal year, the FAA's Toxicology and Accident Research Laboratory at the Civil Aeromedical Institute provided toxicology analysis and site support for post-accident assessments of ValuJet flight 592 on May 11, 1996, and TWA flight 800 on July 17, 1996. In the area of biochemical research, preliminary studies indicated that current projections for pilots dying in aviation accidents indicate a positive blood alcohol level in about 4 percent of the accident cases, as well as the use of over-the-counter drugs in 24 percent of the cases. Researchers also investigated the prevalence of controlled dangerous substances in the bloodstream.

A remarkable view of Earth's horizon was taken by the crew of STS-75.

Studies of the Planet Earth

During FY 1996, NASA's Mission to Planet Earth (MTPE) program accomplished many goals in environmental monitoring. MTPE uses observations from space, the air, and the ground to assist scientists in better understanding how the interaction of Earth's systems of land, water, air, and life influence our climate and environment. MTPE is part of a larger interagency research effort, the U.S. Global Change Research Program, and also includes extensive international cooperation.

MTPE's centerpiece is the Earth Observing System (EOS), a series of advanced interdisciplinary spacecraft that, as of the end of the fiscal year, were scheduled to be launched beginning in 1998. Over a planned 15- to 18-year period, EOS is to make the first sustained, integrated measurements of global changes in Earth's atmosphere, land surface, and water resources. The National Academy of Sciences (NAS) completed its review of MTPE and the EOS program in 1996. The NAS Board on Sustainable Development indicated its strong support for the program's science priorities, validated NASA's plan for near-term EOS missions, urged greater incorporation of advanced technologies in later flights, and suggested a way to improve data processing and distribution.

EOS is to begin with the AM-1 mission, scheduled for a June 1998 launch. AM-1 is to focus on the physical and radiative properties of clouds, trace gases, and air-land and air-sea exchanges of carbon and water. AM-1 development continued on schedule throughout FY 1996 as fabrication, assembly, and test of flight model subsystems proceeded with no significant problems. Technicians completed the fabrication and assembly of the spacecraft's primary structure. All five AM-1 instruments—three sensors from the United States and one each contributed by Canada and Japan—were in final test at the end of FY 1996.

MTPE also made substantial progress on the development of the EOS PM mission, which is to provide measurements of clouds, precipitation and radiative balance, snow and sea ice, sea-surface temperature, terrestrial and oceanic productivity, and atmospheric temperature. During FY 1996, Brazil agreed to provide a PM-1 sensor to aid in weather prediction; the sensor will measure atmospheric humidity and precipitation under clouds.

NASA also initiated three efforts designed to help MTPE evolve in the future. First, NASA expanded its implementation of its new initiative for technology infusion, the New Millennium program. In the spring of 1996, MTPE managers selected the first Earth science mission of the New Millennium program, an advanced land imager, incorporating several innovative design features. Second, MTPE began the Earth System Science Pathfinder program to expedite the acquisition of key scientific data. This program is to accommodate new scientific priorities and infuse new scientific participation into MTPE. NASA managers issued the first Announcement of Opportunity in July 1996. Third, MTPE conducted a joint workshop with the commercial sector to incorporate industry suggestions into the final version of MTPE's commercial strategy, which aims to lower the cost of science data by exploiting cutting-edge industry technologies and information systems.

The EOS Data and Information System (EOSDIS) continued its development during FY 1996, with plans for a federation of prototype Earth Science Information Partners. These changes to EOSDIS, which will provide the data capturing, processing, and archiving functions for EOS, are consistent with the recommendations of the NAS Board on Sustainable Development to broaden the base of potential public and scientific users of EOS data. NASA placed draft solicitations on the Internet for comments and suggestions from potential providers on ways to process creatively and distribute MTPE data products. Work also continued on EOSDIS versions 1 and 2 to support the Tropical Rainfall Measuring Mission and AM-1 flight mission, respectively.

The U.S. Geological Survey (USGS) Earth Resources Observation System (EROS) Data Center's EOSDIS Distributed Active Archive Center distributed 22 terabytes of data in FY 1996. Approximately 5 terabytes of global data products were distributed, including 10-day cloud-free composites of North America and global land cover data created from Advanced Very High Resolution Radiometer (AVHRR) data; digital elevation data sets of Japan, North America, Eurasia, South America, and Africa; and selected Landsat scenes over various areas of the world. An additional 17 terabytes of data were distributed on CD-ROM, consisting primarily of Shuttle Imaging Radar-C (SIR-C) products from data acquired on two 1994 missions of the Space Shuttle *Endeavour*. The Data Active Archive Center also initiated the electronic distribution of data products via the Internet by moving data products to an online mass storage system.

With the completion of an agreement between NASA and the Russian Academy of Sciences Institute for Radioengineering and Electronics, program officials extended EOSDIS to Russia. NASA and the Russian Academy will work together to ensure that specialists catalog each country's data and make them available to Russian and American scientists for EOSDIS research.

In FY 1996, scientists made major progress in using land cover characterization to improve weather prediction. During a joint U.S.-Canadian study of northern forests, the Boreal Ecosystem-Atmosphere Study (BOREAS) project, scientists made an important advance in characterizing the role of the northern forests as a control on water, heat, and momentum transfers between the surface of the Earth and the lower atmosphere. BOREAS researchers also accurately measured the growth rate of the northern forests for the first time, demonstrating that the slow growth of boreal forests results in the low transpiration of water to the atmosphere. They also found that the strong control of forests on water fluxes to the atmosphere is a primary reflection of the strong link between biology and weather. Researchers introduced BOREAS data from ground-based, airborne, and satellite sources into experimental weather prediction models, significantly improving regional weather predictions. BOREAS has become another important part of the MTPE program.

During FY 1996, NASA took the lead on an interagency, long-term initiative to foster the incorporation of Earth system science concepts and results into State and local education systems. State teams of education policymakers and science experts gathered in regional forums, in which each State presented unique action plans for using existing resources to overcome obstacles that prevent the incorporation of Earth system science into the education system. Earlier in the year, NASA convened an interagency panel to peer-review proposals from 33 State teams. Based on the panel's recommendation, NASA awarded 19 grants, and EPA contributed support for an additional 6 grants.

NASA again joined NSF and NOAA in contributing to the interagency Global Learning and Observations to Benefit the Environment (GLOBE) program. More than 2,000 teachers have been trained across the country, and students from around the world continued to make daily measurements and receive visualized results of their compiled data.

Studies linking land cover and land use change to global change indicated that climate variability is a primary determinant of forest metabolism. New observations on annual variations in the growth patterns of the northern forests associated relatively large shifts in photosynthesis with the timing of the leaf cycle. Research also indicated that climate variations on seasonal time scales can modify annual carbon dioxide exchange with the atmosphere in the Northern Hemisphere by 1 billion metric tons of carbon or more each year.

Recent research highlighted the use of synthetic aperture radar (SAR) for natural disaster science and applications. Scientists used SAR to study various natural disasters by precisely documenting topographical changes. FY 1996 examples included measuring the spatial effects of ground motion associated with recent California earthquakes, quantifying regional subsidence caused by groundwater extraction in the Los Angeles area, and measuring volcanic eruption rates at Hawaii's Kilauea volcano. In China, scientists used SAR measurements to locate and study two generations of the Great Wall that centuries of blowing sand had eroded. Radar data also helped scientists understand the way the course of the Nile River has changed over time, the formation of a "supercontinent" 650 million years ago, and the potential for future flooding along the Mississippi River.

In November 1995, NASA launched the Canadian RADARSAT spacecraft on an ELV from Vandenberg Air Force Base, California. Scientists expected RADARSAT to open new avenues of radar exploration of the Antarctic ice sheet and other surface features. The Canadian satellite began operating and acquiring data with SAR, as part of a NASA-NOAA cooperative agreement with the Canadian Space Agency.

NASA also agreed with the Defense Mapping Agency to fly a radar interferometry mission on the Space Shuttle, continuing the Shuttle Radar Laboratory series. NASA and the German space agency, DARA, began negotiating an agreement for the flight of the German X-SAR along with the NASA C-band SAR for this mission, scheduled for May 2000. The specially modified radar system is to produce the most accurate and complete topographic map of the Earth's surface.

To improve the measurement of ground motion produced by underlying geological faults in southern California, NASA, in collaboration with USGS and NSF, began implementing a high-density GPS geodetic array. In addition to providing better data for analyzing this important natural hazard, the GPS array provides a test bed for evaluating the accuracy of new methods of SAR remote-sensing techniques.

Maps produced by USGS, using data from NASA's Airborne Visible and Infrared Imaging Spectrometer (AVIRIS) flying aboard a NASA ER-2 high-altitude research aircraft, cut costs and helped speed the cleanup of hazardous waste at a Superfund site in Colorado. Several Federal agencies used the maps to locate sources of acid mine drainage and heavy metal contamination at the California Gulch Superfund site. This contamination is the result of more than 130 years of mining activities associated with the Leadville Mining District. The imaging spectroscopy mineral mapping allows researchers to identify potential contaminating sources as small as individual mine dumps for evaluation; it also offers the possibility of using AVIRIS to produce relatively inexpensive thematic site maps to aid in remediation at other U.S. sites. Earth scientists use AVIRIS to take measurements related to global climate and environmental change research in ecology, geology, oceanography, snow hydrology, and cloud and atmospheric studies.

In an effort to improve aerial firefighting safety and efficiency, NASA teamed with the Bureau of Land Management, the Forest Service, and the Nevada Division of Forestry to use advanced NASA information technology to fight wildland fires. These agencies also began evaluating an electronic Advanced Navigation Display System, developed by NASA, to aid aerial firefighters in their communications and operations. The system indicates the position of other firefighting aircraft, establishes an airspace structure graphically on the computer screen, identifies areas needing retardant or water drops, and transmits those images to other aircraft. The system uses graphics displays of CD–ROM moving maps, radio modems, and

GPS signals to show each aircraft's position and provide two-way data communications between aircraft.

A new, animated view of the dramatic growth in urban sprawl over the Baltimore-Washington metropolitan region during the past 200 years was produced by the Baltimore-Washington Regional Collaboratory, a cooperative effort of the University of Maryland Baltimore County, USGS, and NASA. Using a combination of historical maps, census records, satellite-based imagery, and GIS's, project officials planned to put the animation tool and its supporting information on the Internet to aid local and regional urban planners.

The development of the next generation of land imagers, Landsat-7, continued on schedule. During FY 1996, technicians completed the telescope assembly integration and mechanical structure and initiated environmental testing. Project personnel also completed a review of the design for the ground system and began development work.

The first flight of the Shuttle Laser Altimeter took place in January 1996, aboard Shuttle flight STS-72. Project managers planned a second mission for FY 1998.

The Lewis spacecraft accepted delivery of all instruments in early FY 1996, with flight scheduled for early 1997. Lewis is to carry 25 new technologies, in addition to three advanced sensors for commercial remote-sensing and Earth science purposes. USGS scientists helped develop a multi-agency aircraft imaging spectrometer managed by the Naval Research Laboratory. NASA selected this spectrometer to be the first hyperspectral imager placed into the Earth's orbit, as part of the Lewis spacecraft.

Agricultural Research Service scientists at the Remote Sensing and Modeling Laboratory in Beltsville, Maryland, working with NASA scientists at the Goddard Space Flight Center, developed improved techniques for measuring crop residue cover. Crop residues, the portion of the crop left in the field after harvest, are an important factor in conserving soil and water, particularly on highly erodible land. About one-third of U.S. cropland is classified as highly erodible land. The project team demonstrated that crop residues fluoresce more than soils and received a patent on the technique. The team began developing a portable agricultural residue sensor.

Scientists at the Remote Sensing and Modeling Laboratory also worked with the National Agricultural Statistics Service to investigate the feasibility of using AVHRR data to classify regions of spring wheat. Typically, researchers use coarse-resolution AVHRR data to classify vegetation on a continental scale. The group succeeded in developing a stratified sampling approach, which uses the high spatial resolution (30 meters) of the Landsat-5 TM (Thematic Mapper) to estimate crop proportions within each AVHRR class. The acreage estimates of spring wheat using remotely sensed data closely matched the acreage estimates reported by the National Agricultural Statistics Service. The scientists incorporated the remotely sensed data into crop growth models to simulate spring wheat yields at the county level. The simulated yields agreed with the ground survey reports of the National Agricultural Statistics Service.

Scientists at USDA's Hydrology Laboratory in Beltsville, Maryland, demonstrated the feasibility of using airborne laser altimeters to measure land surface features over large areas quickly, easily, and accurately. The airborne laser measurements of micro- and macro-topography quantified water retention, infiltration, evaporation, and water movement across land surfaces and into channels. Researchers used channel and gully measurements to estimate soil loss and explain water quality and flow patterns. Measurements of plant canopy distributions across the landscape provided a better understanding of evaporative loss, infiltration, and surface water movement.

Agricultural Research Service scientists at the U.S. Water Conservation Laboratory in Phoenix, Arizona, developed remote-sensing approaches to assist resource managers in making management decisions on farms, rangelands, and natural plant communities. They measured spectral reflectance, canopy temperature, daily growth, and the water status of cotton plants under various irrigation regimes. They also evaluated various crop management scenarios through computer simulations to determine the most cost-effective and environmentally sensitive approaches.

As a part of the Free-Air Carbon Dioxide Enrichment project at the Maricopa Agricultural Center near Phoenix, U.S. Water Conservation Laboratory scientists characterized the response of spring wheat to the interactive effects of elevated carbon dioxide and nitrogen stress by acquiring hyperspectral reflectance data at the leaf and canopy levels. Their small-scale studies provided the detailed knowledge necessary for interpreting imagery obtained from airborne and satellite-based sensors. They also identified the way data derived from the imagery can be used as input in farm management applications.

USDA's Remote Sensing Research Unit at Weslaco, Texas, developed a Cooperative Research and Development Agreement with Site-Specific Technology Development Group, Inc., to design a calibrated digital video imaging system for the assessment of natural resources. Also, the Remote Sensing Research Unit entered into an agreement with EPA's Aerial Surveillance Division in Las Vegas, Nevada, to develop video technology. Technicians assembled a true digital imaging system for evaluation in FY 1996.

Scientists at the Remote Sensing Research Unit determined the salinity of the soil and mapped the yields of 145,000 hectares of wheat and cotton in the Yaqui Valley Irrigation District in Mexico. The unit successfully developed procedures to provide reliable information on the extent and severity of soil salinity and the resulting reductions in crop yields, using field samples, satellite data, and a GIS. These maps provide a permanent record of salinity conditions within fields. Equations describing the reductions in crop yields in response to increasing soil salinity provide data for the cost-benefit analyses of amelioration efforts. The National Institute of Water Technology and the National Water Commission of Mexico used this research to illustrate progress in their areas of responsibility.

The National Agricultural Statistics Service used remote-sensing data to construct area frames for statistical sampling, estimate crop area, create crop-specific, land cover data layers for GIS's, and assess crop conditions. Products from the first three areas were based on medium-resolution digital satellite data, such as the Landsat-5 TM and Satellite Pour l'Observation de la Terre (SPOT) Multispectral Scanner data, while crop condition assessments used low-resolution data from the NOAA-14 satellite.

For area frame construction, the National Agricultural Statistics Service 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 variables such as the percentage of cultivation. The National Agricultural Statistics Service tested data for the Indian Remote Sensing (IRS-1C) satellite and found several technical problems; the Service will be a beta-test site for the corrected IRS-1C data.

During FY 1996, USDA's delta remote-sensing project in Arkansas focused on the analysis of Landsat-5 TM data for the 1995 crop season. An end-of-season analysis produced crop acreage estimates for rice, cotton, and soybeans at county levels plus a crop-specific categorization usable for a digital GIS data layer. National Agricultural Statistics Service analysts working on the delta project also participated in a USDA Government Applications Task Force research and development project to evaluate the feasibility of using National Technical Means data sets for improving statistical information on crop acreage and yield. Researchers compared a subset of the delta project data from Craighead County, Arkansas, to analysis based on the data sets. Scientists began work on an expert system to aid statisticians, rather than remote-sensing analysts, in performing analyses based on Landsat-5 TM or similar remotely sensed data to estimate crop acreage. During the summer, Landsat-5 TM and corresponding ground data were collected for Arkansas in preparation for the end-of-season crop acreage estimation.

A severe drought in the southern Great Plains winter wheat areas caused USDA crop analysts to search for additional crop condition information. In addition to conventional survey data, vegetation condition images based on NOAA-14 AVHRR data aided analysts in describing drought-affected areas. An imagery product indicating the ratio of a 1996 biweekly composite image to its corresponding 1995 biweekly period was first created in May 1996. Spring imagery helped graphically depict the extent of the problem to the media. Summer imagery was useful in analyzing the possible effects of late planting in the Corn Belt. Although the original distribution of the imagery was in paper map form, demand from users for digital copies led to the creation of an Internet Web site available to the general public. This Web site was updated biweekly with new imagery throughout the 1996 growing season.

The Foreign Agricultural Service's satellite remote-sensing program remained a critical element in USDA's analysis of domestic and foreign agricultural production, supply, and demand by providing timely, accurate, and unbiased estimates of global area, yield, and production. Satellite-derived early warning of unusual crop conditions and production made it possible for more rapid and precise determination of global supply conditions, contributed to efficient price adjustment, and helped maximize the returns of U.S. farmers. The agency used AVHRR, Landsat, and SPOT imagery, crop models, weather data, attaché reports, field travel, and ancillary data to predict foreign grain, oilseed, and cotton production. Last year, the Foreign Agricultural Service's remote sensing supported DoS assessments of food needs in the former Soviet Union, particularly in drought-affected Ukraine. The Service also prepared detailed analyses of the U.S. southern Great Plains drought, the northern Mexico drought, and flooding in China and North Korea.

The Farm Service Agency continued to fund the analysis of Landsat TM, SPOT, and AVHRR imagery by its sister agency, the Foreign Agricultural Service, from which it received timely reports on U.S. crop conditions. These imagery-based reports, combined with weather data, crop model results, and GIS products, led to the development of accurate and timely projections and comprehensive evaluations of crop disaster situations. Also, the Farm Service Agency continued to be a partner in the National Aerial Photography Program and the National Digital Orthophoto Program. Seeking to reduce National Aerial Photography Program imagery collection costs, the agency tested the usability of Russian high-resolution KVR-1,000 imagery to augment aerial photography coverage of Hawaii.

The Forest Service used a wide range of remotely sensed data for managing and protecting the 191 million acres of land in the National Forest System—AVHRR data for wide-area coverage and Landsat, SPOT, and aerial panchromatic and multispectral imagery for small- to large-scale coverage. These systems provided data that supported virtually all aspects of ecosystem management, such as land management planning, wildfire detection and suppression, resource inventory construction and updating, and wildlife habitat assessment. Remotely sensed data were also the primary source for the Forest Service's topographic mapping contribution to the National Mapping Program, which is managed by USGS. Forest Service map revisions provide up-to-date information for more than 10,000 1:24,000-scale maps of National Forest System lands. These maps are essential tools for Forest Service resource managers; they also are distributed to the general public.

NASA supported the Forest Service with the acquisition of approximately 30,800 square miles of high-altitude aerial photography over the Chugach and Tongass National Forests in Alaska. In addition, NASA provided real-time Thematic Mapper Simulator imagery of several major fires. The ER-2 aircraft transmitted the imagery to ground users, as it was being acquired, using the Satellite Telemetry and Return Link system.

The Natural Resources Conservation Service shared costs with State and Federal agencies in acquiring aerial photography through the National Aerial Photography Program. Program officials and local agencies began cost-sharing the development of digital ortho-imagery through the National Digital Orthophoto Program, with the goal of completing conterminous coverage of the United States by 2002. Approximately 35 percent of the United States was complete or in progress at the end of FY 1996. The National Resources Conservation Service continued to increase its use of remote sensing to conduct the National Resource Inventory—the most comprehensive and statistically reliable natural resource inventory of its kind in the world. The inventory is used to report how well the Nation is sustaining natural resources on land that is not federally owned. The National Resources Conservation Service uses the National Aerial Photography Program, large-scale true-color aerial photography, color slides, and satellite imagery to interpret and classify more than 800,000 sample sites in forming the inventory's database. The inventory offers land cover and use, soil erosion by water and wind, wetlands, prime farmland acreage, conservation treatment needs, and other natural resource characteristics.

Also, the National Resources Conservation Service continued to cooperate with DoD to use the Navstar GPS Precise Positioning Service (PPS). The Service purchased an additional 285 PPS receivers and used approximately 475 precision lightweight GPS receivers to correlate precise geographic coordinates with natural resource and environmental data for use in making better assessments of agricultural resources with GIS's. The National Resources Conservation Service also provided technical support to other USDA units and Federal agencies, including NASA.

By analyzing meteorological satellite imagery that showed urban lights at night, NOAA scientists inferred population and energy consumption by cities and towns. Defense Meteorological Satellite Program (DMSP) satellites recorded nightly emissions in the visible and near-infrared emission bands at very low levels. Stable emission sources as faint as towns, squid fishermen, the aurora, and moonlit clouds were captured in the images. Several studies demonstrated the technique and its application to population dynamics and economic vitality. NOAA scientists also developed techniques to monitor forest fires by interpreting thermal infrared, near-infrared, and visible emissions from the Geostationary Operational Environmental Satellite (GOES) series, DMSP satellites, and the Polar-orbiting Operational Environmental Satellite (POES) series.

As part of an international experiment on global energy and the water cycle, NOAA developed a global monthly climatology of the fractional area of the surface covered with active green vegetation. Scientists derived this "vegetation index" from AVHRR data. Researchers already used the vegetation fraction in numerical weather forecast models and general circulation models to help specify the energy and water budgets at the surface.

NOAA scientists conducted a study of the effects of changes in land use and land cover on monthly and seasonal averages of diurnal temperature range. The study continued to combine AVHRR data with monthly temperatures and associated metadata from the U.S. Historical Climatology Network for the period 1981 to 1990. The preliminary results indicated that significant differences in diurnal temperature range could be associated with certain predominant land use and land cover types.

NOAA developed an objective algorithm to monitor the global distribution of snow cover from the DMSP Special Sensor Microwave/Imager. In addition, NOAA personnel began developing a method to blend in situ data with a near-surface global temperature product from the DMSP Special Sensor Microwave/Imager. This temperature product integrates measurements from the geostationary and polar-orbiting satellites' infrared bands.

EPA applied remotely sensed imagery, tools, and technologies to a wide range of environmental applications in FY 1996. EPA's Environmental Photographic Interpretation Center (EPIC) continued to utilize current and historical aerial photography to research and identify past and current hazardous waste and other environmental problems. EPIC produced hundreds of aerial photographic products per year on hazardous waste sites around the country. EPIC personnel participated in visualization research efforts that utilized a variety of tools and software, including NASA/JPL surveyor software for creating a video "fly-through" of specific areas of environmental study to support EPA's emphasis on community-based environmental protection.

In partnership with DoD, NASA, DoE, USGS, and the U.S. Fish and Wildlife Service, EPA managed a study of advanced remote-sensing techniques to detect wetlands under forest cover and also applied multiresolution land characterization data to a variety of environmental change detection problems such as water impacts, urbanization, and wetland losses. The multiresolution land characterization program continued to provide land cover data and has completed land cover mapping for a number of States in the Northeast. Scientists completed the global land cover characterization component of this project, using 1-kilometer AVHRR data, and a data set for the Western Hemisphere is available on the World Wide Web.

EPA scientists also conducted research using data from the North American Landscape Characterization data base to determine vegetation changes from 1970 to 1990. Researchers used data from the National Technical Mean data sets as a training and accuracy assessment tool in this process.

EPA's Office of Water analyzed thermal imagery of approximately 950 miles of river in three States in the Northwest, where deforested streambanks have contributed to warmer water temperatures that threaten declining salmon populations. Forward Looking Infrared Radiometer imagery, which detects general temperature patterns, cool groundwater seeps, and areas in which water becomes warmer, provided useful new information for river restoration and salmon habitat management.

EPA's Office of Water also participated in the intelligence community's Government Applications Task Force during FY 1996. Congress created this task force to demonstrate civilian environmental applications of advanced remote-sensing technology. The EPA project measured vegetation structure and topography in riparian zones to calculate the reduction in sunlight reaching the water surface. EPA personnel used the results to model and predict water temperature.

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

USGS continued to operate the National Satellite Land Remote Sensing Data Archive, as mandated by law. A key component of this archive is the data collected over the last 24 years by the Landsat satellites. USGS also began preparing for its role as the operations manager for the Landsat-7 Data Handling Facility. USGS delivered the suite of computer algorithms required for the geometric correction of Landsat-7 data.

In FY 1996, USGS completed its expansion of the EROS Data Center to provide facilities for installing and operating the computer equipment, data archives, and personnel required to receive, process, and distribute data from the EOS and Landsat-7 spacecraft. Delivery of initial equipment components began immediately after the new facility was occupied in April 1996.

DoI continued to cooperate with DoD to use the Navstar GPS PPS. DoI bureaus have purchased approximately 400 precision lightweight GPS receivers since 1995. Each DoI bureau now has the approval to purchase receivers for its authorized users, and DoI established a centralized facility in FY 1996 to service DoI receivers, including the periodic rekeying of the encrypted DoD GPS code. By accessing this code, DoI users obtain more accurate, real-time, on-the-ground geographic location information (approximately 10 meters horizontal accuracy) than is currently available using other GPS technology.

DoI used GPS technology in FY 1996 for a wide range of mapping, inventory, monitoring, and research activities. For example, the Fish and Wildlife Service used GPS for tracking the location of radio-tagged fish, determining the geographic coordinates of survey points, and documenting the locations of endangered species. Fish and Wildlife Service staff frequently worked in such remote areas that GPS was the only feasible means to determine locations.

The Bureau of Indian Affairs continued to use both Landsat and SPOT data and GPS technology for resource mapping (including land cover and land use, vegetation, fire fuels, irrigation networks, and transportation corridors), image mapping, environmental assessments, inventories, and other related GIS support activities. The analysis of both aerial photographs and satellite images directly supported programs in mineral resources, land and water, wildfire management, wildlife habitat, and hazardous material impacts across all lands managed by the bureau.

Remotely sensed data derived from satellites and aircraft and GPS technology continued to play an important role in efforts by the Bureau of Land Management to sustain the health, diversity, and productivity of public lands. The data provided critical information to resource specialists for inventory, assessment, modeling, and monitoring efforts. Bureau of Land Management personnel used aerial photographs and satellite images, supplemented by GIS and GPS technology, to support management activities related to wildlife habitat, wilderness, recreation, rangeland, timber, fire, minerals, and hazardous materials. The use of GPS and GIS technology for spatial data analysis was increased significantly by Bureau of Land Management field personnel because the bureau has implemented the Automated Land and Mineral Record System Modernization program.

During FY 1996, the Bureau of Reclamation used remotely sensed data in support of a number of water resource management projects. Reclamation staff used crop acreage information derived from Landsat TM and SPOT High Resolution Visible data as inputs to models of consumptive water use on rivers. They developed algorithms for estimating snow precipitation rates from the next-generation Doppler weather radar system. They also mapped in-channel and flooded bottomland habitat for endangered fish using large-scale aerial photographs, airborne videography, and thermal scanner images. Technicians mapped noxious wetland weeds with large-scale aerial photographs to evaluate the effectiveness of biological control programs.

The Fish and Wildlife Service increased its use of satellite image data over the past year. Service personnel used Landsat data to create baseline habitat maps in several diverse locations, such as Casco Bay, Maine; the

Delaware Bay area; southern Florida; Alaska; the Pacific Northwest; and the Montana prairie. In many cases, personnel used the habitat information to determine the suitability of the area for endangered species. The Fish and Wildlife Service continued to use satellite data and GPS to verify and update National Wetland Inventory map data.

The National Biological Service has been using Landsat TM and Multispectral Scanner, SPOT, and AVHRR data for a variety of mapping and research applications. This work included ongoing work in the Gap Analysis Program, land cover and change detection mapping in the upper Mississippi River area, the assessment of damage from Hurricane Andrew in Louisiana, an analysis of waterfowl winter habitats in California, and the use of AVIRIS data for estimating snow grain size, albedo, and liquid water content in surface snow in the Sierra Nevada.

The National Park Service's Alaska Field Area acquired and used data from satellite and aircraft platforms for several applications during FY 1996. A land cover mapping project began for Lake Clark National Park and Preserve using SPOT data. New 1:60,000 color-infrared aerial photographs of Glacier Bay National Park for assessing land-cover change were obtained through an agreement between NASA and the Forest Service. The National Park Service established an agreement with DoD to use classified satellite data for resource management applications.

In 1995, a Presidential Executive Order declassified more than 800,000 photographs taken during the 1960's and 1970's from intelligence satellites. These images offer views of the Earth's surface from space for a decade prior to the first Landsat satellite. The USGS EROS Data Center acquired copies of these photographs and began making copies of these images available to the public for the cost of reproduction. Users can access these images through a catalog on the World Wide Web that is accessible through the electronic USGS Global Land Information System.

Since 1992, USGS has conducted the Global Land 1-kilometer AVHRR Pathfinder project in cooperation with NASA, NOAA, the European Space Agency, and an international network of 31 AVHRR data-reception facilities. The network has collected more than 75,000 daily AVHRR observations and archived them at the EROS Data Center. Researchers produced an 18-month time series of cloud-free vegetation index composites for the Earth's land area. The EROS Data Center distributed approximately 1 terabyte of data on tape media and via electronic file transfer. One of the primary uses of the data set is to develop a baseline global land cover data set.

At the Smithsonian Institution's Center for Planetary Studies, researchers used SIR-C data to identify areas for detailed field investigations in Egypt. SIR-C had detected a network of ancient drainage that was not visible on the ground. In January 1996, researchers targeted an expedition to sample the Pleistocene sediments of this drainage network. After correcting the image data using GPS control points, researchers were able to target the location for trenches in the field to within 100 meters. Researchers began dating sediment from these rivers to determine when the climate changed from wet to its present hyperarid condition.

Atmospheric Studies

NASA launched a small spacecraft carrying a Total Ozone Monitoring Spectrometer (TOMS EP-1) in July 1996, and provided another TOMS instrument, which was launched as part of the Japanese Advanced Earth Observing Satellite (ADEOS) in August 1996. The two TOMS instruments began producing the data for continued ozone and ultraviolet trend determinations with improved resolution and precision. New analysis techniques developed for earlier TOMS data provided the first global data set on surface ultraviolet radiation. These results documented the first confirmation of global trends in increasing ultraviolet radiation related to stratospheric ozone depletion, and they provided the basis for improved health effects assessments.

Atmospheric ozone studies also indicated a promising response to policy actions such as the Montreal Protocol, a 1987 agreement that challenges its many international signatories to adopt rigorous environmental standards. NASA and NOAA ground-based measurements documented a continued decrease in the growth of ozone-depleting industrial chemicals in the lower atmosphere, confirming the industrial response to the Montreal Protocol. From these results, scientists expected stratospheric ozone to reach a minimum within the next decade and then begin to recover. In addition, NASA cooperated with private industry researchers to verify the environmental acceptability of the chlorofluorocarbon replacement chemicals. The Shuttle Solar Backscatter Ultraviolet instrument flew in early FY 1996, in support of the continuing mission to monitor the Earth's ozone status.

NASA's Upper Atmosphere Research Satellite successfully completed its fifth year in orbit. It continued to provide data to monitor upper atmospheric structure and variability, the response of the upper atmosphere to natural and human-induced changes, and the role of the upper atmosphere in climate variability.

Scientists developed an improved understanding of long-term climate variability, along with improved climate prediction skills, through studies of natural variability. Global observations by the Stratospheric Gas and Aerosol Experiment and the Earth Radiation Budget Experiment provided a unique understanding of the climate effects of the Mount Pinatubo volcanic eruption. The climate model also produced a prediction of the effects of Mount Pinatubo aerosol substances on surface temperatures, which definitely agreed with subsequent observations. This verification of skill in modeling the effects of aerosols on climate was a major accomplishment in global climate research.

The Optical Transient Detector completed its first year in orbit after uncovering tantalizing links between space-based lightning measurements and the intensity of severe storms. Launched on a private satellite, the orbiting detector produced the first high-quality images of lightning on a global scale, enabling researchers to use lightning flash rates as an aid in predicting tornado formation.

In addition, the United States and Japan signed an agreement on the Tropical Rainfall Measuring Mission in FY 1996. Technicians integrated the spacecraft and payload of five instruments and began testing.

Theseus, an innovative Uncrewed Aerial Vehicle being developed to support research in stratospheric ozone depletion and to validate satellite-based global environmental change measurements made by EOS, moved from the development to testing phase last spring. Theseus flew twice at NASA's Dryden Flight Research Center: on May 24, 1996, for 61 seconds, to an altitude of 60 feet, and again on July 1, 1996, for 1 hour 17 minutes, to an altitude of 8,999 feet.

The EOS Chemistry-1 mission, focusing on the effects of greenhouse gases on global climate, also proceeded on schedule toward a 2002 launch. Scientists conducted a special assessment study of possible cost reductions. This would be done through the aggressive pursuit of new technology and multiple spacecraft to implement the mission, while still maintaining the project's schedule. Project managers awarded 3-month cooperative agreements to eight commercial firms to explore the feasibility of jointly developing low-cost, mid-range spacecraft from existing or imminent product lines for use with the Chemistry suite of instruments.

NASA and NOAA hosted a meeting of the interagency Committee on Earth Observation Satellites to discuss the committee's role in developing an integrated global observing strategy. The meeting endorsed efforts to increase coordination in planning and implementing observing systems to meet shared objectives.

NOAA technicians removed the GOES-7 satellite from operational status in January 1996, after 9 years of uninterrupted service. GOES-9 replaced GOES-7 as the Western Hemisphere's geostationary satellite. Contingencies to bring GOES-7 back into operational status remained in place should the need arise.

The improved resolution and dynamic range of the GOES spacecraft allowed for the development of advanced image products and virtually real-time forecasting techniques. With the new generation of GOES, imagery was taken over the continental United States and coastal waters, Hawaii, and Alaska once every 15 minutes under normal operational modes and at approximately 7.5-minute intervals when severe weather threatened. In special cases, analysts obtained imagery over hurricanes at minute intervals and over tornado thunderstorms once every 30 seconds. This rapid scan imaging made a number of exciting new quantitative measurements and qualitative observations possible. Technicians installed a demonstration, evaluation, and training program that allows for the receipt and analysis of digital GOES imagery at more than 50 National Weather Service field offices. The capabilities to use digital GOES imagery significantly improved the use of satellite imagery for virtually real-time forecasting at those offices.

NOAA personnel also developed real-time experimental satellite products for quantitative precipitation forecast and flash flood prediction. The family of experimental products included precipitation estimates that covered the entire GOES image derived from the GOES-8 Automatic Flash Flood Precipitation Algorithm, precipitation efficiency analyses for detecting precipitable water plumes, and soil wetness indices for flooded areas and ground conditions prior to flash floods.

NOAA researchers began developing a gridded cloud product from the GOES-8/9 imager as a replacement for the sounder product. Other cloud-related research with GOES imager data included images to detect fog using temperature differences, aircraft icing risk images, and an aerosol optical thickness image.

In preparation for the upcoming launch of the NOAA-K satellite, software engineers prepared data formats for ground processing the NOAA-K instrument data and announced the availability of these formats to the user community. Technicians also completed much of the preprocessing software needed to support instrument data product processing.

Under the Shared Processing Network, NOAA's Information Processing Division served a key role in the interagency sharing of data products from the DoD and DoC environmental satellite programs. The Shared Processing Network allowed each of the Government's primary environmental data processing centers to access the satellite data bases located at the other centers. Specifically, DMSP and NOAA's POES program provided many data products.

In October 1996, NOAA's National Environmental Satellite, Data, and Information Service (NESDIS) began regularly producing an experimental version of the GOES infrared histogram program for the National Weather Service's Climate Prediction Center. This experimental version of the software collected GOES infrared data for 1-degree latitude/longitude areas (versus the operational 2.5-degree areas) for input into a global precipitation index.

The Global Climate Perspectives System is a scientific venture sponsored by NOAA's Office of Global Programs. In FY 1996, program scientists and technicians established complex quality control procedures, produced gridded global products, and published numerous scientific papers.

NOAA's Comprehensive Aerological Reference Data Set project completed the building of a database containing daily global upper air observations for the period 1948 to 1992. Program personnel combined data from approximately 20 sources to form this online data base.

NOAA personnel continued their work on the Trace Gas Project. Scientists collected global baseline trace gas data sets on carbon dioxide, methane, ozone, and chlorofluorocarbons. NOAA specialists also checked the data sets for quality control, placed them online, and archived them.

NOAA's Precipitation Metadata project continued to produce unbiased data sets of monthly rainfall and snowfall. Project personnel removed wind-induced turbulence biases by using data on gauge sites, gauge shields, and average monthly wind speeds.

NOAA's Surface Reference Data Center continued to support precipitation validation within the Global Precipitation Climatology project. This data center provided support to the project by collecting and validating precipitation data from test sites around the globe. Work during FY 1996 concentrated on the production of area-averaged validation data for all test sites, with the inclusion of precipitation/elevation adjustment algorithms.

The U.S. Historical Climatology Network is a joint project between DoE and NOAA. During FY 1996, project personnel updated the data set on a workstation-based system, improving efficiency and data handling capability.

The Global Historical Climatology Network is another cooperative data collection and quality assurance project between DoE and NOAA. Project personnel made significant headway in developing version 2, which is to include many more global stations extending back to the 19th century in its coverage of monthly temperature, precipitation, and pressure data. In FY 1996, network personnel released a temperature data set. In addition, they completed the development of the population metadata to assess global temperature trends that are free of urban heat island biases. Analysts developed a near real-time update and analysis system in FY 1996.

NOAA studies of the upper atmosphere using GPS data revealed the flow of areas of ionization in the low-latitude ionosphere. Analysts interpreted GPS signals from several satellites to infer the total electron content of the atmosphere between the ground and the satellite. Measurements from a variety of ground stations and satellites showed that the movement of these areas is controlled by the low-latitude electric fields, a critical parameter for space weather models. This turned out to be a new and exciting technique to monitor ionospheric parameters in a region that is very difficult to observe.

The ozone data set generated from NOAA and NASA Shuttle Solar Backscatter Ultraviolet instruments on NOAA operational satellites and the NASA Nimbus-7 was extended with the launch of the NOAA-14 satellite in FY 1996. An increased number of international researchers used these data, especially for ozone depletion analyses.

Researchers on the AVHRR project began to reprocess all the afternoon data sets from 1981 to 1995 with atmospheric parameter retrieval algorithms. These researchers processed a benchmark period of 18 months in 1987 and 1988 to yield cloud/clear radiances, total cloud amount, Earth radiation budget parameters, and aerosol optical thickness over oceans.

NOAA scientists made formulas available to international users for calculating near-real-time calibration updates for the visible and near-infrared channels of the AVHRR aboard the NOAA-14 spacecraft. Researchers in national space agencies, remote sensing laboratories, weather services, and academia began using the formulas, which were made available on the World Wide Web. Additionally, NOAA initiated an investigation of the feasibility of using the AVHRR to monitor the on-orbit performance of other meteorological satellite sensors.

NOAA scientists developed a fast and accurate procedure for calculating atmospheric spectral transmittances, which are used in satellite observations to determine atmospheric radiances. Researchers also developed a rapid cloud clearing and retrieval procedure for application in high-spectral-resolution observations. NASA personnel have used this as the initial step in the retrieval model for their Atmospheric Infrared Sounder. Additionally, NOAA scientists partially solved the problem of constructing consistent atmospheric data sets, such as temperature sets, from multiple satellite observations.

NOAA's National Climatic Data Center continued to develop global atlases for the marine, surface, and upper-air environments and basic data sets for distribution on CD–ROM. The activities include joint ventures with DoD, NOAA's Environmental Research Laboratories, USDA, and the National Renewable Energy Laboratory.

The National Climatic Data Center also created several new home pages to educate the public in the availability and potential benefits of using satellite data. The first is a general introduction to NOAA's satellite systems, data availability, and methods of access to data. The second is a significant events page, which links satellite images of various environmental phenomena such as hurricanes, fires, and volcanoes to surface charts, radar charts, and various other in-situ measurements. It also includes narrative analyses of the images, and observations, as well as basic classroom information such as how hurricanes are rated and how they form. In addition, the center published several technical reports on hurricanes and tropical storms and posted them on the World Wide Web.

At NSF, scientists made plans to construct a state-of-the-art Polar Cap Observatory at Resolute Bay, Canada, very close to the Earth's north magnetic pole. The centerpiece of this observatory will be a powerful upper atmospheric scatter radar supported by a complement of other radio and optical measurements. In preparation, researchers established an Early Polar Cap Observatory, which contains several optical and radar instruments from U.S. and Canadian scientists for studying the Earth's upper atmosphere. Important first results from the Early Polar Cap Observatory included observations from sensitive optical instruments of waves and tides in the upper atmosphere at heights around 90 kilometers. Scientists modeled unique auroral arc structures, seen only within the polar cap (known as Sun-aligned arcs) and identified by the sensitive remote-sensing instruments using a magnetosphere-ionosphere coupling model. Predictions of this model are in accord with both the satellite and ground observations of such arcs.

NSF continued to support the Global Positioning System-Meteorological (GPS-MET) proof-of-concept project. The demonstration system observed occulted GPS satellite signals received on a low-Earth-orbiting satellite, MicroLab-1. From raw GPS-MET observations, researchers retrieved vertical profiles of ray-bending angle and refractivity. Researchers then used these profiles to compute ionospheric electron density, neutral atmospheric density, pressure, temperature, and moisture profiles. GPS-MET has been exceptionally successful, having accomplished nearly all of its initial goals plus a number of new ones. As a result, NSF believes that GPS-MET technology has gained recognition as a strong candidate for a new, low-cost global observing system to support weather research and prediction, climate research and climate change detection, and ionospheric physics research.

Oceanographic Studies

The TOPEX/Poseidon satellite completed its fourth year of providing definitive data on the principal tidal components of the world's oceans. Understanding tidal patterns is critical in accurately assessing the effects of the oceans on global and regional climate patterns. TOPEX/Poseidon data have provided a precise description of global ocean circulation, a key element of climate change research. During FY 1996, NASA agreed with the French space agency to undertake a follow-on mission to the highly successful TOPEX/Poseidon satellite. The follow-on altimetry radar mission, "Jason-1," was scheduled for launch in 1999. The French space agency is to provide the spacecraft and altimeter, while NASA is to provide the radiometer, ground system, and launch.

Throughout FY 1996, TOPEX/Poseidon data challenged a fundamental oceanographic theory about the speed of large ocean waves—a finding that ultimately could revise science textbooks and improve global weather forecasting. The large-scale ocean waves, which span hundreds of miles from one wave crest to the next, are called "Rossby waves." Using data gathered by the satellite, scientists tracked the waves as they moved through the open ocean and determined that, at mid-latitudes, the Rossby waves were moving two to three times faster than previously thought. Rossby waves can alter currents and their corresponding sea-surface temperatures, thereby influencing the way the oceans release heat to the atmosphere and thus affecting weather patterns. This more precise information about how fast the waves travel may help forecasters improve their ability to predict the effects of El Niño events on weather patterns years in advance. The improved characterization of air-sea interaction was able to increase the forecasting skill for El Niños for the 1980s, compared with previous forecasting procedures. These results suggested that El Niño is more predictable than previously estimated.

NOAA implemented a second, more accurate TOPEX/Poseidon altimeter data stream in July 1996, taking advantage of an automated, near-real-time GPS tracking system operated at the Jet Propulsion Laboratory. NOAA made the resulting data available with a delay of about 2 days for research on global ocean circulation models, such as NOAA's El Niño model.

Additional new science results demonstrated the importance of the El Niño effects on climate and vegetation. Scientists used meteorological satellite data from 1982 to 1990 to document, for the first time, the link between El Niño rainfall perturbations and vegetation stress for Africa, Australia, and South America. The U.S. Aid Famine Early Warning System used the unique technique for identifying stressed vegetation as an early warning indicator of potential food supply problems in Africa.

The NASA Scatterometer was launched in August 1996 aboard the Japanese ADEOS satellite. This radar scatterometer is for sea-surface measurements and also provides measurements of ocean-surface winds in clear sky and cloudy conditions. Such information is valuable for understanding the interaction between the atmosphere and oceans, as well as for improving the prediction and tracking of severe storms.

NOAA scientists, engineers, and technicians moved toward implementing near-real-time ground-processing and delivery systems for SAR imagery from the Canadian RADARSAT satellite and for ocean color and wind measurements from the Japanese ADEOS spacecraft. NOAA is to process data from the NASA Scatterometer on ADEOS for NOAA meteorological and oceanographic models. Japan and Canada are to provide coastal U.S. coverage from the Ocean Color and Temperature Scanner on ADEOS as well as limited RADARSAT SAR imagery to NOAA's CoastWatch program for use in coastal environmental management and research. Researchers at a number of Government and academic laboratories began developing geophysical measurement algorithms for these sensors.

During FY 1996, CoastWatch personnel used near-real-time high-resolution satellite images from AVHRR to monitor the U.S. coastal environment. Products included sea-surface temperature imagery and visible imagery (useful for ice analysis and for the calculation of relative turbidity in estuaries).

NOAA's Laboratory for Satellite Altimetry has been generating near-real-time altimetry data from ESA's European Remote Sensing (ERS) satellite missions since November 1995. Utilizing predicted satellite orbits, sea-surface height information is generated automatically within 12 hours of acquisition and made available to select altimetry groups. These data are particularly suitable for large-scale oceanographic studies in western boundary currents.

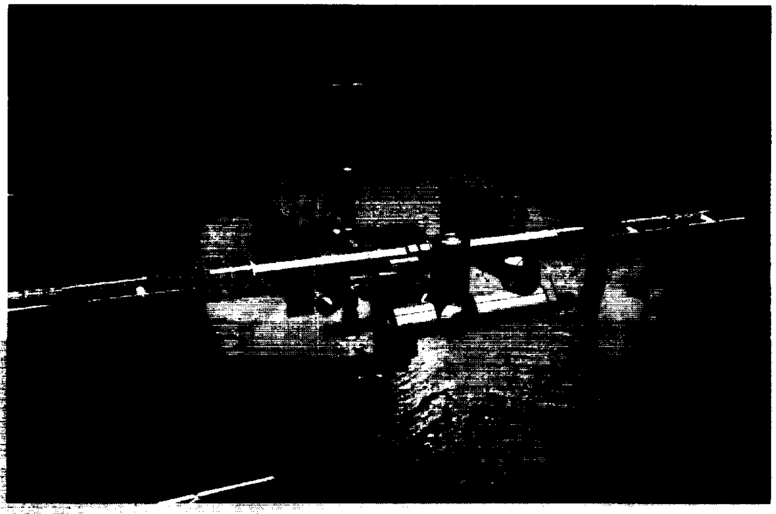
NOAA scientists constructed maps of high-resolution gravity fields that cover the world's oceans using Geosat (Geodetic and Geophysical Satellite) and ERS-1 satellite altimeter data. A comparison with ship tracks showed that these fields can resolve gravity anomalies down to wavelengths of about 25 kilometers. Because ship track coverage of the oceans is sparse, these gravity fields showed fine tectonic details of the sea floor that were previously undetected. Plate tectonic reconstructions constrained by fracture zones and plate boundaries visualized in these gravity maps revealed details of past plate motions. Researchers subsequently used this gravity field to predict sea floor topography by determining the gravity-topography transfer function in local areas via calibration to archival shipboard bathymetric surveys.

NOAA also derived new altimetric marine gravity fields from the ERS-1 geodetic mission data set for the polar oceans. This project to retrieve gravity measurements over ice-covered regions required the reprocessing of the full waveform telemetry data set to correct for errors in surface elevation measurements that occur over ice. This is a cooperative project with the Mullard Space Science Laboratory at the University College of London.

The Comprehensive Ocean-Atmosphere Data Set Project is a multiyear, multi-agency program funded by NOAA to provide an updated reference data set covering the world's ocean environment. FY 1996 accomplishments included the completion of the keying of 2 million ship observations for 1820 to 1860 and 1 million U.S. Merchant Marine observations for 1912 to 1946.

NESDIS scientists developed an experimental sea-surface temperature anomaly product. NESDIS researchers created this product by subtracting a newly developed satellite-only climatology from the current NOAA-14 analysis. Scientists used these products to identify anomalous features, including potential coral bleaching in the tropics (areas where temperatures are anomalously warm).

NOAA's National Marine Mammal Laboratory continued to use satellite tracking to monitor the movements of several species of marine mammals around the world. Specifically, this laboratory has documented the 20,000-kilometer round-trip movements of sea lions between Baja California and British Columbia, the habitat and behavior of Antarctic ice seals, threatened sea lions in Alaska and Russia, and areas within the high seas driftnet fisheries frequented by harbor porpoise in the Pacific Ocean.



This representative illustration shows U.S. international cooperation in space. Phase III of the International Space Station is depicted here in its completed/fully operational state, with elements from the United States, Europe, Canada, Japan, and Russia.

International Aeronautical and Space Activities

Cooperation With Foreign Partners

DoS and NASA continued negotiations on the formal agreements relative to the International Space Station (ISS). During FY 1996, DoS held five rounds of negotiations among the various partners on the ISS Intergovernmental Agreement. At the same time, NASA continued negotiations with the Russian Space Agency (RSA) on a bilateral memorandum of understanding, as well as with the other ISS partners—including Europe, Canada, and Japan—to reflect their specific contributions.

The U.S.-Russia Commission on Economic and Technological Cooperation, known more widely as the Gore-Chernomyrdin Commission, held its seventh meeting in Moscow in July 1996. At this meeting, NASA and RSA officials reached agreement on a memorandum of understanding to define mutual roles and responsibilities on the ISS program. NASA and RSA also agreed on schedule milestones for the early ISS elements, including the Russian-provided Service Module, the Russian-built FGB (functional cargo block) module, and the first U.S.-provided node module.

Following the Administration's new policy on GPS, DoS took the lead in consultations with other governments on developing guidelines for the use of GPS services. DoS led a U.S. Government delegation to Japan in August 1996 and anticipated further talks with Europe and Russia in FY 1997.

DoS also conducted negotiations with Canada on the training of Canadian mission specialists and on several scientific experiments on the Shuttle. On one Shuttle mission, a Canadian mission specialist tested a robotic seeing device, which is to be used to assemble the ISS.

During FY 1996, there was increased international activity related to the study of the Earth's system. In March 1996, under the auspices of the Committee of Earth Observation Satellites, NASA and NOAA hosted a meeting on the space component of an Integrated Global Observing Strategy, where space agencies and international organizations discussed strategies for assuring long-term global observations. The year was also highlighted by increasing international cooperation in NASA's MTPE program, especially with Japan. Through the year 2000, Japan represents more than 60 percent of the international contributions to MTPE. In October 1995, NASA and the National Space Development Agency of Japan (NASDA) signed the memorandum of understanding on the Tropical Rainfall Measuring Mission. In August 1996, NASDA launched its ADEOS spacecraft, carrying two instruments provided by NASA that are designed to measure global ocean-surface winds and atmospheric ozone content.

During FY 1996, cooperation with emerging civil space programs in Latin America significantly expanded. During a visit to Latin America, NASA Administrator Goldin and the president of Argentina's space agency (CONAE) signed the renewal of the NASA-CONAE framework agreement for civil space cooperation on February 29, 1996. In Brazil, Secretary of State Christopher and Brazilian Foreign Minister Lampreia signed a U.S.-Brazilian framework agreement on March 1, 1996, which marked a new phase of space cooperation; NASA and the civilian Brazilian space agency (established in 1994) are to implement this agreement. In Chile, Administrator Goldin continued to encourage Chilean government officials to follow the example of Argentina and Brazil and establish their own civilian space agency.

During February and March 1996, the first joint U.S.-Latin American experiment in crystal growth flew on the Space Shuttle. This experiment may pave the way for the development of effective pharmaceuticals to combat Chagas' disease, which currently affects 15 million people in Central and South America.

In addition to cooperation with Latin America, there were opportunities for expanded cooperation with other nontraditional partners. In April 1996, the chairman of the Indian Space Research Organization met with Administrator Goldin to discuss U.S. receipt of Indian meteorological data from INSAT satellites in near real time. In June 1996, the NASA Administrator and the science and technology minister of the Republic of Korea signed a space and Earth science cooperation framework that established two investigator consultative groups. As a followup to discussions between President Clinton and former Israeli Prime Minister Peres, a NASA delegation visited Israel in July 1996 for discussions with the Israeli space agency. The delegation also visited Tel Aviv University, Hebrew University, and the Desert Research Institute of Ben Gurion University. NASA and Israeli space officials identified the establishment of an EOSDIS node within Israel as an area of mutual interest.

The FAA's Associate Administrator for Commercial Space Transportation provided analytical and policy support to negotiations led by the U.S. Trade Representative to establish a commercial space launch trade agreement between the United States and Ukraine. The negotiations were completed in December 1995, and the agreement was signed on February 21, 1996. The FAA provided expertise for negotiations with Russia to modify the U.S.-Russia commercial space launch trade agreement, making its terms and provisions more compatible with those in the agreements with China and Ukraine. These negotiations were completed in January 1996, and the amendments were signed into force later that month.

In July 1996, the FAA supported the annual consultations with the People's Republic of China concerning the 1995 U.S.-Chinese commercial space launch trade agreement. In addition, the agency continued to serve as chair of the interagency working group on information responsible for monitoring foreign compliance with the U.S.-Chinese, U.S.-Russian, and U.S.-Ukrainian launch trade agreements.

Discussions Concerning Arms Control of Space-Related Weaponry

During FY 1996, the U.S. Arms Control and Disarmament Agency (ACDA) developed and implemented national and international policies relating to missiles and space. ACDA supported U.S. efforts to strengthen and expand the scope of the 28-member Missile Technology Control Regime (MTCR), which works to prevent the proliferation of missiles, space launch vehicles, and unmanned aerial vehicles capable of delivering weapons of mass destruction. The MTCR, the centerpiece of U.S. missile nonproliferation efforts, is the only multilateral nonproliferation and export control arrangement of its kind. During FY 1996, ACDA participated in MTCR discussions that covered regional proliferation issues for the first time. ACDA also worked on the U.S.-sponsored MTCR export control seminar on transshipment attended by both MTCR members and nonmembers who are key transshipment countries. ACDA worked on export control initiatives to aid new joint venture companies with various space launch programs and worked to ensure that U.S. export control policies were administered fairly. ACDA contributed to U.S. regional missile nonproliferation efforts, particularly in southern Asia and the Korean peninsula, to work toward the reduction and eventual elimination of offensive ballistic missile programs and to prevent the acquisition of such weapons from other countries. ACDA also supported the vigorous implementation of U.S. legislation requiring the imposition of sanctions on foreign entities that trade or attempt to trade in missiles or missile technology contrary to the MTCR, and was active in bringing about sanctions against entities in North Korea and Iran.

ACDA has continued its leadership of START treaty implementation policy regarding the use of intercontinental ballistic missiles and submarine-launched ballistic missiles as space launch vehicles in the Joint Compliance and Inspection Commission (JCIC). Since the signing of a September 1995 agreement, the parties to the treaty have been discussing the allocation of space launch facilities among the states of the former Soviet Union that are parties to the treaty and the application of the treaty's telemetry provisions to space launches that employ treaty-accountable space launch vehicles.

ACDA also has promoted the conversion of ballistic missiles and technology to nonweapons applications in its support to the DoD/DoC Ukraine Entrepreneurial Conference. This conference promoted joint ventures between U.S. and Ukrainian companies to convert military and aerospace technologies and facilities to commercial products.

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

Space and Public Diplomacy Abroad

As part of its mission to inform foreign publics of significant American achievements, the U.S. Information Agency (USIA) acquainted worldwide audiences with NASA activities through regular reporting of Space Shuttle flights in the daily *Washington File* and on Voice of America news broadcasts. Voice of America also did a live broadcast with astronauts during an Atlantis-*Mir* linkup.

The Worldnet television service brought live interviews with astronauts in space to audiences in Africa and Latin America. African-American astronaut Winston Scott, who carried a South African flag into space with him, spoke to a large gathering of high school students and government officials in Johannesburg during his flight in January 1996. In support of a space study program in South Africa's schools, the USIA post there distributed a large number of NASA-produced educational materials and organized a program for Scott to visit South African schools.

Worldnet also broadcast an interview from space with astronaut Franklin Chang Díaz to audiences in San José, Costa Rica, and Santiago, Chile. In addition to coverage on national news in both countries, the interview was broadcast live by cable networks throughout Chile, with a potential audience of more than 1 million people.

For every Shuttle docking with the space station *Mir*, USIA officers in Moscow, working with NASA Headquarters, sent media advisories to resident American journalists in Moscow and organized their access to the highly restricted Star City facility. This assistance resulted in regular U.S. television network coverage of the bilateral space program.

Worldnet's Newsfile series carried more than 100 stories featuring NASA activities during the year. Many of these received widespread placement on television stations around the world. USIA also continued to acquire independently produced video programs about NASA's work, such as "Exploring the World Beyond" and "Lift-off to Learning." USIA made these programs available to posts abroad in a variety of languages with all rights, including direct use on foreign television.

APPENDICES

The Galileo spacecraft provided this image of Europa, one of Jupiter's moons. Scientists believe that liquid water may once have existed, or even now exists, beneath Europa's crust.

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 *(through September 30, 1996)*	26	0	1	0
TOTAL	1,368	148	87	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 the 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.

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	26 [c]	19			1	2 [d]			9	1	
TOTAL	1,077	2,519	10	8	50	41	1	1	85	9	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, 1995–September 30, 1996

Launch Date Spacecraft Name COSPAR Designation Launch Vehicle	Mission Objectives	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
Oct. 20, 1995 Space Shuttle *Columbia* (STS-73) 56A Space Shuttle	Carry out microgravity experiments in the U.S. Microgravity Laboratory Spacelab.	~267 km 1 hour 30 minutes 39°	
Oct. 22, 1995 EHF-F6 (USA 114) (UFO-6) 57A Atlas II*	Military UHF communications.	27,571 km 277 km 7 hours 59 minutes 27°	
Nov. 4, 1995 RADARSAT 59A Delta II	Remote sensing.	790 km 785 km 1 hour 41 minutes 98.6°	Canadian spacecraft.
Nov. 4, 1995 SURFSAT 59B Delta II	Summer Undergraduate Research Fellowship Satellite.	1,495 km 935 km 1 hour 50 minutes 100.6°	Microsatellite to assist tests of Deep Space Network. Launched from second stage of Delta II.
Nov. 6, 1995 Milstar 2 (USA 115) 60A Titan IV	Military communications.	Geosynchronous	
Nov. 12, 1995 Space Shuttle *Atlantis* (STS-74) 61A Space Shuttle	Install Docking Module on the *Mir* space station and provide logistic support.	396 km 391 km 1 hour 32 minutes 51.6°	Second of 9 planned flights to Mir.
Dec. 2, 1995 SOHO 65A Atlas Centaur IIAS	Solar and Heliospheric Observatory on space physics mission.	Orbits the Sun	European Space Agency-NASA spacecraft to examine the Sun and its corona.
Dec. 5, 1995 USA 116 66A Titan IV	Classified military reconnaissance.	976 km 156 km 1 hour 36 minutes 97.8° (data estimated by Itar-Tass agency)	Reported to be member of Keyhole constellation.
Dec 14, 1995 Galaxy 3-R 69A Atlas IIA*	Commercial communications satellite.	Geosynchronous	

Successful Launches to Orbit on U.S. Launch Vehicles

October 1, 1995–September 30, 1996

Launch Date Spacecraft Name COSPAR Designation Launch Vehicle	Mission Objectives	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
Dec. 30, 1995 RXTE 74A Delta II	Rossi X-ray Timing Explorer, an astrophysics mission.	583 km 565 km 1 hour 36 minutes 22.9°	
Jan. 11, 1996 Space Shuttle *Endeavour* (STS-72) 1A Space Shuttle	Retrieve Japanese Space Flyer Unit; deploy and retrieve OAST Flyer.	459 km 176 km 1 hour 31 minutes 28.5°	Also carried microgravity and life sciences payloads.
Jan. 14, 1996 OAST Flyer 1B Space Shuttle	Small spacecraft sponsored by NASA's Office of Aeronautics and Space Technology.	307 km 303 km 1 hour 31 minutes 28.5°	Carried four experiments to measure spacecraft contamination, test GPS equipment, test amateur radio equipment, and analyze solar radiation effects on laser-fired ordnance devices.
Jan. 14, 1996 Koreasat-2 3A Delta II*	South Korean commercial communications satellite.	Geosynchronous	
Jan. 31, 1996 Palapa C-1 6A Atlas IIAS*	Indonesian commercial communications satellite.	Geosynchronous	
Feb. 17, 1996 NEAR 8A Delta II	Near Earth Asteroid Rendezvous spacecraft.	Not Earth-orbiting	Will orbit a major asteroid, Eros, and pass by another asteroid, 253-Mathilde. First spacecraft in NASA's Discovery program.
Feb. 22, 1996 Space Shuttle *Columbia* (STS-75) 12A Space Shuttle	Tethered Satellite System reflight; perform microgravity experiments using the U.S. Microgravity Payload (USMP-3).	294 km 294 km 1 hour 31 minutes 28.5°	
Feb. 24, 1996 Polar 13A Delta II	Polar-orbiting space physics satellite.	50,551 km 5,100 km 15 hours 38 minutes 85.9°	
Feb. 25, 1996 TSS-1R 12B Space Shuttle	Deployed and retrieve Tethered Satellite System.	Orbital parameters similar to STS-75	American/Italian satellite. Tether separated, resulting in early termination of experiments.

APPENDIX A-3

(Continued)

Successful Launches to Orbit on U.S. Launch Vehicles
October 1, 1995–September 30, 1996

Launch Date Spacecraft Name COSPAR Designation Launch Vehicle	Mission Objectives	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
Mar. 8, 1996 REX-II 14A Pegasus XL	Radiation Experiment 2.	832 km 801 km 1 hour 41 minutes 89.9°	Small military spacecraft.
Mar. 22, 1996 Space Shuttle *Atlantis* (STS-76) 18A Space Shuttle	Dock with *Mir* space station; transfer astronaut Shannon Lucid to *Mir*.	411 km 389 km 1 hour 33 minutes 51.6°	Third of 9 planned flights to *Mir*. Carried SPACEHAB with experiments and logistic support for *Mir*.
Mar. 28, 1996 GPS IIA (25) (USA 117) 19A Delta II	Global Positioning System navigation satellite.	20,282 km 20,078 km 11 hours 58 minutes 54.7°	
Apr. 3, 1996 INMARSAT 3-FL 20A Atlas IIA*	Communications satellite of international consortium.	Geosynchronous	
Apr. 24, 1996 MSX 24A Delta II*	Midcourse Space Experiment.	905 km 897 km 1 hour 44 minutes 99.3°	Military spacecraft designed to detect missile launches during "midcourse" phase.
Apr. 24, 1996 USA 118 26A Titan IV	Classified military payload.	Orbital parameters unavailable	
Apr. 30, 1996 SAX 27A Atlas I*	Satellite per Astronomia a raggi X.	603 km 583 km 1 hour 37 minutes 96.5°	Italian/Dutch celestial x-ray monitoring telescope.
May 12, 1996 USA 119 29A Titan IV	Classified military payload.	Orbital parameters unavailable	
May 12, 1996 USA 120 29B Titan IV	Classified military payload.	Orbital parameters unavailable	
May 12, 1996 USA 121 29C Titan IV	Classified military payload.	Orbital parameters unavailable	

Successful Launches to Orbit on U.S. Launch Vehicles
October 1, 1995–September 30, 1996

Launch Date Spacecraft Name COSPAR Designation Launch Vehicle	Mission Objectives	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
May 12, 1996 USA 122 29D Titan IV	Classified military payload.	Orbital parameters unavailable	
May 12, 1996 USA 123 29E Titan IV	Classified military payload.	Orbital parameters unavailable	
May 12, 1996 USA 124 29F Titan IV	Classified military payload.	Orbital parameters unavailable	
May 17, 1996 MSTI III 31A Pegasus*	Miniature Sensor Technology Integration spacecraft.	384 km 297 km 1 hour 31 minutees 97.0°	Military spacecraft to monitor baseline data on Earth's atmosphere and environment.
May 19, 1996 Space Shuttle *Endeavour* (STS-77) 32A Space Shuttle	Deploy SPARTAN/IAE and PAMS-STU; conduct microgravity experiments in the SPACEHAB.	287 km 278 km 1 hour 31 minutes 39.0°	See below for information on SPARTAN/IAE.
May 20, 1996 SPARTAN 207 32B Space Shuttle	Deploy IAE.	Orbital parameters similar to STS-77	Shuttle Pointed Autonomous Research Tool for Astronomy.
May 20, 1996 IAE 32C Space Shuttle/SPARTAN 207	Inflatable Antenna Experiment.	Orbital parameters similar to STS-77	
May 22, 1996 PAMS-STU 32D Space Shuttle	Passive Aerodynamically Stabilized Magnetically Damped Satellite–Shuttle Test Unit.	Orbital parameters similar to STS-77	Small experimental spacecraft.
May 24, 1996 Galaxy IX 33A Delta II*	Commercial communcitions satellite.	Geosynchronous	
Jun. 20, 1996 Space Shuttle *Columbia* (STS-78) 36A Space Shuttle	Perform life and microgravity experiments in the Spacelab module (LMS-1).	267 km 267 km 1 hour 30 minutes 39°	

Successful Launches to Orbit on U.S. Launch Vehicles

October 1, 1995–September 30, 1996

Launch Date Spacecraft Name COSPAR Designation Launch Vehicle	Mission Objectives	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
Jul. 2, 1996 TOMS 37A Pegasus XL	Total Ozone Mapping Spectrometer.	Sun-synchronous orbit 500 km 500 km 1 hour 38 minutes 97.4°	
Jul. 3, 1996 USA 125 38A Titan IV	Classified military surveillance spacecraft.	Orbital parameters unavailable	
Jul. 16, 1996 GPS IIA (26) (USA 126) 41A Delta II	Global Positioning System satellite.	20,365 km 20,272 km 12 hours 4 minutes 55.0°	
Jul. 25, 1996 EHF-F7 (UFO-7) 42A Atlas II*	Military communications satellite.	Geosynchronous	
Aug. 21, 1996 FAST 49A Pegasus XL	Fast Auroral Snapshot Explorer, an astrophysics spacecraft.	4,159 km 348 km 2 hours 13 minutes 83°	
Sep. 8, 1996 GE-1 54A Atlas IIA*	Commercial communications satellite	Geosynchronous	
Sep. 12, 1996 GPS IIA (27) (USA 128) 56A Delta II	Global Positioning System satellite.	33,649 km 17,055 km 15 hours 38 minutes 61.5°	
Sep. 16, 1996 Space Shuttle *Atlantis* (STS-79) 57A Space Shuttle	Dock with *Mir*, retrieve Shannon Lucid, and transfer John Blaha, experiments, and logistic support to *Mir*.	385 km 375 km 1 hour 32 minutes 51.6°	Fourth of 9 planned flights to *Mir*. Used SPACEHAB module.

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

U.S.-Launched Satellites
October 1, 1995–September 30, 1996

COMMUNICATIONS

Date	Name	Launch Vehicle	Remarks
Oct. 22, 1995	EHF-F6 (UFO-6)	Atlas II*	Military communications satellite.
Nov. 6, 1995	Milstar 2	Titan IV	Military communications satellite.
Dec. 14, 1995	Galaxy 3-R	Atlas IIA*	Commercial communications satellite.
Jan. 14, 1996	Koreasat-2	Delta II*	South Korean communications satellite.
Jan. 31, 1996	Palapa C-1	Atlas IIAS*	Indonesian communications satellite.
May 24, 1996	Galaxy IX	Delta II*	Commercial communications satellite.
Jul. 25, 1996	EHF-F7 (UFO-7)	Atlas II*	Military communications satellite.
Sep. 8, 1996	GE-1	Atlas IIA*	Commercial communications satellite.

EARTH OBSERVATION AND GEODESY

Date	Name	Launch Vehicle	Remarks
Nov. 4, 1995	RADARSAT	Delta II	Canadian spacecraft; small student spacecraft (SURFSAT) also flew.
May 17, 1996	MSTI III	Pegasus*	Military spacecraft to monitor baseline data on Earth's atmosphere and environment.
Jul. 2, 1996	TOMS	Pegasus XL	Total Ozone Mapping Spectrometer.

NAVIGATION

Date	Name	Launch Vehicle	Remarks
Mar. 28, 1996	GPS IIA (25)	Delta II	Global Positioning System satellite.
Jul. 16, 1996	GPS IIA (26)	Delta II	Global Positioning System satellite.
Sep. 12, 1996	GPS IIA (27)	Delta II	Global Positioning System satellite.

SCIENTIFIC

Date	Name	Launch Vehicle	Remarks
Nov. 4, 1995	SURFSAT	Delta II	Summer Undergraduate Research Fellowship Satellite. Small spacecraft designed to test aspects of the Deep Space Network. Launched from second stage of Delta II.
Dec. 30, 1995	RXTE	Delta II	Rossi X-ray Timing Explorer, an astrophysics spacecraft.
Jan. 11, 1996	OAST Flyer	Space Shuttle	Payload sponsored by NASA's Office of Aeronautics and Space Technology. "Mini-spacecraft" carrying four experiments.
Feb. 24, 1996	Polar	Delta II	Polar-orbiting spacecraft for space physics research.
Feb. 25, 1996	TSS-1R	Space Shuttle	Tethered Satellite System reflight. American/Italian experiment on electricity in space.
Mar. 8, 1996	REX-II	Pegasus XL	Second Radiation Experiment. Military "mini-spacecraft."
Apr. 24, 1996	MSX	Delta II*	Midcourse Space Experiment. Military spacecraft to detect missile launches during "midcourse" phase.
Apr. 30, 1996	SAX	Atlas I*	Satellite per Astronomia a raggi X. Italian/Dutch x-ray monitoring spacecraft.
May 20, 1996	SPARTAN 207	Space Shuttle	Used as platform to launch IAE.

APPENDIX B

(Continued)

U.S.-Launched Satellites

October 1, 1995–September 30, 1996

SCIENTIFIC (continued)

Date	Name	Launch Vehicle	Remarks
May 20, 1996	IAE	Space Shuttle/ SPARTAN 207	Inflatable Antenna Experiment. Reentered atmosphere after several orbits.
Aug. 21, 1996	FAST	Pegasus XL	Fast Auroral Snapshot Explorer, an astrophysics spacecraft.

SPACE PROBES

Date	Name	Launch Vehicle	Remarks
Dec. 2, 1995	SOHO	Atlas Centaur IIAS	Solar and Heliospheric Observatory, a joint ESA-NASA space physics spacecraft.
Feb. 17, 1996	NEAR	Delta II	Near Earth Asteroid Rendezvous spacecraft. Will orbit a major asteroid, Eros, and pass by another asteroid, 253-Mathilde. First spacecraft in NASA's Discovery program.

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

U.S. and Russian Human Space Flights

1961–September 30, 1996

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 (withVostok 6).
Vostok 6	June 16, 1963	Valentina V. Tereshkova	2:22:50	First woman in space; within 5 km of Vostok 5.
Voskhod 1	Oct. 12, 1964	Vladimir M. Komarov Konstantin P. Feoktistov Boris G. Yegorov	1:0:17	First three-person crew.
Voskhod 2	Mar. 18, 1965	Pavel I. Belyayev Aleksey A. Leonov	1:2:2	First extravehicular activity (EVA), by Leonov, 10 min.
Gemini 3	Mar. 23, 1965	Virgil I. Grissom John W. Young	0:4:53	First U.S. two-person flight; first manual maneuvers in orbit.
Gemini 4	June 3, 1965	James A. McDivitt Edward H. White, II	4:1:56	21-min. EVA (White).
Gemini 5	Aug. 21, 1965	L. Gordon Cooper, Jr. Charles Conrad, Jr.	7:22:55	Longest duration human flight to date.
Gemini 7	Dec. 4, 1965	Frank Borman James A. Lovell, Jr.	13:18:35	Longest human flight to date.
Gemini 6-A	Dec. 15, 1965	Walter M. Schirra, Jr. Thomas P. Stafford	1:1:51	Rendezvous within 30 cm of Gemini 7.
Gemini 8	Mar. 16, 1966	Neil A. Armstrong David R. Scott	0:10:41	First docking of two orbiting spacecraft (Gemini 8 with Agena target rocket).
Gemini 9-A	June 3, 1966	Thomas P. Stafford Eugene A. Cernan	3:0:21	EVA; rendezvous.
Gemini 10	July 18, 1966	John W. Young Michael Collins	2:22:47	First dual rendezvous (Gemini 10 with Agena 10, then Agena 8).
Gemini 11	Sep. 12, 1966	Charles Conrad, Jr. Richard F. Gordon, Jr.	2:23:17	First initial-orbit docking; first tethered flight; highest Earth-orbit altitude (1,372 km.).
Gemini 12	Nov. 11, 1966	James A. Lovell, Jr. Edwin E. Aldrin, Jr.	3:22:35	Longest EVA to date (Aldrin, 5 hrs.).
Soyuz 1	Apr. 23, 1967	Vladimir M. Komarov	1:2:37	Cosmonaut killed in reentry accident.
Apollo 7	Oct. 11, 1968	Walter M. Schirra, Jr. Donn F. Eisele R. Walter Cunningham	10:20:9	First U.S. three-person mission.
Soyuz 3	Oct. 26, 1968	Georgiy T. Beregovoy	3:22:51	Maneuvered near uncrewed Soyuz 2.
Apollo 8	Dec. 21, 1968	Frank Borman James A. Lovell, Jr. William A. Anders	6:3:1	First human orbit(s) of Moon; first human departure from Earth's sphere of influence; highest speed attained in human flight to date.
Soyuz 4	Jan. 14, 1969	Vladimir A. Shatalov	2:23:23	Soyuz 4 and 5 docked and transferred two cosmonauts from Soyuz 5 to Soyuz 4.
Soyuz 5	Jan. 15, 1969	Boris V. Volynov Aleksey A. Yeliseyev Yevgeniy V. Khrunov	3:0:56	
Apollo 9	Mar. 3, 1969	James A. McDivitt David R. Scott Russell L. Schweickart	10:1:1	Successfully simulated in Earth orbit operation of lunar module to landing and takeoff from lunar surface and rejoining with command module.

APPENDIX C

(Continued)

U.S. and Russian Human Space Flights

1961–September 30, 1996

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 LM as "lifeboat" until just before reentry.
Soyuz 9	June 1, 1970	Andriyan G. Nikolayev Vitaliy I. Sevastyanov	17:16:59	Longest human spaceflight 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 demon strated 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, 1996

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	Aleksay 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, 1996

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 cosmonaut	May 14, 1981	Leonid I. Popov Dumitru Prunariu	7:20:41	Docked with Salyut 6. Prunariu first Romanian 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 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, 1996

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	ladimir 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 Roben 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 Frances 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. Resnick 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).

APPENDIX C

(Continued)

U.S. and Russian Human Space Flights

1961–September 30, 1996

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 communi cations 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 A. 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, 1996

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. Cleve Sherwood C. Spring Jerry L. Ross Rudolfo Neri Vela Charles D. Walker	6:22:54	Twenty-third STS flight. Launched three com munications 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-Diaz Steve A. Hawley George D. Nelson Roger Cenker Bill Nelson	6:2:4	Twenty-fourth STS flight. Launched one com munications 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 Aleksandur Aleksandrov	9:20:13	Docked with *Mir* space station; Aleksandrov first Bulgarian in space. Crew returned Jun. 17 in Soyuz TM-4.
Soyuz TM-6	Aug. 29, 1988	Vladimir Lyakhov Valery Polyakov Abdul Mohmand	8:19:27	Docked with *Mir* space station; Mohmand first Afghanistani in space. Crew returned Sept. 7, in Soyuz TM-5.
Space Shuttle *Discovery* (STS-26)	Sep. 29, 1988	Frederick H. Hauck Richard O. Covey John M. Lounge David C. Hilmers George D. Nelson	4:1	Twenty-sixth STS flight. Launched TDRS 3.
Soyuz TM-7	Nov. 26, 1988	Aleksandr Volkov Sergey Krikalev Jean-Loup Chrétien	151:11	Docked with *Mir* space station. Soyuz TM-6 returned with Chrétien, Vladimir Titov, and Musa Manarov. Titov and Manarov completed 366-day mission Dec. 21. Crew of Krikalev, Volkov, and Valery Polyakov returned Apr. 27, 1989, in Soyuz TM-7.

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U.S. and Russian Human Space Flights

1961–September 30, 1996

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 Nomman 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-Diaz 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, 1996

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 Krikalevremained 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'Conner 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).

APPENDIX C

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U.S. and Russian Human Space Flights

1961–September 30, 1996

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 Artsebarsky in the TM-12 spacecraft.
Space Shuttle *Atlantis* (STS-44)	Nov. 24, 1991	Frederick D. Gregory Tom Henricks Jim Voss 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	Alexandr Viktorenko Alexandr 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 Alexandr Viktorenko and Alexandr 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, 1996

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-Diaz 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 Poleshchuk	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 com mercial payload module and retrieved European Retrievable Carrier in orbit since August 1992.

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U.S. and Russian Human Space Flights

1961–September 30, 1996

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 human 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 capabilitities 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-Diaz 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. 9, 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, 1996

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 atmos pheric 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	Alexsandr 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-Francois 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

1961–September 30, 1996

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 spaceflight. 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 microgravity 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).

APPENDIX C

(Continued)

U.S. and Russian Human Space Flights

1961–September 30, 1996

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-Diaz 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.

* *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)[l]	Solid	433.6 (SL)	1.01X11.16				
	2. Centaur II: RL10A-4 (2)	LOX/LH_2	92.53/engine	3.05x10.05				

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 14,110[e]	6,350[m]	—	1989, Titan IV
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	3.05x26.4				
2.	LR91-AJ-11	N204/A-50	462.8	3.05x10.0				
Titan IV/				4.3x62.2	—	5,760[n]	—	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/LH2	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]				

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.

i. Applies to Delta II-7925 version only.

j. Two Castor IVA motors ignited at lift-off. Two Castor IVA motors ignited at approximately 57 seconds into flight.

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

l. With Transfer Orbit Stage (TOS).

m. With appropriate upper stage.

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

o. 204-km circular orbit.

p. With Inertial Upper Stage or Transfer Orbit Stage.

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

Space Activities of the U.S. Government

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

FY	NASA Total	NASA Space[a]	DoD	Other[c]	DoE	DoC	DoI	USDA	NSF	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 [a]	...	...	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 [b]	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	707	46	430	35	37	147	6	6	24,790

* 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

Space Activities of the U.S. Government

BUDGET AUTHORITY IN MILLIONS OF EQUIVALENT FY 1996 DOLLARS
(adjusted for inflation)

FY	1996 Deflator	NASA Total	NASA Space	DoD	Other	DoE	DoC	DoI	USDA	NSF	DoT	EPA	Total Space
1959	5.1974	1,720	1,357	2,547	177	177	...	...	...	...	...	...	4,080
1960	5.0759	2,660	2,345	2,848	219	218	...	...	...	0.5	...	...	5,411
1961	5.0297	4,849	4,657	4,094	347	342	...	...	...	5	...	...	9,099
1962	4.9415	9,018	8,880	6,414	988	731	252	...	...	5	...	...	16,282
1963	4.8563	17,837	17,609	7,527	1,258	1,039	209	...	...	10	...	...	26,394
1964	4.7861	24,409	24,007	7,653	1,034	1,005	14	...	...	14	...	...	32,694
1965	4.6828	24,585	24,060	7,371	1,143	1,072	56	...	...	14	...	...	32,574
1966	4.5462	23,527	23,027	7,679	987	850	123	...	...	14	...	...	31,692
1967	4.3953	21,827	21,229	7,314	949	809	127	...	...	13	...	...	29,493
1968	4.2364	19,433	18,767	8,142	751	614	119	0.8	4	13	...	...	27,661
1969	4.0338	16,099	15,417	8,120	570	476	81	0.8	4	8	...	...	24,107
1970	3.8264	14,334	13,572	6,421	440	394	31	4	4	8	...	...	20,433
1971	3.6372	12,043	11,279	5,499	462	346	98	7	4	7	...	...	17,240
1972	3.4568	11,432	10,616	4,864	335	190	107	21	7	10	...	...	15,815
1973	3.2935	11,218	10,187	5,345	359	178	132	33	7	10	...	...	15,891
1974	3.0599	9,293	8,442	5,404	355	129	184	28	9	6	...	...	14,201
1975	2.7833	8,987	8,113	5,266	295	83	178	22	6	6	...	...	13,675
1976	2.5845	9,175	8,335	5,125	287	59	186	26	10	5	...	...	13,747
TQ*	2.4949	2,325	2,118	1,148	80	12	55	7	2	2	...	...	3,346
1977	2.3913	9,130	8,226	5,768	313	53	218	24	14	5	...	...	14,307
1978	2.2231	9,026	8,054	6,087	349	76	229	22	18	4	...	...	14,490
1979	2.0456	9,401	8,244	6,210	362	121	200	20	16	4	...	...	14,816
1980	1.8763	9,832	8,781	7,220	437	75	174	23	26	139	...	...	16,438
1981	1.7031	9,398	8,502	8,222	397	70	148	20	27	131	...	...	17,121
1982	1.5851	9,580	8,762	10,587	493	97	230	19	24	124	...	...	19,842
1983	1.5218	10,463	9,630	13,726	495	59	271	8	30	126	...	...	23,850
1984	1.4577	10,871	9,997	14,861	571	50	344	4	28	146	...	...	25,429
1985	1.4041	10,633	9,723	17,927	814	48	594	3	21	149	...	...	28,465
1986	1.3636	10,645	9,770	19,262	645	48	421	3	31	142	...	...	29,677
1987	1.3243	14,465	12,990	21,569	612	64	368	11	25	143	1	...	35,171
1988	1.2779	11,581	10,635	22,592	942	308	450	18	23	142	1	...	34,169
1989	1.2228	13,413	12,347	21,896	685	119	368	21	26	142	4	6	34,927
1990	1.1725	14,450	13,437	18,309	600	93	285	36	29	147	5	6	32,346
1991	1.1257	15,778	14,686	15,964	785	283	283	33	29	147	5	6	31,435
1992	1.0934	15,654	14,432	16,426	841	244	358	37	32	159	4	8	31,698
1993	1.0680	15,283	13,952	15,065	745	176	346	35	27	148	4	9	29,763
1994	1.0475	15,262	13,640	13,791	630	78	327	32	32	147	5	8	28,061
1995	1.0200	14,130	12,793	10,856	641	61	359	32	33	144	6	7	24,291
1996	1.0000	13,884	12,569	11,514	707	46	430	35	37	147	6	6	24,790

* Transition Quarter

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		
	1994 actual	1995 actual	1996 est.	1994 actual	1995 actual	1996 est.
NASA	13,022	12,543	12,569	12,363	12,593	12,694
Defense	13,166	10,644	11,514	10,973	11,494	11,353
Energy	74	60	46	83	70	46
Commerce	312	352	430	297	330	322
Interior	31	31	35	31	31	35
Agriculture	31	32	37	31	32	37
Transportation	5	6	6	4	5	6
EPA	8	7	6	8	7	7
NSF	140	141	147	139	140	143
TOTAL	26,789	23,816	24,790	23,929	24,702	24,643

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		
	1994 actual	1995 actual	1996 est.	1994 actual	1995 actual	1996 est.
NASA[a]	1,546	1,310	1,315	1,330	1,153	1,187
Defense[b]	6,848	7,196	6,792	7,203	7,132	6,974
Transportation[c]	2,309	2,212	2,052	2,604	2,870	2,676
TOTAL	10,703	10,718	10,159	11,137	11,155	10,837

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

SOURCE: Office of Management and Budget.

APPENDIX F-1

Office of Science and Technology Policy
National Security Council

March 29, 1996

FACT SHEET
U.S. GLOBAL POSITIONING SYSTEM POLICY

The President has approved a comprehensive national policy on the future management and use of the U.S. Global Positioning System (GPS) and related U.S. Government augmentations.

Background

The Global Positioning System (GPS) was designed as a dual-use system with the primary purpose of enhancing the effectiveness of U.S. and allied military forces. GPS provides a substantial military advantage and is now being integrated into virtually every facet of our military operations. GPS is also rapidly becoming an integral component of the emerging Global Information Infrastructure, with applications ranging from mapping and surveying to international air traffic management and global change research. The growing demand from military, civil, commercial, and scientific users has generated a U.S. commercial GPS equipment and service industry that leads the world. Augmentations to enhance basic GPS services could further expand these civil and commercial markets.

The basic GPS is defined as the constellation of satellites, the navigation payloads which produce the GPS signals, ground stations, data links, and associated command and control facilities which are operated and maintained by the Department of Defense; the Standard Positioning Service (SPS) as the civil and commercial service provided by the basic GPS; and augmentations as those systems based on the GPS that provide real-time accuracy greater than the SPS.

This policy presents a strategic vision for the future management and use of GPS, addressing a broad range of military, civil, commercial, and scientific interests, both national and international.

Policy Goals

In the management and use of GPS, we seek to support and enhance our economic competitiveness and productivity while protecting U.S. national security and foreign policy interests. Our goals are to:

- Strengthen and maintain our national security.
- Encourage acceptance and integration of GPS into peaceful civil, commercial, and scientific applications worldwide.
- Encourage private sector investment in and use of U.S. GPS technologies and services.
- Promote safety and efficiency in transportation and other fields.
- Promote international cooperation in using GPS for peaceful purposes.
- Advance U.S. scientific and technical capabilities.

Policy Guidelines

We will operate and manage GPS in accordance with the following guidelines:

- We will continue to provide the GPS Standard Positioning Service for peaceful civil, commercial, and scientific use on a continuous, worldwide basis, free of direct user fees.
- It is our intention to discontinue the use of GPS Selective Availability (SA) within a decade in a manner that allows adequate time and resources for our military forces to prepare fully for operations without SA. To support such a decision, affected departments and agencies will submit recommendations in accordance with the reporting requirements outlined in this policy.
- The GPS and U.S. Government augmentations will remain responsive to the National Command Authorities.
- We will cooperate with other governments and international organizations to ensure an appropriate balance between the requirements of international civil, commercial, and scientific users and international security interests.
- We will advocate the acceptance of GPS and U.S. Government augmentations as standards for international use.
- To the fullest extent feasible, we will purchase commercially available GPS products and services that meet U.S. Government requirements and will not conduct activities that preclude or deter commercial GPS activities, except for national security or public safety reasons.
- A permanent interagency GPS Executive Board, jointly chaired by the Departments of Defense and Transportation, will manage the GPS and U.S. Government augmentations. Other departments and agencies will participate as appropriate. The GPS Executive Board will consult with U.S. Government agencies, U.S. industries, and foreign governments involved in navigation and positioning system research, development, operation, and use.

This policy will be implemented within the overall resource and policy guidance provided by the President.

Agency Roles and Responsibilities

The Department of Defense will:

- Continue to acquire, operate, and maintain the basic GPS.
- Maintain a Standard Positioning Service (as defined in the Federal Radionavigation Plan and the GPS Standard Positioning Service Signal Specification) that will be available on a continuous, worldwide basis.
- Maintain a Precise Positioning Service for use by the U.S. military and other authorized users.
- Cooperate with the Director of Central Intelligence, the Department of State, and other appropriate departments and agencies to assess the national security implications of the use of GPS, its augmentations, and alternative satellite-based positioning and navigation systems.
- Develop measures to prevent the hostile use of GPS and its augmentations to ensure that the United States retains a military advantage without unduly disrupting or degrading civilian uses.

The Department of Transportation will:

- Serve as the lead agency within the U.S. Government for all Federal civil GPS matters.
- Develop and implement U.S. Government augmentations to the basic GPS for transportation applications.
- In cooperation with the Departments of Commerce, Defense, and State, take the lead in promoting commercial applications of GPS technologies and the acceptance of GPS and U.S. Government augmentations as standards in domestic and international transportation systems.
- In cooperation with other departments and agencies, coordinate U.S. Government-provided GPS civil augmentation systems to minimize cost and duplication of effort.

The Department of State will:

- In cooperation with appropriate departments and agencies, consult with foreign governments and other international organizations to assess the feasibility of developing bilateral or multilateral guidelines on the provision and use of GPS services.
- Coordinate the interagency review of instructions to U.S. delegations to bilateral consultations and multilateral conferences related to the planning, operation, management, and use of GPS and related augmentation systems.
- Coordinate the interagency review of international agreements with foreign governments and international organizations concerning international use of GPS and related augmentation systems.

Reporting Requirements

Beginning in 2000, the President will make an annual determination on continued use of GPS Selective Availability. To support this determination, the Secretary of Defense, in cooperation with the Secretary of Transportation, the Director of Central Intelligence, and heads of other appropriate departments and agencies, shall provide an assessment and recommendation on continued SA use. This recommendation shall be provided to the President through the Assistant to the President for National Security Affairs and the Assistant to the President for Science and Technology.

APPENDIX F-2

THE WHITE HOUSE
National Science and Technology Council

September 19, 1996

FACT SHEET
NATIONAL SPACE POLICY

Introduction

(1) For over three decades, the United States has led the world in the exploration and use of outer space. Our achievements in space have inspired a generation of Americans and people throughout the world. We will maintain this leadership role by supporting a strong, stable, and balanced national space program that serves our goals in national security, foreign policy, economic growth, environmental stewardship, and scientific and technical excellence. Access to and use of space are central for preserving peace and protecting U.S. national security as well as civil and commercial interests. The United States will pursue greater levels of partnership and cooperation in national and international space activities and work with other nations to ensure the continued exploration and use of outer space for peaceful purposes.

(2) The goals of the U.S. space program are to:
(a) Enhance knowledge of the Earth, the solar system, and the universe through human and robotic exploration;
(b) Strengthen and maintain the national security of the United States;
(c) Enhance the economic competitiveness and scientific and technical capabilities of the United States;
(d) Encourage State, local, and private sector investment in, and use of, space technologies;
(e) Promote international cooperation to further U.S. domestic, national security, and foreign policies.

(3) The United States is committed to the exploration and use of outer space by all nations for peaceful purposes and for the benefit of all humanity. "Peaceful purposes" allow defense and intelligence-related activities in pursuit of national security and other goals. The United States rejects any claims to sovereignty by any nation over outer space or celestial bodies, or any portion thereof, and rejects any limitations on the fundamental right of sovereign nations to acquire data from space. The United States considers the space systems of any nation to be national property with the right of passage through and operations in space without interference. Purposeful interference with space systems shall be viewed as an infringement on sovereign rights.

(4) The U.S. Government will maintain and coordinate separate national security and civil space systems where differing needs dictate. All actions undertaken by agencies and departments in implementing the national space policy shall be consistent with U.S. law, regulations, national security requirements, foreign policy, international obligations, and nonproliferation policy.

(5) The National Science and Technology Council (NSTC) is the principal forum for resolving issues related to national space policy. As appropriate, the NSTC and NSC will co-chair policy processes. This policy will be implemented within the overall resource and policy guidance provided by the President.

Civil Space Guidelines

(1) The National Aeronautics and Space Administration is the lead agency for research and development in civil space activities.

(2) NASA, in coordination with other departments and agencies as appropriate, will focus its research and development efforts in: space science to enhance knowledge of the solar system, the universe, and fundamental natural and physical sciences; Earth observation to better understand global change and the effect of natural and human influences on the environment; human space flight to conduct scientific, commercial, and exploration activities; and space technologies and applications to develop new technologies in support of U.S. Government needs and our economic competitiveness.

(3) To enable these activities, NASA will:
- (a) Develop and operate the International Space Station to support activities requiring the unique attributes of humans in space and establish a permanent human presence in Earth orbit. The International Space Station will support future decisions on the feasibility and desirability of conducting further human exploration activities.
- (b) Work with the private sector to develop flight demonstrators that will support a decision by the end of the decade on development of a next-generation reusable launch system.
- (c) Continue a strong commitment to space science and Earth science programs. NASA will undertake:
  - (i) a sustained program to support a robotic presence on the surface of Mars by the year 2000 for the purposes of scientific research, exploration, and technology development;
  - (ii) a long-term program, using innovative new technologies, to obtain in-situ measurements and sample returns from the celestial bodies in the solar system;.
  - (iii) a long-term program to identify and characterize planetary bodies in orbit around other stars;
  - (iv) a program of long-term observation, research, and analysis of the Earth's land, oceans, atmosphere, and their interactions, including continual measurements from the Earth Observing System by 1998.
- (d) In carrying out these activities, NASA will develop new and innovative space technologies and smaller, more capable spacecraft to improve the performance and lower the cost of future space missions.

(4) In the conduct of these research and development programs, NASA will:
- (a) Ensure safety on all space flight missions involving the Space Shuttle and the International Space Station.
- (b) Emphasize flight programs that reduce mission costs and development times by implementing innovative procurement practices, validating new technologies and promoting partnerships between government, industry, and academia.
- (c) Acquire spacecraft from the private sector unless, as determined by the NASA Administrator, development requires the unique technical capabilities of a NASA center.
- (d) Make use of relevant private sector remote sensing capabilities, data, and information products and establish a demonstration program to purchase data products from the U.S. private sector.
- (e) Use competition and peer review to select scientific investigators.
- (f) Seek to privatize or commercialize its space communications operations no later than 2005.

(g) Examine, with DoD, NOAA, and other appropriate Federal agencies, the feasibility of consolidating ground facilities and data communications systems that cannot otherwise be provided by the private sector.

(5) The Department of Commerce (DoC), through the National Oceanic and Atmospheric Administration (NOAA), has the lead responsibility for managing Federal space-based civil operational Earth observations necessary to meet civil requirements. In this role, DoC, in coordination with other appropriate agencies, will:
(a) acquire data, conduct research and analyses, and make required predictions about the Earth's environment;
(b) consolidate operational U.S. Government civil requirements for data products, and define and operate Earth observation systems in support of operational monitoring needs; and
(c) in accordance with current policy and Public Law 102-555, provide for the regulation and licensing of the operation of private sector remote sensing systems.

(6) The Department of the Interior, through the U.S. Geological Survey (USGS), will maintain a national archive of land remote sensing data and other surface data as appropriate, making such data available to the U.S. Government and other users.

(7) The Department of Energy will maintain the necessary capability to support civil space missions, including research on space energy technologies and space radiation effects and safety.

National Security Space Guidelines

(1) The United States will conduct those space activities necessary for national security. These activities will be overseen by the Secretary of Defense and the Director of Central Intelligence (DCI) consistent with their respective responsibilities as set forth in the National Security Act of 1947, as amended, other applicable law, and Executive Order 12333. Other departments and agencies will assist as appropriate.

(2) Improving our ability to support military operations worldwide, monitor and respond to strategic military threats, and monitor arms control and nonproliferation agreements and activities are key priorities for national security space activities. The Secretary of Defense and the DCI shall ensure that defense and intelligence space activities are closely coordinated and that space architectures are integrated to the maximum extent feasible, and will continue to modernize and improve their respective activities to collect against, and respond to, changing threats, environments, and adversaries.

(3) National security space activities shall contribute to U.S. national security by:
(a) providing support for the United States' inherent right of self-defense and our defense commitments to allies and friends;
(b) deterring, warning, and, if necessary, defending against enemy attack;
(c) assuring that hostile forces cannot prevent our own use of space;
(d) countering, if necessary, space systems and services used for hostile purposes;
(e) enhancing operations of U.S. and allied forces;
(f) ensuring our ability to conduct military and intelligence space-related activities;
(g) satisfying military and intelligence requirements during peace and crisis as well as through all levels of conflict;
(h) supporting the activities of national policy makers, the intelligence community, the National Command Authorities, combatant commanders and the military services, other Federal officials, and continuity of Government operations.

(4) Critical capabilities necessary for executing space missions must be assured. This requirement will be considered and implemented at all stages of architecture and system planning, development, acquisition, operation, and support.

(5) The Department of Energy, in coordination with DoD, ACDA, and the DCI will carry out research on and development of technologies needed to effectively verify international agreements to control special nuclear materials and nuclear weapons.

(6) Defense Space Sector Guidelines:

(a) DoD shall maintain the capability to execute the mission areas of space support, force enhancement, space control, and force application.

(b) In accordance with Executive Orders and applicable directives, DoD shall protect critical space-related technologies and mission aspects.

(c) DoD, as launch agent for both the defense and intelligence sectors, will maintain the capability to evolve and support those space transportation systems, infrastructure, and support activities necessary to meet national security requirements. DoD will be the lead agency for improvement and evolution of the current expendable launch vehicle fleet, including appropriate technology development.

(d) DoD will pursue integrated satellite control and continue to enhance the robustness of its satellite control capability. DoD will coordinate with other departments and agencies, as appropriate, to foster the integration and interoperability of satellite control for all governmental space activities.

(e) The Secretary of Defense will establish DoD's specific requirements for military and national-level intelligence information.

(f) The Secretary of Defense, in concert with the DCI, and for the purpose of supporting operational military forces, may propose modifications or augmentations to intelligence space systems as necessary. DoD may develop and operate space systems to support military operations in the event that intelligence space systems cannot provide the necessary intelligence support to DoD.

(g) Consistent with treaty obligations, the United States will develop, operate, and maintain space control capabilities to ensure freedom of action in space and, if directed, deny such freedom of action to adversaries. These capabilities may also be enhanced by diplomatic, legal, or military measures to preclude an adversary's hostile use of space systems and services. The United States will maintain and modernize space surveillance and associated battle management command, control, communications, computers, and intelligence to effectively detect, track, categorize, monitor, and characterize threats to U.S. and friendly space systems and contribute to the protection of U.S. military activities.

(h) The United States will pursue a ballistic missile defense program to provide for: enhanced theater missile defense capability later this decade; a national missile defense deployment readiness program as a hedge against the emergence of a long-range ballistic missile threat to the United States; and an advanced technology program to provide options for improvements to planned and deployed defenses.

(7) Intelligence Space Sector Guidelines:

(a) The DCI shall ensure that the intelligence space sector provides timely information and data to support foreign, defense, and economic policies, military operations, diplomatic activities, indications and warning, crisis management, and treaty verification, and that the sector performs research and development related to these functions.

(b) The DCI shall continue to develop and apply advanced technologies that respond to changes in the threat environment and support national intelligence priorities.

(c) The DCI shall work closely with the Secretary of Defense to improve the intelligence space sector's ability to support military operations worldwide.

(d) The nature, the attributable collected information, and the operational details of intelligence space activities will be classified. The DCI shall establish and implement policies to provide appropriate protection for such data, including provisions for the declassification and release of such information when the DCI deems that protection is no longer required.

(e) Collected information that cannot be attributed to space systems will be classified according to its content.

(f) These guidelines do not apply to imagery products, the protection of which is governed by Executive Order 12951.

(g) Strict security procedures will be maintained to ensure that public discussion of satellite reconnaissance by Executive Branch personnel and contractors is consistent with DCI guidance. Executive Branch personnel and contractors should refrain from acknowledging or releasing information regarding satellite reconnaissance until a security review has been made.

(h) The following facts are UNCLASSIFIED:

(i) That the United States conducts satellite photoreconnaissance for peaceful purposes, including intelligence collection and monitoring arms control agreements.

(ii) That satellite photoreconnaissance includes a near real-time capability and is used to provide defense-related information for indications and warning, and the planning and conduct of military operations.

(iii) That satellite photoreconnaissance is used in the collection of mapping, charting, and geodetic data and such data is provided to authorized Federal agencies.

(iv) That satellite photoreconnaissance is used to collect mapping, charting, and geodetic data to develop global geodetic and cartographic materials to support defense and other mapping-related activities.

(v) That satellite photoreconnaissance can be used to collect scientific and environmental data and data on natural or human-made disasters, and such data can be disseminated to authorized Federal agencies.

(vi) That photoreconnaissance assets can be used to image the United States and its territories and possessions.

(vii) That the United States conducts overhead signals intelligence collection.

(viii) That the United States conducts overhead measurement and signature intelligence collection.

(ix) The existence of the National Reconnaissance Office and the identification and official titles of its senior officials. All other details, facts, and products of intelligence space activities are subject to appropriate classification and security controls as determined by the DCI.

(x) Changes to the space intelligence security policy set forth in the national space policy can be authorized only by the President.

Commercial Space Guidelines

(1) The fundamental goal of U.S. commercial space policy is to support and enhance U.S. economic competitiveness in space activities while protecting U.S. national security and foreign policy interests. Expanding U.S. commercial space activities will generate economic benefits for the Nation and provide the U.S. Government with an increasing range of space goods and services.

(2) U.S. Government agencies shall purchase commercially available space goods and services to the fullest extent feasible and shall not conduct activities with commercial applications that preclude or deter commercial space activities except for reasons of national security or public safety. A space good or service is "commercially available" if it is currently offered commercially, or if it could be supplied commercially in response to a Government service procurement request. "Feasible" means that such goods or services meet mission requirements in a cost-effective manner.

(3) The United States will pursue its commercial space objectives without the use of direct Federal subsidies. Commercial sector space activities shall be supervised or regulated only to the extent required by law, national security, international obligations, and public safety.

(4) To stimulate private sector investment, ownership, and operation of space assets, the U.S. Government will facilitate stable and predictable U.S. commercial sector access to appropriate U.S. Government space-related hardware, facilities, and data. The U.S. Government reserves the right to use such hardware, facilities, and data on a priority basis to meet national security and critical civil sector requirements. Government space sectors shall:
- (a) Enter into appropriate cooperative agreements to encourage and advance private sector basic research, development, and operations while protecting the commercial value of the intellectual property developed.
- (b) Identify, and propose appropriate amendments to or the elimination of, applicable portions of U.S. laws and regulations that unnecessarily impede commercial space sector activities.
- (c) Consistent with national security, provide for the timely transfer of Government-developed space technology to the private sector in such a manner as to protect its commercial value, including retention of technical data rights by the private sector.
- (d) To the extent feasible, pursue innovative methods for procurement of space products and services.

(5) Free and fair trade in commercial space launch services is a goal of the United States. In support of this goal, the United States will implement, at the expiration of current space launch agreements, a strategy for transitioning from negotiated trade in launch services toward a trade environment characterized by the free and open interaction of market economies. The U.S. Trade Representative, in coordination with the Office of Science and Technology Policy and the National Economic Council, will develop a strategy to guide this implementation.

(6) Consistent with Executive Order 12046 and applicable statutes, U.S. Government agencies and departments will ensure that U.S. Government telecommunications policies support a competitive international environment for space-based telecommunications.

Intersector Guidelines

The following paragraphs identify priority intersector guidance to support major U.S. space policy objectives.

(1) International Cooperation

The United States will pursue and conduct international cooperative space-related activities that achieve scientific, foreign policy, economic, or national security benefits for the Nation. International agreements related to space activities shall be subject to normal interagency coordination procedures, consistent with applicable laws and regulations. U.S. cooperation in international civil space activities will:
- (a) Promote equitable cost-sharing and yield benefits to the United States by increasing access to foreign scientific and technological data and expertise and foreign research and development facilities;
- (b) Enhance relations with U.S. allies and Russia while supporting initiatives with other states of the former Soviet Union and emerging spacefaring nations;
- (c) Support U.S. technology transfer and nonproliferation objectives;
- (d) Create new opportunities for U.S. commercial space activities; and
- (e) Protect the commercial value of intellectual property developed with Federal support and ensure that technology transfers resulting from cooperation do not undermine U.S. competitiveness and national security.

(f) In support of these objectives:
   (i) NASA and the Department of State will negotiate changes in the existing legal framework for International Space Station cooperation to include Russia in the program along with the United States, Europe, Japan, and Canada; and
   (ii) NASA, in coordination with concerned U.S. Government agencies, will explore with foreign space agencies and international organizations the possible adoption of international standards for the interoperability of civil research spacecraft communication and control facilities.

(2) Space Transportation
 (a) Assuring reliable and affordable access to space through U.S. space transportation capabilities is fundamental to achieving national space policy goals. Therefore, the United States will:
   (i) Balance efforts to modernize existing space transportation capabilities with the need to invest in the development of improved future capabilities;
   (ii) Maintain a strong transportation capability and technology base to meet national needs for space transport of personnel and payloads;
   (iii) Promote reduction in the cost of current space transportation systems while improving their reliability, operability, responsiveness, and safety;
   (iv) Foster technology development and demonstration to support a future decision on the development of next-generation reusable space transportation systems that greatly reduce the cost of access to space;
   (v) Encourage, to the fullest extent feasible, the cost-effective use of commercially provided U.S. products and services that meet mission requirements; and
   (vi) Foster the international competitiveness of the U.S. commercial space transportation industry, actively considering commercial needs and factoring them into decisions on improvements to launch facilities and vehicles.
 (b) The Department of Transportation (DoT) is the lead agency within the Federal Government for regulatory guidance pertaining to commercial space transportation activities, as set forth in 49 U.S.C. 701, et seq., and Executive Order 12465. The U.S. Government encourages and will facilitate U.S. private sector and State and local government space launch and recovery activities.
 (c) All activities related to space transportation undertaken by U.S. agencies and departments will be consistent with PDD/NSTC-4.

(3) Space-Based Earth Observation
 (a) The United States requires a continuing capability for space-based Earth observation to provide information useful for protecting public health, safety, and national security. Such a capability contributes to economic growth and stimulates educational, scientific, and technological advancement. The U.S. Government will:
   (i) Continue to develop and operate space-based Earth observing systems, including satellites, instruments, data management, and dissemination activities;
   (ii) Continue research and development of advanced space-based Earth observation technologies to improve the quality and reduce the costs of Earth observations;
   (iii) Support the development of U.S. commercial Earth observation capabilities by:
   — pursuing technology development programs, including partnerships with industry;
   — licensing the operation and, as appropriate, the export of private Earth observation systems and technologies, consistent with existing policy;
   — providing U.S. Government civil data to commercial firms on a nondiscriminatory basis to foster the growth of the "value-added" data enhancement industry; and

— making use, as appropriate, of relevant private sector capabilities, data, and information products in implementing this policy.

(iv) Produce and archive long-term environmental data sets.

(b) The U.S. Government will continue to use Earth observation systems to collect environmental data and provide all U.S. Government civil environmental data and data products consistent with OMB Circular A-130, applicable statutes and guidelines contained in this directive.

(c) The U. S. Government will seek mutually beneficial cooperation with U.S. commercial and other national and international Earth observation system developers and operators, to:

(i) define an integrated global observing strategy for civil applications;

(ii) develop U.S. Government civil Earth-observing systems in coordination with other national and international systems to ensure the efficient collection and dissemination of the widest possible set of environmental measurements;

(iii) obtain Earth observation data from non-U.S. sources, and seek to make such data available to users consistent with OMB Circular A-130, national security requirements, and commercial sector guidance contained in the national space policy; and

(iv) support, as appropriate, the public, nondiscriminatory direct readout of data from Federal civil systems.

(d) The U.S. Government space sectors will coordinate and, where feasible, seek to consolidate Earth observation activities to reduce overlaps in development, measurements, information processing, and archiving where cost-effective and consistent with U.S. space goals.

(i) In accordance with PDD/NSTC-2, DoC/NOAA, DoD, and NASA shall establish a single, converged National Polar-Orbiting Environmental Satellite System to satisfy civil and national security requirements.

(ii) NASA, DoC/NOAA, DoD, the intelligence community, and DoE shall work together to identify, develop, demonstrate, and transition advanced technologies to U.S. Earth observation satellite systems.

(iii) In accordance with PDD/NSTC-3, NASA, DoC/NOAA, and DoI/USGS shall develop and operate an ongoing program to measure the Earth's land surface from space and ensure the continuity of the Landsat-type data set.

(iv) Consistent with national security, the U.S. Government space sectors shall continue to identify national security products and services that can contribute to global change research and civil environmental monitoring, and seek to make technology, products, and services available to civil agencies for such uses. Both unclassified and, as appropriate, classified data from national security programs will be provided through established mechanisms.

(4) Nonproliferation, Export Controls, and Technology Transfer

(a) The MTCR Guidelines are not designed to impede national space programs or international cooperation in such programs as long as such programs could not contribute to delivery systems for weapons of mass destruction. Consistent with U.S. nonproliferation policy, the United States will continue to oppose missile programs of proliferation concern, and will exercise particular restraint in missile-related cooperation. The United States will continue to retain a strong presumption of denial against exports of complete space launch vehicles or other MTCR Category I components.

(b) The United States will maintain its general policy of not supporting the development or acquisition of space launch vehicle systems in non-MTCR states.

(c) For MTCR countries, we will not encourage new space launch vehicle programs which raise questions from a proliferation and economic standpoint. The United States will, however, consider exports of MTCR-controlled items to MTCR countries. Additional safeguard measures could also be considered for such exports, where appropriate. Any exports would remain subject to the nontransfer provisions of the INF and START treaties.

(d) The United States will work to stem the flow of advanced space technology to unauthorized destinations. Executive departments and agencies will be fully responsible for protecting against adverse technology transfer in the conduct of their programs.

(e) In entering into space-related technology development and transfer agreements with other countries, Executive departments and agencies will take into consideration whether such countries practice and encourage free and fair trade in commercial space activities.

(5) Arms Control

The United States will consider and, as appropriate, formulate policy positions on arms control and related measures governing activities in space, and will conclude agreements on such measures only if they are equitable and effectively verifiable and enhance the security of the United States and our allies. The Arms Control and Disarmament Agency (ACDA) is the principal agency within the Federal Government for arms control matters. ACDA, in coordination with DoD, the DCI, State, DoE, and other appropriate Federal agencies, will identify arms control issues and opportunities related to space activities and examine concepts for measures that support national security objectives.

(6) Space Nuclear Power

The Department of Energy will maintain the necessary capability to support space missions which may require the use of space nuclear power systems. U.S. Government agency proposals for international cooperation involving space nuclear power systems are subject to normal interagency review procedures. Space nuclear reactors will not be used in Earth orbit without specific approval by the President or his designee. Such requests for approval will take into account public safety, economic considerations, international treaty obligations, and U.S. national security and foreign policy interests. The Office of Science and Technology Policy, in coordination with the NSC staff, will examine the existing approval process, including measures to address possible commercial use of space nuclear systems.

(7) Space Debris

(a) The United States will seek to minimize the creation of space debris. NASA, the intelligence community, and DoD, in cooperation with the private sector, will develop design guidelines for future Government procurements of spacecraft, launch vehicles, and services. The design and operation of space tests, experiments, and systems will minimize or reduce accumulation of space debris consistent with mission requirements and cost-effectiveness.

(b) It is in the interest of the U.S. Government to ensure that space debris minimization practices are applied by other spacefaring nations and international organizations. The U.S. Government will take a leadership role in international forums to adopt policies and practices aimed at debris minimization and will cooperate internationally in the exchange of information on debris research and the identification of debris mitigation options.

(8) Government Pricing

The price charged for the use of U.S. Government facilities, equipment, and services will be based on the following principles:

(a) Prices charged to U.S. private sector and State and local government space activities for the use of U.S. Government facilities, equipment, and services will be based on costs consistent with Federal guidelines, applicable statutes, and the commercial guidelines contained within the policy. The U.S. Government will not seek to recover design and development costs or investments associated with any existing facilities or new facilities required to meet U.S. Government needs and to which the U.S. Government retains title.

(b) Consistent with mission requirements, NASA and DoD will seek to use consistent pricing practices for facilities, equipment, and services.

(c) Tooling, equipment, and residual hardware on hand at the completion of U.S. Government programs will be priced and disposed of on a basis that is in the best overall interest of the United States while not precluding or deterring the continuing development of the U.S. commercial space sector.

GLOSSARY

AAS Advanced Automated System (program) (FAA)
ACDA Arms Control and Disarmament Agency
ACE ASOS Controller Equipment
ACO Advanced Concepts Office (NASA)
ACTS Advanced Communications Technology Satellite
ADEOS (Japanese) Advanced Earth Observing Satellite
ADS-B Automatic Dependent Surveillance–Broadcast
AGATE Advanced General Aviation Transport Experiment
AGO Automatic Geophysical Observatory
AMOS Air Force Maui Optical Site
anechoic Neither having nor producing an echo angle of attack. The acute angle of attack between the chord of an airfoil and its direction of motion relative to the air, often referred to as "alpha"; when an airfoil's exceeds the one that provides maximum lift, it goes into a stall, losing air speed and, potentially, the capability of the pilot to control the airplane.
ARC Ames Research Center (NASA)
ARTS Automated Radar Terminal System
ASOS Automated Surface Observing System
ASR-WSP Airport Surveillance Radar-Weather Systems Processor
AST Associate Administrator for Commercial Space Transportation (FAA)
ASTP Apollo-Soyuz Test Project
AST/RO Antarctic Submillimeter Telescope and Remote Observatory (CARA)
astronomical unit A measure for distances in space, equal to the mean distance of the Earth from the Sun—that is, 93,000,000 miles (149,599,000 kilometers)
ATLAS Atmospheric Laboratory for Applications and Science
ATM Asynchronous transfer mode (network)
AT&T American Telephone and Telegraph
ATV Automated Transfer Vehicle
AVHRR Advanced Very High Resolution Radiometer
AVIRIS Airborne Visible and Infrared Imaging Spectrometer
AXAF Advanced X-ray Astrophysics Facility

bioreactor An advanced tissue culturing apparatus
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
BMDO Ballistic Missile Defense Organization (formerly SDIO)
boreal Northern
BOREAS Boreal Ecosystem-Atmosphere Study
boundary layer A layer of fluid, close to the surface of a body placed in a moving stream, that is distinguishable from the main airflow by distinctive flow characteristics of its own caused by friction

CAMI Civil Aeromedical Institute (FAA)
CAN Cooperative Agreement Notice
canard An aircraft or aircraft configuration having its horizontal stabilizing and control surfaces in front of the wing or wings
CARA Center for Astrophysical Research in Antarctica (NSF)
carbon-carbon In one application, an improved form of disk brakes featuring carbon rotors and carbon stators in place of the beryllium formerly used
Cassini A Saturn orbiter/Titan probe
Category I An aircraft approach procedure that provides for approach to a height above touchdown of no less than 200 feet and with runway visual range of no less than 1,800 feet
Category II An aircraft approach procedure with a height no less than 100 feet and visual range no less than 1,200 feet
Category III An aircraft approach procedure involving no minimal decision height and three different minimal visual ranges—at least 700 feet for IIIA, 150 feet for IIIB, and no minimum visual range for IIIC
CD–ROM Compact Disk–Read Only Memory
CdZnTe Cadmium zinc telluride
CGRO Compton Gamma Ray Observatory
CIS Commonwealth of Independent States, a grouping of independent states formerly part of the Soviet Union
cm centimeter
CMB Cosmic Microwave Background (Anistrophy)
CMC Center for Macromolecular Crystallography (NASA)
CNES Centre National d'Etudes Spatiales—the French space agency
COBRA Cosmic Background Radiation Anistrophy (CARA experiment)
Comsat Communications Satellite Corporation
CONAE Acronym for Argentina's space agency
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
Cospas Russian acronym meaning Space System for Search of Vessels in Distress
CRISTA-SPAS Cryogenic Infrared Spectrometers and Telescopes for the Atmosphere-Shuttle Pallet Satellite
CRRES Combined Release and Radiation Effects Satellite
CSA Canadian Space Agency
cryogenic Very low in temperature
CTAS Center-TRACON Automation System

DARA Acronym for the German space agency
DARS Digital Audio Radio Services
dB Decibel
DBS Direct Broadcast Satellite
DCCR Display Channel Complex Rehost (FAA system)
DCI Director of Central Intelligence
DC-X Delta Clipper–Experimental
DC-XA Delta Clipper–Experimental Advanced
DFRC Dryden Flight Research Center (NASA)
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
DOLILU Day-of-Launch I-Load Update (system)
Doppler Shift The apparent change in wavelength of the radiation from a source due to its relative motion in the line of sight
DoS Department of State
DoT Department of Transportation
drag The force, produced by friction, that impedes a body's motion through a fluid
DSCS Defense Satellite Communication System
DSN Deep Space Network
DSP Defense Support Program
DSR Display System Replacement

EA Environmental assessment
EELV Evolved Expendable Launch Vehicle
EHF Extremely High Frequency; between 30,000 and 300,000 megacycles per second
electromagnetic spectrum A collective term for all known radiation, from the shortest-waved gamma rays through x-rays, ultraviolet, visible light, and infrared waves, to radio waves at the long-waved end of the spectrum
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
ELV Expendable Launch Vehicle
enthalpy The heat content of a system undergoing change
envelope The operational parameters within which an aircraft can fly
EOS Earth Observing System—a series of satellites, part of NASA's Mission to Planet Earth, being designed for launch at the end of the 1990's to gather data on global change
EOSAT Earth Observation Satellite Company
EOSDIS EOS Data and Information System
EPA Environmental Protection Agency
EPCO Earth Polar Cap Observatory (NSF)
EPIC Environmental Photographic Interpretation Center (EPA)
EROS Earth Resources Observation System (USGS)

ERS European Remote Sensing (satellite)
ERTS Earth Resources Technology Satellite (known as Landsat)
ESA European Space Agency
ET External Tank
EUMETSAT European Organisation for the Exploitation of Meteorological Satellites
EVA Extravehicular activity

F Fahrenheit
FAA Federal Aviation Administration
FAR Federal Acquisition Regulations
FAST Fast Auroral Snapshot Explorer
FBL Fly-by-light (avionics system)
FCC Federal Communications Commission
FGB Functional Cargo Block (for the International Space Station; acronym is from the Russian term)
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
FY Fiscal year

G or **g** A symbol used to denote gravity or its effects, in particular the acceleration due to gravity; used as a unit of stress measurement for bodies undergoing acceleration
galactic cosmic rays Cosmic rays with energy levels as high as tens of billions of electron volts and velocities approaching the speed of light
Galactic Halo An enigmatic distribution of older stars that appears key to understanding the formation of our galaxy
gamma rays The shortest of electromagnetic radiations, emitted by some radioactive substances
GATT General Agreement on Tariffs and Trade
GBS Global Broadcast Service
GEO Geosynchronous Earth orbit
Geosat Geodetic and Geophysical Satellite
geostationary Traveling about 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
GII Global Information Infrastructure
GIS Geographic Information System
GLOBE Global Learning and Observations to Benefit the Environment (program)
GMT Greenwich Mean Time
GOES Geostationary Operational Environmental Satellite
GPHS General purpose heat source
GPS Global Positioning System
GPS-MET GPS-Meteorological (experiment)
ground effect The temporary gain in lift during flight at very low altitudes caused by the compression of the air between the wings of an airplane and the ground
GSFC Goddard Space Flight Center (NASA)

Hall effect The development of a transverse electric field in a solid material when it carries an electric current and is placed in a magnetic field perpendicular to the current
HEDS Human Exploration and Development of Space
heliosphere The region of the Sun's influence, including the Sun and the interplanetary medium
high-alpha High angle of attack
high-bypass engine A turbo-engine having a bypass ratio of more than four to one, the bypass ratio being the proportion of air that flows through the engine outside the inner case to that which flows inside that case
HIV Human immunodeficiency virus
HPCC High Performance Computing and Communications (program)
HSCT High-speed civil transport
HSR High Speed Research (program)
HST Hubble Space Telescope
HT/MT Heavy Terminal/Medium Terminal (program)
hypersonic Faster than Mach 5; faster than "high speed"
hyper-spectral 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 (e.g., the Earth)

IAE Inflatable Antenna Experiment
IAIPT Interagency Integrated Product Team
ICAO International Civil Aviation Organization
IEOS International Earth Observing System
IITA Information Infrastructure Technology and Applications (component of HPCC)
INMARSAT International Mobile (formerly Maritime) Satellite Organization
Integrated modular avionics Aircraft-unique avionics cabinet that replaces multiple black boxes with shared common equipment and generic software
INSAT Indian Satellite (series)
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 exchange of electronic information

ionosphere That region of the Earth's atmosphere so named because of the presence of ionized atoms in layers that reflect radio waves and short-wave transmissions

IORD Integrated Operational Requirements Document

IPT Integrated Product Team

IRS-1B Indian Remote Sensing–1B (satellite)

ISO International Organization for Standardization

ISS International Space Station

ISTP International Solar Terrestrial Physics Program

ITCOP Interagency tracking, communications, and operations panel

ITU International Telecommunications Union; an intergovernmental organization founded in 1865 that became a specialized agency of the United Nations in 1947

IUS Inertial Upper Stage

IV&V Independent validation and verification

JACEE Japanese American Cosmic-ray Emulsion Chamber Experiment

JAST Joint Advanced Strike Technology (program) (DoD)

JCIC Joint Compliance and Inspection Commission (START)

JPL Jet Propulsion Laboratory (NASA)

JSC Johnson Space Center (NASA)

JSMB Joint Space management Board (DoD-CIA)

K-band Radio frequencies in the 20-gigahertz range

Ka-band A radio frequency in the 30-gigahertz range

KAO Kuiper Airborne Observatory

Kelvin Temperature scale in which absolute zero is 0° and water freezes at 273.16°

km Kilometer

KSC Kennedy Space Center (NASA)

Ku-band Radio frequencies in the 11-12 gigahertz range

Kuiper Airborne Observatory A NASA C-141 aircraft equipped with a 0.97-meter telescope

LACE Low-powered Atmosphere Compensation Experiment (DoD)

laminar Of fluid flow, smooth, as contrasted with turbulent; not characterized by crossflow of fluid particles

Landsat Land [remote sensing] Satellite; also known as ERTS, a series of satellites designed to collect information about the Earth's natural resources

LaRC Langley Research Center (NASA)

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 the Earth)

LeRC Lewis Research Center (NASA)

Lidar Light radar

LIDAR Light Intersection Direction and Ranging

lift The force exerted on an airfoil, such as a wing by a flow of air over and around it, causing it to rise perpendicularly to the direction of flight

LISS Linear Imaging Self-Scanning Sensor

LLWAS-NE Low Level Wind Shear Alert System-Network Expansion

LMS Life and Microgravity Spacelab

low-Earth orbit An orbit of the Earth approximately 100 to 350 nautical miles above its surface

LOX Liquid oxygen

LWIR Long-Wavelength Infrared

LWRHU Lightweight radioisotope heater unit

m Meter

M Mach number—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 mph or 1,192 kilometers per hour

Mach See M

Magellanic Clouds (Large and Small) Two small, irregular galaxies, the closest neighbors to the Milky Way, that are visible from the Southern Hemisphere.

Magellanic Stream A large filament of neutral hydrogen gas from the Milky Way's radio emission that originates at the Small Magellanic Cloud and extends almost one-third of the way around the sky

magnetosphere The region of the Earth's atmosphere where 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 the Earth's

maser Microwave Amplification by Simulated Emission of Radiation—a device introduced in 1953 with multiple applications in physics, chemistry, and radio and television communication

mesopause The layer of the Earth's atmosphere with the lowest temperature, from 50 to 53 miles (80 to 85 kilometers) up

mesosphere That portion of the Earth's atmosphere located 34 to 50 miles (55 to 80 kilometers) up, where temperature decreases with increasing altitude

METEOR Multiple Experiment to Earth Orbit and Return
Mode C transponder A radar beacon receiver/transponder capable of reporting the attitude of the aircraft aboard which it is installed
MOU Memorandum of Understanding
MSS Multispectral Scanner
MSTI Miniature Sensor Technology Integration (Air Force program)
MSX Midcourse Space Experiment (BMDO)
MTCR Missile Technology Control Regime
MTPE Mission to Planet Earth—a program developed by NASA and the world scientific community to provide scientists with data that will allow them to understand the planet as a total system and to measure the effects of the human population on it

NAS National Academy of Sciences
NASA National Aeronautics and Space Administration
NASCOM NASA Communications (network)
NASDA National Space Development Agency (of Japan)
NATO North Atlantic Treaty Organization
NBS National Biological Service (DoI)
NCAR National Center for Atmospheric Research
NCI National Cancer Institute (NIH)
NEAR Near Earth Asteroid Rendezvous
NEO Near-Earth Object
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
NIH National Institutes of Health
NOAA National Oceanic and Atmospheric Administration (DoC); also the designation of that administration's Sun-synchronous satellites in polar orbit
nominal Functioning as designed
NPSS Numerical Propulsion System Simulation
NRA NASA Research Announcement
NRL Naval Research Laboratory
NSF National Science Foundation
NSORS NOAA Satellite Ocean Remote Sensing (program)
NSPD National Space Policy Directive
NSTC National Science and Technology Council
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 TIROS, with other countries of the world
NTM National Technical Means
NWTC National Wind Tunnel Complex

OA Office of Aerospace (DoC)
OASC Office of Air and Space Commercialization (DoC)
OAST Office of Aeronautics and Space Technology (NASA)
ODC Ozone-depleting chemical
ODERACS Orbital Debris Radar Calibration Spheres (payload)
OMB Office of Management and Budget
OMS Operations Management System
on-orbit In orbit
order of magnitude An amount equal to ten times a given value; thus if some quantity was ten times as great as another quantity, it would be an order of magnitude greater; if one hundred times as great, it would be larger by two orders of magnitude
ORFEUS Orbiting and Retrievable Far and Extreme Ultraviolet Spectrograph
OSS Office of Space Science (NASA)
OSTA Office of Space and Terrestrial Applications (NASA)
OSTP Office of Science and Technology Policy (White House)
OTD Optical Transient Detector

PAMS-STU Passive Aerodynamically Stabilized Magnetically Damped Satellite/Satellite Test Unit
PAS PanAmSat (acronym for satellites)
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
PBW Power-by-wire (avionics system)
PCA Propulsion Controlled Aircraft
petrology The science that deals with the origin, history, occurrence, structure, and chemical classification of rocks
photogrammetry The science or art of obtaining reliable measurements by means of photography
piezoelectricity The property exhibited by some asymmetrical crystalline materials that, when subjected to strain in suitable directions, develop polarization proportional to the strain
pixels Short for "picture elements," which provide image resolution in vidicon-type detectors display; bright, granular areas in the chromosphere of the Sun
plasma A gas formed when one or more negatively charged electrons escape from an atom's positively charged nucleus, creating an electrically neutral gas composed of positive and negative particles; because it is ionized, plasma interacts with electric and magnetic fields; approximately 99 percent of matter in the universe is thought to be in the plasma state
plasma sheet An extensive area of low-energy, ionized gases in the tail region of the magnetosphere that undergoes considerable change during magnetospheric storms

POAM Polar Ozone and Aerosol Measurement

POES Polar-orbiting Operational Environmental Satellite (program)

polar orbit The path of an Earth satellite that passes near or over the North and South Poles

power-by-wire The use of electrical power, in place of hydraulics, to move the control surfaces of an aircraft via electromechanical actuators

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

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

RADARSAT Canadian radar satellite

ramjet A jet engine with no mechanical compressor, consisting of specially shaped tubes or ducts open at both ends, the air necessary for combustion being shoved into the duct and compressed by the forward motion of the engine

real-time Immediate, as an event is occurring

red shift Shift of spectral lines toward the red end of the spectrum, indicating motion away from the observer in the lines of sight

resolution With reference to satellites, a term meaning the ability to sense an object; thus, an 80-meter resolution indicates the ability to detect an object of at least 80 meters in diameter

REX Radiation Experiment

Reynolds number A nondimensional parameter representing the ratio of the momentum forces to the viscous forces about a body in fluid flow, named for English scientist Osborne Reynolds (1842–1912); among other applications, the ratio is vital to the use of wind tunnels for scale-model testing, as it provides a basis for extrapolating the test data to full-sized test vehicles

RFP Request for Proposals

RLV Reusable Launch Vehicle

RME Relay Mirror Experiment (satellite) (DoD)

RMS Remote Manipulator System—a remotely controlled arm, developed by Canada and controlled from the orbiter crew cabin, used for deployment and/or retrieval of payloads from the orbiter payload bay

ROSAT Roentgen Satellite

RSA Russian Space Agency

RTCA (formerly the Radio Technical Commission for Aeronautics)

RTG Radioisotope thermoelectric generator

RXTE Rossi X-ray Timing Explorer

s second

SA Selective Availability

SABER Situational Awareness Beacon with Reply (system) (Navy)

SAMPEX Solar, Anomalous, and Magnetospheric Particle Explorer

SAO Smithsonian Astrophysical Observatory

SAR Synthetic aperture radar

SAX Satellite per Astronomia a raggi X (Italian/Dutch celestial X-ray monitoring telescope)

SBS Satellite Business Systems

scramjet Supersonic-combustion ramjet

SDIO Strategic Defense Initiative Organization; see BMDO

SIR Shuttle Imaging Radar

SLS Spacelab Life Sciences (payload)

S&MA Safety and Mission Assurance

SMA Surface Movement Advisor

SOHO Solar and Heliospheric Observatory

solar flare A sudden, intense brightening of a portion of the Sun's surface, often near a sunspot group; these flares, enormous eruptions of energy that leap millions of miles from the Sun's surface, pose a potential radiation hazard to humans in space

solar maximum The period in the roughly 11-year cycle of solar activity when the maximum number of sunspots is present

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

SPAS Shuttle Pallet Satellite

SPIREX South Pole Infrared Explorer

SPOT Satellite Pour l'Observation de la Terre (French satellite for the observation of the Earth)

SPS Standard Positioning Service

squitter Transmitter for aircraft navigation and traffic control signals

SR&QA Safety, reliability, and quality assurance

SRB Solid Rocket Booster

SRL Space Radar Laboratory

SRM Solid Rocket Motor

SRM Solid Rocket Motor Upgrade

SSBUV Shuttle Solar Backscatter Ultraviolet (spectrometer)

SSCE Solid Surface Combustion Experiment

SSME Space Shuttle Main Engine

SSTO Single-stage-to-orbit

stall A loss of lift by an aircraft or airfoil resulting from insufficient air speed or excessive angle of attack

STARS Standard Terminal Automation Replacement System
START Strategic Arms Reduction Treaty
STEP Space Test Experiments Platform
Stirling engine *or* **generator** One in which work is performed by the expansion of gas at high temperature to which heat is supplied through a wall
STOL Short Takeoff and Landing
STOVL Short Takeoff and Vertical Landing (aircraft)
stratosphere The atmospheric zone 12 to 31 miles (20 to 50 kilometers) up, exhibiting increased temperature with increased altitude
STS Space Transportation System
STSC Scientific and Technical Subcommittee (of COPUOS)
sunspot A vortex of gas on the surface of the Sun associated with stray local magnetic activity
super high frequency Any frequency between 3,000 and 30,000 megacycles per second
supernova An exceptionally bright nova (a variable star whose brightness changes suddenly) that exhibits a luminosity ranging from 10 million to 100 million times that of our Sun
SURFSAT Summer Undergraduate Research Fellowship Satellite

TCE Trichloroethylene
TDRS Tracking and Data Relay Satellite
TDRSS TDRS System
Telstar AT&T satellite series
teraFLOPS 10^{12} floating point operations per second
TFE Thermionic Fuel Element
thermionics A field of electronics that uses electrical current passing through a gaseous medium (vacuum tube) instead of a solid state (semi-conductor), permitting use in high-temperature and radiation environments in which other electronic devices fail
thermosphere The atmospheric zone beginning about 53 miles (85 kilometers) up and characterized by a significant rise in temperature with increased altitude
thrust-vectoring system A system on a jet engine to vary the direction of its exhaust nozzles to change the direction of the thrust
TiPS Tether Physics and Survivability (experiment)
TIROS Television and Infrared Operational Satellite
TM (Landsat) Thematic Mapper (instrument)
TOMS Total Ozone Mapping Spectrometer
TOPEX/Poseidon Ocean Topography Experiment
torus A doughnut-shaped figure
TOS Transfer Orbit Stage
TOVS TIROS Operational Vertical Sounder
TRACON Terminal radar control
troposphere That portion of the atmosphere about 7 to 10 miles (11 to 16 kilometers) up where clouds form and convection is active
TRMM Tropical Rainfall Measuring Mission
TSS Tethered Satellite System
TWA Trans World Airline

UARS Upper Atmosphere Research Satellite
UFO UHF Follow-On
UHF Ultra High Frequency; any frequency between 300 and 3,000 megacycles per second
U.S. United States
USAF U.S. Air Force
U.S.C. U.S. Code
USDA U.S. Department of Agriculture
USGS U.S. Geological Survey (DoI)
USIA U.S. Information Agency
USML U.S. Microgravity Laboratory
USMP U.S. Microgravity Payload
USSR Union of Soviet Socialist Republics
USTR U.S. Trade Representative

VAFB Vandenberg Air Force Base
VHF Very High Frequency; any radio frequency between 30 and 300 megacycles per second
viscosity Resistance to flow or change of shape under pressure
VLBA Very Long Baseline Array; a set of 10 radio telescopes in the continental United States, Hawaii, and St. Croix
VNTSC Volpe National Transportation Systems Center (DoT)
VOA Voice of America
vortices Circular patterns of air created from lift generated by the wings (or rotor) of an aircraft or helicopter; the vortices from one aircraft may pose a hazard to following aircraft
VSCS Voice Switching and Control System
VSRA V/STOL System Research Aircraft
V/STOL Vertical/Short Takeoff and Landing

WAAS Wide Area Augmentation System
WCL Water Conservation Laboratory (USDA)
white dwarf Any of a class of faint stars, characterized not only by low luminosity but by masses and radii comparable to that of our Sun
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

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