Aeronautics and Space Report of the President

Fiscal Year 1993 Activities

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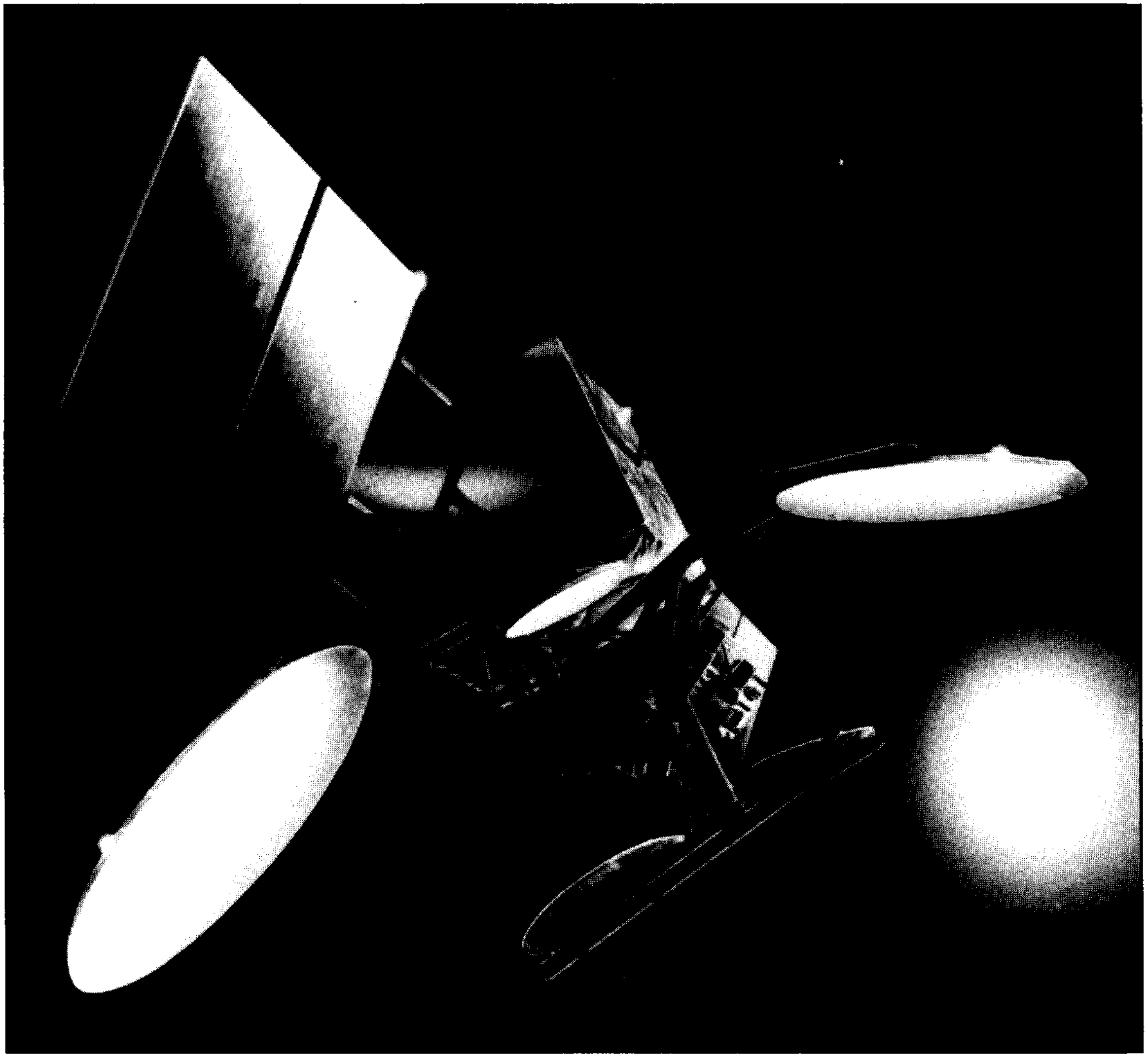
and Space Administration
Washington, DC 20546



Artist's conception of the Advanced Communications Technology Satellite (ACTS) in orbit.

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Executive Summary

Note: 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." This year's report (like last year's) has been prepared on a fiscal year basis, consistent with the budgetary period now used in programs of the Federal Government. The Administration is continuing to work with Congress to amend the National Aeronautics and Space Act of 1958 accordingly.

Fiscal Year (FY) 1993 brought numerous important changes and developments in U.S. aeronautics and space efforts. It included seven Space Shuttle missions and 14 Government launches of Expendable Launch Vehicles (ELVs) carrying a variety of payloads ranging from Global Positioning System (GPS) satellites to those with classified missions. In addition, there were four commercial launches from Government facilities with the Department of Transportation's Office of Commercial Space Transportation providing regulatory oversight and inspection for them and for one other commercial launch. Highlights of the Shuttle missions for the fiscal year included deployment of the Laser Geodynamic Satellite (LAGEOS II), a cooperative endeavor of the U.S. and Italy to obtain precise measurements of the Earth's crustal movement and gravitational field; a mission to study the composition of the Earth's atmosphere, ozone layer, and elements thought to be the cause of ozone depletion via the second Atmospheric Laboratory for Applications and Science (ATLAS); and deployment and retrieval of the German-built Orbiting and Retrievable Far and Extreme Ultraviolet Spectrometer-Shuttle Pallet Satellite (ORFEUS-SPAS), which spent six days in free flight, studying emissions of ultraviolet radiation from deep space. The ELV missions launched 7 GPS satellites; the Navy's second UHF Follow-on (UFO-2) communications satellite; the Array of Low Energy X-ray Imaging Sensors (ALEXIS) satellite to test technology for detecting ultrasoft x-rays emitted from space nuclear testing and to examine ionospheric distortion of VHF radio signals; and a Defense Satellite Communications System (DSCS) III to provide worldwide, secure, uninterrupted communications capability, among other satellites. The year also brought a redesign of the Space Station to reduce costs while retaining participation of the International Partners and adding that of Russia. In aeronautics, efforts included the development of new and improved technologies to improve performance and reduce costs as well as to increase safety and reduce engine noise. In the Earth sciences, a variety of programs across several agencies sought better understanding of global change and enhancement of the environment. In these and other areas discussed below, the 14 Federal agencies involved in aeronautics and space activities have contributed to advancing the Nation's scientific and technical knowledge and furthering an improved quality of life on Earth through greater knowledge, a more competitive economy, and a healthier environment.

National Aeronautics and Space Administration (NASA)

NASA continued in FY 1993 to advance the nation's aeronautical and space goals in a number of different areas. In space science, one of the most significant findings of the year was the recording by NASA's Voyagers 1 and 2, launched in 1977, of the first direct evidence of the long-sought-after heliopause—the boundary separating the Earth's solar system from interstellar space. Also important, precise measurements made by the Cosmic Background Explorer's Far Infrared Absolute Spectrophotometer indicate that 99.97 percent of the early radiant energy of the universe was released within the first year after the Big Bang, widely believed to have started the expansion of the universe about 15 billion years ago. The Hubble Space Telescope, NASA's first Great Observatory launched in April 1990, continued its string of important discoveries despite flaws in its primary mirror. Among many other achievements of astronomers working with HST was the measurement of the distance of the spiral galaxy M81 as 11 million light years, a major step in determining the age of the universe.

Within the solar system, NASA's Magellan spacecraft, launched in May 1989, having successfully completed its original mission of radar-mapping the planet, began collecting data on Venus' gravity. However, its highly elliptical orbit blurred its measurements at the furthest distances from the planet. To slow the spacecraft and circularize the orbit, NASA engineers began a slow process of aerobraking using Venus' atmosphere. This procedure, never used before on a NASA planetary mission, placed Magellan in a position to profile the planet's gravity at the mid- and higher latitudes and poles to give scientists a better picture of Venus' interior. Unfortunately, a NASA mission to the red planet, the Mars Observer, ceased communicating with Earth on August 21, 1993, shortly before it was set to enter Mars orbit on August 24. To determine what caused the loss of communication, a Mars Observer Investigation Board began meeting in September 1993 and presented its findings early in FY 1994. NASA's research into the role of gravity on living systems continued to play a critical role in understanding and mitigating the effects of zero gravity on humans, as well as benefiting the broader medical research community through findings that spin off into non-space related applications.

During 1993, NASA redesigned the Space Station to reduce costs while retaining user capability and maintaining the program's international commitments. The new Space Station design is based on a modular concept and will be built in stages. The European Space Agency undertook a major restructuring effort on its Columbus Programme to downsize and simplify the Attached Pressurized Module, making it compatible with NASA's redesign of the Space Station. And in general, NASA and its international partners, together with Russia, proceeded with efforts to develop the redesigned Space Station. In this connection, NASA and the Russian Space Agency (RSA) continued to study ways to increase Russian participation in the Space Station Program. In June 1992 the U.S. and Russia had signed a Space Cooperation Agreement that called for a Russian cosmonaut to participate in a U.S. Space Shuttle mission and for the Space Shuttle to make at least one rendezvous with Mir. NASA's cooperation with Russia became more focused when the two countries reached an understanding in July 1993 to "define and determine the feasibility of a cooperative human space flight program." Then on September 2, 1992, Vice President Albert Gore, Jr., and Russian Prime Minister Victor Chernomyrdin signed a series of joint statements on cooperation in space, environmental observations/space science, commercial space launches, missile export controls, and aeronautical science.

April 1993 marked the 10th anniversary of NASA's Tracking and Data Relay Satellite System (TDRSS), a revolutionary, space-based network developed to meet telecommunications needs essential to the success of the Space Shuttle, Space Station, and other low Earth-orbiting spacecraft missions. Since becoming operational, TDRSS has relayed approximately 3.5 million minutes of data to the ground, and every subsequent Space Shuttle mission has required its resources. In other areas of space communications, NASA has completed the refurbishment of the Hubble Space Telescope (HST) control center, which was ready at the end of the fiscal year for the HST repair mission in December 1993. Additionally, in FY 1993 NASA provided 48,000 hours of Mission Control services to ten on-orbit science missions.

In aeronautics, the Integrated High Performance Turbine Engine Technology (IHPTET) initiative is a coordinated DoD/NASA/industry effort to double turbopropulsion capability by 2003. Among the programs accomplishments, for the first time ever, it tested an advanced core engine with a magnetic bearing, with the goal of eliminating lubrication systems from future engines. NASA's Advanced Subsonic Technology program has as its goal the facilitation of a safe, productive global air transportation system that includes a new generation of environmentally compatible, economic aircraft that are superior to foreign products. One example of efforts in advanced subsonics involved NASA and Learjet Inc. working together during FY 1993 on new technologies and design methods for the development and testing of a new, high-performance business jet, using supercomputers and wind tunnels at NASA's Ames Research Center in CA. In the supersonic arena, NASA's SR-71 Aircraft Testbed Program conducted baseline flights for aeronautical research to assist industry in making key decisions about developing a High Speed Civil Transport (HSCT). More generally, NASA's High-Speed Research program continued during FY 1993 to focus on resolving critical environmental issues and laying the technological foundation for an economical, next-generation HSCT. During FY 1993, NASA also used the B-52 aircraft to complete two successful airborne launches of the Pegasus rocket, one of which was a commercial launch of a satellite payload for Brazil. In its F-18 High Alpha Technology Program, NASA sought to achieve a basic understanding of high angle-of-attack aerodynamics, including the effects of selected advanced flight control concepts used individually and in combination. NASA also did important aeronautics research using its F-18 Systems Research Aircraft, its V/STOL System Research Aircraft, and its F-15 testbed aircraft.

NASA's studies of the planet Earth included the launch of the joint U.S./Italian Laser Geodynamics Satellite II (LAGEOS II), designed to provide precise measurements of movements in the Earth's tectonic plates, shedding light on how and when earthquakes occur. Also, scientists from the Goddard Space Flight Center, using data from the Total Ozone Mapping Spectrometer (TOMS) on NASA's Nimbus 7 satellite, discovered that global ozone levels in late 1992 and early 1993 reached the lowest levels ever observed. (See below under DoC.) Of great importance in the field of oceanography were the measurements of the Ocean Topography Experiment (TOPEX)/ Poseidon satellite launched in August 1992. These provided the most accurate data yet available on global sea level changes, constituting the first map of ocean topography.

NASA was heavily involved in the commercial development of space technology through its Office of Advanced Concepts & Technology (OACT) established in October 1992. Most of NASA's commercial space initiatives continued to be managed by its Centers for the Commercial Development of Space (CCDSs). Among other developments, two of these CCDSs made several advances and documented a number of successful cooperative initiatives in commercial applications of remote sensing technologies. June 1993 saw the maiden flight of the Spacehab module in the cargo bay of Space Shuttle Endeavour. Privately funded and developed by SPACEHAB, Inc. of Arlington, VA, the module provides an additional 1,100 cubic feet of pressurized experimental space on the Shuttle. NASA also successfully launched the Advanced Communications Technology Satellite (ACTS) from Space Shuttle Discovery in September 1993. ACTS represents the next generation of advanced satellite communications technology. Its fundamental goal is to support industry in its development of technologies that will improve the U.S. economy and enhance its competitiveness abroad. Relatedly, a key mechanism in transferring Federal technology to the private sector is the national network of technology transfer centers sponsored by NASA in cooperation with other Federal agencies. NASA has also joined forces with other Government agencies to manage the Technology Reinvestment Project announced by President Clinton in March 1993 to help U.S. industry respond to the twin challenges posed by decreased defense spending and increased global economic competition.

Department of Defense (DoD)

Like NASA, the DoD continued to engage in a wide variety of aeronautical and space efforts. Air Force Delta IIs successfully launched the 7 GPS satellites. Two Titan IV launches supported classified missions, although the second one ended in failure. Of two Atlas-Centaur I commercial launches, the first failed to send a UFO-1 into proper orbit but the second was successful in placing UFO-2 into geosynchronous orbit. A Pegasus launched an ALEXIS spacecraft into orbit, and an Atlas II placed a DSCS III in geosynchronous orbit. Two of NASA's Scout rockets placed Miniature Seeker Technology Integration-1 and RADCAL satellites into orbit, as well. And on December 2, 1992, the crew of Space Shuttle Discovery (STS-53) launched the classified DoD-1 in the Shuttle's last dedicated DoD mission.

The Pegasus booster, developed by Orbital Sciences Corporation and the Advanced Research Projects Agency (ARPA)—a three-stage, solid propellant, inertially guided, winged launch vehicle—reached full operational status in 1993. To date, Pegasus has successfully performed in all four of its launches. The payload fairing has undergone redesign to resolve problems identified in a flight on July 17, 1991, and to improve reliability and contamination control for future flights. In April 1993, ARPA transitioned the program to the Air Force.

The Taurus Standard Small Launch Vehicle capitalizes on ARPA's previous investment in the Pegasus Air-Launched Vehicle to produce a transportable, ground-launched rocket with greater payload capacity. Taurus development is nearly complete and the program successfully demonstrated, this year, the rapid eight-day equivalent turnaround to process the rocket fully, integrate the payload and conduct simulated launch countdown operations using a full-scale engineering pathfinder. Taurus will be capable of providing rapid, affordable access to space for moderate-sized satellites with minimal launch support and infrastructure.

The Ballistic Missile Defense Organization (BMDO) was the contracting agent for the Single Stage Rocket Technology program whose objective was to demonstrate aircraft-like operations and supportability for future single-stage-to-orbit launch vehicles. McDonnell Douglas' Delta Clipper-Experimental (DC-X) has become the first working, one-third scale technology demonstration vehicle for this concept. The first hover test took place on August 18, 1993. The second flight occurred on September 11 and the vehicle ended the fiscal year with a third successful flight test to 1,200 feet on September 30th. The Air Force completed Centaur upper stage development for the Titan IV in FY 1993 and will be ready to launch the first Titan IV with a Centaur as soon as it has finished recovering from the August 2nd launch failure.

In satellite technology, at the end of the year, the Navstar GPS consisted of 23 operational Block II satellites and 1 research and development Block I satellite, satisfying requirements for highly precise, worldwide, three-dimensional position, navigation, and timing data for military and civilian air, land, and marine operations. The BMDO's Miniature Sensor Technology Integration (MSTI) Program, met several milestones in FY 1993 toward its goal of developing new technologies for detecting and tracking ballistic missiles. Most notably, the program launched its first of a series of satellites on November 21, 1992. The six-day MSTI-1 mission met all of its objectives, and the satellite routinely collected data for over five months. The DSCS program successfully launched a DSCS III satellite on July 19, 1993, as a follow-on to the two DSCS IIIs launched in FY 1992. These three launches marked the start of a replenishment program for the DSCS constellation, which experienced severe launch set-backs from the 1986 Space Shuttle Challenger disaster.

Among the new aircraft in development by the DoD was the B-2, which had completed approximately 30 percent of its flight test program by the end of FY 1993 and was scheduled for delivery to the Air Force's Air Combat Command in December 1993. The Advanced Fighter Technology Integration (AFTI/F-16) program continued flight testing of advanced technologies in support of aircraft with an air-to-surface attack mission. In a rather different area of aeronautics development, Raptor/Talon is a BMDO-funded program to provide U.S. armed forces and their allies an air-based defense against Theater Ballistic Missiles (TBM) by stopping the missiles in their boost phase. During FY 1993, the Raptor demonstrator aircraft, built by Scaled Composites, made 10 successful test flights.

Department of Commerce (DoC)

The DoC and its component organizations continued to engage in a variety of space-related activities. For example, the Space Environment Laboratory of the National Oceanic and Atmospheric Administration (NOAA) has been involved in the international project SOLTIP (SOLar connection to Transient Interplanetary Processes). Its objective is to focus attention on various forms of solar activity to answer basic questions about the transfer of energy, mass, and momentum through the solar wind to the Earth, as well as about the generation of geomagnetic storms. During the year, NOAA continued to operate its two polar-orbiting satellites, NOAA-11 and NOAA-12. The August 9, 1993, Air Force launch of the NOAA-13 satellite to replace the aging NOAA-11 got the satellite into orbit, but all communications with NOAA-13 ceased on August 21, and attempts to restore them have not been successful. An Air Force Titan II launched the last in the NOAA-operated Landsat series of satellites, Landsat-6, on October 5, 1993. After successful separation from the Titan II, the satellite's integral "kick motor" apparently did not deliver it into final orbit, and contact with the satellite ceased. Meanwhile, NOAA continued its studies of global change with Pathfinder—a joint NASA-NOAA program—constituting a new generation of Earth-science and other data sets developed specifically to study global environmental change. Also, in late 1992 NOAA's National Geophysical Data Center (NGDC) released the Global Change Data Base on CD-ROM to the public. Researchers were also using data from the Defense Meteorological Satellite Program's F-10 and F-11 series of polar orbiting satellites to monitor flooding in the Midwest. With regard to NASA and NOAA efforts to monitor Ozone Depletion (see NASA above), the Montreal Protocol, signed in 1987 to phase out use and end the production of ozone-destroying chemicals, appeared to have lowered the use of chlorofluorocarbons to the point where NOAA scientists predicted that the chlorine atoms that break off from them would peak about the year 2000, although the ozone layer would probably not return to "normal" for another 50 to 100 years. NOAA engaged in a great variety of other research efforts involving the atmosphere. For example, it used ship- and ground-based measurements of cloud moisture and rainfall to validate measurements from DMSP satellites.

The National Institute of Standards and Technology (NIST) continued to conduct considerable but declining amounts of research and development activities for NASA, with total NASA obligations for this work declining from a high (in FY 1993 constant dollars) of $7.7 million in FY 1990 to roughly $5.3 million in FY 1993. Among the projects NIST carried out was the measurement and modeling of tropospheric methane, which contributes to global warming, so as to devise ways of controlling human activities contributing to the emission of the gas. Another NIST program has been applying developments in superconducting electronics to provide infrared images for purposes such as conservation, resource management, and event detection through an entirely new type of detector. In one further example of NIST activities, research into crystalline structures has provided knowledge that allows production of improved crystals of mercuric iodide used for high-energy detectors, triglycine sulfate used for sensitive infrared detectors, and gallium arsenide used for the most sophisticated information processing.

DoC's Office of Air and Space Commercialization (OASC) was involved in the development of the U.S./Russia Space Launch Trade Agreement signed on September 2, 1993. OASC has been working with other agencies to generate a consistent Government policy towards medium-resolution commercial remote sensing. Additionally, OASC has participated in discussions with NASA on the commercial implications of the joint U.S.-Russian Space Station program, among other activities. Finally, OASC has been participating in an effort to improve commercial space infrastructures and possibly develop a next-generation commercial launch vehicle.

Department of Energy (DoE)

In 1993 the DoE continued to progress beyond the achievements of more than 30 years of activities in spaceflight research, development, demonstration, and verification. Collaboration with NASA on the Space Exploration Initiative (SEI) continued to mid-fiscal year when deferral of the developmental activities for SEI led to phase-down of several elements such as the SP-100 Space Power Reactor Project jointly performed with NASA and DoD by DoE. Collaboration on advanced computational development for aeronautics continued as the function of one of the seven teams of the Senior Management Review Committee established by the memorandum of understanding signed by the DoE and NASA on July 29, 1992. The two agencies deferred other joint efforts to identify means for the DoE to support developments needed for NASA advancements.

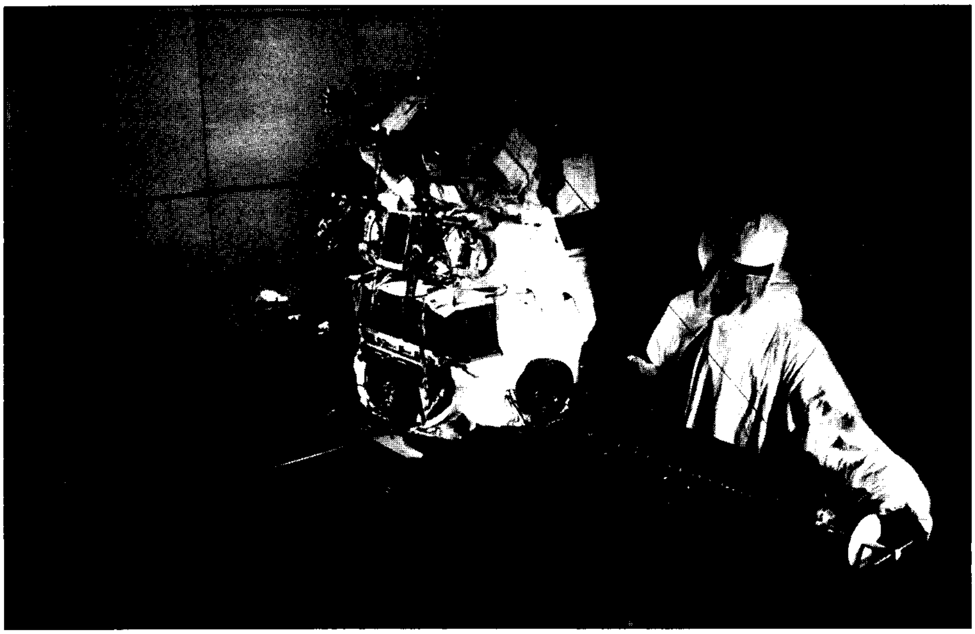
Other DoE activities included building on the successful provision of 37 Radioisotope Thermoelectric Generators (RTGs) to provide nuclear energy for over 20 spacecraft launches. In 1993 advanced versions of the General Purpose Heat Source (GPHS)-RTGs moved toward production for the Cassini mission to Saturn scheduled for launch in October 1997. Work continued on development of advanced thermoelectric cells (as part of the SP-100 program that is being phased out) to provide 25 times the electric power of similar-sized cells used on the Galileo mission in 1989. The DoE also made progress on the design and technological development of in-core thermionic space nuclear reactor systems looking toward the power range of 5 to 40 kilowatts electric (kWe) for missions sponsored by the DoD. The DoE let two industrial contracts including participation of Russian experts to integrate their country's expertise with that of U.S. national laboratories and academic institutions for evaluation of capabilities in space power employing thermionic conversion technologies.

The DoE continued its support of DoD and Air Force technological development aimed at demonstrating the feasibility of a particle bed nuclear reactor for thermal rocket propulsion applications. The DoE participated in review of the Air Force's final environmental impact statement issued in May 1993 for the particle-bed Space Nuclear Thermal Propulsion (SNTP) Rocket Program. The agency also examined the possible use of common facilities for the SNTP and future high-powered nuclear rockets for the SEI applications study in 1992 and 1993 for potential future mission requirements of NASA.

The flight of the Array of Low Energy X-ray Imaging Sensors (ALEXIS) satellite launched by a Pegasus rocket on April 25, 1993, itself carried aloft by a B-52 controlled from Vandenberg Air Force Base, was the first such flight of an all-DoE sponsored satellite. In a 70° inclination, 844 x 749 kilometer orbit, the satellite experienced failure of one solar panel to deploy properly, at first casting doubts on the chances for success of the mission to gather soft x-ray background data and VHF radio effects due to the ionosphere. Successful regaining of control over the spacecraft by the Los Alamos National Laboratory resulted in expectations by the end of the fiscal year that the AeroAstro Incorporated spacecraft would fully meet its original mission requirements. The smaller, faster, and cheaper ALEXIS spacecraft—at a cost of $17 million for it and its integrated components—provides a prototype of less expensive missions to come for DoE and other agencies. (See accompanying photograph.)

Department of the Interior (DoI)

The DoI applied remote sensing from satellites and aircraft to a variety of programs. For instance, the U.S. Geological Survey was using data from Magellan's earlier mapping mission to prepare several map series, including a global map and geologic maps of Venus.



The DoE ALEXIS Satellite in final checkout at the Los Alamos National Laboratory clean room and anechoic chamber. The $17 million cost for the satellite, instruments, integration, and test with ground control from Los Alamos is a first for the Department of Energy. The spacecraft weighs a total of 113 kg and has two experiments. The ALEXIS is a six-telescope, soft x-ray detector array; the BLACKBEARD is a VHF radio receiver and digitizer for study of the ionosphere. The low-cost experimental satellite was ready for launch three years from conception but had to wait for a Pegasus booster to be launched on April 25, 1993. Damage to a solar panel and a magnetometer during launch required a dedicated effort to access the ALEXIS in June 1993. Once that was achieved, data has been received at Los Alamos Control Center at a rate of 100 megabytes per day for both experiments. The mission objectives for the satellite are now expected to be fully met.

The Survey was in its seventh year of participating in NASA's Mars Geologic Mapping program, with several maps completed and ready for publication. The Survey also produced and released global digital maps of the four satellites of Jupiter to support the Galileo spacecraft's encounter with that planet in 1995. The Bureau of Indian Affairs used Landsat Thematic Mapper data to perform land cover inventories and prepare image maps on several Indian Reservations. The Bureau of Land Management used satellite data and aerial photography to promote biological diversity and sustainable development on public lands and to fulfill a variety of other land management responsibilities. The Bureau of Reclamation used remote sensing from satellites and Geographic Information Systems (GISs) to produce crop area estimates leading to more accurate estimates of consumptive water use by agriculture within the Colorado River Basin. The National Park Service continued to develop surface cover information for numerous areas using data from satellites. The U.S. Fish and Wildlife Service Gap Analysis Program has been using Landsat Thematic Mapper data and computerized mapping techniques in 36 states to identify areas that are not being protected so as to maintain biological diversity. Since the U.S. Geological Survey's Earth Resources Observation Systems Data Center was designated the National Satellite Land Remote Sensing Data Archive in 1992, it has been adding other types of satellite data to its holdings of Landsat data; these data support many applications, including efforts by the global change research community to produce a global land cover map and to monitor the greenness of vegetation on a periodic basis throughout the year.

Department of Transportation (DoT)

Federal Aviation Administration (FAA)

The FAA continued an active 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 U.S. and abroad, and to support the requirements of national defense. Agency progress under the ongoing Capital Investment Plan included completing installation of the Peripheral Adapter Module Replacement Item, the first element of the Advanced Automation System (AAS), at all 20 Air Route Traffic Control Centers. When fully deployed, the AAS will replace the automated equipment now in use in controlling air traffic. To improve air traffic controller communications, the FAA deployed a prototype Voice Switching and Control System. Examples of other safety-related actions included writing a draft specification for a standard stop bar lighting system designed to reduce runway incidents and completing factory testing of the first seven production Microwave Landing Systems. In a joint program with the Coast Guard, the FAA successfully completed engineering model tests of the Loran-C Automatic BLINK system. It makes the use of Loran-C transmissions safer for pilots during nonprecision, instrument-approach landings. In addition, the agency published manufacturing standards for GPS satellite receivers.

The FAA continued research efforts with NASA to investigate structural integrity, flight loads, and corrosion. Working with its counterparts in the United Kingdom and Canada, the agency completed a series of full-scale fire tests to optimize an on-board cabin water spray system. The FAA also finished construction of the first runway section fully instrumented for pavement research. Additionally, the agency tested a soft-ground arresting system, proving that such a technique could safely stop a commercial-size aircraft without damage. Among its other safety-related programs, the FAA made significant strides in the study of icing, windshear, and other atmospheric hazards.

Progress continued on programs to increase airport capacity. As part of those efforts, the FAA commissioned the first Precision Runway Monitor at Raleigh-Durham airport. That system uses an electronically scanned secondary radar with high accuracy, improved display, and an automated predictor to provide visual and aural alerting when a pilot deviates from the proper flight path. The agency also continued research to optimize terminal traffic flow and proceeded with development of a comprehensive all-weather surface traffic automation system.

Under its civil aviation security mandate, the FAA pursued an extensive research and development effort that focused on such areas as explosives detectors, screening devices, aircraft hardening, airport security, and human factors. The agency opened a security research laboratory at its Technical Center and published final criteria for explosives detection systems. Among the many other programs undertaken during the fiscal year, the FAA tested four prototype luggage containers and initiated a project to gather data on x-ray screener improvements.

Office of Commercial Space Transportation (OCST)

OCST provided regulatory oversight and monitoring for five commercial launches in FY 1993, four of them successful. This brought the total of U.S. commercial launches of space vehicles to 35 by the end of the fiscal year. These and planned future activities reflect a growing and diverse commercial launch industry that includes the development of reentry vehicles, air-launched rockets, single-stage-to-orbit technology, and commercial launch sites. During FY 1993 the OCST had a total of nine commercial space transportation proposals in various stages of review and issued two new licenses. Among its other activities, OCST has begun discussions with industry representatives on single-stage-rocket vehicles, the first of which is the one-third scale model of the DC-X, developed by McDonnell Douglas and undergoing testing at the end of the year. The Office also assisted in reviewing applications for a DoD grant program to improve the commercial space launch industry's infrastructure. Some grants were approved to assist in the creation of commercial launch sites in FL, AK, CA, and NM. OCST has initiated a program to encourage the commercial space industry to develop voluntary standards and has continued to conduct a comprehensive research program to respond to anticipated developments in commercial space transportation. The Office participates in the National Security Council's Task Force on Cooperation with the Russians, originally established to assist with the U.S./Russia Summit, held in Vancouver in April 1993. OCST developed market data for the Task Force to use at the Summit meeting and for the Gore/Chernomyrdin meeting in September.

U.S. Department of Agriculture (USDA)

There were a great many uses for remote sensing in the USDA. For example, the Soil Conservation Service used Landsat imagery to determine the extent of the Midwest floods, then employed a combination of satellite imagery plus digital soil and land-use data to assess flood damage at the state and county level with respect to soil and land-cover concerns. The National Agricultural Statistical Service employed remote sensing data as an aid to crop and acreage estimation and in assessment of crop conditions. The Forest Service has continued to require remote sensing for a variety of ecosystem management activities, including vegetation mapping, inventory, and identification of critical wildlife habitat. Similarly, the Foreign Agricultural Service's satellite remote sensing program continued to be a critical element in the USDA's analysis of foreign agricultural production, supply, and demand—providing timely and accurate estimates of global area, yield, and production. Also, the Agricultural Research Service has developed models using a combination of meteorological and remotely sensed data to measure moisture and energy fluxes at river basins to aid in understanding how the land surface affects climate and climate change.

Federal Communications Commission (FCC)

There were two new domestic, fixed communications satellites launched for the United States during FY 1993. Named Galaxy VII(H) and IV(H), they were launched from Kourou, French Guiana, by Ariane launch vehicles on October 27, 1992, and June 24, 1993, respectively. With these launches and the retirement of several satellites, there were 32 domestic-fixed satellites in orbit between 69° and 139° west longitude on the geostationary orbital arc as of the end of the fiscal year. The International Telecommunications Satellite Organization (INTELSAT), launched no new satellites during the fiscal year but continued to offer through its 19-satellite system such business services as international telex, teleconferencing, data, facsimile, and video. The U.S. did not launch any separate international satellite systems either. Pan American Satellite's PAS-1 located at 45° west longitude and the Columbia Communications satellites located at 41° and 174° west longitude continued to provide services similar to those of INTELSAT. The International Maritime Satellite Organization (INMARSAT) likewise did not add to its complement of four INMARSAT II and seven older satellites during the course of the fiscal year. With these satellites, INMARSAT continued to provide global mobile satellite communications for commercial, distress, and safety applications at sea, on land, and in the air. Among new services offered during the year, on October 1, 1992, INMARSAT announced that an advanced satellite distress alerting system for ships at sea, INMARSAT-E, had become operational for the eastern Atlantic Ocean Region. This marked a significant step in implementing the Global Maritime Distress and Safety System.

U.S. Environmental Protection Agency (EPA)

The EPA, primarily through its Environmental Monitoring Systems Laboratory in Las Vegas, NV, (EMSL-LV) with assistance from its Atmospheric Research and Exposure Assessment Laboratory in Research Triangle Park, NC, also routinely conducted research and provided technical support using remote sensing as part of its overall environmental monitoring program. The agency used large-scale aerial photography to develop site characterization data during the remedial actions under the Comprehensive Environmental Response, Compensation, and Liability Act, as well as to support site selection and monitoring at hazardous waste facilities operated under the Resource Conservation and Recovery Act. It developed and used remote sensing systems to support the provisions of the Clean Water Act. In FY 1993, the EMSL-LV completed approximately 150 aerial photographic site characterization projects. Also during the year, aerial photography and satellite data supported a broad variety of pollution, global change, pollution prevention, compliance, and other ecosystem monitoring studies, such as those of critical-habitat areas for wildlife. The Environmental Photographic Interpretation Center—a branch of EMSL-LV—provided support to the EPA's regional offices through the analysis of aerial photographs and documentation of the impacts associated with the severe flooding along the Mississippi River and its tributaries. In addition, the EPA continued (with NASA support) to use and develop light detection and ranging systems to monitor urban plumes and emission sources as well as to measure ozone, sulfur dioxide, and particulates. Finally, the EPA was using a geographic information system for data integration and analysis in support of many of its programs.

National Science Foundation (NSF)

The NSF has conducted forefront, space-related research using ground-based instrumentation. The lidar technique has proved to be especially promising in measuring the middle atmosphere in support of global change studies. After three years of operation, scientists at Colorado State University were able to show that the mesopause, the layer of the Earth's atmosphere with the lowest temperature, actually displays a double minimum, contrary to accepted models. Scientists from the University of Illinois installed a lidar instrument on the Lockheed Electra aircraft operated by the National Center for Atmospheric Research. They flew over Canada and Alaska for more than 25 hours to study the atmospheric properties associated with noctilucent clouds, which occur in a thin layer at altitudes near 85 kilometers. SRI International deployed a lidar instrument at Sondre Stromfjord, Greenland, to operate in conjunction with an NSF-supported atmospheric facility. It will measure middle atmospheric properties at very high latitudes where chemical and dynamical processes are especially complex. A consortium consisting of scientists from Maryland, Clemson, and Utah State universities began making measurements of the stratosphere and mesosphere using a lidar instrument developed at Logan, UT. These lidar observations are extremely important because the middle atmosphere and phenomena that occur there such as the noctilucent clouds are extremely sensitive to changes caused by global warming and the introduction of anthropogenic chemicals into the atmosphere. During the past decade scientists have observed that the middle atmosphere has been growing cooler and wetter, and understanding the origin of this change requires long-term measurements on a global scale.

In the field of space physics, observations carried out by the Center for Particle Astrophysics, an NSF science and technology center, in conjunction with an Australian team at Mt. Stromlo Observatory near Canberra, have produced strong evidence for invisible matter in a halo surrounding the Milky Way galaxy. Somewhat relatedly, study of Sagittarius A* (Sgr A*) provided important findings about this small but very luminous radio source located at the very center of our spiral Milky Way galaxy. SGR A* is ten million times more energetic than the sun but is smaller than the solar system; it appears to be a black hole. In a different area, observations with the National Radio Astronomy Observatory 12-meter millimeter-wave telescope on Kitt Peak have led to the discovery of molecular clouds more than 12 billion light-years from the Earth. Future observations such as these will provide, for the first time, a precise view of how gases became stars and stars became galaxies at the dawn of the universe. In a quite different area, astronomers used radial velocities and the distances of remote clusters of galaxies in several directions to measure how our local group of galaxies was drifting through space.

Smithsonian Institution

Through basic research at the Smithsonian Astrophysical Observatory (SAO) in Cambridge, MA, as well as the Center for Earth and Planetary Sciences and the Laboratory for Astrophysics at the National Air and Space Museum in Washington, DC, the Smithsonian Institution continued to contribute to advances in space science. For instance, in April an ultraviolet coronograph designed at the SAO for studies of the sun's extended corona, or hot outer atmosphere, was one of two instruments comprising the Spartan-201 satellite deployed and retrieved by astronauts aboard NASA's Space Shuttle Discovery. Preliminary analysis of the ultraviolet observations of structures and features extending far above the sun's surface suggest scientists may be able to determine—and ultimately predict—how material is accelerated out of the sun to form the solar wind. Simultaneously with the Spartan mission, scientists throughout the world carried out coordinated observations from space and the ground to correlate the satellite's ultraviolet observations with those in other wavelengths and other regions of the sun's corona. The coordinated campaign, which included a Smithsonian-IBM-built sounding-rocket-borne x-ray telescope and a white light coronograph telescope (also aboard Spartan-201, provided by the High-Altitude Observatory in Boulder, CO), should produce the most complete information ever assembled on the solar wind's acceleration. Together with other participants, SAO also designed the Small Expendable Tether Deployable System, which was launched as a secondary payload aboard a Delta II rocket from Cape Canaveral, FL, on March 29. The 85-pound satellite, attached by a 20-kilometer-long flexible cable to the Delta's second-stage rocket, allowed SAO's scientists to compare data on tether dynamics with computer models of predicted behavior in preparation for future flights, the first of which occurred on June 26 when another Delta II from Cape Canaveral launched an electrodynamic tether called the Plasma Motor Generator on a six-hour flight that demonstrated the ability of a tether to generate an electrical current in space.

Department of State (DoS)

The U.S. effort to redesign the Space Station and broaden the international partnership therein to include the Russian Federation was the primary focus of the State Department's efforts in the fields of aeronautics and space activities during FY 1993. Relations with the Canadian, Japanese, and European governments were an important consideration as the redesign process produced a new approach and these partners were persuaded of the political and technical merits of involving the Russians in the program. The U.S.-Russia Commercial Space Launch Agreement of September 2, 1993, established basic rules for government involvement in the commercial space launch market regarding subsidies, marketing inducements, corrupt business practices, etc. Among other things, this agreement permits the Russians to contract with international customers for the launch of up to eight telecommunications satellites, in addition to INMARSAT-3, to geosynchronous Earth orbit between September 2, 1993 and December 31, 2000. Elsewhere, the DoS led a U.S. delegation to the Second Space Conference of the Americas held in Santiago, Chile, April 26-30, 1993. Of particular note was agreement by delegations on a U.S. proposal for expanding regional cooperation on the use of the international satellite-aided search and rescue system, COSPAS-SARSAT, which the U.S., France, Canada, and Russia operate collectively. Also during 1993, the DoS supported seven separate Space Shuttle activities by providing a direct link to U.S. embassies in countries with emergency landing facilities. It negotiated the extension of a Space Tracking Agreement with Spain.

Following recommendations developed in FY 1992 for INTELSAT's Board of Governors and shepherded by DoS, DoC, and the FCC, the INTELSAT Assembly of Parties voted to relax and streamline procedures affecting private satellite competitors. DoS and DoC then established a new private satellite policy to allow American licensees to have full advantage of the better international climate. The two U.S. companies with operating satellites, Pan American Satellite and Columbia Communications, were immediate beneficiaries of these improved international and domestic arrangements. During FY 1993, the Republic of the Marshall Islands, Bahrain, and Armenia joined INTELSAT, bringing its membership to 128 countries that owned and operated the sole global communications satellite system in the world. The new member countries for INMARSAT during 1993 were the Slovak Republic, Georgia, Bangladesh, and Brunei Darussalam, bringing its total membership to 71. Both INTELSAT and INMARSAT were looking at structural change to further enhance their responsiveness to user needs, and private competitors were expanding their operations in the wake of new opportunities.

U.S. Arms Control and Disarmament Agency (ACDA)

During FY 1993, ACDA participated in policy development and negotiations on a number of space-related arms control and missile nonproliferation issues. These included reformulation of U.S. policy on ballistic missile defense (BMD), reorienting American efforts from a deployment to a research program and reaffirming the traditional interpretation of the Anti-Ballistic Missile Treaty, plus strengthening the Missile Technology Control Regime (MTCR), which requires members to control all missiles, space launch vehicles (SLVs), and unmanned air vehicles capable of delivering weapons of mass destruction. The Regime treats SLVs in the same way as missiles, since the technologies are essentially the same for both. ACDA was also active in U.S. bilateral and regional negotiations on key missile proliferation problems, including successful termination of the Russian-Indian program to transfer Russian rocket engines and technology to the Indian space program. Russia has agreed, in return for the lifting of U.S. sanctions, to cease such transfers and observe MTCR standards for future exports. Other activities included: negotiations on termination of both the Argentine Condor II ballistic missile program and the South African SLV program; negotiations with China, thus far unsuccessful, to resolve the issue of Chinese transfers of M-11 missile technology to Pakistan, and the subsequent imposition of U.S. sanctions; and participation in the U.S. missile nonproliferation initiative in South Asia, aimed at slowing and ultimately reversing the ballistic missile competition between India and Pakistan.

The United States Information Agency (USIA)

The USIA informed audiences abroad of American achievements in space and used NASA innovations to further public diplomacy around the world. The global radio network Voice of America (VoA) covered the space program in news stories, correspondent reports, special features, and documentaries broadcast in 48 languages. In a historic agreement, USIA implemented a new digital audio service via INTERSPUTNIK, the Russian satellite system, providing VoA and Radio Liberty programs to Russia and other states formerly part of the Soviet system. USIA's Worldnet television service offered numerous programs on NASA and the U.S. space effort. And the Wireless File of USIA continued to provide news articles for placement in local publications around the world.

Space Launch Activities

Space Shuttle Missions

During Fiscal Year (FY) 1993, the National Aeronautics and Space Administration (NASA) successfully completed seven Space Shuttle missions. These were, in order of flight, STS-52 (STS standing for Space Transportation System), STS-53, STS-54, STS-56, STS-55, STS-57, and STS-51. Throughout the year, NASA continued to have a shuttle fleet consisting of orbiters Columbia, Discovery, Atlantis, and Endeavour. All launches took place at Kennedy Space Center (KSC), FL.

The launch of STS-52 (Columbia) occurred on October 22, 1992. One objective of this mission was the deployment of the Laser Geodynamic Satellite (LAGEOS II), a cooperative endeavor of the U.S. and Italy to obtain precise measurements of the Earth's crustal movement and gravitational field. In addition, this mission was the first in a series of flights of the U.S. Microgravity Payload (USMP-1), containing three scientific and materials-processing experiments to be carried out in an environment of reduced gravity. Columbia landed safely at KSC on November 1, 1992. The mission of STS-53 (Discovery) began on December 2, 1992. It was the last dedicated Department of Defense (DoD) mission, launching the classified DoD-1 satellite on December 2. Discovery returned safely to Edwards Air Force Base (EAFB), CA, on December 9, 1992.

The first flight of calendar year 1993, STS-54 (Endeavour), began with a launch on January 13, 1993. This mission included deployment of a Tracking and Data Relay Satellite (TDRS) and operation of the Diffused X-ray Spectrometer Hitchhiker experiment, which collected data on stars and the surrounding galactic gases. The mission also included the second group of Physics of Toys experiments, which were broadcast to classrooms throughout the nation. To expand knowledge of the differences between training on Earth and working in space, the crew conducted a 4-hour and 28-minute Extravehicular Activity (EVA) in the cargo bay. STS-54 landed successfully at KSC on January 19, 1993.

On April 8, 1993, STS-56 (Discovery) began a mission to study the composition of the Earth's atmosphere, ozone layer, and elements thought to be the cause of ozone depletion. The principal tool for this study was the second Atmospheric Laboratory for Applications and Science (ATLAS). The Shuttle crew also deployed a Spartan-201 retrievable, free-flying satellite to study the sun's outer atmosphere and the solar wind. Discovery landed safely at KSC on April 17, 1993, with the Spartan-201 on board.

NASA successfully launched STS-55 (Columbia) on April 26, 1993. Referred to as Spacelab D-2, this was a reimbursable mission contracted by the German Space Agency. Experiments, some of which were collaborative with U.S. scientists, dealt with materials science, biology, and space technology. The orbiter carried a European Space Agency (ESA)-designed research facility to study the effects of weightlessness upon the human body. In addition, it carried an ultra-sophisticated, remote-controlled robotic arm to demonstrate the ability of a high-tech robot to complete delicate grasping and stacking tasks. This mission marked Columbia's 100th day of space flight and ended on May 6, 1993, when the orbiter returned safely to EAFB.

The fourth flight of Endeavour, STS-57, began on June 21, 1993 and marked the debut of Spacehab, a commercially-owned, pressurized module for conducting experiments in a human-tended environment. Spacehab-01 carried over 20 NASA-sponsored experiments and another sponsored by ESA. Focus was on materials processing, life sciences, biotechnology, and microgravity science. The other major task of the crew of STS-57 was to bring back the European Retrievable Carrier (EURECA-1), which the crew of STS-46 (Atlantis) had deployed in August 1992. The STS-57 crew also performed an EVA almost six hours long to latch two EURECA antennae into place and to gain spacewalk experience for the upcoming servicing mission to correct the flaws in the primary mirror of the Hubble Space Telescope (HST), replace its solar arrays, etc. After successfully completing these missions, STS-57 landed at KSC without mishap on July 1, 1993.

NASA launched STS-51 (Discovery), the final flight of the fiscal year, on September 12, 1993. The mission featured the deployment and retrieval of the German-built Orbiting and Retrievable Far and Extreme Ultraviolet Spectrometer-Shuttle Pallet Satellite (ORFEUS-SPAS), which spent six days in free flight, studying emissions of ultraviolet radiation from deep space. The Discovery crew also deployed the Advanced Communications Technology Satellite (ACTS), a testbed for future satellite communication systems ranging from high-definition television (HDTV) to high-speed data transmission. Additionally, two crew members performed an EVA of seven hours to test tools and spacewalking techniques for use on the HST servicing mission in late calendar year 1993. Discovery successfully completed the first night landing ever attempted at KSC on September 22, 1993.

Expendable Launches

Both NASA and the DoD employed a number of expendable launch vehicles (ELVs) during the course of the year. The DoD launched twelve ELVs of its own, an Atlas E, an Atlas II, a Pegasus, two Titan IVs and seven Delta IIs. In addition, contractors conducted four commercial launches from government facilities with minimal government oversight. These included one Delta II, one Pegasus, and two Atlas-Centaur I launches. NASA's launches consisted of two Scout rockets.

The first Delta II launch was the commercial operation. It occurred on October 12, 1992, lifting a DFS-3 Kopernikus satellite into geosynchronous orbit to provide television, radio, and data communications services throughout Germany. Other Delta IIs launched Global Positioning System (GPS) satellites into orbit on November 22, 1992; December 18, 1992; February 2, 1993 (local time, February 3 by Greenwich Mean Time); March 29, 1993 (March 30, GMT); May 12, 1993 (May 13, GMT); June 26, 1993; and August 30, 1993.

Both Titan IV launches supported classified missions. The first launch on November 28, 1992, from Vandenberg Air Force Base (VAFB), CA, successfully delivered the classified payload into orbit. The second launch, also from VAFB, ended in failure on August 2, 1993. Approximately 100 seconds after launch, the Titan IV exploded over the ocean. While the Air Force awaited results of a failure investigation board, it delayed two further Titan IV launches at Cape Canaveral but hoped to resume Titan IV launches by early 1994.

The first Atlas-Centaur I launch of the year occurred on March 25, 1993, from Cape Canaveral. The General Dynamics rocket carried the Navy's first UHF Follow-on (UFO-1) communications satellite (also known as UHF-1), built by Hughes Aircraft Company, into orbit. Because of under-performance by the Atlas stage, the launch vehicle left the satellite in orbit at a lower altitude than required. With insufficient fuel aboard the spacecraft to achieve operational orbit, the Navy declared the satellite a total loss and moved it into an orbit above geosynchronous altitude to prevent it from being a hazard to other satellites. Following a comprehensive investigation and corrective action, the Atlas fleet returned to flight. On September 3, 1993, a second Atlas-Centaur I successfully launched UFO-2, which reached its required geosynchronous orbit and transitioned to normal operating mode with all systems nominal. A Pegasus air-launched space booster produced by Orbital Sciences Corporation launched a Brazilian spacecraft, SCD-1, and an Orbital Communications Corp. Capabilities Demonstration Satellite (known as OXP) on February 9, 1993. NASA provided reimbursable support for this commercial launch, including provision of a B-52 to carry the Pegasus to 40,000 feet where it was released and its first-stage motor ignited. A second Pegasus launched an ALEXIS spacecraft into orbit on April 25, 1993. The purpose of the satellite was to test technology for detecting ultrasoft x-rays emitted from space testing and to examine ionospheric distortion of VHF radio signals.

The sole Atlas II launch during the year occurred on July 19, 1993. It placed a Defense Satellite Communications System (DSCS) III into geosynchronous orbit to provide world-wide, secure, uninterrupted communications capability in support of globally distributed DoD users. The Atlas E launch took place on August 8, 1993 (August 9, GMT), from Vandenberg AFB, CA, to place the NOAA-13 satellite into orbit for the National Oceanic and Atmospheric Administration. The purpose of the satellite was to provide global environmental observations; land, sea, and air temperature and moisture profiles; and to detect emergency beacons from ships and planes. The satellite went into orbit successfully but subsequently suffered a power failure.

The first of NASA's Scout rockets launched during 1993 carried a DoD payload, Miniature Seeker Technology Integration-1 (MSTI-1), into sun-synchronous orbit on November 21, 1992, from Vandenberg AFB. The second Scout launched another DoD satellite named RADCAL into polar orbit on June 25, 1993. The purpose of the RADCAL is to provide space-based radar calibration for over 70 ground-based radars and to verify GPS use for satellite positioning.

The Office of Commercial Space Transportation (OCST) in the Department of Transportation (DoT) provided regulatory oversight and monitoring for five launches in FY 1993, as shown in the table below. The effect of two General Dynamics launch failures (one in FY 1992) caused a significant reduction in the number of commercial launches for the year.

Company	***Payload***	***Date***
McDonnell Douglas	Kopernikus	10/12/92
Orbital Sciences Corp.	SCD-1/OXP	02/09/93
EER Systems	Consort 6	02/19/93
General Dynamics	UFO-1	03/25/93*
General Dynamics	UFO-2	09/03/93

**This mission was not successful. (See narrative above.)*

Space Science

Astronomy and Space Physics

Beginning in the early 1960s with the first orbiting astronomical observatories, space science has benefited greatly from the ability to "observe" phenomena in the universe unhindered by the distortions caused by the Earth's atmosphere. Important discoveries continued in FY 1993. One of the most significant was the recording by NASA's **Voyagers 1 and 2**, launched in 1977, of the first direct evidence of the long-sought-after heliopause—the boundary separating the Earth's solar system from interstellar space. The radio emissions providing this evidence were too faint to be detected from Earth, but the two spacecraft, travelling well beyond the solar system, began detecting them in August 1992, although it was months later before scientists recognized their source as being the boundary of the heliosphere.

NASA's **Cosmic Background Explorer** (COBE), launched in November 1989, also added significantly to knowledge of the universe. Precise measurements made by COBE's Far Infrared Absolute Spectrophotometer indicate that 99.97 percent of the early radiant energy of the universe was released within the first year after the Big Bang, widely believed to have started the expansion of the universe about 15 billion years ago.

The **Hubble Space Telescope**, NASA's first Great Observatory launched in April 1990, continued its string of important discoveries. By photographing a striking mirror-image of a distant galaxy through a natural "lens" formed by the gravity of a cluster of foreground galaxies, HST may have begun to unlock the secrets of "dark matter" puzzling astronomers for decades. The spacecraft has already provided scientists with new information on the nature of distant galaxies. HST's images have also revealed to scientists that star-forming galaxies were far more prevalent in the clusters of the younger universe than in the more recent clusters of galaxies near the Earth today and that many more stars than previously confirmed may form planetary systems. Among many other achievements of astronomers working with HST was the measurement of the distance of the spiral galaxy M81 as 11 million light years, a major step in determining the age of the universe.

NASA's second Great Observatory, the **Compton Gamma Ray Observatory** (GRO) launched in April 1991, yielded new data on gamma ray bursts that undercut the two most widely accepted theoretical models attempting to explain those great mysteries of astronomy, although the new findings have yet to reveal the true causes of the gamma rays. GRO also discovered a powerful pulsar not previously observed, the first such discovery by a U.S. spacecraft in more than 15 years.

NASA's **Extreme Ultraviolet Explorer** (EUVE), launched in June 1992, obtained the first "sighting" ever made of an object beyond our galaxy observed in the little explored extreme ultraviolet portion of the electromagnetic spectrum. During its first year of operation, EUVE also allowed astronomers for the first time to observe ionized helium in the gas that floats among the sun and nearby stars. Also, the satellite may allow scientists to learn more about the composition and velocities of matter entering possible black holes through observations of rare objects known as BL Lacs, which are surprisingly visible in the EUV and are theorized to be centered on massive black holes.

Using the **Roentgen Satellite**—a joint project of Germany, the U.S., and the United Kingdom launched in June 1990—astronomers discovered a huge concentration of mysterious dark matter, apparently confirming previous suggestions that most of the dark matter in the universe may be concentrated in and around small groups of galaxies. The finding from the x-ray observatory added weight to the theory that perhaps up to 95 percent of the mass of the universe consists of dark matter. The potential implication of this discovery, which needs confirmation from other x-ray observations, was that there might be enough mass in space to bring the expansion of the universe to a halt or near halt.

The **International Ultraviolet Explorer**, launched in January 1978 in cooperation with the European Space Agency and the British Science and Engineering Research Council, provided new evidence that red supergiants, the largest stars known, end their existence in massive explosions known as supernovae. Before this direct observation in March 1993, astronomers could only speculate that this occurred, so the evidence marked an important advance in stellar astronomy, substantiating decades of work in the field. Closer to home, in April an ultraviolet coronograph designed at the Smithsonian Astrophysical Observatory (SAO) for studies of the sun's hot outer atmosphere, or extended corona, was one of two instruments comprising the **Spartan-201** satellite deployed and retrieved by astronauts aboard NASA's Space Shuttle Discovery. Preliminary analysis of the ultraviolet observations of structures and features extending far above the sun's surface suggest scientists may be able to determine—and ultimately predict—how material is accelerated out of the sun to form the solar wind, a hot, electrically charged gas that pours out of the sun at over a million miles an hour. Among other effects, it produces magnetic storms near Earth that may disrupt communications systems and trigger power outages. Some researchers suspect the solar wind may also be linked to both short-term weather patterns and long-term climatic changes. Simultaneously with the Spartan mission, scientists throughout the world carried out coordinated observations from space and the ground to correlate the satellite's ultraviolet observations with those in other wavelengths and other regions of the sun's corona. The coordinated campaign, which included a Smithsonian-IBM-built sounding-rocket-borne x-ray telescope (known as the Normal Incidence X-ray Telescope—or NIXT—and launched from White Sands Missile Range, NM) and a white light coronograph telescope (also aboard Spartan-201, provided by the High-Altitude Observatory in Boulder, CO), should produce the most complete information ever assembled on the solar wind's acceleration.

Despite the advantages enjoyed by orbiting observatories, scientists continued to make discoveries using research facilities on Earth. For example, an astronomer from NASA's Jet Propulsion Laboratory and a graduate student used observations made at **Kitt Peak National Observatory** in AZ to correct information reported in 1988. They showed that a distant radio galaxy previously thought to contain old stars—older than some estimates of the age of the universe—may instead be a very young system caught in the act of formation billions of years ago, when the light seen today first left the galaxy.

Space scientists at NASA's **Ames Research Center**, mimicking interstellar conditions in a laboratory, showed that certain wavelengths of light from distant stars were being absorbed by unexpectedly large organic molecules spread throughout the vacuum of space. If correct, this discovery solved an 80-year-old mystery about the source of the absorption and may influence the theory of solar system formation.

Observations carried out by the **Center for Particle Astrophysics**, a National Science Foundation (NSF) science and technology center, in conjunction with an Australian team at Mt. Stromlo Observatory near Canberra, have produced strong evidence for invisible matter in a halo surrounding the Milky Way galaxy. The scientists detected the dark matter by bending light rays from a star as the dark matter passed between the Earth and the star, creating the so-called gravitational lensing effect. This result, like the findings of Roentgen Satellite, could help solve one of the central mysteries in our understanding of the nature of the universe: the characteristics of the dark matter.

Somewhat relatedly, study of **Sagittarius A*** (Sgr A*) provided important findings about this small but very luminous radio source located at the very center of our spiral Milky Way galaxy. SGR A* is ten million times more energetic than the sun but is smaller than the solar system; it appears to be a black hole. Observations with the Very Long Baseline Array (VLBA, a set of 10 radio telescopes in the continental U.S., Hawaii, and St. Crois) at 43 GHz, a high frequency with which the VLBA provides imaging of unprecedented resolution, reveal that the size of Sgr A* is less than 3 astronomical units. Observations such as these, over time, will give astronomers the opportunity to study the details of the astrophysics of a black hole in the nucleus of a galaxy. The knowledge gained can be extrapolated to an understanding of the physics of the nuclei of very energetic galaxies such as the quasars and the radio galaxies.

In a different area, observations with the National Radio Astronomy Observatory 12-meter millimeter-wave telescope on Kitt Peak in Tucson, AZ, have led to the discovery of **Molecular Clouds** more than 12 billion light-years from the Earth. These very distant accumulations of molecular gas have masses larger than that of a galaxy such as the Milky Way. The molecular clouds are part of the early history of the universe, when galaxies were first forming. Future observations such as these will provide, for the first time, a precise view of how gases became stars and stars became galaxies at the dawn of the universe.

In another development, on March 28, 1993, astronomers using the Very Large Array (VLA, a set of 27 radio telescopes near Socorro, NM) observed light from **Supernova SN1993J** in the nearby galaxy M81. Two days later, SN1993J became the brightest supernova seen in the northern hemisphere in two decades. Astronomers made radio observations with the VLA several times a day in the first week following the outburst, and they detected emission from the supernova on April 1. They monitored the steady increase in the radio flux density at five VLA microwave frequencies over the next six months. As a result, SN1993J became by far the best-studied radio supernova ever observed. Interpretation of this uniquely detailed dataset has allowed the first direct determination to be made of the mass of the star that exploded as well as of the rate the star shed the outer layers of its atmosphere in its final years. With further analysis it should be possible to glean from the radio data an understanding of the efficiency of the physical process by which relativistic particles (cosmic rays) are accelerated in supernova events.

In a quite different area, astronomers used radial velocities and the distances of remote clusters of galaxies in several directions to measure how our local group of galaxies was drifting through space. Such studies have suggested the existence of a "**Great Attractor**," a concentration of mass thought to lie in the direction of the Hydra-Centaurus supercluster, whose gravity causes a bulk flow of material toward itself. Bulk flows of galaxies are expected as a natural consequence of the large-scale structure of the universe. The amplitude of the flows as a function of the spatial scale offers information on the power spectrum of the mass distribution in the universe and thus can potentially discriminate between the various theories of formation for both large-scale structures and galaxies themselves. For many years, bulk flow associated with the Great Attractor defined the largest structural scale known in the universe, but more recently astronomers have begun to examine larger volumes of space to search for structures on even larger spatial scales. Work by astronomers at the National Optical Astronomy Observatories and the Baltimore-based Space Telescope Science Institute, using the Kitt Peak National Observatory's 4-meter and 2.1-meter telescopes and the Cerro-Tolodo Interamerican Observatory's 1.5-meter telescope (in Chile), suggests that bulk flows continue over distance scales nearly three times larger than the previously known limit of 6,000 kilometers per second.

In the area of astrophysics, finally, the Boulder Laboratories of the National Institute of Standards and Technology (NIST) has recently made highly accurate (0.1 part per million) measurements of the fine-structure frequencies of the singly-ionized atomic nitrogen (N^+). This measurement and other high-accuracy spectral measurements by NIST have been supported by NASA's Office of **Laboratory Astrophysics**. The objective of such accurate spectral measurements is to provide sufficient information on atomic and molecular species to enable searches in the upper atmosphere and the interstellar medium. The N^+ measurements provided solid confirmation of the tentative radio astronomy observations of this species, which is an important constituent of the interstellar medium. Moreover, the laboratory measurements define a second frequency that can be used in future radio astronomy studies.

Solar System Exploration

Within the solar system, studies of individual planets continued to be pursued with spacecraft as well as ground-based telescopes. For example, the last findings by NASA's **Pioneer Venus Orbiter** provided strong new evidence that the planet Venus once had three and a half times more water than previously thought—enough to have covered the entire surface between 25 and 75 feet (7.6 and 22.8 meters) deep. (Most scientists believe that early oceans on Venus vaporized as a result of a greenhouse effect.) After providing this evidence and other data about the planet's ionosphere and atmosphere, the spacecraft burned up in the atmosphere on October 8, 1992, after 14 years of exploration.

Also studying Venus was NASA's **Magellan** spacecraft, launched in May 1989. Having successfully completed its original mission of radar-mapping the planet, Magellan began collecting data on Venus' gravity near the beginning of FY 1993. However, its highly elliptical orbit blurred its measurements at the furthest distances from the planet. To slow the spacecraft and circularize the orbit, NASA engineers began a slow process on May 25, 1993, of dipping Magellan into Venus' atmosphere for minutes at a time on each orbit in a process known as "aerobraking." This procedure, never used before on a NASA planetary mission, was necessitated by the lack of sufficient thruster fuel onboard to make the change in orbit. In its new position, reached in August 1993, Magellan was positioned to profile the planet's gravity at the mid- and higher latitudes and poles to give scientists a better picture of Venus' interior. In the process, they also learned about greenhouse heating close to the planet's surface and strong cooling in the upper atmosphere, processes that could affect the Earth in the future.

In the development of aerobraking for **Magellan**, the only way planners could predict how the process would work was through computer simulation. In a cooperative research program between Ames Research Center and Stanford University, funded by NASA's Office of Advanced Concepts and Technology, researchers developed a computer code to model the millions of individual particles of atmosphere that collide with and flow over the surface of the spacecraft. If the simulation had not been accurate, aerobraking could have resulted in the loss of the spacecraft. For the future, the code can provide accurate predictions of aerobraking for other spacecraft in the upper atmospheres of Earth and other planets.

Meanwhile, the **U.S. Geological Survey** was using data from Magellan's earlier mapping mission to prepare several map series. A global map of Venus (1:50,000,000 scale) and a set of maps at 1:10,000,000 scale were finished by the end of the fiscal year and in the process of publication. Also, the Survey was in the process of producing geologic maps at scales of 1:5,000,000 and 1:1,500,000. Additionally, the Survey was in its seventh year of participating in NASA's Mars Geologic Mapping program, with several maps completed and ready for publication on compact disk while high-resolution geologic maps (1:500,000 scale) were being prepared to help select Mars landing sites for future U.S., Russian, and European missions.

Earlier in the fiscal year, photos from NASA's **Viking Orbiter**, launched in 1975, revealed that Mars was once, and may still be, more seismically active than the Moon though less so than the Earth. NASA planned further study of this seismic activity through a series of Mars landers planned for the period 1996 to 2003.

Unfortunately, another NASA mission to the red planet, **Mars Observer**, ceased communicating with Earth on August 21, 1993, shortly before it was set to enter Mars orbit on August 24. To determine what caused the loss of communication, a Mars Observer Investigation Board under the chair of Dr. Timothy Coffey began meeting in September 1993 and was scheduled to present its findings early in FY 1994. Already in September 1993, however, NASA announced the establishment of a study team at its Jet Propulsion Laboratory to examine a variety of low-cost spacecraft, instruments, and launch options for a possible return mission to the planet to recover some of the scientific objectives of Mars Observer.

Observations from **Hubble Space Telescope** indicate that Jupiter's moon Io has a smaller atmosphere than previously thought. Nevertheless, despite continual volcanic activity, Io's surface has remained largely unchanged since it was first photographed by the Voyager spacecraft in 1979. Such findings are important because Io is the solar system's most dynamic and evolving moon and has significant indirect effects upon Jupiter's immense magnetosphere and aurorae.

Scientists who placed instruments aboard NASA's **Kuiper Airborne Observatory** (a C-141 aircraft equipped with a 0.97-meter telescope) also studied Io, finding what they believed were water molecules frozen in the surface ices of Jupiter's natural satellite. Conducting infrared examinations from above 99 percent of the Earth's atmospheric water vapor, the scientists found spectral evidence of the water for which they had been searching for years. Another group of scientists, however, later disputed that the spectral evidence pointed to H_2O, claiming that it indicated the presence instead of SO_2. The difference of interpretation remained to be resolved as the fiscal year ended.

Also with regard to Jupiter, NASA's **Galileo** spacecraft—launched in October 1989—flew by Earth on December 8, 1992, completing a three-year gravity-assist program and setting a course to reach Jupiter in December 1995. In the process of flying past the Earth, the spacecraft obtained a great many images and spectral scans of the northern regions of the Moon and various areas of the Earth over a period of several days. Galileo also obtained photographs in August 1993 of the asteroid Ida, showing that it is not geologically as youthful as scientists had theorized.

On earlier passes by the Earth and Moon in 1990 and 1992, Galileo had obtained images and compositional data that the U.S. Geological Survey processed to produce new multispectral image mosaics. The Survey also produced and released global digital maps of the four satellites of Jupiter to support the spacecraft's encounter with that planet in 1995.

Using a new instrument on the United Kingdom Infrared Telescope in Hawaii, scientists working at NASA's Ames Research Center and elsewhere meanwhile discovered that the distant planet **Pluto** is covered with surface ices that are 98 percent nitrogen. Previously, scientists had believed the surface of the planet was dominated by methane because the extremely small amounts of that substance absorb sunlight much better than nitrogen and so are easier to detect.

In a rather different kind of solar system exploration, NOAA's **Space Environment Laboratory** in Boulder, CO, has been involved in the international project SOLTIP (SOLar connection to Transient Interplanetary Processes). This solar/interplanetary program is part of STEP (Solar Terrestrial Energy Programme). Its objective is to focus attention on various forms of solar activity (flares, coronal holes, erupting filament, coronal mass ejections, etc.) and to track their interplanetary manifestations as the disturbances propagate towards the Earth's magnetosphere. The basic scientific questions are directed toward the transfer of energy, mass, and momentum through the solar wind to the Earth, as well as toward the need to forecast the generation of geomagnetic storms.

Other Space Science

During FY 1993 NASA's research into the role of gravity on living systems continued to play a critical role in understanding and mitigating the effects of zero gravity on humans, as well as benefiting the broader medical research community through findings that spin off into non-space related applications. Analysis of data from the June 1991 **Spacelab Life Sciences-1** (SLS-1) mission led to advances in biomedical practice on Earth in clinical medicine, biocomputation, and medical diagnostic systems. Many of the findings provided long-awaited confirmation of theories of adaptation to space flight. Others have compelled a reassessment of ideas about how individual bodily systems function on Earth and adapt to space flight. These unexpected results will allow us to understand more about the control of red blood cell mass and its relationship to anemia. They have disproved the theory that differences in regional blood flow to the lungs are totally dependent on gravity. The scientific achievements from SLS-1 will open up new areas of scientific study and be immediately useful in developing countermeasures for use by astronauts on long-duration missions. In addition, a commercial unit for testing the function of the body's blood pressure sensors, developed from a key SLS-1 experiment, is already helping diagnose patients who experience faintness and dizziness, including the chronically bedridden. The SLS-1 results will likely contribute to advancing treatments for cardiac patients, understanding certain blood disorders, and advancing brain research through studies of neural networks. These results could also initiate a potential new direction in the fight against osteoporosis in postmenopausal females.

The **Spacelab Life Sciences-2** mission, flown in October 1993 aboard Space Shuttle Columbia, continued and extended the SLS-1 experiments through the longest mission yet in the history of the Space Shuttle program. Results of this mission are eagerly anticipated as analysis of mission data continues through the next two years.

The results of experiments on the first **International Microgravity Laboratory** flown in January 1992 and the joint U.S.-Japanese **Spacelab-J** in September 1992 led to major advances in the field of gravitational developmental biology. Both sets of experiments used amphibians to test the effects of microgravity on embryo development. Both showed that although there are noticeable differences between embryo development in space and on Earth, the embryo has a considerable plasticity and is able to develop into a viable tadpole in space with no major abnormalities.

Three life sciences experiments sponsored by NASA flew on the German **Spacelab Mission D-2** in April 1993. Experiments tested differences in astronauts' blood pressure reflexes after adaptation to zero gravity and the effects of microgravity on the lungs. An SLS-1 follow-on study investigated cardiovascular adaptation. These experiments will provide valuable information about basic bodily functions for the design of countermeasures that will enable humans to remain healthy and productive for much longer stays in space. Commercial equipment, based on flight hardware from the blood pressure experiment, is helping to diagnose patients with symptoms of orthostatic hypotension (reduced blood pressure upon assuming an upright posture) on the ground.

The **Space Shuttle Middeck** continues to be used for small, relatively inexpensive life sciences experiments. In 1993 experiments helped to provide a cohesive view of the influence of gravity on bone development, to understand why plant development is detrimentally affected by microgravity, and to verify microgravity-elicited changes in cell function.

In 1993 the NASA life sciences division developed a program in **Advanced Technology Development** to focus on technologies needed by the NASA science community, while simultaneously promoting the transfer of these advanced technologies into the private sector.

NASA and the National Institutes of Health (NIH) have continued and furthered the cooperative activities initiated in 1992. In connection with various memoranda of understanding, NASA and the National Institute on Deafness and Other Communications Disorders agreed to contribute $500,000 a year for five years to a Center for Vestibular Research at Northwestern University Medical Center to address problems of significant interest to both agencies; NASA and the National Heart, Lung, and Blood Institute are jointly sponsoring a Center in Integrative Physiology at the University of Texas' Southwestern Medical Center; NASA and the National Institute on Arthritis and Musculoskeletal and Skin Disease issued a joint research announcement soliciting research for musculoskeletal cell culture experiments to fly on the Space Shuttle as small payloads in the middeck.

Life sciences have achieved important strides through cooperation with international space agencies. Cooperative space missions between Russia and the U.S. (discussed below) will allow the U.S. to obtain life science data on long-term human physiological adaptations to space flight and to understand better Russian medical monitoring, countermeasures, and operational medical programs. In December 1992 a delegation traveled to Moscow to visit Russian medical facilities and develop a protocol for a **Telemedicine Demonstration Project** (TDP). This enabled NASA to begin working with the Russian Medical Information Agency in developing the TDP-Spacebridge to Moscow. Already, this protocol has resulted in a number of accomplishments, including the loan of advanced DoD telepathology/teleradiology equipment to Russia and joint conduct of clinical oncology sessions using this equipment. NASA's international partners, including Canada, the European Space Agency, France, Germany, and Japan, are also participating in the planning and implementation of SLS-4, Neurolab. This cooperation, along with joint international meetings among these space agencies, is laying the groundwork for future cooperation on Space Station.

During FY 1992, NASA had conducted more peer-reviewed, hands-on U.S. space research in microgravity science than it had performed cumulatively in all years since Skylab (1973-74). Results from those experiments became available in FY 1993. Those from the **First International Microgravity Laboratory** (IML-1) and the **First U.S. Microgravity Laboratory** (USML-1) missions are providing insights into the behavior of certain processes in space and helping to resolve important questions in ground-based research. Protein crystal growth, a process complicated on Earth because of gravity-caused convection, is easier to achieve in space. Crystallizing proteins is critical to determining the structure and therefore the function of these important building blocks of life. Information about structure and function provides insight into cures and treatments of diseases and contributes to understanding life processes. Experiments using two different crystallization techniques flew on IML-1, with proteins ranging from an enzyme important to the digestion of milk in both babies and adults to canavalin, a substance obtained from bean plants and a major source of the world's nutritional protein. USML-1 extended and improved upon these experiments. The best crystals of Malic enzyme ever obtained were grown on this flight. It has potential use in the development of antiparasitic drugs. Also, data obtained from space-grown crystals of bovine proline isomerase—a target of transplant rejection studies—was superior to data from the best Earth-grown crystals. Analysis of inorganic crystal growth experiments from IML-1 and USML-1 is showing some interesting and unusual results. Mercuric iodide crystals, which can have exceptional and useful electronic properties, were grown more rapidly and with fewer defects on IML-1 than had previously been possible on Earth. Semiconductor crystals with important applications ranging from integrated circuits to solid-state lasers were grown with improved structural perfection in the reusable Crystal Growth Furnace aboard USML-1. In-flight studies of the solidification of metal alloys, combustion and surface tension on IML-1 and USML-1 have both refined current theories and provided experimental results that contradict existing theories. Experimental studies of the thermocapillary flow phenomenon, for example, are of inherent scientific interest and may be an important factor in many industrial processes.

Analysis of scientific results from the **First U.S. Microgravity Payload** (USMP-1), a Shuttle mission based in the cargo bay and launched October 22, 1992, have begun to provide valuable data towards testing a Nobel-prize-winning theory on the phase transition behavior of very cold liquid helium at its "lambda point" (where solid, liquid, and gaseous helium coexist). An international experiment involving the U.S. and the French space agency investigated solidification phenomena of metals and semiconductors. The mission also demonstrated the value of controlling the experiments from Earth to improve the quantity and quality of results without the direct use of astronauts. During the mission, scientific investigators on the ground sent over 5,000 interactive commands directly to their instruments on orbit. This is a procedure of vital importance for maximum use of the international space station.

NASA also sponsored a project in microgravity science designed to enhance understanding of combustion science by taking advantage of a unique microgravity environment. Researchers at the Department of Commerce's National Institute of Standards and Technology (NIST) cooperated in this project by developing a 3D ignition and flame spread computer code and were planning validation experiments for a space flight in 1995 to study **Radiative Ignition and Subsequent Flame Spread over Cellulosic Materials**. Preliminary exploratory flights with similar hardware had already occurred using drop towers and were underway at the end of the fiscal year on a NASA Lear jet.

Also in the area of microgravity science, the performance of **High-technology Crystals** controls the development of the information processing required by American industry to remain competitive. This performance is determined by crystalline order, which is affected by gravity and therefore being studied by NASA. NIST activity fundamental to this NASA program has shown order in crystals grown in microgravity and on Earth; the nature of the differences; and the origins of these differences so they can be duplicated reliably and inexpensively in terrestrial growth. This knowledge allows production of improved crystals of mercuric iodide used for high-energy detectors, triglycine sulfate used for sensitive infrared detectors, and gallium arsenide used for the most sophisticated information processing.

NIST was also engaged in other research funded by NASA to provide an understanding of the effect of microgravity on **Solidification Processes** so that scientists and engineers can predict and control those processes. For example, in space experiments and especially those subject to vibration, the gravitational field varies over time. These variations influence fluid flow, hence solute segregation during solidification. This segregation must be controlled to allow preparation of materials with optimum properties. During FY 1993, NIST researchers calculated the effects of gravitational accelerations to enable predictions of the effects to be expected in solidification experiments under typical microgravity conditions. They obtained specific results applicable to materials for which space experiments, planned by solidification scientists in coordination with NASA, were underway.

Space Flight and Space Technology

Space Shuttle

The Space Shuttle's primary purpose continued in FY 1993 to be transporting people and cargo safely into low-Earth orbit (100 to 350 nautical miles above the Earth). As of the end of the year, there remained four active **Orbiters** in NASA's fleet: Columbia, Discovery, Atlantis, and Endeavour. As the year ended, Columbia was in an Orbiter Maintenance Down Period (OMDP) at the Orbiter Facility in Palmdale, CA. Following this OMDP, the Shuttle fleet will have 3 orbiters capable of extended duration flights (up to 16 days). Additionally, Atlantis was being modified for docking capability with the Russian space station, Mir, a mission scheduled for the third quarter of FY 1995.

The **Space Shuttle Main Engine** (SSME) program continued its aggressive test activity during FY 1993. Engineers conducted more than 80 ground tests, accumulating more than 33,000 seconds in support of development, certification, and flight programs. NASA made significant progress in the development of hardware designed to increase the safety and reliability of the SSME. During the year, engineers conducted over 30,000 seconds of testing in the development of the oxidizer turbopump as part of the Alternate Turbopump Program (ATP). Preliminary testing of the Large Throat Main Combustion Chamber at the Marshall Space Flight Center Technology Test Bed demonstrated that NASA had achieved significant reductions in temperatures and pressures in the main combustion chamber without performance degradation. The Stennis Space Center initiated testing of the Block I SSME upgrade configuration (Phase II plus powerhead, single coil heat exchanger, and ATP oxidizer turbopump) and was progressing at the end of FY 1993 toward certification and first flight in 1995.

The **Advanced Solid Rocket Motor** (ASRM) program was terminated by Congress in the 1994 NASA appropriations conference bill. For FY 1994, Congress did provide funding for the purpose of terminating ASRM contracts and shutting down the construction of facilities in Yellow Creek, MS. As FY 1994 began, NASA was formulating a plan to carry out the termination in an expeditious fashion.

NASA was also working to provide a replacement main combustion chamber for the Space Shuttle Main Engine using a completely different fabrication approach involving a precision-cast structural outer jacket and a "formed platelet," inner hydrogen-cooled combustion liner. The new **Advanced Main Combustion Chamber** can be manufactured at one-sixth the cost of the present chamber, yielding improved reliability and durability in one-third the construction time. Engineers have successfully demonstrated the new construction in hot firings in a subscale thrust chamber. The full-scale chamber is scheduled for full-scale testing in the late spring of 1994.

The **Solid Rocket Booster** continued to perform well in the seven FY 1993 Shuttle flights. There were two static test firings of motors manufactured before the Challenger accident. These were the last of 11 pre-redesign motors that have been used for test purposes. Activities were continuing at the end of the year to develop a new, non-asbestos insulation to replace the asbestos-containing materials in the motor and to prepare for tests of a designed modification to the aft skirt structure to improve its strength. NASA also began a new activity to eliminate the use of ozone-depleting substances used in manufacturing the booster.

In the area of **Shuttle Systems Integration**, the Day-of-Launch- I-Load-Update (DOLILU-I) system was available for all FY 1993 missions. This system updates the flight trajectory to account for the actual winds on the day of launch. Pitch and yaw updates to the flight computer have significantly improved the launch probability. Integration efforts during FY 1993 also included structural loads analyses; development of the requirements to allow interaction between the Space Shuttle and Space Station information management systems; resolution of inflight anomalies, waivers, and changes; liftoff clearance certification; and software development and testing for the control of each mission. The DOLILU-II system, which will uplink the main engine control tables, solid rocket trim data, and aerodynamic control data on the day of launch, will further improve the ascent trajectory of the Shuttle. This improved system was expected to be certified by October 1994, with its first flight scheduled for that calendar year.

The **Space Shuttle Ground Processing** preparation for launches was significantly improved due to several innovations in management and procedures in conjunction with enhancements in automation. The latter included automation of planning, documentation, and work control. These enhancements reduced the work effort per mission on the preparation sequence by approximately one-third and preparation timeliness by approximately one-half since the return to flight following the Challenger disaster. This increased efficiency was accompanied by a streamlining of the workforce, reduced costs, and improved safety.

Finally, building from technology of the cancelled **Flight Telerobotic Servicer Program**, NASA's Langley Research Center and Johnson Space Center have developed a hydraulic manipulator system testbed and a flight qualifiable Shuttle compatible arm. The testbed at Langley was successfully tested remotely from Johnson, demonstrating the feasibility of remote control of a flight system and verifying video and data networks for telerobotic control.

Single Stage Rocket Technology (SSRT) Program

The Ballistic Missile Defense Organization (BMDO) was the contracting agent for the SSRT program whose objective was to demonstrate aircraft-like operations and supportability for future single-stage-to-orbit launch vehicles. If successfully developed, such a vehicle could reduce the cost of launching payloads by an order of magnitude. McDonnell Douglas' Delta Clipper-Experimental (DC-X) has become the first working, one-third scale technology demonstration vehicle for this concept. The contractor officially rolled out the DC-X on April 3, 1993. McDonnell Douglas completed design and construction of the vehicle, its flight operations control center and ground support system in just over 18 months from contract award. By June 17, 1993, the system completed a total of nine hot fire and three cryogenic cold flow tests at the White Sands Test Facility (WSTF) in NM. The progression of tests went through successively larger cryogenic loadings to various hot fire tests, including a simulated 64-second flight profile. The tests actuated all vehicle and support systems in preparation for flight testing at the White Sands Missile Range (WSMR). Before the start of this flight testing, two static firings on the WSMR launch mount, using all the relocated support systems, verified the total system's readiness for flight testing. The first hover test took place on August 18, 1993, only two years from contract award. The DC-X flew to a height of 150 feet, hovered briefly, translated to 350 feet, hovered again, and then descended to a soft landing on its landing gear. The second flight occurred on September 11 and followed essentially the same flight profile but only going to 300 feet. The vehicle ended the fiscal year with a third successful flight test to 1,200 feet on September 30. All tests, both static and flight, took place with an operations crew of only 3 people and a total support team of 25, demonstrating the primary goal of aircraft-like operations and supportability.

Other Launch Systems

The **Pegasus** booster, developed by Orbital Sciences Corporation and the Advanced Research Projects Agency (ARPA), is a three-stage, solid propellant, inertially guided, winged launch vehicle that reached full operational status in 1993. To date, Pegasus has successfully performed in four out of four launches. An optional hydrazine-propelled fourth stage can be added as required for additional performance or precision orbital injection. Launch procedures for the Pegasus involve being carried aloft by a conventional transport or bomber aircraft and then released at approximately 40,000 feet, where the first-stage motor is ignited. The payload fairing has undergone redesign to resolve problems identified in a flight on July 17, 1991, and to improve reliability and contamination control for future flights. At the conclusion of ground testing of these modifications, ARPA transitioned the program to the Air Force in April 1993. The first Air Force-managed flight occurred on April 25, 1993. As FY 1993 ended, a new version of the booster called Pegasus XL was under development in a jointly managed effort between the Air Force and NASA. The XL offers increased performance so that a payload of 500 lbs. (up from 380) could be boosted to a 400-nautical-mile polar orbit by stretching the length of the original Pegasus' first and second stages. The Air Force is acquiring Pegasus XL for launch of Space Test Program payloads. The first Air Force launch of Pegasus XL is scheduled for the second quarter of FY 1994.

The **Taurus** standard small launch vehicle has capitalized on ARPA's previous investment in Pegasus to produce a ground-launched rocket with greater payload capacity. Taurus uses three Pegasus solid-rocket motors (with the wing removed), stacked atop a Peacekeeper first stage to construct a vehicle capable of placing 1,900 pounds in a 400-nautical-mile polar orbit. Taurus is fully road-transportable and can operate from austere launch sites independent of existing space launch centers. Requiring only a bare concrete pad, the Taurus team demonstrated that it could establish a launch site within 5 days of arrival and that the encapsulated payload could be mated to the rocket in the final 72 hours before launch. This capability will provide assured, affordable, and rapid access to space for moderate-sized payloads despite hostile action or natural disasters that could deny the use of existing facilities. The rocket passed major milestones this year with the successful completion of the qualification test program and a total of four Pathfinder demonstrations using a full-scale engineering vehicle. These demonstrations, the last of which occurred at the launch site, validated the eight-day equivalent access-to-space timeline, the integration and test of the launch vehicle and payload, and all procedures required to activate the launch site and conduct launch operations. The first launch is scheduled for early 1994.

The **Inertial Upper Stage** (IUS) continued to be the most accurate upper stage in the Air Force inventory. The Air Force has used IUS to deliver the Defense Support Program (DSP) spacecraft from low-Earth orbit at about 150 nautical miles, after two different burns of the IUS solid stages, to geosynchronous orbit at over 22,000 nautical miles. The Air Force plans for the IUS to continue to support the DSP into the next century. Additionally, the Air Force will continue to assist NASA by procuring IUSs to support upcoming Shuttle missions, such as the launching of Tracking, Data, and Relay System spacecraft.

The Air Force completed Centaur upper stage development for the **Titan IV** in FY 1993 and will be ready to launch the first Titan IV with a Centaur as soon as it has finished recovering from the August 2, 1993, launch failure (see above). The Titan IV Solid Rocket Motor Upgrade (SRMU) development program completed its fifth successful static test firing in FY 1993, demonstrating complete recovery from early design flaws that caused failure during the first test in April 1991.

Satellites

The **Navstar Global Positioning System** (GPS) is a space-based, radio navigation system satisfying requirements for highly precise, worldwide, three-dimensional position, navigation, and timing data for military and civilian air, land, and marine operations. It consists of space, control, and user segments. When completed, the GPS operational constellation will consist of 24 satellites (Block II) that operate in inclined, semi-synchronous (i.e., 12-hour) orbits. Deployment of the system continued during FY 1993 with the launch of seven GPS Block II satellites. At the end of the year, the system consisted of 23 operational Block II satellites and 1 research and development Block I satellite. The last Block I satellite will be replaced with a Block II satellite in early 1994. After this 24th Block II satellite is on orbit, the Air Force will launch replacement satellites on an as-needed basis to sustain the GPS constellation. The GPS control segment updates the satellite broadcasts, which provide position accuracies to within 16 meters for military users and 100 meters for civilian users. Delivery of GPS receivers to all of the Armed Services continued in 1993. The production of a new handheld military receiver began in 1993 with the goal of delivering over 80,000 units to the services by 1999. ARPA has completed the development of three of these receivers. They weigh only eight pounds and require 12.5 watts of power. They will permit satellite navigation to an accuracy of four meters without interaction with satellite ground stations. The flight demonstration of these receivers, scheduled for 1994, will be a key step in increasing satellite autonomy. Such operation by the satellite, independent of ground contact, should contribute greatly to reduced life-cycle costs in future space systems.

In related developments, the Federal Aviation Administration (FAA) recognized that as GPS neared operational status, civil aviation users would experience a significant change in the way they navigated through the airways and landed at airports. The transition from a ground-based to a space-based navigation system was a major program underway at the FAA. The agency was cooperating with the International Civil Aviation Organization to exploit the benefits of GPS. By the end of FY 1993, it had established numerous agreements with foreign countries, such as those in the Commonwealth of Independent States. The FAA and NASA continued work on establishing the feasibility of using GPS to satisfy precision approach requirements for conditions of poor visibility. During FY 1993, the FAA issued the standards for manufacturers to build satellite receivers for use in all phases of flight except precision approaches to runways. In June 1993, the agency approved use of satellite navigation for all phases of flight except precision approaches. It also wrote a draft standard for the use of satellites and associated ground equipment for such approaches.

ARPA's **Advanced Space Technology Program** (ASTP) is aimed at achieving an affordability breakthrough in the development, launch, and operation of satellite systems. To date, the ASTP has pursued projects that demonstrate low-cost access to space; reduced size, weight, power, and cost of satellite components; and first-generation, lightweight satellite capabilities. ARPA completed this phase during FY 1993 and has produced two new launch vehicles (Pegasus and Taurus), ten small satellites (MACSATs and Microsats—see the FY 1992 report—plus PEGSAT mentioned in the 1989-1990 report), and numerous advanced, miniaturized components including the GPS receivers.

The **Defense Support Program** (DSP) provided a highly available, survivable, space-based surveillance system to detect and report missile and space launches as well as nuclear detonations in near real time for the National Command Authorities and theater commanders. The DSP system consisted of a constellation of satellites in geostationary orbits, fixed and mobile ground processing stations, one multipurpose facility, and a ground communications network. The most recent (DSP-I) block of satellites will provide the DoD with enhanced missile warning and surveillance capabilities. In 1993, the Air Force continued modernization projects for sustained and improved DSP warning and surveillance. These included initiation of projects to replace the fixed ground stations and obsolete data processing computers, as well as continuation of projects to replace data reception, transmittal, and recording hardware. The program also completed delivery of the final increment of the upgraded Mobile Ground System to the Air Force Space Command for survivable operations with the DSP-I block satellites. These projects will allow DSP to maintain a viable warning capability until it is replaced by the Improved Space-Based Tactical Warning/Attack Assessment (ISB, TW/AA) system in the next decade.

This **ISB, TW/AA** system will capitalize on the infrared sensor technology developed since the first DSP satellite went into orbit two decades ago. The new system is intended to provide a high probability of detection against the threats of the future, characterized by shorter-range and dimmer missile launches (as compared with those of the former Soviet systems), deployed in numerous less developed countries around the world. The new system will be designed to meet this threat with continuous, worldwide coverage. It will also provide quicker warning messages to the field commanders than DSP offers. Engineers will design the satellites for longer lifetimes to reduce life-cycle costs and will use cross links to eliminate overseas ground stations used for DSP. As a result of these design improvements, the ISB, TW/AA system should be ready to support military forces engaged in future conflicts anywhere in the world.

In the meantime, the BMDO has undertaken a program that demonstrates the improvements possible from applying commercially available, ground processing power to satellite constellations already in orbit. This program, **TALON SHIELD**, processes the infrared sensor data from DSP early warning satellites as they observe ballistic missiles during booster flight. TALON SHIELD receives the data from multiple satellites viewing the same area of the Earth. Using advanced digital processing and efficient triangulation algorithms, it provides near real-time launch warning and impact-point prediction for theater-class missiles. The system passes the data on to the region under attack to cue other sensors and defensive weapon systems. TALON SHIELD has made no changes to the satellites on orbit and is completely compatible with DSP satellites that will be launched in the near future. Simply with improvements in ground-based sensor data processing, TALON SHIELD has demonstrated launch-point accuracy four times better than that provided by older data analysis capabilities; its launch azimuth capabilities have improved three-fold over older systems; and its impact region estimates are ten times more accurate than those of its predecessors. Yet these improvements do not come at the sacrifice of speed; TALON SHIELD delivers this information to U.S. forces in the field less than two minutes after DSP's original observation. Moreover, the development and installation costs of the system have been less than a tenth the cost of a new spacecraft. During 1993, TALON SHIELD observed planned tests of U.S. systems as well as foreign targets of opportunity. The BMDO-supported demonstration of TALON SHIELD was expected to be completed in FY 1994, with the Air Force Space Command transitioning the system to a limited operational capability in FY 1995.

Another BMDO effort, the **Miniature Sensor Technology Integration (MSTI) Program**, met several milestones in FY 1993. The overall objective of the government-industry program is to develop a robust, modular, lightweight spacecraft to meet various research needs of BMDO. The near-term objectives initiated in FY 1993 were to demonstrate on-orbit, through a series of missions, new technologies for detecting and tracking ballistic missiles, similar to the Iraqi Scuds fired during the Persian Gulf War. Under Air Force Phillips Laboratory management and with NASA's Jet Propulsion Laboratory as the prime space vehicle supplier, the program launched its first of a series of satellites on November 21, 1992, from Vandenberg AFB, CA, using a NASA-provided Scout launch vehicle. The six-day MSTI-1 mission met all of its objectives, and the satellite routinely collected data for over five months. Following the successful launch and operations, the Phillips Laboratory team continued work on the design, construction, integration, and testing of MSTI-2, -3, and -4 satellites. MSTI-2 was slated for a late 1993 launch on the last planned NASA Scout mission. This will provide BMDO with significant theater missile tracking research while providing robust Earth infrared backgrounds and emissions research. MSTI-3 and -4 were scheduled for launch in 1994. MSTI was the cornerstone of the DoD's effort to investigate the dual-use application of missile detection and tracking assets for civilian applications. In particular, the program was investigating the use of its sensor not only to track missiles but also to improve understanding of the Earth's environment and global changes, as well as to monitor ecological disasters. Moreover, the MSTI program offered the DoD an ability to conduct space-based research with international partners. Finally, the program, including its field deployable mobile command and control assets, provided the DoD with a "space operations testbed" for exploring advanced satellite command and control and spacecraft utilization concepts.

On April 25, 1993, the U.S. Air Force launched into an 844 x 749-kilometer orbit a Department of Energy (DoE) experimental satellite aboard a Pegasus launch vehicle. The **ALEXIS Satellite** (standing for Array of Low Energy X-ray Imaging Sensors) demonstrates a smaller, faster, and cheaper spacecraft bus and new instruments sponsored by the DoE's Office of Research and Development and led by the Astrophysics and Radiation Measurement group at Los Alamos National Laboratory. In addition to the x-ray detectors, constituting one of two experiments on the 113 kilogram satellite, it has a very high frequency receiver and digitizer for the BLACKBEARD experiment to study ionospheric effects on VHF radio frequency radiation. In this pathfinder project, collaboration between Los Alamos National Laboratory, Sandia National Laboratories, and a small, startup aerospace company, AeroAstro Inc., provided the capability for design, construction, integration, test, launch, and flight control of small, capable, and cost-effective satellites. The experiments, spacecraft, and integration cost approximately $17 million. Besides demonstrating new technical capabilities for detection of proliferation of nuclear weapons, the experiments have been performing state-of-the-art measurements in the areas of astrophysics and ionospheric physics. During the launch, damage occurred to a solar panel and to a magnetometer. The ground crew was able to get both experiments in regular operation, returning an average of 100 megabytes per day of data to ground control at Los Alamos. As of the end of the fiscal year, the original scientific mission was expected to be completed with data coverage over a full 70° orbital swath with the six low-energy, x-ray telescopes and with ionospheric effects on VHF radiation from lightning and human-made sources.

Beginning in July 1993, the DoD began a tri-agency study effort with the Department of Commerce (DoC) and NASA to determine the feasibility of merging all, or parts of, the DoD's **Defense Meteorological Satellite Program** (DMSP), the Polar-orbiting Operational Environmental Satellites (POES) of the National Oceanic and Atmospheric Administration (NOAA), and NASA's Earth Observation System (EOS—see below). The White House Office of Science and Technology Policy (OSTP) will use the recommendations of the tri-agency study to develop an implementation plan for a converged program by April 30, 1994. Meanwhile, the effort to reduce the overall size of DMSP ground terminals continued with the award of the Small Tactical Terminal (STT) development contract. This system will gather data from DMSP and civilian satellites in a portable, combat-capable configuration. The DMSP program continued its support of the first complete digital archive of civilian and military weather satellite data. These data will be available to DoD, government, civilian agencies, and universities to enhance environmental research activities such as global climate change. (For other military satellites, see below under Communications Satellites.)

In another development related to satellite technology, the Jet Propulsion Laboratory Micro-precision Control/Structure Interaction Program delivered two products of its technology to be used for NASA's **Hubble Space Telescope** servicing mission that took place after the end of the fiscal year in December 1993. Program engineers developed controlled optics modeling software and used it to analyze the precise corrective prescription for the spherical aberration in the telescope's main mirror. This technology also has applications to future space and ground-based optical instruments. Additionally, the engineers developed a solid state actuator system and incorporated it into the telescope's new Wide Field/Planetary Camera. This hardware allows ground operators to make highly precise adjustments to the alignment of the new corrective optics.

As of the end of the fiscal year, NOAA was operating three types of environmental satellite systems: POES; the Geostationary Operational Environmental Satellites (GOES); and the Landsat series of satellites. The two operational POES satellites were **NOAA-11 and NOAA-12**, launched in September 1988 and May 1991, respectively. NOAA-11 remained the operational afternoon satellite and NOAA-12, the operational morning satellite. In addition, two earlier satellites continued to operate in a stand-by mode, providing direct readout services and recorded data from the Earth Radiation Budget Experiment (ERBE) and the ozone observing instrument, the Solar Backscatter Ultraviolet Radiometer (SBUV). On August 9, 1993, the Air Force launched the NOAA-13 satellite to replace the aging NOAA-11, but all communications with NOAA-13 ceased on August 21. Attempts to restore them have not been successful. A formal failure review board has convened to determine the probable cause of the failure. The next in this series of satellites, NOAA-J, has been called up for earliest launch in May/June 1994. Although it was originally configured to be a morning satellite, the contractor is reconfiguring NOAA-J for the afternoon orbit with the SBUV instrument on board. In the meantime, NOAA planned to activate the SBUV instrument on NOAA-9 to provide ozone-tracking data, while the NOAA-11 and NOAA-12 satellites continued to provide operational sounding and image data. The Space Environment Monitor (SEM) radiation environment instrument continued to operate on the NOAA-12 spacecraft. An identical instrument was scheduled as of the end of the fiscal year for launch during FY 1994 on the NOAA-14 spacecraft. An upgraded SEM was scheduled for launch on the first of the new series of NOAA polar orbiters in FY 1995 or 1996.

Normally, NOAA has maintained two operational **GOES** satellites in geosynchronous orbit above the equator, providing coverage of the Atlantic Ocean, the Western Hemisphere, and the eastern Pacific Ocean. As of the end of the fiscal year, NOAA had only one operational GOES in orbit, GOES-7, launched in February 1987. It had been moved from providing coverage in the Atlantic during the hurricane season to the west to provide coverage of the Pacific and the Central U.S. during the non-hurricane season. At the end of the fiscal year, GOES-7 was located at approximately 112° west longitude, and since February 1993, the Atlantic coverage has been provided by the "loan" of the European Meteosat-3 satellite, on location at 75° west longitude. The next in the series of U.S. GOES satellites, GOES-I, was on schedule as of the end of the fiscal year for launch in the late spring/early summer of 1994. This Earth-oriented satellite will carry separate imager and sounder instruments, replacing the existing geostationary satellites' single instrument that provides both functions, but not concurrently. Each of the new instruments will improve the current capabilities for monitoring the Earth's dynamic weather by providing atmospheric soundings on a full-time basis and imagery as frequently as every six minutes over selected areas of 1,000 kilometers^2.

An Air Force Titan II launched the last in the NOAA-operated Landsat series of satellites, **Landsat-6**, on October 5, 1993. After successful separation from the Titan II, the satellite's integral "kick motor" apparently did not deliver it into final orbit, and contact with the satellite ceased. A Landsat-6 Failure Review Board has convened to determine the probable cause of the failure.

One further development in the area of satellite technology was the launching of two **Tether Systems** conceived and designed by the Smithsonian Astrophysical Observatory but involving other participants including the University of Genoa. The first system, designated the Small Expendable Tether Deployable System, was launched as a secondary payload aboard a Delta II rocket from Cape Canaveral, FL, on March 29. The 85-pound satellite was attached by a 20-kilometer-long flexible cable to the Delta's second-stage rocket, and during the 80-minute deployment, the entire length of tether slowly unreeled until the payload began swinging like a pendulum. Once it ceased swinging and came to a vertical position, it was severed and allowed to burn up as it reentered the Earth's atmosphere. Meanwhile, it allowed SAO's scientists to compare data on actual tether dynamics with computer models of predicted behavior in preparation for future flights of similar systems. The next such flight occurred on June 26 when another Delta II from Cape Canaveral launched an electrodynamic tether called the Plasma Motor Generator on a six-hour flight that demonstrated the ability of a tether to generate an electrical current in space. The tether consisted of two plasma contractors, or hollow cathode tubes, at either end of a 500-meter-long, thin copper cable coated with teflon. As the system cut through the thin ionosphere, ionized xenon gas in the tubes generated a weak electrical current (approximately 0.3 ampere, with an electromotive force of 100 volts) along the line.

Space Station

During 1993, NASA redesigned the Space Station at the direction of President Clinton to reduce costs while retaining user capability and maintaining the program's international commitments. The redesign effort in the spring of 1993 with the participation of the International Partners resulted in three options that NASA reported in June to the Advisory Committee on the Redesign of the Space Station. Option A was a Modular Approach; Option B was called Freedom Derived and most closely resembled Space Station Freedom; while Option C was a Single Launch Core Station. After reviewing the Advisory Committee's recommendations, the President instructed NASA to implement a modified version of Option A to maximize the use of the investment in the previous design and maintain the commitment of our International Partners, while reducing development and operations costs. Option A, with appropriate enhancements became (provisionally) Space Station "Alpha" shortly before the end of the fiscal year. The new Space Station design is based on a modular concept and will be built in stages. The new design draws heavily on the previous Space Station Freedom investment by incorporating most of its hardware and systems. The power system, truss, modules, and many distributed systems will be essentially the same as planned for Freedom. Changes essentially took the form of simplifying previous features such as the data management system plus using hardware already developed, such as the U.S. Bus-1 or the Russian Salyut for propulsion, guidance, navigation, and control. The Bus-1 and Salyut are capable of being modified for Space Station use with modest design changes and costs.

NASA has already designed, developed, and tested major portions of the Space Station systems and hardware. The Man Tended Capability Critical Design Review, completed in July 1993, certified that the previously baselined program had reached sufficient maturity to justify beginning the manufacture of flight hardware. In order to reach this advanced state of design, NASA achieved many facility, testing, hardware, and software milestones during 1993. These included: manufacturing facility modifications, test hardware production, major testing, software development, production of early assembly flight hardware, procurement of flight hardware material, and production planning. NASA contractors and engineers built and tested test hardware for Space Station elements such as: the unpressurized berthing adapter, star tracker, propulsion modules, truss segments, foot restraints, cupola, nodes, environmental control and life support systems, and electrical power system. They also manufactured some components of flight systems such as solar cells for photovoltaic arrays to provide power generation and bulkheads for the solar array rotary joints.

With respect to international contributions to the Space Station Program, Japan's Science and Technology Agency and its National Space Development Agency, in anticipation of an overall critical design review in 1995, conducted several detailed design reviews of the Japanese Experiment Module and Exposed Facility systems and subsystems throughout the latter part of FY 1993. The Canadian Space Agency conducted successful critical design reviews of the Space Station Remote Manipulator System and the Mobile Base System. The Canadians also conducted a preliminary design review of the Special Purpose Dextrous Manipulator. The European Space Agency undertook a major restructuring effort on its Columbus Programme to downsize and simplify the Attached Pressurized Module, making it compatible with NASA's redesign of the Space Station. The Italian Space Agency, which is providing the Mini-Pressurized Logistics Module for the U.S., completed its preliminary design review on October 8, 1993. (See also Other Aeronautical and Space Activities, Cooperation with Russia and Other Foreign Policy Issues.)

Energy

To date, the U.S. has successfully employed 37 **Radioisotope Thermoelectric Generators** (RTGs) on over 20 spacecraft launches covering a variety of different space applications. An RTG is a static device (one without moving parts) that directly converts the heat from the decay of the radioisotope Plutonium-238 (Pu-238) into electricity. RTGs have demonstrated the long lifetimes, self-sufficiency, environmental independence, and operational flexibility demanded by a variety of space missions, including the capability to operate well beyond specified mission lifetimes and above designed power levels. For example, the multi-hundred-watt RTG on the Voyager 2 spacecraft, launched in August 1977, continues to operate after its encounters with Jupiter, Saturn, Uranus, and Neptune and as it continues on into space. A new model RTG with a more efficient fuel design called the General Purpose Heat Source (GPHS) RTG has been the latest in a series of nuclear power sources developed for space applications by DoE. The GPHS-RTG operated successfully on the

Galileo and Ulysses missions, launched in October 1989 and October 1990, respectively.

DoE program activities in FY 1993 focused on production of both GPHS components and GPHS-RTG thermoelectric converters in order to meet the anticipated power system requirements to use them on the Cassini mission to Saturn, scheduled for an October 1997 launch. DoE's restart of production and assembly for GPHS components has proceeded on schedule. Oak Ridge, TN, has been producing iridium-alloy, clad vent sets for use at Los Alamos National Laboratory (LANL), NM, in fuel-clad weld development, product characterization programs, and pre-production start-up operations. The Savannah River Plant, SC, completed start-up activities for fuel reprocessing and shipped four kilograms of Pu-238 powder to LANL. LANL completed process development for fuel pellet and fuel-clad fabrication in preparation for beginning production of the flight unit in FY 1994. RTG assembly and test planning plus preparation activities at the Mound Plant of EG&G Mound Applied Technologies in Miamisburg, OH, have proceeded according to plan. The prime system contractor has reestablished production capability for the thermoelectric unicouple; completed production of unicouple qualification test hardware; and begun production of flight hardware.

DoE has developed new concepts for smaller and lighter-weight RTGs for the Pluto Fast Flyby design effort. It has completed review and evaluation of advanced, higher-efficiency power converters in concert with the Advanced Technology Insertion program. This included concepts for alkaline metal, thermophoto-voltaic, and Stirling engine technology. This work will continue in the future to identify and possibly develop an advanced converter at the 20 percent efficiency level.

During FY 1993 DoE continued its work on the **SP-100 Space Reactor Power System Program**, which was developing nuclear reactor power system technology to provide tens to hundreds of kilowatts of electrical (kWe) power for civil and defense space applications. However, this program is scheduled for termination in FY 1994. Although the program is being phased out, DoE has established technical readiness for most of the key system components. It made significant progress in key technological areas during the year, building on earlier accomplishments. Previously, design, testing, and fabrication efforts had shown that a 100 kWe system with a mass of less than 4,600 kilograms was achievable; that a thaw concept could be implemented, allowing restart in space after a system shutdown; and that reactor fuel and fuel pins with a seven-year life can be fabricated.

During FY 1993, efforts also focused on continuing the development of the **Thermoelectric Cells** being designed to produce 25 times the electric power available from the similar sized cells used on the Galileo mission. Engineers tested several prototype, single-cell assemblies at operational temperatures for 4,000-5,000 hours. For the power converter, engineers demonstrated assembly of a prototypic 4 x 6 array of thermoelectric cells, including the bonding of the converter liquid metal heat exchanger ducts to the 4 x 6 array. The testing of two materials test loops containing lithium at 1,350° kelvin successfully demonstrated the welding and fabrication techniques required to produce space reactor power system components and coolant loops from high-temperature, refractory niobium alloys. One loop operated for over 3,000 hours and the other for 1,000 hours. Engineers have completed tests for void and thaw characterization of lithium. Thaw and extrusion tests have confirmed that the reactor design accommodates lithium thaw with minimal stress on reactor components. Engineers have also made significant progress in developing the self-actuating thermoelectric electromagnetic pumps that will transport the lithium from the reactor to the power conversion system. They have demonstrated techniques to form the pump ducts explosively and to bond thermoelectric cells to the ducts. They have completed the fabrication of the first demonstration pump assembly containing the pump ducts and thermoelectric cells. Also, engineers fabricated a prototypic control drive assembly and began testing it.

Progress has also occurred on design and technology development of in-core **Thermionic Space Nuclear Reactor Systems**. Work continued in FY 1993 under the Thermionic Space Nuclear Power System Design and Technology Demonstration Program sponsored by DoE, the BMDO, and the Air Force's Phillips Laboratory. The primary objective of the program is to develop two designs to the point that a preliminary design review and technology freeze could be completed, thereby enabling the DoD to determine the utility of a system for a potential flight demonstration. These designs satisfy BMDO and Air Force requirements focusing on mission applications in the electric power range of 5 to 40 kilowatts. Both industrial contractors under this program have subcontracts with Russian entities to integrate Russian expertise in this area into both the design and technological demonstration aspects of the program. Significant accomplishments include the completion of parametric trade studies resulting in a baseline design for each system concept and in a definition of technology and critical component demonstrations required to validate those designs; continued development of point designs at 40 kWe meeting all functional and safety requirements; thermionic fuel element component fabrication in Russia; and the completion of creep testing of emitter materials in Russia.

Work also continued on the **Thermionic Fuel Element (TFE) Verification Program**. It began in 1986 to resolve feasibility issues surrounding long-life, high-power (2 megawatts electric) thermionic space reactors for DoD mission applications. It has expanded the data base on performance and lifetime of TFEs and has demonstrated a TFE lifetime of about 18 months. To date, the program has identified no physical mechanisms that could limit lifetimes to less than two years. In response to changing DoD requirements (such as shorter lifetimes and lower power levels), the DoE restructured the program late in FY 1992 to support the Thermionic System Design and Demonstration Program. In FY 1993, efforts focused primarily on the fabrication and irradiation of a six-cell TFE and the continued irradiation testing of additional multicell TFEs in a thermal reactor environment. FY 1994 activities will feature the post-irradiation examination of TFEs and TFE components. The TFE Verification Program will be closed out by the end of FY 1994.

Finally, DoE has cooperated with DoD and the Air Force in a technological program aimed at demonstrating the feasibility of obtaining high-performance capability from a particle bed nuclear reactor in a thermal propulsion application. The Air Force completed a final environmental impact statement for this **Space Nuclear Thermal Propulsion Program** in May 1993. The program has achieved important particle fuel and fuel element development and testing, as well as some overall system design development. During FY 1993 the DoE also conducted a series of studies to explore the possibility of using common nuclear thermal propulsion facilities to meet the testing needs of this program as well as potential NASA needs.

Safety and Mission Assurance

Along with the seven successful Space Shuttle flights and numerous robotic spacecraft missions already discussed, the U.S. experienced some mission failures. Despite careful preparation and planning, the Mars Observer is, as noted above, presumed lost due to a spacecraft failure. Also, the NOAA-13 spacecraft, managed by NASA for NOAA, appears to have experienced a power system failure. Despite these unexpected setbacks in an ambitious science program, FY 1993 was marked by many successes, as already discussed. To ensure even greater successes in the future, NASA was developing advanced risk assessment techniques and methods for use in the new "faster, better, cheaper" environment in which NASA has begun operating. The agency has been exploring newer and more efficient ways of assessing and managing risk, using such techniques as uncertainty analysis and probabilistic risk assessment for selected areas of the Shuttle and Space Station programs. To support the new and smaller missions in the Discovery program, NASA has streamlined the traditional Safety, Reliability and Quality Assurance approach, which relied heavily on documentation, independent analysis, and reviews to minimize mission risk. Newer policies and practices identify mission success criteria and assure that there is sufficient definition of the risks to performance, cost, and schedule. The overall goal is to assist the project manager in the development of a well-structured risk model during the early phases of the project to serve as a guide in designing those portions of the project where the payoff is highest, thus conserving the limited resources available to the project.

In order to prevent repeating past failures and to capitalize on past successes, late in the fiscal year NASA joined the Air Force, Navy, and FAA in what is fast becoming the interagency aerospace lessons learned system. This system already contains more than 4,500 lessons ready for immediate use. As of the end of the fiscal year, NASA had begun contributing lessons to the interagency system and NASA centers were establishing processes by which the lessons will be used in the development of new aerospace hardware and procedures. NASA's Office of Safety and Mission Assurance also continued to provide decision makers with independent assessments of risk for such matters as inspection procedures after Shuttle aborts on the launch pad and Space Shuttle Main Engine transducer failures. The office has also been in the forefront of significant streamlining of functional management in the agency, involving 17 functional areas to ensure continual improvement, among other goals. The office participated actively in the development and initial operation of a new International Space Organization subcommittee on standards for Space Systems and Operations. Cooperation with the DoT and industry in a workshop conducted through the American Institute for Aeronautics and Astronautics was a first step toward developing U.S. standards for commercial space launch vehicles. Finally, NASA—in conjunction with the University of West Virginia—was in the process of bringing on line a new facility to support Independent Verification and Validation of software. This facility will provide a single NASA focal point for verification and validation of software to assure proper safety and mission assurance requirements are incorporated.

Other Space Technology

The Ballistic Missile Defense Organization continued during FY 1993 to develop experiments that will fly on a joint BMDO/United Kingdom **Space Technology Research Vehicle** (STRV-1b) satellite in the spring of 1994. The flight through the Earth's trapped radiation belts will demonstrate the survivability of analog neural networks, silicon germanium infrared sensors, and other advanced electronics, as well as the ability of adaptive control systems to damp out unwanted vibration from space cryocoolers, needed to obtain clear, accurate imaging from sensors.

Three BMDO experiments will fly on the **Space Test Program Experimental Platform** (STEP) Mission 3 satellite in September 1994. BMDO continued development in FY 1993 of these experiments, which will integrate new technologies for vibration control of large structures, detection of impacts on sensitive materials of the Earth's space environment, and detection of external threats to satellites. The technology for vibration control can also be used, through technology transfer, to improve television and telephone communications from antennas on commercial communications satellites.

BMDO also continued to develop **SPEAR-III**, the third rocket in a series of sub-orbital tests designed to study the interactions between high voltage systems and the space plasma associated with the space environment. SPEAR-III will carry four lightweight experiments designed to limit damage to spacecraft subsystems from the highly charged space plasma. Launch was scheduled (as of the end of the fiscal year) for February 1994 from NASA's Wallops Flight Facility.

In a miscellany of **Technological Developments**, Martin Marietta adopted NASA-sponsored high-performance electric propulsion (arcjet) technology in early FY 1993 for station keeping on the upcoming Intelsat 8, Asiasat, and Echostar communications satellites, with the arcjet technology being instrumental in Martin Marietta's winning the contracts. Also, an advanced, high-temperature rocket motor developed under NASA sponsorship and an upgraded arcjet will also be featured in the next generation of satellites by one of the major U.S. producers. And as a spin-off of the ion propulsion program at Lewis Research Center, engineers developed a plasma contactor for use on Space Station to ground the structure relative to the space plasma.

In January 1993 the robot **Dante** partially descended into the volcanic crater of Mt. Erebus in Antarctica until controllers aborted the mission due to a severed fiber optics cable, which resulted in the loss of communications between the robot and its control station. Developed by NASA and Carnegie Mellon University, Dante tested prototype robotic technologies for uncrewed planetary exploration and to advance scientific knowledge of the volcano. Despite the setback, the project successfully tested new telerobotic technologies and the remote operation of the robot via satellite communications with time delay. Dante was a model for performing missions better, faster, and cheaper, having been built in only 11 months under a $2 million NASA grant to Carnegie Mellon University.

Other related **Robotic Developments** included use of a satellite link to maneuver a Russian-built robot in a Moscow laboratory in collaboration among NASA's Ames Research Center, McDonnell Douglas Space Systems, the Russian Academy of Sciences, the Institute for Space Research, and the Russian Space Agency. The rover robot was a prototype of a design Russian scientists hope to land on Mars in 1996. The objective of the project was to prove the feasibility of the teleoperator interface, developed at Ames, and used to steer the robot.

In a quite different area, NASA's Office of Advanced Concepts and Technology selected 52 proposals to develop small-technology flight experiments in the **IN-Space Technology Experiments Program** (IN-STEP), whose objective is to validate technological concepts developed by NASA, industry, and universities for space flight testing and evaluation. The awards cover eight areas of technology identified as high priority by NASA's customers. Recent awards include a tank pressure control experiment that provided data required to develop the technology for pressure control of cryogenic tankage; this will aid in the design of future space systems using supercooled fluid storage. Additionally, a heat pipe experiment confirmed many predicted heat transport limits. This research will lead to improvements in the thermal control systems of future spacecraft as well as terrestrial microelectronic applications.

FY 1993 also saw NASA complete the fabrication of a two-stage **Stirling Cooler** used to maintain temperatures down to 30° kelvin, needed for extremely sensitive sensors. Accomplishments included lower temperature capability, long lifetime, a high level of reliability, low weight, low power consumption, and low levels of vibration. This technology enables light-weight, long-duration missions of instruments using ultra-cold detectors. Also related to cryogenics, in a cooperative program with major companies working on ELVs, NASA has made significant progress in developing new aluminum-lithium alloys that could reduce the weight of cryogenic tanks by 10-15 percent without significantly raising costs.

Earth-observing satellites planned by NASA will need very sensitive arrays of **Detectors** to provide infrared images for purposes such as conservation, resource management, and event detection. A program at DoC's National Institute of Standards and Technology (NIST) has been applying developments in superconducting electronics to meet this need with an entirely new type of detector. Specifically, NIST has carried out improvements in an initial design of a detector intended to lead to a practical focal-plane array of superconducting infrared detectors based on kinetic inductance (effectively, the degree of penetration of a magnetic field into a superconductor). This has resulted in a sensitivity comparable to that in the best semiconducting detectors. Researchers have implemented an improved design that has a figure of merit some 20 times better than the earlier design, and at the end of the fiscal year measurements were underway to determine the effect of the improvement on the sensitivity.

Space Communications

Communications Satellites

There were two new commercial **Domestic, Fixed Communications Satellites** launched for the United States during FY 1993. Both were replacement satellites launched into locations of predecessors nearing the ends of their fuel lives. These satellites will provide domestic service into the next decade and will offer users a wide range of services including video, high-speed data, private network, and audio services. Named Galaxy VII(H) and IV(H), they were launched from Kourou, French Guiana, by Ariane launch vehicles on October 27, 1992, and June 24, 1993 (June 25, GMT), respectively. With these launches and the retirement of several satellites, there were 32 domestic-fixed satellites in orbit between 69° and 139° west longitude on the geostationary orbital arc as of the end of the fiscal year.

Relatedly, NASA successfully launched the **Advanced Communications Technology Satellite** (ACTS) from Space Shuttle Discovery in September 1993. ACTS represents the next generation in communications satellites. Its fundamental goal is to test and prove advanced communications technologies and to evaluate the potential applications of the technologies. These demonstrations were expected to promote the creation of new telecommunications services, thus improving the nation's economy and enhancing U.S. competitiveness in the global telecommunications market. During the 2-year ACTS Experiments Program, participants from industry, academia, and Government will investigate applications in medical imagery, long-distance education, business and supercomputer networking, high-definition television, and many other areas. An extensive network of ground stations will support the satellite, operating in the Ka-band frequency and offering unique features that differentiate them from current satellite communications ground stations. The High Data Rate (HDR) Terminal, for example, is capable of transmitting at significantly higher data rates than is possible with current technology. In a joint venture with ARPA, the HDR terminal will connect fiber networks across the U.S. as far as Hawaii, creating a seamless, high-speed communications network. The experiments will test the ability of the network to support real-time user interaction with complex environmental models created with supercomputer visualization, to distribute medical imagery for diagnosis, and to provide high-data-rate military communications. The flight-testing of the ACTS technologies will eventually lead to lower cost, better service, greater convenience, and improved reliability to telecommunication customers around the world.

For the military, the **Defense Satellite Communications System** (DSCS) continued to serve as the long-haul, high capacity communications system supporting the worldwide command and control of the U.S. Armed Forces and other Government agencies. The DSCS program successfully launched a DSCS III satellite on July 19, 1993, as a follow-on to the two DSCS IIIs launched in FY 1992. These three launches marked the start of a replenishment program for the DSCS constellation, which experienced severe launch set-backs from the 1986 Space Shuttle Challenger disaster. These launches also mark both the initial DSCS use of the Atlas II launch booster coupled with an inertial upper stage for achieving Earth orbit and significant modifications to the satellites for enhanced user services. The satellite launched this year will be cut over to operational traffic in early FY 1994 in the West Pacific as a replacement for the older DSCS III currently on station. The cutover of this new DSCS III will permit a substantial reconfiguration of the constellation with the older DSCS III moved into the Indian Ocean as a replacement for a DSCS II, thereby improving services to the DSCS customers in that area. Then, the constellation for the first time will consist of five mission-supporting, fully-capable DSCS IIIs located in the East Atlantic, West Atlantic, East Pacific, West Pacific, and Indian Ocean areas. In addition, the residual on-orbit satellite resources having partial capability will consist of two DSCS IIs launched before FY 1983, one DSCS II launched in FY 1989, and two DSCS IIIs launched in 1982. Two more DSCS IIIs are scheduled to be launched in FY 1994. Five other DSCS III satellites presently in storage are scheduled for launch between FY 1995 and FY 1999.

The DSCS control segment continued to provide semi-automated management of DSCS resources to maintain the satellite communications network in alignment with the needs of the operational commanders. As of the end of FY 1993 there were five DSCS operations centers and three auxiliary satellite control terminals operated and maintained by the U.S. Army Space Command worldwide. During FY 1993, proficient network management of DSCS space and ground resources enabled support of a wide variety of contingencies and high priority requirements including various presidential trips and the United Nations Operations Somalia relief effort (Continue Hope).

The **Milstar** program, intended as the cornerstone of the DoD's military satellite communications architecture in the future, was still in development during FY 1993. When operational, it will be a multichannel, EHF/UHF satellite communications system to provide survivable, enduring, jam-resistant, and secure voice and data communication for the Armed Forces and other users. The Air Force was the lead service for procuring Milstar satellites, a dispersed mission control network, airborne terminals, and ground command post terminals. The Army and Navy also had programs for terminal development and procurement. The Milstar program successfully underwent a Defense Acquisition Board program review in October 1992, which approved the Air Force's proposed acquisition strategy for the Milstar program, including the development of the Milstar II satellites with a new medium-data-rate payload. The contractor delivered the first Milstar satellite in February 1993. At the end of the fiscal year, it was awaiting launch, which had been delayed due to the recent failure of a Titan IV booster. Satellite number two was complete and in testing as the year ended. Satellite number three was being prepared for medium-data-rate payload.

The **Fleet Satellite Communications System** (FLTSATCOM) provided worldwide Navy and DoD UHF satellite communications through a constellation of four Navy-owned FLTSAT and three leased satellites positioned in geosynchronous orbit at four locations around the Earth. These satellites will eventually be replaced by the new series of UFO satellites being developed by Hughes Aircraft Company for the Navy. A UFO satellite was successfully launched on September 3, 1993. Upon completion of on-orbit testing, the satellite will be positioned over the Indian Ocean to establish initial operational capability for the UFO constellation. The Navy expected to achieve this capability in December 1993.

The International Telecommunications Satellite Organization **(INTELSAT)**, a consortium established in 1964 and consisting (in September 1993) of 128 member countries that owned and operated the sole global communications satellite system in the world, launched no new satellites during the fiscal year. During FY 1993 the Republic of the Marshall Islands, Bahrain, and Armenia were new countries that joined INTELSAT. INTELSAT continued to offer through its 19-satellite system such business services as international telex, teleconferencing, data, facsimile, and video. The INTELSAT Board of Governors met in Washington, D.C., from September 9-15 and authorized INTELSAT Management to purchase three additional INTELSAT VIII/VIII-A spacecraft from Martin Marietta Astro Space and to lease one Russian Express satellite to satisfy increasing demand for communications services. These 4 satellites increased the number on order for INTELSAT to 15, the first of which was launched early in FY 1994. The remaining 14 were scheduled for launch over the next 3 years.

The International Maritime Satellite Organization (**INMARSAT**), a London-based international organization founded in 1979 with 71 member countries as of October 1993, likewise did not add to its complement of four INMARSAT II and seven older satellites during the course of the fiscal year. New member countries during 1993 were the Slovak Republic, Georgia, Bangladesh, and Brunei Darussalam. Of the INMARSAT II satellites, two were located over the Atlantic Ocean, one over the Pacific, and one over the Indian Ocean. With these satellites, INMARSAT continued to provide global mobile satellite communications for commercial, distress, and safety applications to over 30,000 ships, aircraft, and land mobile facilities throughout the world. The U.S. signatory, COMSAT Corp., holds a 23 percent share in the organization. On October 1, 1992, INMARSAT announced that a new, advanced satellite distress alerting system for ships at sea, INMARSAT-E, had become operational for the eastern Atlantic Ocean Region, covering not only the Atlantic but the eastern Pacific to the Persian Gulf and the Arabian Sea. This marked a significant step in implementing the Global Maritime Distress and Safety System. Another important development in satellite communications was the commercial start-up of INMARSAT-M service, providing mobile digital voice, fax, and data services through small, transportable terminals or shipboard antennas for use on boats as small as 35 feet. Service began in November 1992 for the western Atlantic Ocean Region and in January 1993 for the Pacific Ocean Region. Coverage in the eastern Atlantic Ocean Region began in the spring of 1993, with full global coverage expected during the first half of 1994. In July 1993, digital satellite communications through INMARSAT-B became available to some customers. This made voice, data, and video communications as much as 50 percent cheaper than comparable analog services under INMARSAT-A. Eventually, INMARSAT-B will fully replace the more expensive analog services. Finally, in September 1993, COMSAT Aeronautical Services announced three new satellite communications services for aircraft—computer modem, secure voice, and 9.6 kilobits-per-second fax—allowing business travellers on international flights to enjoy many of the services available in offices on the ground when those aircraft services were expected to become operational early in 1994. INMARSAT also had four "third generation" satellites under construction.

As of the end of the fiscal year INMARSAT satellites provided virtually the only commercial mobile-satellite service in the world. However, companies in other countries, as well as several in the U.S., had plans to launch competing systems. Plans of these new service providers included satellite service globally to pocket telephones. INMARSAT has its own program (Project 21) to identify and deploy a pocket telephone technology. Technical and feasibility studies on Project 21 continued, but as of the end of the fiscal year, the INMARSAT Council had not made the decision to proceed with the project. Competition in developing and marketing this new service promises to be intense over the next few years. The new competitors were planning, in most cases, to use satellites in lower orbits where less power would be required for the mobile terminal than from geosynchronous orbit and thus a smaller antenna would be required. On the other hand, it will be more difficult technically and more costly to coordinate transmissions among the non-stationary and much larger number of satellites involved. INMARSAT has eliminated a low Earth orbit system from further consideration in its Project 21.

Space Network

April 1993 marked the 10th anniversary of NASA's **Tracking and Data Relay Satellite System** (TDRSS), a revolutionary, space-based network developed to meet telecommunications needs essential to the success of the Space Shuttle, Space Station, and other low Earth-orbiting spacecraft missions. TDRSS began with the launch of the first satellite on April 4, 1983. Since then, four other satellites have joined it in orbit, the latest on January 13, 1993. TDRSS is able to support up to 24 user spacecraft simultaneously, including the Space Shuttle. It neither processes nor alters communications but functions solely as a repeater to extend the "line-of-sight" from a spacecraft to a ground site. At its highest capacity, the TDRSS is able to transfer in one second the equivalent of a 20-volume encyclopedia containing over 34 million words. Each satellite uses three-axis stabilization and weighs about 5,000 pounds (2,540 kg), making it one of the largest, heaviest, and most complicated satellites ever launched into geosynchronous orbit. Each satellite measures 57 feet (17.4 meters) across its solar panels. Since becoming operational, TDRSS has relayed approximately 3.5 million minutes of data to the ground, and every subsequent Space Shuttle mission has required its resources.

NASA's two TDRSS ground stations received Native American names as a result of a contest held among New Mexican students. The names selected were Cacique (kah-see-keh, meaning "leader") and Danzante (dahn-zahn-teh, meaning "dancer"). These names stem from the Tortugas tribe of Tortugas, NM, who preserve their culture through traditional dance. Four female students from Zia Middle School, Las Cruces, NM, submitted the winning entry. They compared the TDRSS to the Tortugas dancers, who communicate through complex maneuvers, as do the satellites, while the ground terminals are the leaders of the orbital dance.

Communications and Data Systems

The NASA Communications (NASCOM) network provided data and voice transmission capacity for 7 crewed Space Shuttle missions and 22 uncrewed launch vehicles during FY 1993. The services included telemetry, tracking, command, and data acquisition for each mission. Several enhancements to this network became operational during FY 1993. For example, NASA completed an Interfacility Fiber Optic Link (IFL), which connects the White Sands Ground Terminal and the second Tracking and Data Relay Satellite Ground Terminal in New Mexico. This link enhances the exchange of operational data between these sites, increases ground terminal capacity, and significantly improves the reliability of the expanded TDRS constellation that is being planned to meet the requirements for future data-intensive scientific missions. NASCOM also implemented the German Space Operations Center multiplexer system, which was used for the German Spacelab mission (Spacelab D2) on April 26, 1993. NASCOM provided diversely routed circuits from the Goddard Space Flight Center in Greenbelt, MD, to Germany, providing the data and voice capability for ground control operators in Germany to communicate with the astronauts on board the spacecraft to assure mission success.

NASA has completed the refurbishment of the Hubble Space Telescope (HST) control center, which was ready at the end of the fiscal year for the HST repair mission in December 1993. Included in this refurbishment are new software programs and calibration data bases for the new instruments. Additionally, in FY 1993 NASA provided 48,000 hours of Mission Control services to ten on-orbit science missions

(HST, IUE, Compton Observatory, EUVE, UARS, COBE, ERBS, NIMBUS-7, SAMPEX, and IMP-8). The new control center concept, called the Transportable Payload Operations Control Center (TPOCC), was successfully demonstrated with the launch of the first SAMPEX mission on July 3, 1992. The lessons learned and software from the SAMPEX TPOCC were in the process of being applied to subsequent missions as the year ended. They have demonstrated a significant development cost savings through reuse of over 75 percent of existing software. The preparation of data systems for the International Solar-Terrestrial Program (ISTP) was complete by the end of the year, waiting to meet launch requirements in April and June of 1994.

To date, NASA has processed over 14 trillion bits of data (approximately equivalent to 100 million pages of text) from free-flyer scientific spacecraft and delivered them to scientific communities. As part of NASA's ongoing efficiency and standardization efforts, the agency developed a testbed to verify recommendations of the Consultative Committee on Space Data Systems (CCSDS) regarding space/ground protocols. The testbed also provided a prototype for NASA's modernization of its data processing system. The agency conducted a technology transfer workshop for this testbed, with participation from over 300 industry representatives. Finally, the development of an operational data processing system using very large scale integration technology was nearing completion for the Small Explorer-2 (SMEX-2) Fast Auroral Snapshot (FAST) mission scheduled for launch in August 1994.

Ground Network

NASA's Ground Network facilities provided communications to a wide variety of NASA and international missions. These included Space Shuttle; a variety of Earth-orbiting spacecraft performing numerous Earth-observing missions; planetary orbiters; and deep space missions. Ground Network facilities also provided communications services during launch, flight, and recovery of high-altitude balloons and sounding rockets, used to enable research in such scientific disciplines as geophysics, astrophysics, and astronomy. The worldwide capability further allowed ground-based controllers to navigate the spacecraft, to configure them for scientific observations, and to recover the resulting data. Notable events covered during the past year included the encounter of the spacecraft Galileo with the asteroid Ida and the recovery of pictures of this asteroid; likewise, the aerobraking of the spacecraft Magellan in orbit about Venus. Further uses of the Ground Network facilities included astronomical observations employing radio and radar. A notable achievement was the radar observation and imaging of the near-Earth crossing asteroid, Toutatis, in December 1992, which obtained pictures 100 times as detailed as the best earlier images of such asteroids.

Advanced Systems

During FY 1993, NASA extended the capability of the Space Network to include communications with scientific balloons that were beyond the line-of-sight from mission control, when the Goddard Space Flight Center successfully flight tested a low-cost transponder on a Long Duration Balloon Project. The gondola and payload maintained contact with mission control via the Space Network throughout the flight. The feasibility of extending this capability to experimental aircraft was being studied as the year ended. In past years NASA has obtained several of the most significant improvements in communications with deep space missions by increasing the radio-frequency of the space-to-ground links. This year, additional advances were made by the Deep Space Network (DSN). Beginning in January 1993, the Jet Propulsion Laboratory (JPL) in Pasadena, CA, successfully conducted a Ka-band (33 GHz) Link Experiment (KaBLE) with the Mars Observer spacecraft. Using advanced technology, the DSN Research Station at Goldstone, CA, simultaneously acquired and tracked this spacecraft at Ka-band and X-band (8 GHz) for over a seven month period. This was the first Ka-band experiment to receive telemetry from and perform ranging on a deep space mission. The lessons learned from KaBLE were evolving into the operational DSN as the year ended. In another area, it has become clear that space missions in the future may require laser beams to communicate larger quantities of scientific data. A milestone in technology was passed in December 1992 when JPL engineers beamed laser pulses over a distance of 3.7 million miles (6 million kilometers) to a camera on the Galileo spacecraft. To minimize cloud blockage, laser beams were transmitted simultaneously from the Table Mountain Observatory near Wrightwood, CA, and the Starfire Optical Range of the Air Force's Phillips Laboratory near Albuquerque, NM.

Aeronautical Activities

Technological Developments

Within the Federal Government, the DoD, the Federal Aviation Administration (FAA), and NASA engaged in the development of new and improved technologies within the aeronautical field. An important example was the **National Aero-Space Plane** (NASP), a joint DoD-NASA program to develop and validate technologies for an entirely new generation of hypersonic vehicles, such as single-stage-to-orbit space planes that could fly at hypersonic speeds (greater than Mach 5) to provide flexible, efficient space-launch capability with horizontal takeoffs and landings on runways using airbreathing technology. The program has completed initial feasibility studies and advanced to the technology-development phase. The current phase of the NASP program will be completed at the end of FY 1994.

The NASP program has conducted component hardware fabrication, materials manufacturing, and aerodynamic, mechanical, and thermal ground tests with impressive results. Progress in aeropropulsion was highlighted by a series of wind-tunnel tests. Long-duration tests up to Mach 14 of a large-scale model of a NASP supersonic combustion ramjet (scramjet) combustor provided valuable new data. The test periods of more than ten seconds have provided a wealth of such data for simulated flight speeds above Mach 8. The new large-scale tests can match many of the test conditions for flight and have satisfied the objective of helping to interpret the much more extensive sets of short-duration, pulsed-tunnel data. Other propulsion activities included Rocketdyne tests at the CalTech T5 tunnel and related work at the "HYPULSE" facility in New York. These provided new insights into the design and operation of scramjet fuel injectors at Mach 16 flight conditions. Tests up to Mach 18 in the Naval Surface Weapons Center Tunnel Number 9 in Maryland have contributed valuable data on NASP inlet configurations. These and other aeropropulsion advances were matched by improvements in the associated laser-based instrumentation techniques and by updated methodologies for computer analyses. Relatedly, hydrogen-cooled structures simulating the engine inlet lip were successfully tested at Mach 15 conditions.

Previous work had advanced slush-hydrogen fuel technologies from laboratory exercises to large-scale production and ground handling. More recent activities addressed on-board fuel-related operations. NASP on-board requirements differ significantly from those for the liquid-hydrogen tanks on rocket boosters. The latter are vertically oriented and use gravity, pressurized gas, and the booster's acceleration to drain the tanks. NASP tanks are horizontally mounted, have much larger surface areas of fuel, and must accommodate recirculation of fuel in the actively cooled structures. The NASP fuel system must cope with fuel flow ranging from a super-cold (cryogenic) slush up through superheated hydrogen gas. NASP aerodynamics have focused largely on three areas. NASA's Langley Research Center and McDonnell Douglas completed a series of tests of the X-30 configuration in 1993. They covered the speed regime from takeoff to Mach 17+ to provide a solid data base on aerodynamics, stability, and controllability. Boundary-layer transition from smooth (laminar) to turbulent strongly affects local structure heating (and, consequently, vehicle weight) and engine inlet performance. Tests and predictive-tool development for hypersonic boundary layers have emphasized improvements to predictive tools, especially to account for the effects of shock waves. The third area, propulsion/airframe integration, saw major advances in the development of test techniques.

In the area of materials science, production of high-temperature metallic composites was made feasible with a breakthrough in materials processing techniques. New coatings technologies are providing superior oxidation resistance for carbon-carbon heat shields and for highly conductive metallic alloys used in actively cooled engine components. The NASP team has also conducted successful thermal and mechanical tests of NASP panel assemblies, which have joints, numerous fasteners, and complex curves. These structures represent specific segments of the X-30 fuselage. Other realistic tests of heat exchangers, engine hot gas seals, actively cooled leading-edge-type structures, and internal substructures were also successful. Aeroelastics, the coupling of aerodynamic loads and structural characteristics, was substantially advanced by both analysis and special tests in the NASA Langley Transonic Dynamics Tunnel (the national facility for aeroelastic testing). The culmination of work to date has been the definition of NASP structural and controls requirements to match the expected flight-path conditions.

There have been advances in many other areas, such as instrumentation, simulation, and computational fluid dynamics (CFD). For example, improvements in strain-gauge designs are now providing the rugged, dependable instrumentation essential for piloted flight-research vehicles. In addition, CFD has become a routinely applied but very powerful tool for either analyzing data or predicting the behavior of purely conceptual flow fields. NASP has transferred CFD tools to industry experts to enhance both hypersonic calculating efficiency and fidelity in the simulation of natural phenomena. U.S. industry has adopted a number of other NASP technological spinoffs as well. These include materials for automobile engines, computer systems, heart valve replacements, pipes for deeper oil wells, and NASP computational algorithms for advanced vehicle and engine developments.

The joint **X-31A Enhanced Fighter Maneuverability (EFM)** program is a cooperative effort involving Germany, the U.S. Navy, the U.S. Air Force, NASA, Rockwell International, and Deutsche Aerospace (formerly Messerschmitt-Bolkow-Blohm) to determine the overall utility characteristics and limitations of a military aircraft employing advanced control concepts and systems through flight evaluation. The program includes two aircraft built under sponsorship of ARPA and the German Government. The X-31 features light-weight, carbon-carbon external thrust deflection paddles, a moveable inlet lip, and a flight control system to provide superior control during post-stall maneuvering flight. The aircraft demonstrated pilot-friendly handling during aggressive maneuvering up to 70 degrees angle of attack (AOA). During FY 1993, the flight envelope was fully expanded to 225 knots for maneuver entry using a thrust vane deflection authority to 35 degrees. As part of the envelope expansion, aft fuselage strakes were added to counter nose pitch-up bias, nose strakes were investigated to reduce high angle-of-attack asymmetry, and control law modifications were investigated to provide better angle-of-attack controllability. Concurrent with the final stages of improving aircraft agility throughout the post-stall regime, the X-31 began an evaluation of combat capabilities using a modified F-18 adversary. During the first half of FY 1994, the F-18 will be employed in unrestricted one-on-one engagements to verify simulation trends and tactics and to assess effects on pilots generated by this form of combat maneuvering. In addition, engineers were integrating an advanced helmet-mounted audio-visual display system to examine situation awareness during close-in combat. Finally, program engineers were readying a single point experiment to demonstrate quasi-tailless flight using the X-31's advanced thrust vectoring system at supersonic speeds. After this, the program was scheduled to end in March 1994.

Another new aircraft in development by the DoD was the **B-2**, whose primary mission remained to enable any theater commander to hold at risk and, if necessary, attack an enemy's warmaking potential. As of October 6, 1993, six of the aircraft were undergoing testing, having accumulated 1,351 hours of flight test in a total of 288 sorties. Approximately 30 percent of the flight test program was complete by the end of FY 1993. Test pilots have experienced the full flight envelope with altitudes and speeds up to 100 percent of those expected under operational conditions. The B-2 has released both nuclear and conventional bomb shapes, indicating that the aircraft design and aerodynamic airflow are well suited for both nuclear and conventional bombing missions. The program has not experienced any fuel leaks, a significant achievement for such a large aircraft with integral, internal body cavity fuel tanks. The airplane successfully completed its structural test program. The durability and strength of the airframe meet all operational requirements. In addition, the B-2 completed electromagnetic compatibility and Tempest (electronic security) testing seven weeks ahead of schedule. In July 1993, the B-2 entered climatic testing at the Eglin Air Force Base Climatic

Laboratory for a series of rigorous tests over a six-month period. All tests before the end of the fiscal year were successful and have verified the system operation and integration of the first operational B-2 scheduled for delivery to the Air Combat Command in December 1993.

The **Advanced Fighter Technology Integration** (AFTI/F-16) program continued flight testing of advanced technologies in support of aircraft with an air-to-surface attack mission. It developed a prototype Automatic Ground Collision Avoidance System (Auto GCAS) for the AFTI Air-to-Ground mission scenario and used this during the AFTI flight tests of low altitude night missions. The Auto GCAS design uses a Digital Terrain System carried on board the aircraft to represent the terrain digitally and preclude controlled flight into that terrain. Flight testing of the prototype system ended in 1992 but has resumed in 1993 to replicate recent F-16 mishaps and demonstrate the viability of Auto GCAS in actual operational scenarios. AFTI applications in the future include the development of a full envelope system as a cooperative partnership between this Wright Laboratory Advanced Development program and the F-16 Systems Project Office.

In a rather different area of aeronautics development, **Raptor/Talon** is a BMDO-funded program to provide U.S. armed forces and their allies an air-based defense against Theater Ballistic Missiles (TBM) by stopping the missiles in their boost phase. Raptor is the high-altitude, pilotless aerial vehicle that will patrol over enemy TBM launch areas. Talon is the light-weight interceptor missile that will negate the enemy TBM before booster burn-out. During FY 1993 the Raptor demonstrator aircraft, built by Scaled Composites, made 10 successful test flights. Using technologies and lessons learned from the aircraft named Voyager that made the first around-the-world journey without landing or refueling, the demonstrator went from aircraft design to first flight within one year. Another version of Raptor named Pathfinder is a flying solar-electric wing. As the fiscal year ended, it was preparing for its first low-altitude flight test in October 1993. Built by AeroVironment, Pathfinder built upon the technologies developed for the Solar Challenger, which flew across the English Channel in 1981 powered entirely by sunlight. At mid-latitudes, Pathfinder's energy collection and storage system should be capable of supporting flights of indefinite duration.

Another project, the **Integrated High Performance Turbine Engine Technology** (IHPTET) initiative is a coordinated DoD/NASA/industry effort to double turbopropulsion capability by 2003 in all three classes of turbine engines—turbofans/turbojets; turboshafts/turboprops; and expendables. Begun in 1987, IHPTET incorporates virtually all government and industry resources dedicated to research and development of turbine engines for military aircraft and missiles. The program's accomplishments in FY 1993 included two IHPTET Phase I large demonstrator engines tested under the Air Force/Navy Joint Technology Demonstrator Engine program. Both the Pratt & Whitney XTE65 and General Electric XTE45 engines demonstrated performance improvements over the XF119 engine that served as a baseline—a 22 percent increase in thrust/weight and an 18 percent reduction in fuel burn. Also, the Compressor Research Facility at Wright-Patterson AFB successfully tested swept fan technology and transitioned it to industry. The program demonstrated new "supercooling" technologies for turbine engine hot sections, including an Allison concept that used quasi-transpiration cooling and a Pratt & Whitney concept called Superblade. The Turbine Research Facility achieved operational status, making it possible for the first time to evaluate turbine aerodynamic and cooling concepts economically using real engine hardware. For the first time ever, an advanced core engine was tested with a magnetic bearing, with the goal of eliminating lubrication systems from future engines. Finally, the program formed a government/industry/university consortium to address the phenomenon of bladed-disk force response—a major area of concern throughout the military and industrial complex.

In the face of severe competition from subsidized foreign competitors with American industry, NASA's role in civil aeronautics is more important than ever in developing technology, in cooperation with the FAA and industry, to ensure that the latter is prepared to meet the demands of global competition as well as those of growing air traffic volume and accompanying safety requirements. NASA's **Subsonic Systems Technology** programs have as their goals the facilitation of a safe, productive global air transportation system that includes a new generation of environmentally compatible, economic aircraft that are superior to foreign products. During FY 1993, NASA researchers were working with their counterparts in industry in several areas including: Fly-By-Light/Power-By-Wire, to develop lightweight, highly reliable optical systems that eliminate the electromagnetic interference associated with purely fly-by-wire systems; Aging Aircraft, to develop prediction methods and nondestructive evaluation technologies to detect flaws or fractures that may shorten the safe structural life of commercial aircraft; Advanced Composites Technology (ACT), to establish cost-effective methods of joining composite wings and fuselages to meet goals of 50 percent weight and 25 percent cost savings over those necessary for metallic transports; Advanced Turboprop (ATP), to reduce airframe and engine noise levels by 3-4 decibels in the near term, relative to the existing state of the art, and 7-10 decibels over the longer term.

In 1993 NASA successfully completed flight tests of **Fiber-optic Sensors** on flight research aircraft. The benefits of fiber optics are lighter weight and the inherent immunity of fiber optics to electromagnetic interference. Ten flight control sensors underwent engineering flight tests to evaluate how fiber optic sensors would react in flight. These trials are the foundation for subsequent tests when the pilot will use the signals from the fiber-optic sensors to control the flight research aircraft and prepare the way for tests on civil transport aircraft. To provide tools to the industry that prove the electronics in its aircraft are truly immune to interference, engineers expose aircraft electronics to a variety of high-intensity radiated fields in a Gigahertz Transverse Electromagnetic Chamber and a reverberation chamber. These tools will allow NASA to validate the analytical tools used by the FAA and industry as they ensure that electronic systems in aircraft are immune to the effects of electromagnetic fields.

NASA has also developed **Improved Methods** that predict the effects of service history and the environment on the durability of the airframe structure and transferred them to airplane manufacturers and the FAA. Engineers have developed and demonstrated advanced nondestructive inspection methods focused on techniques for inspecting large areas to reduce costs without decreasing reliability. They developed a new thermal imaging prototype to detect disbonds and corrosion in joints of aircraft structures, and they demonstrated it at commercial airline maintenance facilities. The new systems have economical, broad-area inspection capability to describe regions of disbonds and corroded areas of the aircraft structure with great accuracy. Also, airplane manufacturers and airlines have been field testing a portable, battery-operated, hand-held electromagnetic instrument developed to detect small fatigue cracks in riveted joints and prototype instruments. This technology has broad applications beyond the aerospace industry to the automotive, electric power and utility, shipbuilding, and medical industries.

As aircraft noise continued to be a persistent domestic and international concern, NASA achieved progress during FY 1993 in the ATP program with the testing of Pratt & Whitney's 10-foot diameter fan Advanced Ducted Propulsion engine in the Ames Research Center's 40 x 80 foot wind tunnel that showed significant reductions for aircraft engine noise—15 decibels for engine fan noise, for instance. To meet the goals of the ACT program, NASA has been investigating all stages of manufacturing from material selection and processing to structural design and manufacturing. In FY 1993, engineers fabricated a large top (or crown) fuselage panel using advanced automated fiber-placement machines. By using a computer-controlled machine to place the composite fibers, engineers produced a panel requiring one-forth the number of fasteners needed for an aluminum panel, significantly reducing the cost of production. Tests indicated that innovative techniques in building wing panels have outstanding damage tolerance and a strong potential for cost savings.

In the supersonic arena, NASA's **SR-71 Aircraft Testbed Program** conducted baseline flights for aeronautical research to assist industry in making key decisions about developing a High Speed Civil Transport (HSCT). The SR-71 is particularly well suited for this research because of its ability to meet and exceed the projected HSCT cruise speeds of Mach 2.4 at 60,000 to 65,000 feet. During FY 1993, NASA began baseline flight research to support development and validation of softened sonic boom design methods for improvement in HSCT aircraft handling qualities for better performance, and the development of laser techniques to provide remote sensing of freestream flight conditions to meet several HSCT aircraft needs. Also during this period, the SR-71 testbed aircraft conducted checkouts for two space science sensors and one commercial communication satellite payload.

More generally, NASA's **High-Speed Research** program continued during FY 1993 to focus on resolving critical environmental issues and laying the technological foundation for an economical, next-generation HSCT. With the rapidly growing market for long-range transoceanic air travel, such an aircraft could be crucial to the competitive posture of the American aircraft industry in the next century. In 1993, progress continued in assessing the potential atmospheric impact of HSCT aircraft. Using two-dimensional global models, NASA examined a range of aircraft operational scenarios, and predictions indicate the possibility of very small effects on stratospheric ozone from a fleet of low-emission HSCT aircraft. During the year, NASA's ER-2 high altitude science aircraft gathered key additional atmospheric measurements on research flights to test that the chemistry of the models is representative of all seasons and geographic locations and will accurately simulate the atmospheric chemical process of the proposed aircraft emissions and operations. As the year ended the National Academy of Sciences was completing a review of the program's atmospheric research to help assure that current scientific knowledge is being accurately reflected and that planned research activities over the next two years will reduce the key uncertainties. In parallel research, the effectiveness and practicality of the low NOx combustor technology being developed for future HSCT engines was further reinforced by results of flame tube testing at higher inlet temperatures with no significant increase in NOx production. (NOx is any of several compounds of nitrogen and oxygen.) Related research in ceramic matrix composite materials and processes for the low-emission combustors also achieved significant results in FY 1993 with successful development of advanced fibers that meet the program goals for strength, temperature, and commercial production feasibility.

A second major environmental requirement for any future HSCT is meeting acceptable airport noise levels. This presents a formidable challenge in that it represents nearly a 10-fold reduction in noise compared to the only supersonic transport currently in service, the Concorde. Testing of improved engine noise-reduction concepts such as the mixer-ejector exhaust nozzle continued in 1993 with one nozzle achieving the required reduction while also producing reasonably high thrust efficiency levels. Research efforts to reduce the weight of the long, complex exhaust systems also progressed with related development of several fabrication approaches on new, high-temperature, intermetallic matrix composite materials.

While studies have concluded that an economically viable HSCT is not dependent upon supersonic overland flight capability, previous testing of small-scale aircraft models has shown the potential to soften the sonic boom with minimal penalties in aerodynamic efficiency. Efforts in this area continued during 1993 and were complemented by initiation of flight research to investigate sonic boom propagation in the atmosphere. (See coverage above of SR-71.) Research directed at significantly improving aerodynamic efficiency also continued, with a key effort focussing on the use of suction on the leading edge of the wing to maintain laminar flow on the surface. The benefits of this technology offer the potential for an 8.5 percent reduction in maximum takeoff weight. During FY 1993, the program flew a modified F-16XL to further investigate the ability to maintain laminar flow over most of the surface of a representative HSCT wing and successfully demonstrated the fabrication process for the wing glove suction system. In airframe materials and structures technology, development continued on lightweight advanced titanium alloys, organic matrix composites, adhesives, and sealants needed to endure temperatures up to 350° Fahrenheit and 60,000 flight hours.

Although actual flight of the HSCT aircraft is more than 10 years in the future, a team of industry and NASA pilots experienced their first HSCT "flights" in FY 1993 through use of a NASA flight simulator. The cockpit included head-up and head-down displays, computer-generated visual scenes, controllers, and a representative control panel. Participants conducted evaluations of descent, approach, landing, and go-around over a range of wind and turbulence to help define key requirements for advanced flight deck technologies.

NASA's **Hypersonics Research** program is an ongoing activity that generates technologies necessary for the design and development of advanced airbreathing hypersonic vehicles. The multi-disciplinary program stresses the fundamental understanding and control of the physical phenomena of hypersonic flight. While the emphasis is on airbreathing accelerating configurations, the program is also generating technology for cruise and reentry vehicle applications. NASA has made research grants to three universities for hypersonics research across the range of aeronautical disciplines. NASA researchers have performed analyses for generic-vehicle forebody flowfields to ascertain real gas effects on lift, drag, and pitching moment. They have completed fundamental studies on supersonic combustion. These characterized the basic mechanisms by which hydrogen fuel damages Beta 21S Titanium alloys. The research also included a detailed feasibility study of a Mach 5 waverider (wing configuration) aircraft. Engineers were developing high-temperature fiber optic instrumentation for the hostile environment of elevated Mach number flows. They completed analyses, wind tunnel testing, and mock-ups for the FY 1995 hypersonic cross-flow boundary-layer transition flight experiment that will piggyback onto the first stage of a scheduled Pegasus flight.

During FY 1993, NASA also used the **B-52** aircraft to complete two successful airborne launches of the Pegasus rocket, one of which was a commercial launch of a satellite payload for Brazil. The airplane was also used, in support of the Air Force, to complete F-111 parachute drop tests for crew module recovery.

In its **F-18 High Alpha Technology Program**, NASA sought to achieve a basic understanding of high angle-of-attack aerodynamics, including the effects of selected advanced flight control concepts used individually and in combination. The program has demonstrated the use of external engine thrust deflection paddles to achieve controlled full rudder pedal sideslips at 65 degrees angle of attack. It has also demonstrated a significant increase in roll rate, an important factor in winning air combat engagements. Computational breakthroughs have resulted in the ability to calculate the separated and vortical flow characteristics about the entire F-18 aircraft at high angle of attack. During FY 1993, NASA obtained flight data in support of the High Alpha Nose-down Guidelines (HANG) evaluation and the Real Time Thrust Measurement (RTTM) methodology. It also obtained forebody/leading edge extension data through 65 degrees alpha for computational fluid dynamics and wind tunnel correlation. The program conducted technology transfer tours in June 1993 that were extremely well received by the 12 industry and government groups visited.

NASA also had an F-18 **Systems Research Aircraft** (SRA) program that it offered as a testbed for the use of many industrial companies and government agencies. The subsystems currently planned and under test promise to have important impact on the weight and fuel burn characteristics of advanced subsonic civil aircraft yet to be designed. As such, these programs will have an important impact on job creation and the competitiveness of U.S. industry. During FY 1993, the program got the aircraft instrumented and then successfully flight tested its smart actuators as part of the Electrically Powered Actuation Design program.

NASA used its **F-15** testbed aircraft to develop and demonstrate the benefits of integrating selected flight controls with selected engine controls (engine, nozzle, and inlet) for maximal performance, minimum fuel burn for a particular thrust setting, or engine life improvement. The technology has enormous implications for reducing the operating cost of future aircraft, particularly long-range, cruise-dominated, subsonic and supersonic civil transport aircraft. During FY 1993, the program demonstrated and validated real time performance optimization at supersonic flight conditions. Also the F-15 demonstrated the first planned landing of an aircraft using only propulsion power for flight control. The software for propulsion-only flight control provides a significant safety enhancement for civil and military aircraft in the event conventional flight control surfaces are inoperable.

NASA's **Flight Research Instrumentation and Test Techniques** program emphasizes the transition of university ideas and concepts into products and processes that will improve the productivity of flight testing. During FY 1993 engineers developed a new analysis method for quickly determining structural mode responses during ground vibration tests. They were transitioning it to industry as the year ended. They also concluded research on a laser system employing a "sheet pairs" principle, which was designed to measure angle of attack, angle of sideslip, and aircraft velocity.

NASA's **Vertical/Short Takeoff and Landing (V/STOL)** technological program included three elements in FY 1993. The first element, a V/STOL System Research Aircraft (VSRA) employed a Harrier aircraft equipped with an integrated attitude and thrust control research system. The program also included provisions to evaluate new cockpit displays that assist a pilot in guiding his aircraft from forward flight to hover and vertical landings on small ships or confined sites. During FY 1993, NASA completed initial checkout flights of the VSRA equipped with modified digital flight controls and cockpit displays. A second element at Ames Research Center involved an evaluation of a Mixed Flow Vectored Thrust STOVL concept from McDonnell Douglas using Ames' fixed-base simulator. The third element consisted of a test of a modular V/STOL Hot Gas Ingestion model, conducted at NASA's Lewis Research Center.

NASA's **Critical Technologies Research** effort has sought to develop innovative concepts and a variety of theoretical, experimental, and computational tools needed for the design and operation of the next generation of aircraft. In materials research, analytical modeling of polymer resins has enabled chemists to predict the toughness of new and untried molecular formulations. The result has been more consistent quality at reduced cost as well as materials that are more stable at high temperatures. Use of piezoelectric materials and shape memory alloys in control applications has led to active suppression of aircraft wing flutter and buffet and passive control of panel flutter. Engineers have improved computational tools for prediction of structural behavior, resulting in greater accuracy and reduced cost. They have also improved simulations of complete aircraft and propulsion systems, synthesis tools, and the like to help prioritize NASA's aeronautics research and to aid industry in its systems studies.

An example of developments in the area of guidance and control involved development of algorithms for advanced control of Vertical Takeoff and Landing vehicles. The purpose of the algorithms is to provide greatly simplified design and implementation of the control system. In another program cosponsored with the Air Force, Pratt & Whitney, and General Electric, recent test results on a large-scale catalytic heat exchanger for use with fuels absorbing a high level of heat have resulted in increased confidence in this technology.

Relatedly, NASA's Computational Fluid Dynamics program focuses on interaction and technology transfer with U.S. aerospace industry, to provide tools for improving the competitiveness of the industry in the world market. During FY 1993, two distinct computer codes for resolving problems with fluid flow became integral parts of the aircraft design process for a major U.S. airframe manufacturer. One code applies to low-speed (take-off and landing) applications in the design of new high-lift wings. The other code, including a NASA-developed turbulence model, provides final verification of wing design for the same manufacturer. To reduce drag and improve lift performance for high-lift wing systems, NASA and a major U.S. airframe manufacturer have developed the micro-vortex generator concept, which dramatically reduces flow separation without adversely affecting cruise performance.

NASA also continued to be integrally involved during 1993 with the airframe manufacturers in the area of both subsonic and supersonic laminar flow control. The agency has provided a technique that has become the standard in the engineering industry for predicting the onset of transition to turbulence. This technology is enabling research and development of extended laminar flow control systems by the industry for future subsonic and supersonic civilian transports. Finally, NASA has determined the effects of leading edge thickness and the surface roughness of compressor stage blades on engine performance. The agency has provided recommendations to the U.S. aerospace engine industry on alternate leading edge shapes for the blades, on the blade refurbishment process, and on the need for tighter control of manufacturing tolerances. If implemented, these recommendations can improve both short- and long-term engine performance.

Like NASA and the DoD, the **FAA** was developing advanced technical capabilities through a wide array of programs. For example, the FAA continued to study traditional airworthiness and certification techniques as applied to fly-by-wire/fly-by-light (FBW/FBL) concepts. In coordination with NASA, the agency proceeded with research in fault tolerant architecture and electromagnetic effects assessment associated with FBW/FBL, as well as the new power-by-wire concepts. Also, the FAA and NASA initiated a joint research program, with industry and academic participation, to develop new technologies for quieter subsonic jet aircraft engines and airframes. Additionally, efforts were underway as the year ended to analyze government and industry recommendations for assessing the environmental impacts of future civil supersonic aircraft. The FAA completed a study of a simplified helicopter noise certification procedure that led to adoption of a new appendix to the Federal Air Regulation, Part 36, and finished writing a proposed advisory circular describing acceptable criteria for safe departure profiles that would also reduce noise. The agency created the Environmental Costing Model to compute the estimated costs to air carriers of fleet modernization alternatives to meet transition schedules to quieter aircraft. In the new Noise Impact Routing System, the FAA also applied the latest optimization technology to airspace analysis and design of improved route networks that minimize community noise impact. Moreover, during FY 1993 the agency began forming the Federal Interagency Committee on Aviation Noise to assist other agencies in providing a forum for discussion of FAA and public proposals for future noise research. The FAA also established a research and development study group to review and recommend land use measures around airports in order to minimize the impact of aircraft noise through a nationally accepted land use policy.

Air Traffic Control and Navigation

Among the many activities of the FAA in this area, the **Traffic Alert and Collision Avoidance System** (TCAS) uses air-to-air interrogations of transponder-equipped aircraft to provide pilots with advisories indicating the range, bearing, and altitude of aircraft posing potential threats. In the mid-1990s, the FAA will require TCAS I, a low-power system that provides alerting but not recommended escape maneuvers, in turbine-powered commercial airplanes with 10 to 30 passenger seats. The TCAS II version, which alerts the pilot to traffic and advises whether to climb or descend when a potential conflict occurs, became mandatory in all commercial aircraft of more than 30 seats on December 31, 1993. During FY 1993, the FAA continued to develop minimum operating standards for TCAS enhancements, which will provide traffic alerts and resolution advisories that include right or left turns as well as altitude changes.

In a joint project, the FAA and the Coast Guard developed and tested an **Automatic Signal BLINK** system for Loran-C transmitter stations that will provide an additional level of system integrity when Loran-C is used by pilots as a nonprecision, instrument approach aid to airports. Signal BLINK is a recognizable change that begins when the signal should not be used for navigation. The automatic system will act as a back-up to the conventional, manual BLINK now used by transmitter station operators. During FY 1993 the FAA participated in engineering model tests and helped prepare for the prototype tests that will begin in early 1994.

Another FAA program, the **Advanced Traffic Management System** sought to develop enhanced automation capabilities for air traffic flow management. In FY 1993 the FAA installed at its Command Center a test version of computer algorithms for a new generation of alternative aircraft routings and dynamic programs to reduce ground delay at multiple airports.

The FAA also continued to modernize voice communications for air traffic controllers with its integrated **Voice Switching and Control System**. This will offer improved communications performance through touch screen controls and computer-controlled voice-channel technology. In January 1993, the FAA completed factory acceptance testing of the prototype upgrade system and deployed it in March to the Technical Center in Atlantic City, NJ, for additional testing. Also in March, the agency confirmed a decision to begin limited production of the system. As the fiscal year ended, the FAA was preparing for factory acceptance testing and operational test and evaluation of the actual system before deploying it to the first operational site at the Seattle Air Route Traffic Control Center (ARTCC).

An essential part of aircraft movement on airport surfaces is proper guidance during taxiing. Thus, the FAA must design and maintain the **Visual Guidance Systems** (lighting, marking, and signs) to avoid any ambiguity in their intended operational use. During FY 1993 the agency developed a draft specification for a standard stop bar lighting system (to prevent an aircraft from entering the runway area without proper approval), based on International Civil Aviation Organization (ICAO) recommendations and previous testing at John F. Kennedy International Airport. The agency continued an initial in-service evaluation of the system at Seattle-Tacoma International Airport during the fiscal year.

Pre-departure clearance **Aeronautical Data Link** service continued at 30 airports, speeding operations while reducing controller workload and voice frequency congestion. Participation grew to include eight U.S. carriers, as well as Finair and Scandinavian Airlines, while general aviation participants increased to 260 aircraft. During FY 1993, the FAA continued an aggressive development and operational evaluation program for the Tower Data Link Service (TDLS), which includes pre-departure clearance Phase II, Flight Data Input and Output emulation, and Digital Automatic Terminal Information Service (ATIS). The agency held a TDLS national kickoff meeting to introduce the planned program to the air traffic community. The FAA also completed successful Digital ATIS field evaluations at Pittsburgh and Baltimore-Washington International Airports, resulting in the refinement and incorporation of requirements that will provide further benefits to both pilots and controllers. During the fiscal year, the FAA actively supported the development of U.S. and international standards for the Aeronautical Telecommunications Network (ATN) that would integrate a number of different air-ground data links, as well as ground data networks, into a seamless inter-network environment. During FY 1993, the FAA published the U.S. standards for the initial air traffic control data link services and continued development of U.S. ATN standards.

The goal of the FAA's **Precision Runway Monitor** program is to increase airport capacity through safe reduction of constraints on the use of parallel or converging runways during instrument meteorological conditions (poor visibility). To achieve this goal, the FAA has been using an electronically scanned secondary radar with high accuracy, improved display, automated predictor, and visual/aural alerting of deviations from the proper flightpath. On June 30, 1993, the FAA commissioned the first of these systems, consisting of an upgraded version of the prototype hardware, at Raleigh-Durham Airport, NC. Work continued on five production systems at Bendix Communications Division of Allied Signal. The FAA planned to place the new system at four additional airports, with the fifth production unit replacing the prototype at Raleigh-Durham. The FAA also continued to study possible applications of the technology at airports with closer runway spacings and with three or four parallel runways.

The FAA proceeded with the development of a comprehensive, all-weather **Surface Traffic Automation System** that will automate ground movement and increase surface capacity. This developmental program combines the Differential Global Positioning System and other surface sensors with a surveillance data link that displays target location with alphanumerical data tags and processes track and flight data. The system will automatically provide the controller with optimal arrival and departure taxi routes in all weather conditions, as well as taxi route conformance assurance. In FY 1993, the FAA and Volpe National Transportation Systems Center began researching alternative technologies for alphanumeric data tags. Also, the agency and the Air Force together with Lincoln Laboratories of MIT began analysis of an automated dependent surveillance system.

Another FAA initiative, the **Terminal Area Surveillance System** (TASS), sought to develop and deploy a terminal area system consisting of several sensors interfaced with a processing system that fuses input data and develops weather products and target reports from all available sources. The two types of surveillance required in the terminal area are air traffic and environmental. Air traffic includes both airborne and surface targets, some of which are equipped with radar beacon transponders. The purpose of environmental surveillance is to detect and predict meteorological phenomena. During FY 1993, the FAA established a team to define the system's operational requirements, prepared an acquisition plan, and readied a functional system description for evaluation by industry. The agency also began a simulation program to assess requirements and new technologies and evaluated exploratory work in microburst prediction, wake vortex detection, and active phased array radars.

The FAA's **Terminal Air Traffic Control Automation** program seeks to provide optimized terminal traffic flow by expeditiously incorporating proven automation technology. This promises to reduce controller workload, improve traffic efficiency, and enhance safety in the terminal air traffic system. During FY 1993, the FAA completed development of a Converging Runway Display Aid (CRDA) that allows continued use of a pair of intersecting runways during instrument meteorological conditions. The airports at St. Louis, Boston, Philadelphia, and Cincinatti have implemented this software enhancement and have realized increased acceptance rates of up to 33 percent in certain conditions. The agency continued to work on a follow-on effort, the Controller Automation Spacing Aid (CASA), that will extend CRDA technology to other applications to improve throughput of aircraft to the runway.

The FAA also continued cooperation with NASA in their joint research and development efforts on the **Center-TRACON (Terminal Radar Approach Control) Automation System** (CTAS), an integrated feedback program that uses aircraft-specific trajectory calculations to schedule and sequence aircraft to the runway. Following testing of the system at Stapleton International Airport, CO, and the nearby air route traffic control center in Longmont, the FAA began during FY 1993 to train controllers at the Dallas-Fort Worth, TX, approach control facility on the system's final approach spacing element for further testing of the system there. The FAA planned to begin an operational assessment of the CTAS scheduling element in early FY 1994.

As the fiscal year ended, Allied Signal Inc. was in full production of the 26 **Microwave Landing Systems** (MLSs) for operation in Category I conditions, which involve a runway visual range of not less than 1,800 feet, and the FAA had witnessed the successful factory production testing of the first seven systems. They will be used to demonstrate the economic and operational benefits of MLS. Engineering and site preparation were underway at more than 20 airports. The Raytheon and Wilcox Corporations continued the dual development of the Category II and III MLS, for use in conditions of more limited visibility than Category I. Both companies successfully completed systems requirements and systems design reviews, establishing overall system baselines. As of the end of the year, they were progressing on schedule for the delivery of the first test systems to the FAA Technical Center in mid-1996.

When completed, another FAA program, the **Advanced Automation System** (AAS) will upgrade the capacity and reliability of the airspace system, increase controller productivity, provide greater fuel efficiency, minimize delays, and give the flexibility needed for future enhancements. The FAA plans to replace the equipment now used by controllers with new computer software, processors, tower position consoles, and controller workstations called sector suites. During the fiscal year, the agency successfully installed and commissioned the system's first element, the Peripheral Adapter Module Replacement Item, at all 20 Air Route Traffic Control Centers ahead of schedule. The FAA also redesigned the entire AAS to establish an achievable schedule for implementation of the Initial Sector Suite System with first operational readiness scheduled for October 1996. As part of the AAS project, a strategic planning activity was underway at the end of the year to ensure that the Terminal Advanced Automation System (TAAS), Area Control Computer Complex, and Tower Control Computer Complex segments can be fielded in such a way as to provide maximum benefits in a timely, achievable way. The FAA has made extensive use of the Development Demonstration Facility for early evaluation and risk mitigation of Initial Sector Suite System functionality, and the TAAS hardware was installed at the facility as the year ended. Also, during FY 1993 the FAA placed into operation at the Technical Center a Tower Integration Laboratory. This laboratory is used for testing and evaluation of data management, control, and display systems and components for air traffic control tower applications, for developing the transition engineering tools, processes and procedures to be used for integration and implementation, and for operational evaluation of tower-workstation/controller interfaces under simulated, high-realism, and load conditions.

Weather-related Aeronautical Activities

During FY 1993 the FAA continued its progress on three projects aimed at improving **Aviation Weather Services**. Working with the Air Force, the agency was developing the Integrated Terminal Weather System, which promises to provide very short-range forecasts and warning notices for pilots and air traffic controllers. The FAA tested prototypes of this system at the Orlando and Dallas-Fort Worth airports. Another project involved the Aviation Gridded Forecast System (AGFS), which provides more accurate and timely weather information from the National Weather Service for aviation use. Using AGFS, the FAA and the National Oceanographic and Atmospheric Administration's Forecast Systems Laboratory began preliminary testing of improvements in analysis and forecasting of weather data at Denver's Stapleton International Airport. In a third project, the National Science Foundation and the National Center for Atmospheric Research continued to assist the FAA in developing the Aviation Weather Products Generator, which will create data for the AGFS grid tailored for an en route application. During FY 1993, NOAA and the FAA undertook evaluations of prototype products for aviation users at Stapleton, the FAA Technical Center, and at NOAA's National Aviation Weather Advisory Unit in Kansas City.

Relatedly, the FAA defines the aircraft atmospheric **Icing** environment to include super cooled clouds, snow, ice crystals, freezing precipitation, and mixed conditions from ground level through all flight levels. During FY 1993, the agency continued to screen and assess commuter class aircraft with potential susceptibility to icing-induced stalls. In cooperation with NASA and the DoD, the FAA worked to develop simulation methodologies, analytical techniques, and instrumentation calibration standards from which to design and test ice protection systems. The agency also investigated the technologies associated with ground anti-icing and deicing fluids to determine optimal application procedures, hold-over timetables, and associated aerodynamic effects. Additionally, the FAA is undertaking research, development, and evaluation of surface ice detectors and related technologies. The FAA and National Center for Atmospheric Research continued research efforts to better diagnose weather information and forecast inflight icing conditions that might require ground deicing of aircraft. The agency conducted tests of radar-based algorithms to predict snowfall rates in the winter of 1992-1993 at the Denver airport. In cooperation with the FAA, United Airlines deicing personnel evaluated prototype products. The agency also studied the ability of various numerical weather models to predict accurately weather information needed to forecast icing conditions, and it proceeded with studies to determine an icing index independent of aircraft type. Additionally, the FAA and NOAA's Wave Propagation Laboratory investigated techniques for detecting super cooled liquid water, which is important in determining icing hazard potentials.

During the year, the FAA completed "The Forward Look Windshear Detection Systems Requirements," a document that will be issued as an advisory circular. The agency also made plans to certify airborne doppler radars as Forward Looking **Windshear** Detection devices, equipment that will provide advance warning of hazardous windshear. Airlines have placed nearly 1,000 firm orders for the new equipment, developed under a cooperative program involving the FAA, NASA, and industry. As the year ended, NASA and the FAA were considering whether pilots needed formal training to interact with the new instruments. Development efforts continued on radar and Lidar (laser radar) for use in detecting windshear. The FAA also proceeded with its work on integrating output from airborne detection devices with the Air Traffic Control system and began to plan for other applications of this technology.

The FAA had commissioned 169 federally procured **Automated Weather Observation Systems** (AWOSs) by the end of FY 1993, with an additional 250 non-federal AWOSs providing real-time weather observations at airport where weather data were not previously available. In cooperation with the National Weather Service, the FAA continued its program to acquire Automated Surface Observing Systems (ASOSs). The agency ordered 110 additional systems during FY 1993, and by the end of the fiscal year 220 systems had been installed, although none had been commissioned. In addition, the FAA installed the AWOS Data Acquisition System (ADAS) at six air route traffic control centers. ADAS acquires, processes, and disseminates data from the AWOSs and ASOSs.

During 1993 the FAA was in the process of developing an **Electromagnetic Environment** data base to address atmospheric electrical hazards posed by high intensity radiation fields (HIRFs), emissions that could interfere with electronic systems. The agency continued research to determine the adverse effects from lightning and HIRF on all advanced-technology airframes and systems. In a joint program, the FAA, NASA's Langley Research Center, Lawrence Livermore National Laboratory, and the National Institute for Standards and Technology examined the effectiveness of shielding aircraft and airframes from HIRF. Through cooperative efforts with industry and other governmental agencies, the FAA proceeded with full-scale testing, data collection, and modeling of the susceptibility of flight control systems to HIRF in an effort to determine damage levels to aircraft.

The FAA planned for the acquisition of 47 **Terminal Doppler Weather Radar** (TDWR) systems for deployment at 45 airports. TDWR provides timely detection of hazardous wind shear in and near airport terminal approach and departure corridors and reports that information to pilots and controllers. During FY 1993, the FAA began dismantling the testbed system at Orlando and installed the first permanent TDWR at Oklahoma City. It will use that system for training purposes. The agency also deployed a second TDWR to Houston with commissioning scheduled for FY 1994.

Flight Safety and Security

In other efforts to make flight safer, the FAA published a three-volume set of reports, entitled "Test Methods for Composites: A Status Report." These provide information on tension, compression, and shear testing of composite materials that manufacturers can use in designing aircraft structures. The agency also completed a report on principles and practices for the maintenance and repair of **Components and Structures** made of advanced materials and will incorporate this information into a repair maintenance handbook for FAA inspectors. In addition, the agency finished its examination of the possible corrosive effects on wheels of compounds released during tire outgassing at high temperatures; it concluded that the concentrations of corrosive compounds were too low to present a serious hazard.

During the course of the year, the FAA engaged in a number of tests and other activities to improve **Aircraft Crashworthiness**. For example, it completed an analysis of the previous year's vertical impact test and published a final report evaluating the structural response of the fuselage, floor, and seat restraint systems of the Fairchild Metro III airplane. The agency initiated a joint testing program with NASA and the DoD to investigate the crash impact resistance of airframes constructed of thermoset/fiber composite material systems. The FAA also upgraded the computer program KRASH with an algorithm for aircraft water impacts and concluded water impact/ditching studies for both commuter aircraft and rotorcraft, with special emphasis on the performance of flotation devices and on occupant survivability. Additionally, the agency demonstrated the adaptability of child restraint systems in carrier aircraft and studied dynamic crashworthiness standards for commuter aircraft seats. Tests of transport category seat crashworthiness allowed the agency to guide industry in seat design for the future Boeing Model 777 aircraft.

In the area of **Aging Aircraft Research**, the FAA in coordination with NASA organized nine workshops to discuss ongoing research into structural integrity, nondestructive investigation, flight loads, and corrosion. The two agencies cosponsored the 5th International Conference on Structural Airworthiness of New and Aging Aircraft. As part of its cooperation with the FAA, NASA was in the process of adapting an existing x-ray system to inspect aircraft wings, turbines, and propeller blades for corrosion, cracks, and disbonding. The FAA also continued international cooperative agreements covering aging aircraft research with its counterparts in the United Kingdom, the Netherlands, Japan, and Australia. It reached a new agreement with Canada and formed a consortium with Iowa State University and various engine manufacturers to develop improved methods for inspection of engine rotating components. In October 1992, the FAA designated Rutgers University and the Georgia Institute of Technology as a (combined) Center of Excellence in Computational Modeling of Aircraft Structures with the goal of examining crash-scenario and structural modeling relevant to the current fleet of aging aircraft and to new technologies. Among many other activities, the agency completed an assessment of the capabilities of emerging nondestructive inspection techniques; undertook residual strength and fatigue tests of full-scale curved fuselage panels containing multiple site damage; augmented research and development capabilities at its Aging Aircraft Nondestructive Inspection Validation Center by acquiring transport aircraft with high service times for use as test beds; developed a prototype, light-weight, low-cost recorder to collect data on flight loads for small airplanes; and concluded a field experiment of eddy current inspection reliability that was conducted at several industrial aircraft maintenance facilities.

With respect to **Fire Safety**, together with its counterparts in the United Kingdom and Canada, the FAA completed a series of full-scale fire tests to optimize an on-board cabin water spray system previously effective against a range of postcrash fires. The results indicated that the quantity of water required on a variety of aircraft may be reduced by 90 percent by zoning the system and using thermal detectors to activate each zone. Such zoning increased the survival time and improved visibility compared with a system that continuously discharged water throughout the cabin. The FAA also prepared and made public a fire research plan to guide long-term safety efforts, created a new operating group to manage aircraft fire safety research, and established an interagency coordinating group to focus attention on development of new fire-resistant materials. Other efforts to improve aircraft fire safety included cooperative efforts with both the Department of Energy and the National Research Council to accelerate development of sophisticated computer models for fire prediction and use of emergency material technologies.

Relatedly, the FAA tested a research firefighting vehicle to improve **Aircraft Rescue and Firefighting** (ARFF) response capabilities under conditions of poor visibility. It compared Forward Looking Infra-Red and Global Positioning System technologies to see which provided the best navigational capabilities for ARFF vehicles during heavy fog, and it continued development of a vehicle performance standard.

During FY 1993 the FAA continued tests of unleaded **Aviation Gasoline** in an effort leading to a new fuel specification by the American Society for Testing and Material. The agency studied the knock characteristics of various fuels with different fuel additives and developed plans for an extensive flight test program for an unleaded aviation gas substitute to be used in general aviation piston engines. Work to date on several types of ethanol/gasoline mixtures as replacement fuels for general aviation engines indicate that these fuels show considerable promise.

The FAA continued to be concerned with safety issues involving movement of aircraft and other vehicles on **Airport Surfaces**. The braking action of an aircraft can deteriorate drastically because of snow, water, or large deposits of rubber on the runway, taxiway, or apron, causing an aircraft to slide sideways or overrun the runway. In a joint effort with the Port Authority of New York and New Jersey, the FAA performed tests to measure the effects of rubber buildup on the use of aircraft anti-icing and runway deicing fluids. The agency designed those tests to show how the fluids would affect runway friction and help reestablish realistic guidelines for rubber removal. Relatedly, during FY 1993 the FAA developed an analytical computer model to provide identification of promising arrester design parameters and then performed tests with an agency B-727, proving that a commercial-size aircraft could be safely arrested without damage.

In the area of **Airport Pavement Technology**, the FAA published in April 1993 its first comprehensive Airport Pavement Program Plan, which outlined plans to develop advanced pavement design methodologies based on sound theoretical principles and full-scale validation tests. These plans should facilitate development of advanced techniques needed to assess the effects on airport pavements of the loads created by the new generations of larger and heavier civil transport aircraft. In addition, in August 1993 the FAA completed the preliminary design and feasibility study for the first National Airport Pavement Test Machine facility. It will provide full-scale testing data urgently needed to investigate the response and performance of airport pavements subjected to the complex gear loads of the new-generation aircraft. In September 1993 the FAA then led the research effort to complete the construction of the first runway section fully instrumented for pavement research. Located at Denver International Airport and equipped with 460 sensors and state-of-the-art acquisition devices, the runway section allowed information about pavement response and performance to be obtained instantly under normal operating conditions. The agency was also engaged in a study to determine the criteria for assessing runway roughness. It will use the study to determine appropriate limits and corrective measures for irregular runway profiles.

The FAA continued to develop technology designed to prevent or mitigate the hazard of **Turbine Rotor System Failure**. Test and evaluation results have demonstrated the ability of advanced, lightweight material barriers to absorb the high-energy rotor fragments liberated by small turbine engine failures. During FY 1993, the agency completed a prototype demonstration of a unique x-ray inspection system that successfully detected simulated disk cracks in a rotating turbine rotor subassembly, offering a possible means of improving preventive maintenance.

Another hazard of flying is the threat of **Bird Ingestion into Jet Engines**. The FAA completed a study of the performance of high bypass turbine engines after bird ingestion. This showed that during departures, engines sustained about twice as much damage as those that ingested birds during arrival. The agency will use the results of this effort to assess current regulatory requirements.

During FY 1993, the FAA also addressed **Certification Issues** related to improved flight safety assessments for new aircraft using advanced displays, modified operational profiles, flight management systems and procedures. Technical emphasis concentrated on obtaining updated flight test data and analysis of fly-by-wire; computer-based, automated flight control systems; and equipment that improves techniques for certification/safety assessment.

In addition, the FAA continued research and development to enable safe and efficient operation of **Vertical Flight Aircraft** in the National Aviation System. The agency initiated work to improve coordination and cooperation with NASA and the DoD on programs of mutual interest, such as rotorcraft terminal approach procedures, analysis of tiltrotor technology, rotorcraft noise mitigation, and dual-use technology. Research into improving navigation and air traffic control services for rotorcraft continued, and the FAA consolidated rotorcraft steep angle approach and terminal airspace design requirements into a coordinated research and development program plan. The FAA conducted initial research evaluating steep-angle, Differential Global-Positioning-System, precision-instrument-approach flight tests at NASA's Ames Research Center. As part of the effort to identify the potential of GPS technology for rotorcraft use, the agency flew non-precision instrument approach flight tests in helicopters and developed a GPS non-precision instrument approach to a hospital heliport. Such tests were a part of the overall goal of enhancing the safety of helicopter instrument flights in poor weather. Heliport research resulted in publication of a heliport design report on emergency rooftop evacuation and a report on the hazards to rotorcraft from magnetic resonance imagers at medical facilities. Work continued to provide solutions and alternatives for improved access and more efficient use of center-city heliports by rotorcraft. The agency also initiated analysis of the economic feasibility and airspace impact of using civil tiltrotor for short-haul air transportation. It completed its analysis of potential delay reduction and cost savings in the National Airspace System from implementing civil tiltrotor in the Northeast corridor.

The FAA also continued its program to strengthen **Aviation Security** through research and development. In November 1992, the agency opened and dedicated a security research laboratory at its Technical Center. It will use the facility to conduct research, testing, and evaluation in the areas of bulk and trace/particle detection of explosives. In March 1993, the FAA began a cooperative demonstration program involving the deployment of agency-owned, commercially available explosives detection equipment to various airports to screen carry-on electronic devices. In May the agency conducted a seven-week combined test of technology, analyzing several pieces of integrated explosive detection equipment in various configurations at Miami International Airport. As part of an overall assessment of commercial aircraft for vulnerability to explosive effects, the FAA enlisted the National Institute for Aerospace Studies and Service to help address potential terrorist threats and identify system design changes that could mitigate vulnerability. During the fiscal year, the agency tested four prototype luggage containers for use on wide-body commercial aircraft. It also completed a security vulnerability analysis at Baltimore-Washington Airport and began testing an enhanced security system there. Additionally, the FAA published final criteria for explosives detection systems that permit airports to employ any of several different detectors. During the fiscal year, the Screener Proficiency Evaluation and Reporting System compiled data analysis, and the agency generated a final report on improvements in x-ray screener performance. The FAA also initiated demonstration projects at two major airports to gather data on x-ray screener improvements in an operational environment.

In a final area of flight safety, NASA was engaged in a project to develop a computer-assisted **Engine Control System** that allows a plane to land safely employing only engine power if its normal control surfaces—such as elevators, rudders, and ailerons—are disabled. This program reached an important milestone when a NASA F-15 touched down at Dryden Flight Research Facility, CA, with its flight controls deliberately locked. It used only engine power for control. The control system varied the speed of the engines either singly or together to guide the aircraft to a safe landing, proving the capability of the technology. The system may be incorporated into future aircraft designs to provide a much greater margin of safety in the event of hydraulic failure, such as that causing the crash of a United Airlines DC-10 at Sioux City, IA, in 1989.

Aviation Medicine and Human Factors

In the area of **Aviation Medicine**, the FAA completed development of a technique for electronically recreating operational errors and incidents in air traffic control. Future applications of that system include increased capabilities to evaluate causal factors in the occurrence of errors, enhanced specialist training in air traffic control, and improved field performance assessments. The FAA conducted two industry workshops to identify and resolve flight safety issues pertinent to emergency medical service and completed risk evaluation tests on the use of night vision goggles in civilian air ambulance operations. Investigation in FAA hypobaric chambers defined the safety of packing materials for biologically hazardous substances under conditions of rapid decompression. As part of an exchange with the Russian Ministry of Transportation in the field of aviation medicine, the FAA initiated cooperative research projects to study effects on pilot performance of antihypertensive medications and wearing glasses.

In **Human Factors Research**, the FAA began work to develop and validate a computer-based test of the readiness for duty of employees in safety-sensitive positions—to be administered just prior to the start of a work day. During the fiscal year, the agency completed studies on the effect of automation on corporate aircraft pilots, on the factors that influence pilot decisions on the use of automatic features, and on the Aviation Safety Reporting System's data on problems pilots experienced in using flight management systems. The agency also initiated a program of research to address human factors associated with accidents in general aviation. Additionally, the FAA finished development and simultaneous evaluation of a flight deck information management system for the terminal area arrival flight phase. Several airlines evaluated an improved instrument approach procedure chart in the commercial format for flight training simulators. The FAA also completed a survey of pilot usage and problems with GPS and LORAN-C receivers, and it conducted laboratory and flight tests of pilot performance and training requirements for several GPS receivers.

The FAA signed new five-year interagency agreements with NASA for fatigue research, decision making and crew resource management research, data link human factors research, and the development of an automated performance measurement system for flight recorder data. In this connection, a new method for combatting flight crew fatigue that NASA developed has been expanded into a training module for U.S. commercial air carriers, overnight cargo carriers, military pilots, and the National Transportation Safety Board. Some of the commercial airlines are using the training for other groups, such as mechanics and flight attendants.

In addition, the FAA signed an agreement with the Naval Training Systems Center for flight crew training research. It also awarded research grants for: (1) analysis of the current spectrum of flight deck automation approaches and identification of potential safety or training issues; (2) tradeoff studies of different degrees of data link automation; (3) validation of methodology and development of advanced qualification program model curricula, training requirements, and evaluation criteria for regional and commuter airlines; (4) development and evaluation of a proof-of-concept, digital, video debriefing station for use by line operational simulation instructors and check pilots; and (5) research on shared pilot/controller decision making in the evolving National Airspace System.

During FY 1993 the FAA finished classifying the quantification of voice errors in the en route air traffic environment and continued with the next study phase using voice tapes from the terminal area environment. The agency installed a personal, computer-based, visual simulator of an air traffic control tower at Chicago's O'Hare airport and began evaluating it as a training aid for ground controllers. The FAA prepared a draft human factors handbook and checklists for use by air traffic controller teams assigned to evaluate new systems under development. The agency finished a computer model of Atlanta's Hartsfield airport and began collecting data on ground and local controller communications at the airport. It also initiated experiments to determine the effects of human signal detection and false alarm responses for future surface traffic automation systems. Finally, the FAA in cooperation with Transport Canada continued its research into aeronautical decision making to promote aviation safety. As part of that effort, the agency initiated work on an expert decision making program to help flight crews react better in stressful situations. Additionally, the FAA began projects to study ways of enhancing the performance of technicians through computer-based training and job-aiding systems. The agency also initiated a project to investigate methods for improving maintenance and work-site communication.

Studies of the Planet Earth

Spacecraft launched into Earth orbit over the past 35 years have enabled humans to observe the home planet repeatedly and on a global basis, allowing scientists in a great variety of disciplines to study the Earth as a whole and parts thereof in ways analogous to practices carried on by other scientists in a laboratory. Applications of this comparatively new capability have ranged widely but can be broken down basically into terrestrial, atmospheric, and oceanographic studies, although there was considerable overlap among these categories in some programs and projects.

Terrestrial Studies and Applications

Terrestrial studies themselves encompass a broad range of activities. One of these during FY 1993 was the launch of the joint U.S./Italian **Laser Geodynamics Satellite II** (LAGEOS II), designed to provide precise measurements of movements in the Earth's tectonic plates. Deployed from the Space Shuttle Columbia in October 1992, the satellite is covered with hundreds of reflectors that "bounce" laser pulses beamed from Earth stations back to their sources. Measurements of the time it takes a pulse to travel to the satellite and back to Earth allow high accuracy in determining specific positions, and repeated measurements over many years will tell scientists how far specific locations have moved relative to one another. Since most earthquakes and volcanic eruptions occur where plates meet, LAGEOS II is expected to shed light on how these cataclysmic events occur and when they are likely to happen. To this end, a team of 27 international investigators representing the U.S., Italy, Germany, France, the Netherlands, and Hungary will study the data from LAGEOS II.

Also relevant to terrestrial studies were two flights of the **Space Radar Laboratory** (SRL) projected in 1994. The SRL flights will acquire multi-wavelength/polarization radar images of the Earth's surface. These will be used for making maps, interpreting geological features, studying ice processes, conducting bio- and geochemical as well as soil-moisture investigations, and studying resources.

Meanwhile, **Analysis of Existing Data** contributed significantly to our understanding of the Earth during FY 1993. In October 1992, geologists at NASA's Jet Propulsion Laboratory and at Louisiana State University released a report citing the discovery of several previously unknown earthquake faults in California's northeastern Mojave Desert. They made the discoveries by analyzing images taken by the Landsat Thematic Mapper at optical, infrared, and radar wavelengths. Analysis of the images, combined with field observations and earthquake information, indicated that the area is crossed by many young fault lines.

Also, a NASA-University of New Hampshire study released in 1993 indicated that, while the rate of tropical deforestation in the **Brazilian Amazon Basin** was decreasing, the overall extent of the deforestation and its adverse effects on the tropical forest habitat have increased since the late 1970s. Data from the Landsat 4 and 5 satellites covering 1978-1988 indicate that although the extent of deforestation is less than expected, it has increased substantially and created degradation of natural habitats on the fringes of deforested areas, posing a significant threat to the habitat of plant and animal species.

Scientists also partially completed work during FY 1993 on the initial **Pathfinder Data Sets** for the 20-month benchmark period of April 1987 through November 1988. Pathfinder—a joint NASA-NOAA program—constitutes a new application of Earth-science and other data sets, developed specifically to study global environmental change. Pathfinders take advantage of the long history of satellite observations in existing archives that are reprocessed to add new features and/or refinements. In particular, stable calibration, including both instrument drift and inter-instrument calibration within a series is needed so a consistent, geophysical product can be generated to cover a time series. The benchmark period includes field campaigns, spans several growing seasons, and covers a period when satellite sensors were all operating correctly. Pathfinder sets include data from the Advanced Very High-Resolution Radiometer (AVHRR) and TIROS Operational Vertical Sounder on the NOAA polar-orbiting satellites, the Visible and Infrared Spin-Scan Radiometer (VISSR) Atmospheric Sounder on the two GOES satellites operating during the period, the Special Sensor Microwave/Imager (SSM/I, on Defense Meteorological Satellite Program satellites), Scanning Multichannel Microwave Radiometer on the Nimbus 7 spacecraft launched in October 1978, and Landsat/Land Cover Change Pathfinders, which used data from the Landsat satellites launched beginning in the 1970s to study land cover. Data from the Landsat Multispectral Scanner and Thematic Mapper were added to the Pathfinder activity in 1992.

In late 1992, NOAA's National Geophysical Data Center (NGDC) released the **Global Change Data Base** on CD-ROM to the public. Data from AVHRR on vegetation, ecosystems, climate, topography, soils, a global vegetation index, and other topics have been integrated for improved multivariate analysis on Geographic Information Systems (GISs) and other software. The NGDC was in the process of compiling additional CD-ROMs for this series, which pioneers new techniques of scientific peer review for data compilations, improved documentation, attention to geolocation, and integrated analysis.

NGDC has also been developing techniques to seek rigorous associations between layers of the Global Change Data Base to recreate the **Global Vegetation Index** (computed from AVHRR imagery) as a function of vegetation types, climate, soils, and other information in the data base. Better environmental data bases would improve the models, but existing data can nevertheless produce better descriptions of the Earth's environment than currently exist.

Researchers from NOAA were also using data from the Defense Meteorological Satellite Program's F-10 and F-11 series of polar orbiting satellites to monitor flooding in the Midwest. Using an experimental **Soil Wetness Index** derived from the SSM/I on these satellites, the researchers have succeeded in monitoring the areal extent of flooding under nearly all weather conditions except active precipitation. As the fiscal year ended a climatology of this index was being developed for the period 1991 to the present.

Within the Department of the Interior (DoI), the **Bureau of Indian Affairs** continued to conduct resource inventory and image mapping projects to support its Indian Integrated Resource Information Program. Analysts used Landsat Thematic Mapper data to classify agricultural land use/cover on the Winnebago and Omaha Indian Reservations in NE. They also performed land cover inventories on the Zuni and Ramah Indian Reservations in NM, with emphasis on modeling fire fuels potential. Numerous image maps employed Landsat Thematic Mapper and (French) Satellite Pour l'Observation de la Terre (SPOT—satellite for the observation of the Earth) panchromatic data. Reservation-wide products also were prepared for the Standing Rock (SD/ND), Jicarilla Apache (NM), Ft. Berthold (ND), Spokane (WA), and Umatilla (OR) Reservations.

The **Bureau of Land Management** used satellite data and aerial photography to promote biological diversity and sustainable development on the public lands through ecosystem-based land management.

Remotely sensed data from a variety of sensors continued to play a critical role in all aspects of inventory, assessment, modeling, and monitoring to support ecosystem-based management activities. Analysis of aerial photographs and satellite data from Landsat, SPOT, and AVHRR supported ecosystem-based management of mineral resources in NV and UT; recreation in WY; wildlife habitat and grazing in NM, ID, and CO; threatened or endangered species in CA and OR; and hazardous material management at a number of sites throughout the western U.S.

The **Bureau of Reclamation** used remote sensing from satellites and GISs to generate more accurate estimates of consumptive water use by agriculture within the Colorado River Basin. Accurate crop area estimates are essential for making accurate estimates of consumptive water use. To produce crop area estimates, bureau analysts map agricultural field boundaries from aerial photographs and panchromatic SPOT imagery, storing them in a GIS. They have been developing techniques for combining the high spatial accuracy of the boundaries stored in the GIS with crop classification information derived from timely but spatially coarse Landsat Thematic Mapper and multispectral SPOT imagery. This approach provides accurate crop area estimates and results in improved estimates of consumptive water use.

The **National Park Service** continued to develop surface cover information for numerous areas via computer-based classification of Landsat Thematic Mapper data. Results included a vegetation/land cover map at Denali National Park, AK, as part of a plan to design and construct new park trails; a land cover map to augment the GIS data base for Death Valley National Monument, CA/NV; and an integrated image processing/GIS approach for distinguishing agricultural land from natural vegetation in Niobrara National River, NE.

The **U.S. Fish and Wildlife Service** has been using Landsat Thematic Mapper data and computerized mapping techniques in the Gap Analysis Program to depict the distribution of vegetative cover types, terrestrial vertebrates, and other key indicator species in 36 state-wide projects. By comparing these data with land-use practices and ownership, managers have been able to identify "gaps" or areas that are not being managed and protected to maintain biological diversity. As part of the global change research and wetlands status and trends programs, remote sensing continued to be used to map wetland types and monitor wetland health and hydrology in the Lower Mississippi River Valley and along the Gulf Coast. Sources of data included Landsat Thematic Mapper, AVHRR, and airborne multispectral scanner and radar data.

The **U.S. Geological Survey**'s Earth Resources Observation Systems Data Center has archived, processed, and distributed Landsat data since the launch of Landsat 1 in 1972. The Land Remote Sensing Policy Act of 1992 designated the center as the National Satellite Land Remote Sensing Data Archive. This designation has broadened the center's responsibility for preserving and providing long-term access to satellite-acquired, remotely-sensed data of the Earth's land areas. The 21-year collection of approximately a million Landsat scenes is the largest component of the archive, whose personnel have begun converting the data from aging magnetic media to new cassette tapes to preserve them for future use. Approximately 15 percent of the Landsat data was converted to this new medium during FY 1993. Archive personnel have been adding other types of satellite data to their holdings. Since April 1992, the U.S. Geological Survey has been working with NASA, NOAA, the European Space Agency, and more than 20 foreign ground receiving stations to collect AVHRR data of 1-kilometer resolution for each daily pass of relevant satellites over the Earth's land surface. These data support many applications, including efforts by the global change research community to produce a global land cover map and to monitor the condition (greenness) of vegetation on a periodic basis throughout the year. The Survey has been coordinating this program with the International Geosphere-Biosphere Program and the Committee on Earth Observation Satellites. The Data Center began compiling digitally-processed and mosaicked AVHRR data sets, including vegetative greenness, operationally for the conterminous U.S. since 1990, distributing them on CD-ROMs. Researchers have used these data with other Earth science data sets covering elevation, climate, and ecological regions to develop a prototype digital data base on land-cover characteristics for the conterminous U.S. The effectiveness of this information for environmental simulation modeling became evident in several case studies of global change research, land and water resource management, and environmental risk assessment. In a different area, the Survey developed computer algorithms to provide a spectral match of data from the NASA Airborne Visible and Infrared Imaging Spectrometer with a library of spectral characteristics of geologic materials, yielding a semi-automated procedure for mapping mineralogy in areas of exposed bedrock and soils. Using this process, researchers mapped subtle changes in clay mineralogy to understand better the workings of geologic processes and the environmental degradation of soils and water.

In the U.S. Department of Agriculture (USDA), the use of Landsat imagery continued to increase within the **Soil Conservation Service** (SCS) during FY 1993. It used Landsat imagery to determine the extent of the Midwest floods, then employed a combination of satellite imagery plus digital soil and land-use data in the service's Geographic Resource Analysis Software System to assess flood damage at the state and county level with respect to soil and land-cover concerns. The SCS was also evaluating the use of Landsat and SPOT imagery to identify wetlands, detect changes in them, and review and update wetland inventories. The SCS remained a primary contributor, user, and developer of aerial photographic and digital orthophotographic imagery. The service used digital orthophotography (one meter resolution) as the primary base map for collecting and digitizing GIS data layers containing information on natural resources. The SCS remained the lead agency within the USDA contributing to the National Aerial Photography Program and to the development of a National Digital Orthophotography Program.

The **National Agricultural Statistical Service** (NASS) employs remote sensing data in area sampling frame construction (using data from small sample areas as an aid to crop and acreage estimation), direct estimation of planted crop area, and assessment of crop conditions. Products from the first two areas have been based mainly on digital Landsat-5 Thematic Mapper data. Crop condition assessment has been using data from the NOAA-11 satellite. NASS has continued to use the Computer-Aided Stratification and Sampling (CASS) system to create area frames for use in its agricultural surveys. Using digital Landsat and Digital Line Graph (road and water boundary) data, the CASS system enables the user to assign each piece of land to one of a variety of categories based on percent of cultivation and/or land use. With continued support from NASA's Ames Research Center, NASS has used the Oklahoma area frame (created in 1992 using CASS) in its first survey in 1993, has completed the California frame (begun in 1992), and has started on the New York frame. It will employ digital SPOT data for urban areas in New York. The second Landsat application in NASS continued the Delta Remote Sensing Project using Thematic Mapper data to estimate plant acreage for major crops in Arkansas. NASS provided this data on acreage for rice, cotton, and soybeans in Arkansas to the Agricultural Statistics Board on August 1, 1993, for its use in making the official estimate. Thematic Mapper classifications also provided the basis for county estimates and color theme maps. Using NOAA-11 AVHRR data, finally, NASS created and used color map products to monitor crop conditions over large areas during the 1993 growing season. NASS distributed maps biweekly to decision makers in the USDA and to various NASS state statistical offices. These color maps depicted changes in vegetation vigor by comparing 1993 indices with those from similar periods in 1992. Although limited by the one kilometer resolution of the data, the maps were quite useful for large area reviews of the Midwest flood regions plus areas affected by drought in the southeast.

The USDA's **Forest Service**, which manages 191 million acres of National Forest System, has continued to require remote sensing for a variety of ecosystem management activities, including vegetation mapping, resource change detection, land management planning, damage assessment following natural disasters, identification of critical wildlife habitat, support to law enforcement, inventory, and mapping. Timely and accurate information on ecosystem components is vital for good resource management. The need for remote sensing data and associated technologies such as GIS and GPS has increased as resource managers are required to perform complex spatial data analysis to support the Forest Service's ecological approach to multiple use management. Consequently, the service has integrated remotely sensed data (satellite, aerial photography, airborne video, scanner, and radar) from a variety of sources into its operations at all levels of the agency. GPS technology is revolutionizing field survey and inventory methods. At the end of the fiscal year, over 800 GPS receivers were in use and the Forest Service was administering 25 community base stations. In addition, the agency was moving toward the development of an integrated information structure to help define uniform processes for ecological classification, resource mapping, and inventory. Remotely sensed data provided unique information over large areas quickly and inexpensively to promote good management decisions and generate cost-effective results.

Similarly, the **Foreign Agricultural Service's** satellite remote sensing program continued to be a critical element in the USDA's analysis of foreign agricultural production, supply, and demand—providing timely and accurate estimates of global area, yield, and production. For example, the agency used satellite imagery, remotely sensed weather data, and crop models to support State Department relief activities by evaluating regional grain production in the former state of Yugoslavia, focusing on Bosnia. The Foreign Agricultural Service also prepared a detailed assessment of the flooding in the U.S. Midwest, using Landsat Thematic Mapper data, classification algorithms, and GIS analysis to class counties according to flooding severity and its effects on crop conditions. The USDA used this information to prioritize its disaster relief efforts.

Also in the USDA, the **Agricultural Research Service** has developed a remote sensing instrument to detect residue on the soil surface. Such residue increases water infiltration while minimizing erosion. Consequently, accurate measurement of the residue is important for program monitoring. The instrument (still being tested and not yet deployed) uses an ultraviolet light source and a response detector at appropriate wavelengths to differentiate between soil and residue. Also, a newly developed Water Deficit Index will allow producers to use remote sensing to provide accurate measurements of crop water need at all stages of crop growth. The USDA expects that this development will substantially reduce water use for irrigation while maintaining crop growth and yield. The service has also developed models using a combination of meteorological and remotely sensed data to measure moisture and energy fluxes at river basins. This is important to understanding how the land surface affects climate and climate change. Finally, a combination of technologies including aircraft video multispectral sensing, differential GPS location data, and a within-farm field GIS coupled with computer map-driven equipment that differentially applies fertilizers and chemicals is allowing producers to optimize yield and production cost while protecting the environment by supplying only the chemicals necessary for seasonal growth of the crop. This is particularly important with our concerns about the agricultural contribution to chemical leaching from ground and surface water. Researchers, agribusinesses, and other producers are working together at several locations to implement this new "prescription" or "precision" method of farming.

The U.S. **Environmental Protection Agency** (EPA), primarily through its Environmental Monitoring Systems Laboratory in Las Vegas, NV (EMSL-LV), with assistance from its Atmospheric Research and Exposure Assessment Laboratory in Research Triangle Park, NC, also routinely conducted research and provided technical support using remote sensing as part of its overall environmental monitoring program. The agency used large-scale aerial photography to develop site characterization data during the remedial actions under the Comprehensive Environmental Response, Compensation, and Liability Act, as well as to support site selection and monitoring at hazardous waste facilities operated under the Resource Conservation and Recovery Act. It developed and used remote sensing systems to support the provisions of the Clean Water Act. In FY 1993 the EMSL-LV completed approximately 150 aerial photographic site characterization projects. Also during the year, aerial photography and satellite data supported a broad variety of pollution, global change, pollution prevention, compliance, and other ecosystem monitoring studies, such as those of critical-habitat areas for wildlife. The Environmental Photographic Interpretation Center (EPIC)—a branch of EMSL-LV—provided support to the EPA's regional offices through the analysis of aerial photographs acquired in cooperation with the Army Corps of Engineers and of documentation of impacts associated with the severe flooding along the Mississippi River and its tributaries. The agency used this information to identify the flood's effects on industrial and agricultural facilities for assessment of hazardous and toxic waste movement and containment. As the year ended, EPIC was in the process of conducting further analysis of pre- and post-flood aerial photographs to identify and map changes that have occurred at known waste disposal sites impacted by the flooding. In addition, the EPA continued (with NASA support) to use and develop light detection and ranging systems to monitor urban plumes and emission sources as well as to measure ozone, sulfur dioxide, and particulates. Finally, the EPA was using a GIS for data integration and analysis in support of many of its programs. (For other information on terrestrial studies, see the coverage of the Miniature Sensor Technology Integration Program above.)

Atmospheric Studies

In partnership with Aurora Flight Sciences Corporation and some other organizations, NASA was engaged in the **Small High Altitude Science Aircraft (Perseus)** program to develop an airplane that can fly above 80,000 feet subsonically to acquire "in situ" atmospheric science data useful in understanding the cause and effect relationship between engine exhaust emissions and ozone depletion or other adverse atmospheric impact. The first closed-loop run of the Perseus' Rotax 912 engine occurred in September 1992, and the Perseus aircraft rollout occurred in December 1992. Delivery and checkout of the Harvard Science Payload and Ames Engineering Data System followed in August 1993.

Other NASA and NOAA efforts to monitor **Ozone Depletion** brought some disturbing environmental news early in the fiscal year. (The ozone layer protects the Earth from excessive doses of the sun's ultraviolet rays.) Scientists from the Goddard Space Flight Center, using data from the Total Ozone Mapping Spectrometer (TOMS) on NASA's Nimbus 7 satellite, discovered that global ozone levels in late 1992 and early 1993 reached the lowest levels ever observed. Although falling values had been predicted for 1992, the actual observed values were substantially lower than predicted (some two to three percent lower than in any previous year). Extensive analysis of independent data from the Solar Backscatter Ultraviolet Spectral Radiometer (SBUV/2) on the NOAA-11 satellite and a NASA TOMS instrument on the Russian Meteor 3 spacecraft confirmed the Nimbus 7 results. In addition, preliminary findings from the SBUV instrument flown on the Space Shuttle (SSBUV) as part of the ATLAS-2 mission in April 1993 were in agreement with the TOMS data. Comparison of all these spaceborne data with the ground-based World Standard Dobson Instrument and the Dobson network indicated that the satellite instruments' measurements were consistent during this period.

The ozone levels were especially low in the midlatitudes of the northern hemisphere, including large portions of North America. The December 1992 midlatitude ozone levels were 9 percent below normal, while January figures were 13-14 percent below normal. TOMS measurements also showed that the area of ozone depletion over Antarctica, commonly referred to as the "ozone hole," was the largest on record as of late 1992. The "hole" also persisted longer than usual, not breaking up until early December. In addition, observations from NASA's Upper Atmosphere Research Satellite (UARS), launched in September 1991, found that ozone destroying forms of chlorine existed in the Arctic stratosphere for much longer in the winter of 1993 than during a comparable period in 1992, leading to ozone levels 10 percent below those in 1992, with some regions up to 20 percent lower. Though recovering somewhat, lower than normal global ozone levels persisted into the summer months. Fortunately, scientists at NOAA could foresee an end to the decline in the ozone layer. The Montreal Protocol, signed in 1987 to phase out use and end the production of ozone-destroying chemicals, appeared to have lowered the use of chlorofluorocarbons to the point where NOAA scientists predicted that the chlorine atoms that break off from them would peak about the year 2000, although the ozone layer would probably not return to "normal" for another 50 to 100 years.

Also relevant to ozone measurement, the Ballistic Missile Defense Organization flew the Polar Ozone and Aerosol Measurement (POAM-II) experiment as part of the SPOT-3 spacecraft launched on an Ariane-4 rocket on September 25, 1993. POAM-II will measure the Earth's stratospheric environment, particularly the aerosols, nitrogen dioxide, water vapor, and ozone depletion between 10 and 60 kilometers over the north and south poles.

Meanwhile, the TOMS instrument on Nimbus 7 failed in May 1993 after providing data since November 1978, during which time it had served as the primary monitor of global ozone levels. Another NASA TOMS instrument went into orbit on the Russian Meteor 3 in August 1991, and the NOAA SBUV/2 instrument had been measuring ozone since January 1989, while the SSBUV has flown annually on the Space Shuttle since 1989.

NASA's ozone measurements are part of the agency's **Mission to Planet Earth** (MTPE) program, a long term effort seeking to provide the measurements necessary to help understand the Earth as a unified system and to help distinguish the effects of natural and human-induced global climatic change. Using the unique perspective available from space, NASA and its domestic and international partners have been observing, monitoring, and assessing large-scale environmental processes that affect climate change. NASA's contribution to the U.S. Global Change Research Program (USGCRP) includes measurements from instruments on free-flying spacecraft and the Space Shuttle; aircraft, in-situ, and ground-based observations; a comprehensive data and information system to process and distribute the findings; and a modeling effort designed to help understand, and eventually predict, the behavior of and changes in the Earth's system. The first phase of MTPE includes the expected flight by NASA and its partners of more than 20 missions through 1998. The first such mission was that of the Upper Atmosphere Research Satellite in September 1991. Data from MTPE and other global change research efforts will enable policy makers to formulate prudent policies regarding the future of the global environment.

An important part of MTPE Phase 1, the **ATLAS-2** mission aboard STS-56 in April 1993 was the second in a series of such spacelabs studying solar output as well as the chemistry and dynamics of the middle atmosphere over a solar cycle of 11 years. These measurements are important because even small changes in the sun's total irradiance or its spectral distribution can have a significant influence on the Earth's climate. Similarly, changes in the quantity of trace gases in the atmosphere can have both climatic and other effects. Scientists also use measurements from ATLAS flights to correlate data from UARS. The ATLAS series is projected to fly a core series of instruments that are recalibrated after each mission. This will enable scientists to differentiate between changes in the way UARS instruments measure over time and actual atmospheric phenomena. Scientists were still studying data from ATLAS-2 as the year ended.

The second phase of MTPE is the **Earth Observing System** (EOS) program, a series of spacecraft planned to carry a variety of sophisticated instruments to make the most comprehensive measurements ever of the interrelated elements of the global environment. These measurements—along with those from other MTPE satellites, ground experiments, and scientific research—should enable scientists to model the Earth as a total system and to project the ways human activity has affected and will affect the planet. NASA's program is part of the International Earth Observing System (IEOS), in which satellites and instruments from Europe, Japan, and Canada are being closely coordinated to provide complementary data on different aspects of the Earth's biosphere. The first EOS satellite (EOS-AM1) launch is targeted for June 1998. (The AM indicating a morning crossing time over the equator.) Progress toward this goal continued in FY 1993, with completion of preliminary design reviews on three of the five EOS-AM1 instruments as well as similar reviews of components of the EOS-AM1 spacecraft.

Development also continued on the **EOS Data and Information System** (EOSDIS), the means by which information from EOS and other Earth science satellites will be translated into useful information and made available to scientists worldwide. The evolutionary nature of EOSDIS will allow it to keep pace with advancing technology, while offering unprecedented ease of access for researchers. In March 1993, NASA started development of a key component of the system—the EOSDIS Core System (ECS)—with award of a contract to Hughes Applied Information Systems of Seabrook, MD, for design, development, and operation of the ECS. A major program milestone, the system requirements review, took place in September 1993. In addition, discussions continued throughout 1993 with NASA's international partners on establishing the data agreements needed to make IEOS and other information available for research purposes to scientists worldwide.

Also in the area of atmospheric studies, tropospheric methane (CH_4) is second only to carbon dioxide (CO_2) in its effects on **Global Warming.**

Although the tropospheric CH_4 concentration is a small fraction (5 percent) of the CO_2 levels, CH_4 accounts for about 12 percent of global temperature rise, due to strong absorption in a relatively transparent part of the infrared spectrum. In order to quantify emission sources for the CH_4 between those stemming from human activities such as leaks of natural gas and those occurring naturally, NIST was engaged in intensive CH_4 measurement and modeling, using isotopic methods to differentiate between the two. The ultimate goal of this research, of course, was to devise ways to control the human activities contributing to the emission of CH_4.

The **National Science Foundation** (NSF) supported three programs involving ground-based observations of atmospheric properties related to global change: CEDAR (Coupling, Energetics, and Dynamics of Atmospheric Regions), GEM (Geospace Environment Modeling), and SunRISE (Radiative Inputs of the Sun to Earth). Based on previous observations and modeling, scientists now know that an increase of greenhouse gas concentrations will cool the middle atmosphere and increase the occurrence of noctilucent clouds. In 1993, atmospheric scientists under support from the NSF have made great strides in applying new research techniques and facilities to the investigation of processes and phenomena in the middle atmosphere.

In one example of the progress that has been made in this area, scientists from Colorado State University studied the temperature in the **Middle Atmosphere** using a sodium lidar facility that has been routinely operated since 1991. Its measurements have indicated that the temperature profile in this altitude range does not always display the single minimum that most atmospheric models assume. Instead, this minimum, referred to as the mesopause, occurs in two areas, one near 86 kilometers and the other near 99 kilometers. The temperature at the lower altitude varies with the season in a manner that is more consistent with the behavior predicted by atmospheric models. The upper minimum only varies by about 16 degrees throughout the year and its origin is still unexplained.

In another example, during the summer of 1993, atmospheric scientists and students from universities and industry conducted airborne measurements of **Arctic Noctilucent Clouds** along flight paths that extended across much of western Canada and Alaska. These clouds are the highest in the Earth's atmosphere, originating from sunlight that is scattered off ice crystals at altitudes between 80 and 90 kilometers. Ice crystals can only form at these altitudes in the high latitude summer mesopause, which paradoxically is colder than the winter mesopause. With temperatures between 120° and 140° kelvin, the summer mesopause has the coldest temperatures on Earth. The clouds are observed at twilight and dawn at high latitudes during the summer when the sun is below the horizon but still illuminates high altitude aerosol layers. Scientists have reported an increase in the frequency with which these clouds occur during the last century, leading some to speculate on a connection between the clouds and the introduction of anthropogenic greenhouse gases into the atmosphere. The group of scientists that conducted the observations flew aboard a Lockheed Electra aircraft owned by NSF and operated by the National Center for Atmospheric Research. Project scientists coordinated the flights with selected overpasses of NASA's UARS.

Scientists have also been conducting studies of the middle atmosphere at two other strategic locations. Maryland, Clemson, and Utah State universities have developed a lidar in **Logan, UT**, to observe waves launched by wind systems over the Rocky Mountains. And SRI International deployed a lidar at **Sondre Stromfjord, Greenland**, to operate in conjunction with a large atmospheric radar facility also funded by the NSF. This is the highest latitude at which the U.S. operates a lidar facility and is critically important in understanding the complex chemical and dynamical processes that occur in the polar regions.

With support from NSF, SRI International was in the process of overseeing construction of a facility to house instruments used for making observations in **Arctic Canada**. It is to include a 1,400 square foot building with living quarters and four optical domes, a detached generator building, and a 1.5 kilometer-long road connecting the site to the nearby hamlet of Resolute Bay in the Northwest Territories. With rising concerns about the depletion of ozone in polar regions, atmospheric scientists have recognized the importance of making observations at these high latitudes. By next summer, the facility will include an all-sky imaging instrument to measure airglow and auroral emissions, two radiowave devices for measuring ionospheric drifts, and a Canadian-supplied interferometer for detecting temperatures and winds in the upper atmosphere.

Other instruments that have been developed with support from the **CEDAR** program have led to new capabilities for monitoring the atmosphere from the ground. The demands placed upon industrial partners in the development of these instruments have led to technical advances. For example, scientists from Utah State University recommended design changes to an interferometer built by Bomem Corp. The company found that the new device had marketing potential and has sold similar models to universities, industry, and the government. Three other universities (Colorado, Clemson, and New Hampshire) developed and deployed radars that use the trails left by meteors to measure winds in the middle atmosphere. These instruments join an existing array of similar radars that collectively offer a means to study global climatology of the middle atmosphere. Previous measurements have been used to establish the existence of a two-day tidal wave in the middle atmospheric motion. Boston University scientists have developed a ground-based technique for studying the space environment to altitudes up to 12,000 kilometers. The method makes use of combining measurements from a sensitive spectrometer and any one of the large atmospheric radar facilities supported by NSF. They have validated the ability to measure ionized and neutral hydrogen concentrations by making observations from the radar sites in Greenland, MA, and PR.

Finally, NSF has taken a unique position in supporting studies of the effects of solar variability on global change. The **SunRISE** program is directed at monitoring and understanding this variability. NSF plans to support the design, construction, and deployment of two precision solar photometric telescopes optimized for accurate observations of sunspots, faculae, and other photospheric brightness inhomogeneities. Scientists will couple these observations with theoretical and modeling efforts that are integral parts of the program.

NOAA, of course, engaged in a great variety of research efforts involving the atmosphere. For example, it used ship- and ground-based measurements of **Cloud** moisture to validate similar SSM/I measurements from DMSP satellites. It also compared the data about cirrus clouds from surface-based sensors with observations from satellite sensors. It has been using data from the GOES 7 and Meteosat 3 satellites to develop a new forecasting tool for winds derived from cloud motions. These and other developments were important both for short-range weather forecasting and because the lack of accurate cloud physical processes in climate models is currently thought to be the major source of uncertainty in the longer-range prediction of climatic change due to the greenhouse effect. For the latter reason, NOAA's National Environmental Satellite, Data, and Information Service (NESDIS) has been using information from the Tiros Operational Vertical Sounder, GOES 7's Visible-and-Infrared-Spin-Scan-Radiometer Atmospheric Sounder, and AVHRR to develop a greater understanding of clouds, their amounts, types, and components. In collaboration with NASA, NOAA's Office of Global Programs, and several universities, NESDIS was also using satellite data to determine the influences of land-surface phenomena upon clouds and radiation. This work has produced evidence, for example, that, as of 1988, deforestation in Brazil was influencing an increase in the frequency of dry-season afternoon cumulus clouds.

With regard to **Precipitation Estimates**, there has been a lack of detailed, uniform observations over the Great Lakes, so NOAA has been using hourly infrared imagery from the GOES satellite in conjunction with raingage measurements to provide what it hopes will be better information for water budget models of the region. NOAA scientists have also compared SSM/I estimates of rainfall over land and oceans for the 1987-1992 period with radar measurements and raingage reports. This effort, supported by NOAA's Climate and Global Change Program, has already demonstrated the utility of SSM/I for providing monthly rainfall estimates comparable to surface-based observations. To help predict flash floods, NOAA has used GOES data to study the relationships between water vapor plumes and the upper- and lower-level circulation patterns related to rainfall of 125 millimeters or more in a 24-hour period. It has also been devising a Flash Flood Index, which will eventually include data from GOES and SSM/I. (For other information on atmospheric studies, see also coverage of the MSTI program and the Environmental Protection Agency above.)

Oceanographic Studies

Of great importance in the field of oceanography were the measurements of the **Ocean Topography Experiment (TOPEX)/Poseidon** satellite launched in August 1992. These provided the most accurate data yet available on global sea level changes, constituting the first map of ocean topography. Oceanographers will use it to calibrate the computer models that help forecast future changes in climate. The satellite uses a radar altimeter to measure sea surface height over 90 percent of the world's ice-free oceans. In combination with very precise determination of the spacecraft orbit, the altimetry data has yielded global maps of the ocean's topography with an accuracy of within 3 centimeters (1.2 inches). From this data, scientists will be able to determine the speeds and directions of ocean currents worldwide, thereby gaining a greater understanding of the role oceans play in regulating the Earth's climate. Using data from TOPEX/Poseidon in early 1993, scientists analyzed a prominent "Kelvin wave" that appeared in TOPEX/Poseidon altimeter data. This large, warm-water mass moving along the Equator is typically the condition that gives rise to an El Niño event, dramatically affecting fish harvests in the eastern equatorial Pacific. El Niños are also believed to be responsible for other meteorological developments, including significant rainfall and temperature variations across the U.S.

Also in the area of ocean science, from November 1992 to February 1993, NASA joined scientists from 15 nations and several other U.S. agencies in a **Tropical Ocean Global Atmosphere/Coupled Ocean-Atmosphere Response Experiment** (TOGA/COARE) based in Townsville, Australia. This field experiment, which involved oceanographic ships, buoys, aircraft, and spacecraft, should help researchers better understand tropical air-sea interactions. It also offered scientists involved in the joint U.S./Japan Tropical Rainfall Measuring Mission (TRMM) Earth Probe a unique opportunity to test candidate algorithms being developed for the satellite mission, planned for launch in 1997.

In addition, analysis of data from a series of joint research aircraft flights sponsored by NASA's Ocean Biogeochemistry Program and the NSF in the Pacific region (part of the international **Joint Global Ocean Flux Study**) revealed an unexpectedly high productivity of microscopic plants near the equator in the Pacific Ocean. The NASA researchers gathered more than 35 hours of data over the Pacific during the airborne campaigns. They then linked these data with observations from the Space Shuttle to guide NSF ships to the areas of high productivity.

In the area of tactical oceanography, Ball Aerospace Corporation was developing the **Geodetic/Geophysical Follow-on** (GFO) satellites for the Navy, with the first radar altimeter satellite expected to be launched in late 1995 and up to two additional satellites as needed to provide the Navy an operational capability until a radar altimeter can be placed aboard the DMSP satellites. GFO will provide timely, worldwide, and extremely accurate measurements of ocean topography via direct read out to ships at sea and selected shore sites. It will also store data on board and provide full orbital coverage to the Naval Oceanography Command's primary numerical forecasting centers. The direct-read-out data will enhance on-scene tactical support, with forecasting centers using the stored data to improve the performance of ocean circulation models. The Navy completed the preliminary design review for the program in October 1993. The critical design review is scheduled for April 1994.

Also, **CoastWatch**, a part of the NOAA Coastal Ocean Program, sought to provide satellite, in-situ, and weather model information in near real time to federal and state environmental decision makers. It did this by providing products via eight CoastWatch Regional Sites (CRSs) covering all U.S. Coastal states. Selected NOAA facilities, such as the National Marine Fisheries Service laboratories, have been serving as CRSs. These CRSs store products produced centrally or locally and make them available via Internet or dial-up modem to state and national resource offices, Federal environmental agencies, and university researchers. Satellite products provided to CoastWatch users consist of mapped images of AVHRR data, which are produced twice a day over all U.S. coastal regions. The NESDIS satellite mapping system that supports this effort reached full operational capability in September 1992. Since then, products have included sea surface temperature imagery and visible imagery (useful for ice analysis and for calculation of relative turbidity in estuaries). All CoastWatch mapped satellite images continued to be archived by NOAA's National Oceanographic Data Center and are available retrospectively via a near-line storage system accessible to Internet users. CoastWatch data are applied in coastal areas of the western U.S. in the operation of El Niño Watch and Red Tide/Domoic Acid Watch. Also, CoastWatch surface temperatures are used to model evaporation, net longwave radiation, latent and sensible heat fluxes, and their spatial patterns over the Great Lakes.

The period 1992-1993 has been especially exciting for the **Satellite Altimetric Community** owing to the availability of new data from the European Space Agency's Remote Sensing Satellite (ERS-1) launched in 1991, TOPEX/Poseidon, and declassified data from the Navy's Geodetic and Geophysical Satellite (Geosat) launched in 1985. NOAA's National Ocean Service (NOS) has been actively involved in data preparation, distribution, and analysis. The declassification of the Geosat data for the southern hemisphere in 1992 permitted NOAA's National Ocean Service to produce for release in 1993 by NOAA's National Oceanographic Data Center two CD-ROMs containing the information. Satellite altimetry continues to have an extraordinary impact on the Earth sciences because the sea surface topography measured by radar altimeters can be used to map the gravity field of the Earth. To date, however, only Geosat data have possessed both the accuracy and density of coverage necessary to resolve tectonic details clearly in the marine gravity field on a global basis. Because the majority of the world's oceans are in the southern hemisphere, the declassification of Geosat data for areas south of latitude 30° S. permitted scientists to view the fine-scale tectonic features of much of the world's gravity field, and hence the sea floor, for the first time because the inaccessible southern ocean has been only sparsely surveyed by ship. This mapping of the gravity field has resulted in numerous discoveries about the sea floor and underlying crust, and NOS has computed and distributed this gravity field to the public in the form of full-color posters and an atlas as well as digital data on CD-ROM.

Other Aeronautical and Space Activities

Discussions Concerning Arms Control of Space Related Weaponry

In FY 1993, the DoD established new priorities and related program decisions for its Ballistic Missile Defense (BMD) program. The highest priority became the development and deployment of Theater Missile Defense. The second priority became National Missile Defense for the U.S., which is oriented toward limited long-range ballistic missile threats to the U.S. that may emerge after the turn of the century. The focus of the second program is research and technology development, not deployment. The last priority became advanced follow-on BMD technologies. This is a research program directed toward the development of technologies offering promise for improved performance in both tactical and strategic defenses. Space-based interceptors are in this category. Consequently, the U.S. is no longer pursuing development and deployment of space-based missile defenses or a Global Protection Against Limited Strikes (GPALS) system.

The Clinton Administration has reaffirmed the U.S. commitment to the Anti-Ballistic Missile (ABM) Treaty. Additionally the administration announced on July 13, 1993, that the "narrow" or "traditional" interpretation of the ABM Treaty is the correct one, and therefore the ABM Treaty prohibits the development, testing, and deployment of sea-based, air-based, space-based, and mobile land-based ABM systems and components, without regard to the technology used. On October 1, 1993, at the conclusion of the Fourth ABM Treaty Review in Geneva, delegations of the Republic of Belarus, the Russian Federation, Ukraine, and the U.S. reaffirmed their commitment to the Treaty and agreed that it remained important to maintain its viability in view of political and technical changes. These developments further de-emphasized space-based ballistic missile defenses.

Russia, Ukraine, and Kazakhstan have all been considering converting some of their Intercontinental Ballistic Missiles (ICBMs) and Submarine-Launched

Ballistic Missiles (SLBMs), to be reduced under the Strategic Arms Reduction Treaty (START), to Space Launch Vehicles (SLVs) and then providing space launch services using such vehicles. On this issue, the U.S. must be assured that the START restrictions on such activities are adhered to. Moreover, START prohibits transfers of strategic offensive arms to third countries, and this prohibition extends to SLVs that are converted ICBMs or SLBMs. U.S. obligations under the Missile Technology Control Regime (MTCR) also apply with respect to transfers of hardware or technology to non-MTCR countries. Finally, the international marketing and sale of launch services using converted ICBMs and SLBMs must be regulated by the same civil space agreements that regulate civilian space launch systems. The U.S. has such a bilateral agreement with Russia providing, *inter alia*, that Russia will observe MTCR standards for future exports. The agreement will permit Russia to contract for up to eight launches into geosynchronous orbit between 1996 and 2000 (see below).

The MTCR continues to be the centerpiece of U.S. multilateral missile nonproliferation efforts. Originally, the MTCR controlled the export of hardware and technology that could contribute to missiles, SLVs, and unmanned air vehicles capable of delivering a payload of 500 kilograms to a range of 300 kilometers. The MTCR has recently been expanded in scope to cover delivery vehicles for all weapons of mass destruction (nuclear, chemical, and biological) and all systems intended for delivery of such weapons. The membership of the Regime has also expanded, now comprising 25 countries. Because the technology for developing an SLV is essentially identical to that for a ballistic missile, the MTCR requires members to control the export of such technology in the same way; only exports to programs judged not to contribute to systems capable of delivering weapons of mass destruction are acceptable under the MTCR.

FY 1993 saw the U.S. deeply involved in bilateral negotiations with countries engaged in missile proliferation. With the U.S. having imposed sanctions on entities in both Russia and India because of the transfer of Russian cryogenic rocket engines and related technology to the Indian Space Research Organization, the U.S. and Russia agreed in July 1993 that the U.S. would lift the sanctions in return for the essential termination of the transfers and Russian agreement to observe MTCR standards in future exports. At the same time, the U.S. took actions to allow Russia to compete for international commercial space launch contracts and to cooperate in the U.S. Space Station program. This opened the path for Russia to qualify for membership in the MTCR, an avowed objective of Russia and the MTCR partners. Relatedly, in response to the ongoing ballistic missile competition between India and Pakistan, the U.S. has undertaken a diplomatic initiative aimed at slowing and ultimately reversing the missile programs of both countries. Culminating years of U.S. diplomatic efforts, the Argentine government terminated the Condor II ballistic missile program. The government of South Africa terminated its missile-related SLV program, also after long negotiations with the U.S., thus placing itself on the path leading to MTCR membership—a goal the U.S. fully supports. By contrast, missile-related negotiations with China have been difficult and thus far, unsuccessful. Having lifted previous U.S. sanctions, imposed because of missile proliferation, in return for Chinese assurances that it would observe MTCR export standards, the U.S. again imposed sanctions because of growing evidence China was engaged in the transfer of M-11 missile technology to Pakistan, in violation of its pledge.

Cooperation with Russia

Concurrent with the Space Station redesign (discussed above), NASA and the Russian Space Agency (RSA) continued to study ways to increase Russian participation in the Space Station Program. In June 1992 the U.S. and Russia had signed a Space Cooperation Agreement that expanded cooperation in space activities between the two countries. Specifically, the agreement called for a Russian cosmonaut to participate in a U.S. Space Shuttle mission and for the Space Shuttle to make at least one rendezvous with Mir. In October 1992, NASA and the RSA concluded another agreement that began the implementation of that program. Cosmonauts Sergei Krikalev and Vladimir Titov arrived in November 1992 at the Johnson Space Center to begin their training as Space Shuttle flight mission specialists. Plans call for Krikalev to be a mission specialist on STS-60 in early 1994. Planning continued in FY 1993 for the flight of a U.S. astronaut on the Soyuz for a long-duration stay (more than 90 days) on the Russian Space Station Mir in 1995 and for a Shuttle rendezvous with Mir scheduled for June 1995. Meanwhile, NASA had also signed a study contract in June 1992 to investigate space systems and capabilities available in the Russian space program for potential application within the U.S. space program. This study, which continued into FY 1993, covered such areas as the use of Soyuz-TM as an interim Assured Crew Return Vehicle, automated rendezvous and docking, life sciences exchange, and other additional applications for Space Station.

NASA's cooperation with Russia became more focused when the two countries reached an understanding in July 1993 to "define and determine the feasibility of a cooperative human space flight program." To do this, a Russian Integration Team began operations in Crystal City, VA, with representatives from the RSA and NASA. The team worked toward two objectives—defining an interim program for use of Mir-1 and Space Shuttle before the Space Station becomes operational and conducting a "top level" Space Station study to determine how to add Russian capabilities to the Space Station. The Russian Integration Team completed its initial study on the addition of Russian capabilities to the Space Station on August 30, 1993, concluding that a combined Space Station with U.S., international partner, and Russian contributions was feasible and had attractive performance and program capabilities.

On September 2, 1992, Vice President Albert Gore, Jr., and Russian Prime Minister Victor Chernomyrdin signed a series of joint statements on cooperation in space, environmental observations/space science, commercial space launch, missile export controls, and aeronautical science. The joint statement on space cooperation specified that in pursuing potential cooperation with Russia, NASA would work with its current international partners and in accordance with existing international obligations. The space cooperation agreement called for proceeding in two phases—expanded Shuttle/Mir cooperation and then an interim human-tended space science capability, using an upgraded Mir module with a U.S. laboratory module and the U.S. Space Shuttle. In the first phase, Mir will be available for U.S. experiments including up to two years of "astronaut stay time." The second phase would allow significant scientific experimentation to take place in a microgravity environment while providing practical space operations experience that will be useful for Space Station operations. As the year ended, the Russian Integration Team continued to work on the details of these phases. The other agreements called for such things as the sharing of data from space for environmental monitoring and global change research; opening the commercial space launch market to Russia; promoting the nonproliferation of missiles; and cooperating on research in aeronautics. The two sides agreed to establish a framework for new collaboration in fundamental research, taking advantage of the complementary facilities and expertise in the U.S. and Russia. (For further details on these matters, see Appendix F-2.)

With regard to the commercial launch agreement, at the June 1992 summit between Presidents George Bush of the U.S. and Boris Yeltsin of Russia, the U.S. agreed to support the selection of a Russian launcher for the INMARSAT-3 satellite and to enter into negotiations on an agreement on commercial space launch that would allow future Russian launches of western spacecraft. Russian entry, with its major space launch capacity developed under the priorities of Soviet central planning and with no market-based notion of costs and prices, required a transition agreement limiting Russian activity in order to prevent undue disruption of normal competition among market-oriented western providers. Negotiations, led by the U.S. Trade Representative and the RSA, began in September 1992. After several rounds of talks, the two sides negotiated a final agreement that they initialled on July 6, 1993. Vice President Gore and Prime Minister Chernomyrdin formally signed it on September 2. The agreement established basic rules of the road for government involvement in the commercial space launch market regarding subsidies, marketing inducements, corrupt business practices, etc. These permit the Russians to contract with international customers for the launch of up to eight telecommunications satellites, in addition to INMARSAT-3, to geosynchronous Earth orbit between September 2, 1993, and December 31, 2000. Russia is also permitted three launches (of seven satellites each) to low Earth orbit for Motorola's Iridium system. Additionally, the U.S. agreed to consider Russian proposals for other launches to low

Earth orbit on a case-by-case basis as this uncertain market develops. The agreement also requires Russia to charge prices comparable to those in the west for similar services. In the mature and static market for launches to geosynchronous Earth orbit, a Russian bid more than 7.5 percent below the lowest western bid would trigger consultations where the Russians would be required to explain and justify such a bid.

Other Foreign Policy Issues

The Presidential decision to undertake a major redesign of the Space Station had significant implications for the International Partners in this important international cooperative undertaking. Growing concern about the uncertainty of Space Station's costs and the technical risks in its actual construction put the program in increasing danger of losing its domestic support in the U.S. At the same time, however, partner governments had committed some $8 billion to their contributions and had already spent $3.2 billion. Thus, they were not happy to learn in February 1993 of the U.S. decision to redesign the Space Station. Through a series of ad hoc meetings with representatives of the partner governments in Washington, the Department of State (DoS) took action to reassure the partners that their concerns and interests would be taken into account in the redesign process. One of the first results of this DoS involvement was the development of agreed ground rules for the redesign process so as to factor in the partners' concerns. To provide a political forum for these concerns to be addressed, DoS hosted two Intergovernmental Consultative Meetings in Washington on May 13 and June 11, 1993. The first meeting served to register at the political level the partners' interest in ensuring that the U.S.-initiated changes in the program not erode their own bases of domestic support for participation. The second provided the partners with an opportunity to make their views known on the three finalized options.

In June the President's decision directed NASA to refine the Option A scaled-down, modular approach and to explore the feasibility of involving the Russians in some aspects of the redesigned Space Station program, as already seen. As NASA's redesign team began intensified bilateral discussions to this end with the RSA, DoS undertook to assuage partner governments by making clear that the redesigned Space Station would proceed whether or not the Russians were involved; State also sought to persuade the partners of the political and technical merits of the Russian involvement. With the completion of the NASA-RSA study at the end of August, DoS instituted in concert with NASA an informal group where partner representatives could regularly make known their views on emerging issues. In September a State representative participated in a briefing in Paris to explain the U.S. views on Russian participation to partner government representatives. The success of this effort to improve consultation with the partners became evident shortly after the end of the fiscal year when, at the intergovernmental meeting in Paris on October 16, the partner governments agreed to explore collectively the idea of inviting the Russians into the partnership.

In other areas, the DoS led a U.S. delegation to the Second Space Conference of the Americas held in Santiago, Chile, April 26-30, 1993. The conference brought together policy makers and respected authorities in space research from the Western Hemisphere to consider opportunities for regional cooperation. It was a unique mix of representatives from space agencies, non-governmental organizations, and foreign ministries designed to take stock of the current state of cooperation and lay the foundation for a fuller understanding of the prospects for greater collaboration on a regional scale. The U.S. participated actively and was greatly impressed with the results. Of particular note was agreement by delegations on a U.S. proposal for expanding regional cooperation on the use of the international satellite-aided search and rescue system, COSPAS-SARSAT, which the U.S., France, Canada, and Russia operate collectively. (Statistics on COSPAS-SARSAT's rescues were not available on a fiscal year basis, but through the first week of December 1993, there had been 413 rescues through the system during the calendar year, bringing total rescues to that date up to 3,506 since the inception of the system in 1982.)

Also during 1993, the DoS supported seven separate Space Shuttle activities by providing a direct link to U.S. embassies in countries with emergency landing facilities. It negotiated the extension of a Space Tracking Agreement with Spain. Per Presidential directive, DoS created an interagency working group that reviewed the coverage of spacecraft and related components. Chaired by the DoS, the Space Technical Working Group (STWG) consisted of representatives from State, DoC, DoD, and other executive agencies. The group was established to identify and recommend removal from the U.S. Munitions List (USML) commercial satellites and related articles covered by the Coordinating Committee Industrial List (IL) except where such movement would jeopardize U.S. national security interests. In pursuing this objective, the STWG also sought to eliminate real and apparent overlaps between the USML and the Commodity Control List (CCL). The STWG developed language to capture all military GPS receivers on the USML; to transfer certain commercial communications satellites that do not possess characteristics requiring them to remain on the USML, from that list to the CCL; to transfer components, parts, accessories, and associated equipment for those satellites to the CCL; and to transfer passive, receive-only remote sensing ground stations to the CCL as well.

DoS also facilitated U.S. Government participation in international space science, satellite remote sensing, and related environmental applications programs. During the year the DoS coordinated interagency review of several agreements involving intellectual property, data management, export licensing, and bilateral regulatory issues. Of particular note was the conclusion of agreements with the European Organization for the Exploitation of Meteorological Satellites (EUMESAT) and the Mongolian government that established unique and precedent-setting cooperation in vital geostationary spacecraft system backup, global environmental monitoring, and international data management policy. The DoS also participated in interagency deliberations on the convergence of civil and military meteorological satellite systems, development of a Space-based Global Change Observing System to support the U.S. Global Change Research Program, licensing of private remote sensing systems, and planning for the future Landsat-7 program.

Following recommendations developed in FY 1992 for INTELSAT's Board of Governors and shepherded by DoS, DoC, and the FCC, the INTELSAT Assembly of Parties voted to relax and streamline procedures affecting private satellite competitors. Meeting in Sydney, Australia, November 3-6, 1992, the Assembly decided to give a presumptive favorable finding to all private systems except those carrying more than 1,250 circuits of public switched network (telephone and telegraph) per satellite. INTELSAT member countries are required by Article XIV(d) of the INTELSAT Agreement to consult with all other members before establishing any separate international satellite systems. On the heels of this U.S. policy success within the INTELSAT organization, the State Department's Bureau of International Communications and Information Policy and the Commerce Department's National Telecommunications and Information Administration jointly established a new private satellite policy to allow American licensees to have full advantage of the better international climate. In a January 8, 1993, letter the agencies told the FCC that private systems should be allowed to exploit fully the new opportunity to provide international telephone and telegraph services. The two U.S. companies with operating satellites, Pan American Satellite and Columbia Communications, were immediate beneficiaries of these improved international and domestic arrangements.

Recognizing the necessity of change in the face of growing competition, the INTELSAT Assembly also called for the establishment of a special working group to consider not only further revisions to Article XIV(d) procedures but also any other changes appropriate to ensure the health of INTELSAT. The working group held its first meeting in September 1993 and established an ambitious work program to consider a full range of options for the future of INTELSAT. Also, over the past year the INTELSAT Board of Governors has taken significant steps to improve opportunities for companies that are not signatories to the INTELSAT Operating Agreement to deal directly with INTELSAT headquarters in Washington for ordering service, billing, and investment. This was yet another step in transforming the organization into a more commercially responsive provider of facilities.

The Ninth Assembly of Parties of INMARSAT took place in Paris from October 5-8, 1993. The assembly accepted the recommendation of the Intersessional Working Group (IWG) on the Article 8 (separate systems approval) process. The IWG recommended that all applications for separate systems made between the Ninth Assembly and the next ordinary assembly in 1995 would be determined, *a* *priori*, to have no adverse economic impact on INMARSAT. The INMARSAT Council will continue to review issues of technical compatibility and could, if necessary, recommend that an extraordinary assembly be called to consider any case that might possibly cause significant economic harm. The assembly decided to constitute a new IWG to study further matters related to the financial structure of INMARSAT, including investment determination; matters relating to access to the system; and any proposed options for the future structure and status of the organization. The assembly requested that the council report its proposals on the adaptation of the structure of the organization to the future environment, including all the financial aspects, by the end of February 1994 and that the IWG report to the next session of the assembly with regard to the implementation of its recommendations.

Commercial Development and Regulation of Space Technology

To date, a total of 35 U.S. **Commercial Launches** of space vehicles has taken place. These and planned future activities reflect a growing and diverse commercial launch industry that includes the development of reentry vehicles, air-launched rockets, single-stage-to-orbit technology, and commercial launch sites. The industry is also beginning to develop voluntary standards to increase industry safety and competitiveness. According to the latest DoT Commercial Launch Manifest, issued by the Office of Commercial Space Transportation (OCST) in September 1993, more than 42 commercial launches are expected to take place in the next few years. In January 1993 OCST distributed its first Launch Forecast Report, which covers current and near-term worldwide launch events conducted by domestic and foreign launch firms. The report is scheduled to be published quarterly and will include U.S. commercial launches, government payload missions, and foreign commercial launches.

During FY 1993 the OCST had a total of nine commercial space transportation proposals in various stages of review. It issued two new licenses, conducted five determinations of maximum probable loss for insurance requirements, and participated in four failure investigations. These figures do not, however, provide a full or accurate picture of the changing nature and complexity of the commercial space transportation industry.

One instance of that change is Orbital Sciences Corporation's **Pegasus**, a launch vehicle capable of placing a variety of small payloads in orbit. The vehicle is first carried to an altitude of approximately 40,000 feet by a specially modified B-52 or civil L-1011 aircraft. The first commercial launch was of a satellite for Brazil, licensed in December 1992, using a B-52 carrier aircraft operated by NASA. The company is now modifying an L-1011 that it will operate under FAA jurisdiction. The licensing of this Pegasus/L-1011 combination has required OCST to develop close working relationships with other regulatory agencies that are not traditionally involved in commercial space activities, such as the FAA and the National Transportation Safety Board.

Another example of the commercial space industry's growth and diversity is Space Industries International's planned launch of the **"Freeflyer"** spacecraft developed under the NASA COMmercial Experiment Transporter (COMET) program. It will contain a number of experiments for industry and academic researchers and include a reentry vehicle capable of returning the experiments to Earth. The reentry system will use orbital information from the U.S. Space Command in CO and will land at the Utah Test and Training Range (UTTR). OCST is conducting both a Vehicle Safety Approval and an Operations Review in order to authorize this mission. The Freeflyer is to be launched on a Conestoga rocket in the first flight of this new launch vehicle developed by EER Systems Corporation.

OCST has begun discussions with industry representatives on single-stage-rocket-technology vehicles, the first of which is the one-third scale model of the **DC-X**, developed by McDonnell Douglas. If fully developed, the DC-X will be a completely reusable, one-stage launch system capable of placing people and payloads in orbit and returning them to Earth. Regulating this or other similar proposals requires OCST to continue refining its regulatory process.

OCST has participated in reviewing applications for a DoD grant program to improve the commercial space launch industry's infrastructure. Some of the grants will assist in efforts to create **Commercial Launch Sites** in FL, AK, CA, and NM. The OCST has encouraged and been active in this development. The state of Hawaii has issued a draft state Environmental Impact Statement (EIS) for a planned commercial launch site, and OCST has been involved with the development of Hawaii's Federal EIS. OCST also served as a cooperating agency for the site specific environmental assessment for the COMET Freeflyer recovery at the UTTR in 1994.

OCST has begun a program to encourage the commercial space industry to develop **Voluntary Standards**. Through the American Institute of Aeronautics and Astronautics, OCST sponsored a series of workshops to identify those areas where the development of voluntary industry standards offer the highest potential for ensuring public safety and enhancing international competitiveness. In addition, the Office joined with NASA and industry to fund a secretariat position in a new subcommittee for space in the International Standards Organization. The new group, known as SC-14, is charged with developing international standards for commercial space activity.

OCST also continued to conduct a comprehensive **Research Program** to respond to anticipated developments in commercial space transportation. This includes risk analyses and assessments, the development of risk management strategies and options, the development of licensing procedures and standards for new space vehicles and activities, and the evaluation of factors that affect risks in space and their relationship to design and operational practices.

OCST participates in the National Security Council's **Task Force on Cooperation with the Russians.** It was originally established to assist with the U.S./Russia Summit, held in Vancouver in April 1993. OCST developed market data for the Task Force to use at the Vancouver Summit and for the Gore/Chernomyrdin meeting. OCST will continue to work with this Task Force as it develops joint U.S./Russian projects in science and technology and supports the Joint Commission on Energy and Space.

In addition, OCST served as a member of the U.S. interagency negotiating team, led by the Office of the U.S. Trade Representative (USTR), for the development of the **U.S./Russia Space Launch Trade Agreement.** During the negotiating period, OCST took part in preliminary discussions with the Russians regarding their entry into the international commercial launch market; provided market analyses and statistics on the impact of Russian entry into the market; and assisted with the drafting of the text of the agreement. As discussed above, Vice President Gore and Russian Prime Minister Chernomyrdin signed the agreement on September 2, 1993, during the historical two-day meeting of the U.S.-Russian Joint Commission on Energy and Space. OCST, along with the interagency community, will continue its work in this area by monitoring Russia's compliance with the provisions outlined in the agreement.

DoC's Office of Air and Space Commercialization (OASC) was also involved in the development of the agreement. OASC coordinated DoC's review of the document, and before it was signed, the office worked closely with the USTR and other government agencies to negotiate the terms of the agreement. The office also met with U.S. industry representatives to discuss ideas and concerns regarding the structure of the agreement. Moreover, OASC served as a member of the interagency working group that prepared the agenda for the September 1-2, 1993, meeting of the Joint Commission on Economic and Technology Cooperation, chaired by Vice President Gore and Prime Minister Chernomyrdin. OASC representatives attended the second day of the meeting, which was dedicated to discussions of U.S.-Russian space cooperation and the signing of the agreements already discussed. OASC, along with NOAA, continued to represent the DoC as a member of the Secretariat Working Group on Science, Environment and Space, the formation of which resulted from the September meeting.

OCST, meanwhile, has also been working with other Federal agencies on the **U.S./People's Republic of China (PRC) Memorandum of Agreement** (MOA) Regarding International Trade in Commercial Launch Services. OCST carries out DoT's responsibility as the chair agency of the Interagency Working Group on Information, which collects, analyzes, and provides information needed to monitor the compliance of the PRC with the terms and conditions of the MOA.

OCST is also a participant in the **National Facilities Study**, led by NASA and the DoD and concerned with ways of improving the infrastructure for the nation's space launch facilities. To further support the development of new space launch infrastructure or improvement of existing facilities, in January 1993 OCST completed and distributed a report entitled *United States Commercial Space Transportation Infrastructure and Long-Term Financing Plan.*

To return to OASC, that office worked closely with members of the GPS community concerning the announcement by the Secretary of Commerce and the President of Magellan Systems Corp. of a joint venture between the CA-based firm and a consortium of three major Japanese companies. The goal of the arrangement is to produce an on-board navigational system for Japanese automobiles using **GPS** technology so as to capture a market that could exceed $5 billion annually by the end of this decade.

OASC has been working with other agencies to generate a consistent Government policy towards medium-resolution commercial **Remote Sensing**. The goal is to encourage the growth of the U.S. remote sensing industry while preserving U.S. national security interests. OASC has met with representatives of numerous remote sensing firms both in meetings and at conferences to discuss their business needs and concerns regarding a comprehensive U.S. Government policy. OASC also assisted with preparing testimony for DoC's Under Secretary for Oceans and Atmosphere (NOAA) to use in a recent appearance at a Senate Intelligence Committee hearing on commercial remote sensing.

Additionally, OASC has participated in discussions with NASA on the commercial implications of the joint U.S.-Russian Space Station program discussed above. It has sponsored briefings to the DoC by NASA officials who are exploring ways to build a next-generation commercial space station, a project that could result in closer NASA-DoC technical partnership. OASC has initiated an informal DoC-NASA working group to cooperate further on **Commercial Space Issues.**

Finally, OASC has been participating in an effort led by the OSTP and involving numerous Government agencies, as well as U.S. industry, to strengthen U.S. capabilities with the improvement of commercial space infrastructures and the possible development of a next-generation **Commercial Launch Vehicle.**

In a totally separate development related to space commercialization and regulation, in May 1993 the **FCC** granted PanAmSat, operator of the first Separate International Satellite System of the U.S., conditional authority to construct a second and third hybrid (C- and Ku-band) Separate International Communications Satellite System for operation at orbital locations 43° West and 169° East longitudes. Relatedly, in July 1993 the FCC completed two consultations with INTELSAT according to Article XIV(d) of the INTELSAT agreement. The first concerned the PanAmSat system at 169° East longitude, scheduled for launch in May 1994. The second consultation, for the Orion Satellite Corporation whose satellites are intended for orbital positions at 47° and 37.5° West longitudes, updated an earlier consultation required because of technical modifications made to the Orion satellites.

NASA, too, was heavily involved in the commercial development of space technology through its Office of Advanced Concepts & Technology (OACT) established in October 1992 by a merger of the Office of Commercial Programs and the Space Technology Directorate. A focus of NASA's commercial space initiatives continued to be its **Centers for the Commercial Development of Space** (CCDSs). Located across the nation, these 17 centers sought to increase U.S. industry's involvement and investment in space-related enterprises. Examples of the CCDSs' efforts to identify and capitalize on the real possibilities of space-related commerce appear below.

In the general category of **Protein Crystallography**, after 16 research flights on the Space Shuttle and extensive ground research the Center for Macromolecular Crystallography (CMC) at the University of Alabama at Birmingham, a NASA CCDS, has developed the world's largest database on the subject. Working with industry, NASA, Government laboratories, and other academic research institutions, the CMC strives to reduce costs and risks associated with space-based protein crystal growth, biomedical research, and drug design/development. Current commercial research in this area could lead to a new generation of drugs, potentially used to help treat cancer, rheumatoid arthritis, periodontal disease, influenza, septic shock, emphysema, and AIDS.

Preparations have made substantial progress for the first flight of the **Wake Shield Facility** on STS-60 in January 1994. It will become the first commercial production facility to manufacture extremely pure materials in low Earth orbit. The facility is essentially a 12-foot stainless steel disk with four attachment points for small payloads. It will trail 40 miles behind the Shuttle for two days of free flight, be retrieved, and return to Earth. The Space Vacuum Epitaxy CCDS at the University of Houston and Space Industries, Inc. of League City, TX, conceived and built it for approximately one-sixth of the cost that traditional aerospace hardware development programs would have incurred.

During FY 1993, NASA made several advances and documented a number of successful cooperative initiatives in commercial applications of **Remote Sensing** technologies. NASA's Earth Observation Commercial Applications Program continues to produce valuable spinoffs of these technologies into the private sector to improve public service and enhance U.S. competitiveness. Two of NASA's CCDSs also work toward similar goals in the field of remote sensing. Among the many notable achievements were the testing by NASA and two companies of the ability of NASA's satellite remote sensing to survey a wide ocean area off the West Coast in order to pinpoint vessel location, direction, and speed. This application can enhance the efficiency of law enforcement efforts and may also be used to address ship safety or to provide near real-time fisheries monitoring. On land, a NASA-sponsored team developed a faster, cheaper way to update regional land-use information, which is expected to save urban planners and map makers a lot of time and money as well as provide them with more accurate information about an area's resources. The team developed a unique GIS that provides information about a region's population distribution and many other features vital to research planners in rapidly growing regions. Potential applications range widely from market research to insurance risk assessment. Finally, NASA's Ames Research Center used aerial and satellite images to help CA wine growers battle a serious insect problem facing the state's $10 billion-a-year wine industry. Sensitive electronic scanners on aircraft and satellites helped a team of government, industry, and universities map and analyze phylloxera (root louse) damage in northern CA. These scanners can detect plant stress before it is visible to the naked eye, aiding vintners to develop plans for replanting.

June 1993 saw the maiden flight of the **Spacehab** module in the cargo bay of Space Shuttle Endeavour. Privately funded and developed by SPACEHAB, Inc. of Arlington, VA, the module provides an additional 1,100 cubic feet of pressurized experimental space on the Shuttle, quadrupling the available working and storage volume. The first flight carried 15 commercial experiments. Four of NASA's CCDSs and the Johnson Space Center collaborated with 24 industry affiliates to perform biotechnology experiments. Four other CCDSs and NASA's Langley Research Center collaborated with 11 industrial partners to perform experiments in materials science. Many of Spacehab-01 investigators will continue their research on subsequent Spacehab flights, the next of which is scheduled for January 1994.

A key mechanism in transferring Federal technology to the private sector is the national network of technology transfer centers sponsored by NASA in cooperation with other Federal agencies. The network's core structure includes six **Regional Technology Transfer Centers** (RTTCs) located throughout the country and the National Technology Transfer Center (NTTC) in Wheeling, WV. The RTTCs have recently developed regional networks that involve more than 70 affiliated organizations operating at the state and local levels. During their first full year of operation (January-December 1992), the RTTCs provided services to more than 2,500 private sector clients. To boost awareness of these opportunities, the Ohio Department of Development and NASA's Great Lakes Industrial Technology Center (GLITeC) in Cleveland initiated a minority enterprise called TECHSHARE, which began in April 1993 to inform minority- and women-owned companies in Ohio about available sources of Federal technology, reaching more than 125 such businesses. Recognizing the importance of commercializing invention, GLITeC and NASA's Lewis Research Center (LeRC) engaged students from diverse fields to evaluate the technical and commercial feasibility of LeRC technology. Under this Student Technology Evaluation Program, graduate students from Case Western Reserve University worked with 90 patents and 30 disclosures, completing detailed market opportunity analyses for 40 of them. They identified 9 companies interested in pursuing licensing agreements with LeRC, 28 interested in an Advanced Coatings Consortium, and 11 interested in on-going technology transfer relationships with LeRC. Relatedly, OACT began a three-year technology commercialization experiment in February 1993 by funding two Technology Commercialization Centers, one at Ames and the other at Johnson Space Center in an effort to foster new industry and create new jobs.

During 1993 the **NTTC** designed a new, on-line electronic bulletin board to enhance its current gateway service. Called Business Gold-NTTC Online, it will begin operating in early 1994, featuring a comprehensive directory of Federal Research and Development laboratories and highlighting Federal technologies available for commercialization. This augmented the NTTC's toll-free information gateway (800/678-NTTC), which allows companies to access technologies and expertise from more than 700 Federal laboratories nationwide.

The nation's top technology managers gathered in Baltimore, MD, in December 1992 at **Technology 2002**, the third national technology transfer conference and exposition. Sponsored by NASA, *NASA Tech Briefs* magazine, and the Technology Utilization Foundation, the conference featured more than 120 presentations and 250 exhibitors. Two other conferences, the President's National Technology Initiative and the MIT Entrepreneurial Technology Transfer Conference coincided with Tech 2002 in Baltimore, attracting over 6,000 attendees and over 130 media representatives.

NASA has also joined forces with the NSF, ARPA, DoE's Defense Programs, DoT, and NIST to manage the **Technology Reinvestment Project**. Announced by President Clinton in March 1993, this is a $472-million effort to help U.S. industry respond to the twin challenges posed by decreased defense spending and increased global economic competition. One thrust of the project is to reorient the military/industrial base toward dual-use technologies, processes, and products. Companies, state and local governments submitted 2,800 proposals to the project during a two-month solicitation period ending in late July. Generally, proposals had to include provision for commercial application of the technology and for the company to provide at least 50 percent of the funding.

In another project, the **Small Business Innovation Research Program** (SBIR), NASA sought to stimulate technological innovation in the U.S. by using small, minority, and disadvantaged firms to help meet Federal research and development needs and to encourage commercial applications of federally supported research innovations. As required by law, NASA allocated 1.5 percent of its FY 1993 extramural research and development budget to fund SBIR. In November and December 1992, NASA selected 348 research proposals for negotiation of Phase I contracts to establish the feasibility of research and development concepts. In January 1993, the agency announced the selection of 38 Phase II proposals for further development, with a total value in contract awards of about $19 million. An example of a success story from NASA's SBIR program was the Glasair II kit-built general aviation aircraft made of composite materials, the first such aircraft that has verified lightning protection.

Space Education and Publicity

Throughout FY 1992 many Government agencies engaged actively in educating the American people about space-related developments, in publicizing them both in the U.S. and abroad, and in using their resources to improve American education. The **Federal Coordinating Council for Science, Engineering, and Technology's Committee on Education and Human Resources** focussed the programs of 16 participating Federal agencies, including NASA, on improving primary and secondary teaching and learning in mathematics, science, history, and geography; on helping teach students to use their minds effectively; and on ensuring that every American would gain the knowledge and skills necessary to compete in the global economy and to be an effective citizen.

NASA has responded to the country's increased attention to education with enthusiasm. Born during the Mercury, Gemini, and Apollo years, NASA's continuing educations efforts used the agency's mission to support the national education reform movement with programs extending from grade school to graduate school. A wide array of elementary and secondary programs seeks to foster systemic and permanent change in educational programs in science, mathematics, and technology, targeting students, teachers, and administrators. A variety of programs in higher education supports faculty preparation and enhancement while providing undergraduate and graduate opportunities through active involvement in NASA research. These include the Aerospace Education Services program, the National Space Grant College and Fellowship Program, the Teacher Resource Center Network, and the Spacelink computer information service. Finally, NASA has fostered educational partnerships with other educational, industrial, and nonprofit organizations and associations such as Space Camp, the Challenger Centers, and the National Science Teachers Association.

Similarly, NOAA's efforts to increase educational outreach through applying the capabilities of **CoastWatch to Schools** (kindergarten through 12th grade and undergraduate) have included teacher workshops, a network of active teachers similar to the one used by the American Meteorological Society, CoastWatch participation in pertinent national and regional educational conferences, formal teacher training programs, and use of the well-developed marine education capability in the Sea Grant system. The Great Lakes Environmental Research Laboratory (GLERL) will be working with the Environmental Research Institute of Michigan (ERIM) to make Great Lakes CoastWatch near real-time, high resolution satellite data available for K-12 classroom educational projects and teaching materials through the NASA- and NOAA-funded Space Technology Education Program implemented at ERIM. In addition, NOAA's National Geophysical Data Center's Global Change Data Base includes the Global Change Educational Diskette Project. This product combines environmental data for Africa with extensive documentation, plus a training exercise manual designed for schools and for self-teaching of the use of GISs to explore regional environments. The product contains both satellite-derived and ground-based data.

Along the same lines, the **OCST Program Affairs Division** continued its outreach program to expand public understanding of the commercial space transportation industry and its growing importance as a national asset and component of international competitiveness. It also worked with the legislative branch to increase knowledge of this newest transportation mode among members of Congress. Also during FY 1993, OCST participated with the Aerospace States Association and Spaceport Florida Authority in the first "Rockets for Schools" program, under which high school students from across the country were brought to Florida to learn of careers in commercial space industry while participating in a variety of space related activities, including the launch of an actual scientific research rocket. The program aimed at increasing participation in science and math courses, particularly among women and minority students.

While these and similar programs were working to improve education in the U.S., the United States Information Agency (USIA) informed audiences abroad of American achievements in space and used NASA innovations to further public diplomacy around the world. The global radio network **Voice of America** (VoA) covered the space program in news stories, correspondent reports, special features, and documentaries broadcast in 48 languages. Each Space Shuttle mission was reported from Cape Canaveral, and VoA examined planetary probes from Washington or the NASA sites responsible for them. Science writers attended NASA briefings at Goddard Spaceflight Center in MD and Johnson Space Center in TX to prepare for the Hubble Space Telescope repair mission. NASA's Jet Propulsion Laboratory in CA and the VoA entered into a joint venture to develop the prototype of a receiver for a digital audio broadcast and began transmitting digital audio services to South America and Europe to enhance signal quality. In a historic agreement, USIA implemented a new digital audio service via INTERSPUTNIK, the Russian satellite system. The new service provides VoA and Radio Liberty programs to Russia and other states formerly part of the Soviet system.

USIA's **Worldnet** television service offered numerous programs on NASA and the U.S. space effort, including 6 interactive dialogues, 86 newsfile stories, 7 TV satellite file pieces, 13 science world features, and 32 newly acquired video programs. Interactive dialogues included discussions on women in space, Spacehab, and science education, with astronaut Dr. Ellen Ochoa and journalists in Caracas, Venezuela. Dr. Ochoa was also the guest on a telepress conference with journalists in Rio de Janeiro, Brazil.

The Wireless File of USIA continued to provide **News Articles** for placement in local publications around the world. Highlights of the approximately 40 included NASA articles covered all seven Space Shuttle missions in FY 1993, the Magellan spacecraft, and the latest news on the reduced-cost Space Station. Also, USIA's regional magazines featured stories relating NASA activities to their particular audiences. *Topic* magazine, produced in French and English for African readers, told for example of Astronaut Frederick Gregory's visit to Africa. *America Illustrated*, reaching readers in Russia and the surrounding region, carried items on Hubble Space Telescope, a new archive for NASA's space films, and the search for extraterrestrial intelligence. Relatedly, Moon rock samples continued to be popular attractions around the world. In FY 1993 seven showings of Moon rocks in four countries drew more than 200,000 visitors.

APPENDIXES

Appendix A-1

U.S. Government Spacecraft Record

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

Calendar Year	Earth Orbit[a]		Earth Escape[a]	
	Success	Failure	Success	Failure
1957	0	1	0	0
1958	5	8	0	4
1959	9	9	1	2
1960	16	12	1	2
1961	35	12	0	2
1962	55	12	4	1
1963	62	11	0	0
1964	69	8	4	0
1965	93	7	4	1
1966	94	12	7	1[b]
1967	78	4	10	0
1968	61	15	3	0
1969	58	1	8	1
1970	36	1	3	0
1971	45	2	8	1
1972	33	2	8	0
1973	23	2	3	0
1974	27	2	1	0
1975	30	4	4	0
1976	33	0	1	0
1977	27	2	2	0
1978	34	2	7	0
1979	18	0	0	0
1980	16	4	0	0
1981	20	1	0	0
1982	21	0	0	0
1983	31	0	0	0
1984	35	3	0	0
1985	37	1	0	0
1986	11	4	0	0
1987	9	1	0	0
1988	16	1	0	0
1989	24	0	2	0
1990	40	0	1	0
1991	32[c]	0	0	0
1992	26[c]	0	1	0
1993 *(through September 30)*	24[c]	0	0	0
TOTAL	1,283	144	83	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, as on Feb. 9, 1993, when a single Pegasus launch vehicle placed two satellites in orbit. (See Appn. A-3.)

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	13[c]	62			2	1			9	1	
1992	25[c]	55			2	3			5[b]	2	
TOTAL	961	2,373	10	8	45	32[d]	1[d]	1	49	6	2
1993 *(through Sept. 30)*	17[c]	38			1				4[d]		
TOTAL	978	2,411	10	8	46	32[d]	1[d]	1	53	6	2

[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 excludes commercial expendable launches.

[d] The Weekly Satellite Situation Report for Aug. 20, 1992, incorrectly listed a Chinese launch of an Australian satellite (AUSSAT B1 on Aug. 13) as an Australian launch. This error was repeated in last year's appendix but is corrected here. Similarly corrected are erroneous entries in last year's appendix of Canadian and Indonesian satellites as launches by those countries.

APPENDIX A-3

Successful U.S. Launches

October 1, 1992–September 30, 1993

Launch Date (GMT). Spacecraft Name, COSPAR Designation, Launch Vehicle	Mission Objectives, Spacecraft Data	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
Oct. 12 DFS-3 66A Delta II	*Objective:* To provide televsion, radio, and data communication services throughout Germany. *Spacecraft:* Kopernikus	35,832.0 35,738.0 1,436.1 0.0	Launched by McDonnell Douglas for Germany. In geosynchronous orbit.
Oct. 22 Space Shuttle Columbia (STS-52) 70A	*Objective:* To study the influence of gravity on basic fluid and solidification processes using U.S. Microgravity Payload (USMP)-1 and to deploy the second Laser Geodynamics Satellite (LAGEOS II) to measure the Earth's crustal movement plus nine secondary payloads in an international mission with cooperative efforts between NASA and the French, Italian, and Canadian space programs as well as the European Space Agency (ESA). *Spacecraft:* Shuttle orbiter carrying the experiments listed above.	299.0 290.0 90.4 28.4	Fifty-first flight of Space Transportation System (STS). Piloted by James D. Wetherbee and Michael A. Baker. Mission Specialists Charles L. Veach, William M. Shepherd Tamara E. Jernigan. Payload Specialist Steven G. MacLean. Launched from KSC, 1:09 p.m. EDT. Landed at KSC, 9:05 a.m. EST, Nov. 1. Mission duration: 9 days, 20 hours, 57 minutes.
Oct. 23 LAGEOS II 70B	*Objective:* To measure regional crustal deformation, improve geodetic reference datum and Earth orientation, measure secular variation in Earth's gravitational field and wandering of Earth's polar axis plus variations in Earth rotation. *Spacecraft:* No moving parts, designed for use as a target for laser ranging from 65 sites around the world, operated by 30 countries.	5,951.0 5,616.0 222.5 52.7	In a joint NASA and Italian Space Agency mission, the passive satellite was successfully launched from Columbia at 9:56 a.m. EDT. In orbit.
Oct. 31 CTA 70C	*Objectives:* To test the Canadian Space Vision System, itself designed to enhance human vision in connection with operation of the Canada arm, by taking it through a series of maneuvers, and then to release and track the Canadian Target Assembly (CTA) in space using the Space Vision System. *Spacecraft:* A small satellite.	243.0 164.0 88.4 28.4	Released from Columbia and tracked on Oct. 31. Reentered the atmosphere and burned up Nov. 1.
Nov. 21 MSTI-1 78A Scout	*Objective:* To demonstrate low-cost, light-weight modular test bed for Miniature Seeker and Sensor technologies. *Spacecraft:* Miniature Seeker Technology Integration-1	446.0 341.0 92.2 96.7	Launched into sun-synchronous orbit by NASA for the DoD at Vandenberg AFB. Remained in orbit until Jul. 18, 1993.
Nov. 22 GPS 79A Delta II	*Objective:* To provide radio positioning and navigation, including position, velocity, and timing data to the DoD and civilian users. *Spacecraft:* A Block II satellite in the NAVSTAR Global Positioning System.	20,251.0 18,341.0 681.4 53.5	Sixteenth in a series of operational GPS satellites. System expected to be composed of 24 satellites in inclined, semi-synchronous orbit. In orbit.
Nov. 28 USA 86 83A Titan IV	*Objective:* To deliver a classified payload into orbit. *Spacecraft:* Not announced.	Not available	Launched from Vandenberg AFB, CA. In orbit.

Successful U.S. Launches

October 1, 1992–September 30, 1993

Launch Date (GMT). Spacecraft Name, COSPAR Designation, Launch Vehicle	Mission Objectives, Spacecraft Data	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
Dec. 2 Space Shuttle Discovery (STS-53) 86A	*Objective:* To deploy the last major DoD classified payload currently planned for the Shuttle fleet. Secondary objectives include ten different payloads including Space Tissue Loss (STL) and Battlefield Laser Acquisition Sensor Test (BLAST). *Spacecraft:* Shuttle orbiter with 13 detailed test objectives and 12 detailed supplementary objectives.	381.0 372.0 92.0 57.0	Fifty-second STS flight. Piloted by David M. Walker and Robert D. Cabana. Mission Specialists Guion S. Bluford, Jr., James S. Voss, and Michael Richard Clifford. Launched from KSC at 8:24 a.m. EST. Landed at Edwards AFB, CA, 3:43 p.m. EST Dec. 9. Mission duration: 7 days, 7 hrs., 19 min.
Dec. 2 DoD 1 USA 89 86B	*Objectives:* To deliver a classifed payload into orbit. *Spacecraft:* Deployable spacecraft and associated airborne deployment system.	Not available	Launched from Discovery, 9th dedicated DoD Shuttle mission. In orbit.
Dec. 18 GPS USA 87 89A Delta II	*Objective:* To provide radio positioning and navigation, including position, velocity, and timing data to the DoD and civilian users. *Spacecraft:* A Block II satellite in the NAVSTAR Global Positioning System.	20,323.0 20,039.0 718.0 54.7	Seventeenth in a series of operational GPS satellites. System expected to be composed of 24 satellites in inclined, semi-synchronous orbit. In orbit.
Jan. 13 Space Shuttle Endeavour (STS-54) 3A	*Objective:* To deploy Tracking and Data Relay Satellite (TDRS)-6 and operate the Diffused X-ray Spectrometer Hitchhiker experiment to collect data on stars and the surrounding galactic gases. Other objectives included the second Physiological and Anatomical Rodent Experiment (PARE-2), a Solid Surface Combustion Experiment, and the second group of Physics of Toys experiments to be broadcast to classrooms throughout the nation. *Spacecraft:* Shuttle orbiter with above experiments and equipment.	307.0 302.0 90.6 28.4	Fifty-third STS flight. Piloted by John H. Casper and Donald R. McMonagle. Mission Specialists Gregory J. Harbaugh, J. Harbaugh, Mario Runco Jr., and Susan J. Helms. Launch from KSC 8:59 a.m. EST. Landed at KSC 8:38 a.m. EST. Jan. 20. Mission duration: 6 days, 23 hrs., 39 min.
Jan. 13 TDRS-6 3B	*Objective:* To launch the sixth in a series of communication satellites in the Tracking and Data Relay Satellite System (TDRSS) to provide communications with the Space Shuttle and other spacecraft in low-Earth orbit. *Spacecraft:* Satellite equipped with two solar arrays, two single access antennae, a C-band antenna, a K-band antenna, and an omni antenna.	35,708.0 35,704.0 1,431.9 0.5	Designated TDRS F until in orbit, following release from Endeavour's cargo bay, on Jan. 14 it reached its initial destination following two successfult booser firings of the inertial upper stage. In orbit.
Feb. 3 GPS USA 88 7A Delta II	*Objective:* To provide radio positioning and navigation, including position, velocity, and timing data to the DoD and civilian users. *Spacecraft:* A Block II satellite in the NAVSTAR Global Positioning System.	20,359.0 20,005.0 718.0 54.8	Eighteenth in a series of operational GPS satellites. System expected to be composed of 24 satellites in inclined, semi-synchronous orbit. In orbit.

APPENDIX A-3

(continued)

Successful U.S. Launches

October 1, 1992–September 30, 1993

Launch Date (GMT). Spacecraft Name, COSPAR Designation, Launch Vehicle	Mission Objectives, Spacecraft Data	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
Feb. 9 OXP-1 9A Pegasus	*Objective:* To demonstrate new, commercial, global, mobile communications from low-Earth orbit. *Spacecraft:* An experimental, demonstration satellite weighing about 32 lbs., the size of a large briefcase, for transmitting brief messages with hand-held communicators.	794.0 732.0 100.1 25.0	Launched by Pegasus rocket, carried to 40,000 feet for release and first-stage motor ignition in a NASA B-52, which had taken off from KSC. In orbit.
Feb. 9 SCD 1 9B Pegasus	*Objective:* To monitor cloud cover, rainfall, flood and tide levels, and air quality over Brazil. *Spacecraft:* Satelite de Coleta de Dados (SCD), a remote, sensing spacecraft that collects environmental data from ground sensors in the Amazon River Basin.	793.0 729.0 100.1 25.0	Launched by Pegasus rocket, carried to 40,000 feet for release and first-stage motor ignition in a NASA B-52, which had taken off from KSC. In orbit.
Mar. 25 UFO-1 15A Atlas-Centaur I	*Objective:* To provide communications and UHF links for the U.S. Navy, Strategic Command, and Army/Marine Rapid Deployment Forces. *Spacecraft:* A 6,319-pound satellite with a planned lifetime of 14 years and greater communications capacity than the Navy's current communications spacecraft.	36,108.0 36,041.0 1,450.9 27.1	Because of malfunction of the Atlas stage, the satellite went into lower orbit than required. With insufficient fuel to move it to operational orbit, the Navy moved it above geosynchronous altitude and declared it a total loss. In orbit.
Mar. 30 GPS USA 90 17A Delta II	*Objective:* To provide radio positioning and navigation, including position, velocity, and timing data to the DoD and civilian users. *Spacecraft:* A Block II satellite in the NAVSTAR Global Positioning System.	20,292.0 20,073.0 718.0 55.0	Nineteenth in a series of operational GPS satellites. System expected to be composed of 24 satellites in inclined, semi-synchronous orbit. In orbit.
Mar. 30 SEDS I 17B Delta II	*Objective:* To allow scientists to compare data on actual tether dynamics with computer models of predicted behavior. *Spacecraft:* The Small Expendable Tether Deployable System (SEDS I), an 85-pound satellite attached by a 20-kilometer-long flexible cable to the Delta's second-stage.	Elements not available	During the 80-minute deployment, the entire length of tether slowly unreeled until the payload began swinging like a pendulum. Once it ceased swinging and came to a vertical position, it was severed and allowed to burn up as it reentered the Earth's atmosphere.
Apr. 8 Space Shuttle Discovery (STS-56) 23A	*Objective:* To provide the orbiter Discovery and the Spacelab pallet as a platform for experiements on the Atmospheric Laboratory for Applications and Science (ATLAS) payload, to monitor global ozone with the Shuttle Solar Backscatter Ultraviolet instruments, and to study the solar wind and the sun's corona, among other purposes. *Spacecraft:* Shuttle orbiter featuring 12 development test objectives and 15 detailed supplemental objectives.	307.0 295.0 90.5 57.0	Fifty-fourth STS flight. Pilot by Kenneth D. Cameron and Stephens S. Oswald. Payload Commander C. Michael Foale. Mission Specialists Kenneth D. Cockerell and Ellen Ochoa. Launched from KSC 1:29 a.m. EDT. Landed at KSC 7:37 a.m. Apr. 17. Mission duration: 9 days, 6 hrs., 9 min.

APPENDIX A-3

(continued)

Successful U.S. Launches

October 1, 1992–September 30, 1993

Launch Date (GMT). Spacecraft Name, COSPAR Designation, Launch Vehicle	Mission Objectives, Spacecraft Data	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
Apr. 11 SPARTAN-201 23B	*Obejctive:* To study the velocity and acceleration of the solar wind and observe aspects of the sun's corona. *Spacecraft:* Shuttle Point Autonomous Research Tool for Astronomy (SPARTAN-201), a free-flying payload with two telescopes, the White Light Coronagraph (WLC) and the Ultraviolet Coronal Spectrometer (UVCS).	311.0 295.0 90.3 57.0	Astronauts released the Spartan instruments platform from Discovery at 2:11 a.m. EDT and recovered it between 3:20 a.m. and 4:02 a.m. EDT on Apr. 13.
Apr. 25 ALEXIS 26A Pegasus	*Objective:* To test technology for detecting ultra-soft x-rays emitted from space nuclear testing and to examine ionospheric distortion of VHF radio signals. *Spacecraft:* Array of Low Energy X-ray Imaging Sensors (ALEXIS) Spacecraft, featuring a smaller, faster, and cheaper spacecraft bus, x-ray detectors, and a very high frequency receiver and digitizer.	844.0 749.0 99.6 70.0	First such flight of an all-DoE sponsored satellite. It cost $17 million for the satellite and its integrated components. In orbit.
Apr. 26 Space Shuttle Columbia (STS-55) 27A	*Objective:* To launch, operate, and return Spacelab D-2, a German-sponsored payload for conducting microgravity research, to Earth. *Spacecraft:* Shuttle orbiter featuring a Spacelab long module with transfer tunnel, a unique support structure for mounting experiments outside the module, and the autonomous payload, Reaction Kinetics in Glass Melts—all to investigation material and life sciences, space technology, automation, and robotics. Secondary objective: Shuttle Amateur Radio Experiement II.	306.0 298.0 90.5 28.4	Fifty-fifth STS flight. Piloted by Steven R. Nagel and Terence T. Henricks. Mission Specialists Jerry L. Ross, Charles J. Precourt, Bernard A. Harris, Jr. Payload Specialists Ulrich Walter and Hans Schlegel. Launched from KSC 10:50 a.m. EDT. Landed at EAFB, CA., 10:29 a.m. EDT May 6. Mission duration: 9 days, 23 hrs., 39 min.
May 13 GPS USA 91 32A Delta II	*Objective:* To provide radio positioning and navigation, including position, velocity, and timing data to the DoD and civilian users. *Spacecraft:* A Block II satellite in the NAVSTAR Global Positioning System.	20,342.0 20,020.0 717.9 55.0	Twentieth in a series of operational GPS satellites. System expected to be composed of 24 satellites in inclined, semi-synchronous orbit. In orbit.
Jun. 21 Space Shuttle Endeavour (STS-57) 37A	*Objective:* To provide a platform for experiments on the SPACEHAB 1 payload and to retrieve the ESA's European Retrievable Carrier satellite deployed from Atlantis Aug. 2, 1992. There were also 7 secondary objectives, 16 developmental test objectives, and 11 detailed supplemental objectives. *Spacecraft:* Shuttle orbiter featuring SPACEHAB, a commercially developed, pressurized module that provides about 1,100 cu. ft. of additional pressurized volume to the Shuttle's habitable working space and supports primarily orbiter middeck-type experiments.	483.0 407.0 93.5 28.4	Fifty-sixth STS flight. Piloted by Ronald J. Grabe and Brian J. Duffy. Mission Specialists G. David Low, Nancy J. Sherlock, Peter J. K. Wisoff, and Janice E. Voss. Launched from KSC 9:07 a.m. EDT. Recovered Eureca at 12:36 p.m. EDT Jun. 24. Landed at KSC 8:52 a.m. EDT Jul. 1. Mission duration: 9 days, 23 hrs., 46 min.
Jun. 25 RADCAL 41A Scout	*Objective:* To provide space-based radar calibration for over 70 ground-based radars and to verify GPS use for satellite positioning. *Spacecraft:* Radar Calibration (RADCAL) experiment.	883.0 752.0 101.3 89.6	Twenty-second consecutive successful Scout launch. In orbit.

APPENDIX A-3

(continued)

Successful U.S. Launches

October 1, 1992–September 30, 1993

Launch Date (GMT). Spacecraft Name, COSPAR Designation, Launch Vehicle	Mission Objectives, Spacecraft Data	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
Jun. 26 GPS USA 92 42A Delta II	*Objective:* To provide radio positioning and navigation, includin position, velocity, and timing data to the DoD and civilian users. *Spacecraft:* A Block II satellite in the NAVSTAR Global Positioning System.	20,248.0 20,115.0 718.0 54.7	Twenty-first in a series of operational GPS satellites. System expected to be composed of 24 satellites in inclined, semi-synchronous orbit. In orbit.
Jun. 26 Plasma Motor Generator 42B Delta II	*Objective:* To demonstrate the ability of a tether to generate an electrical current in space. *Spacecraft:* The tether consisted of two plasma contractors, or hollow cathode tubes, at either end of a 500-meter-long, thin copper cable coated with teflon.	844.0 196.0 94.8 25.7	Launched from Cape Canaveral AFS 9:27 a.m. attached to second stage of Delta II. Decayed 30 August 1993.
Jul. 19 DSCS III USA 93 46A Atlas II	*Objective:* To provide a world-wide, secure, uninterrupted communications capability in support of globally distributed DoD users. *Spacecraft:* Improved, third-generation Defense Satellite Communications System (DSCS) satellite.	35,743.6 35,743.6 1,440.0 0.0	Initial DSCS use of the Atlas II launch booster coupled with an inertial upper stage for achieving Earth orbit. Satellite to be cut over to operational traffic in early FY 1994 in the West Pacific. In orbit.
Aug. 9 NOAA-13 50A Atlas E	*Objective:* To provide global environmental observation; land, sea, and air temperature and moisture profiles; and to detect emergency beacons from ships and planes. *Spacecraft:* A 3-axis-stabilized, near-polar-orbiting satellite equipped with an Advanced Very High Resolution Radiometer, a High-resolution Infrared Sounder, a Solar Backscatter Ultraviolet Spectral Radiometer, plus Search and Rescue instruments provided by Canada and France among other equipment.	860.0 846.0 102.0 98.9	The purpose of the satellite was to replace the aging NOAA-11, but all communications with NOAA-13 ceased Aug. 21 and attempts to restore them have not been successful. In orbit.
Aug. 30 GPS USA 94 54A Delta II	*Objective:* To provide radio positioning and navigation, including position, velocity, and timing data to the DoD and civilian users. *Spacecraft:* A Block II satellite in the NAVSTAR Global Positioning System.	20,257.0 20,109.0 718.0 59.0	Twenty-second in a series of operational GPS satellites. System expected to be composed of 24 satellites inclined, semi-synchronous orbit. In orbit.
Sep. 3 UFO-2 USA-96 56A Atlas-Centaur I	*Objective:* To provide communications and UHF links for the U.S. Navy, Strategic Command, and Army/Marine Rapid Deployment Forces. *Spacecraft:* Second of nine UHF satellites built for the Navy by Hughes Space and Communications Corp. to replace an aging Fleet Satellite Communications System.	36,446.0 35,140.0 1,436.5 5.1	Successfully launched into geosynchronous orbit and transitioned to normal operating mode with all systems nominal. In orbit.

APPENDIX A-3
(continued)

Successful U.S. Launches

October 1, 1992–September 30, 1993

Launch Date (GMT). Spacecraft Name, COSPAR Designation, Launch Vehicle	Mission Objectives, Spacecraft Data	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
Sep. 12 Space Shuttle Discovery (STS-51) 58A	*Objective:* To deploy a satellite that will serve as a testbed for new communications satellite technology as well as to deploy and retrieve a U.S./German free-flying scientific observation satellite, among numerous other missions. *Spacecraft:* Shuttle orbiter with Advanced Communications Technology Satellite (ACTS), Orbiting and Retrievable Far and Extreme Ultraviolet Spectrometer-Shuttle Pallet Satellite (ORFEUS-SPAS), plus nine other cargo bay and in-cabin payloads.	307.0 275.0 90.3 28.4	Fifty-seventh STS flight. Piloted by Frank L. Culbertson, Jr., and William F. Readdy. Mission Specialists James H. Newman, Daniel W. Bursch, and Carl E. Walz. Launched from KSC at 7:45 EDT. Landed at KSC at 3:56 a.m. EDT Sep. 22. Mission duration: 9 days, 20 hrs., 11 min.
Sep. 12 ACTS 58B	*Objective:* To flight test high-risk, advanced communications satellite technology for providing up to three times the communications capacity for the weight of today's satellites, 20 times the rate of communications between users, and other advances over existing technology. *Spacecraft*: Basically rectangular satellite equipped with two solar arrays, a 30-GHz receiving antenna, a C-band omni antenna, a steerable antenna, and a 20 GHz transmitting antenna among other equipment.	35,929.0 35,709.0 1,437.8 0.2	Deployed from Discovery at 5:13 p.m. EDT. Transfer Orbit Stage fired on time 45 min. later and boosted it to its planned orbit. Second mission of Transfer Orbit Stage and first use on a Shuttle mission. In orbit.
Sep. 13 ORFEUS-SPAS 58C	*Objective:* To investigate very hot and very cold matter in the universe using the retrievable ASTRO-SPAS spacecraft built by Germany. *Spacecraft:* ASTRO-SPAS containing the one-meter diameter ORFEUS-Telescope with the Far Ultraviolet Spectrograph and the Extreme Ultraviolet Spectrograph plus the Interstellar Medium Absorption Profile Spectrograph and the Surface Effects Sample Monitor.	304.0 270.0 90.1 28.4	The Discovery crew released ORFEUS-SPAS on the morning of Sep. 13. Mission Specialist Dan Bursch recaptured the satellite at 7:50 a.m. EDT on Sep. 19 using the Shuttle's robotic arm.

APPENDIX B-1

U.S.-Launched Applications Satellites, 1987- Sep. 1993

Date	Name	Launch Vehicle	Remarks
		COMMUNICATIONS	
Mar. 20, 1987	Palapa B-2P	Delta 182	Indonesia domestic communications.
Sep. 29, 1988	TDRS-3	Space Shuttle	Space-based communications and tracking satellite.
Mar. 13, 1989	TDRS-4	Space Shuttle	Space-based communications and tracking satellite.
Sept. 25, 1989	Fltsatcom F-8	Atlas/Centaur	Sixth, and last in series of geosynchronous satellites, for U.S. Navy.
Jan. 1, 1990	Skynet 4A	Titan III	Launched for British Ministry of Defense.
Jan. 1, 1990	JCSAT 2	Titan III	Second of dual Titan III launch, for Japanese Communications Satellite Co.
Jan. 9, 1990	Syncom IV-5	Space Shuttle	Leasat 5, fourth in series of satellites, for U.S. Navy.
Mar. 14, 1990	Intelsat 6 F-3	Titan III	Launched for INTELSAT.
Apr. 13, 1990	Palapa-B2R	Delta	Launched for Indonesia.
Jun. 23, 1990	Intelsat 6 F-4	Titan III	Launched for INTELSAT.
Aug. 18, 1990	BSB-2R	Delta	Launched for British Satellite Broadcasting.
Aug. 2, 1991	TDRS-5	Space Shuttle	Space-based communications and tracking satellite.
Feb. 10, 1992	DSCS III	Atlas II	Launched by the Air Force for the DoD.
Mar. 14, 1992	Galaxy 5	Atlas I	Commercial communications satellite.
May 14, 1992	Palapa-B4	Delta	Launched for Indonesia.
Jun. 10, 1992	INTELSAT K	Atlas IIA	Launched for INTELSAT.
Jul. 2, 1992	DSCS III	Atlas II	Launched by the Air Force for the DoD.
Aug. 31, 1992	Satcom C4	Delta II	Commercial communications satellite.
Oct. 12, 1992	DFS-3	Delta II	Launched by McDonnell Douglas for German communications.
Jan. 13, 1993	TDRS-6	Space Shuttle	Space-based communications and tracking satellite.
Feb. 9, 1993	OXP-1	Pegasus	Experimental, demonstration satellite for transmitting brief messages with hand-held communicators.
Mar. 25, 1993	UFO-1	Atlas-Centaur I	Launched for the Navy but to a useless orbit.
Jul. 19, 1993	DSCS III	Atlas II	Launched by the Air Force for the DoD.
Sep. 3, 1993	UFO-2	Atlas-Centaur I	Second of nine UHF satellites to replace the Navy's Fleet Satellite Communications System.
Sep. 12, 1993	ACTS	Space Shuttle	Test of advanced communications satellite technology.
		WEATHER OBSERVATION[a]	
Feb. 26, 1987	GOES 7	Delta 179	Launched for NOAA, operational as GOES-Pacific.
Jun. 20, 1987	DMSP F-8	Atlas E	Third in block 5D-2 series, DoD meteorological satellite.
Feb. 2, 1988	DMSP F-9	Atlas E	DoD Meteorological satellite.
Sep. 24, 1988	NOAA-11	Atlas E	Launched for NOAA, to repair NOAA-9.
Dec. 1, 1990	DMSP F-10	Atlas E	DoD meteorological satellite.
May 14, 1991	NOAA-12	Atlas E	Launched for NOAA.
Nov. 28, 1992	DMSP F-11	Atlas E	DoD meteorological satellite.
Feb. 9, 1993	SCD 1	Pegasus	Satellite to monitor cloud cover, rainfall, flood and tide levels, and air quality over Brazil.
Aug. 9, 1993	NOAA-13	Atlas E	Launched for NOAA but communications lost Aug. 21, 1993.
		EARTH OBSERVATION AND GEODESY[b]	
Oct. 23, 1992	LAGEOS II	Space Shuttle	Joint NASA-Italian satellite for a variety of Earth observation and geodetic missions.

[a] Does not include Department of Defense satellites that are not individually identified by launch.

[b] Previously separate categories. See also Weather Observation for satellites with multiple missions including Earth observation.

APPENDIX B-1

(continued)

U.S.-Launched Applications Satellites, 1987-Sep. 1993

NAVIGATION[a]

Date	Name	Launch Vehicle	Remarks
Apr. 25, 1988	SOOS-3	Scout	Dual satellites, part of Navy navigation system.
Jun. 16, 1988	NOVA-2	Scout	Third of improved Transit System satellites, for DoD.
Aug. 25, 1988	SOOS-4	Scout	Dual Satellites, part of Navy navigation system.
Feb. 14, 1989	GPS-1 (Block II)	Delta	Global Positioning System Satellite.
June 10, 1989	GPS-2 (Block II)	Delta	Global Positioning System Satellite.
Aug. 18, 1989	GPS-3 (Block II)	Delta	Global Positioning System Satellite.
Oct. 21, 1989	GPS-4 (Block II)	Delta	Global Positioning System Satellite.
Dec. 11, 1989	GPS-5 (Block II)	Delta	Global Positioning System Satellite.
Jan. 24, 1990	GPS-6 (Block II)	Delta	Global Positioning System Satellite.
Mar. 26, 1990	GPS-7 (Block II)	Delta	Global Positioning System Satellite.
Aug. 2, 1990	GPS-8 (Block II)	Delta	Global Positioning System Satellite.
Oct. 1, 1990	GPS-9 (Block II)	Delta	Global Positioning System Satellite.
Nov. 16, 1990	GPS-10 (Block II)	Delta	Global Positioning System Satellite.
Jul. 4, 1991	GPS-11 (Block II)	Delta	Global Positioning System Satellite.
Feb. 23, 1992	GPS-12 (Block II)	Delta	Global Positioning System Satellite.
Apr. 10, 1992	GPS-13 (Block II)	Delta	Global Positioning System Satellite.
Jul. 7, 1992	GPS-14 (Block II)	Delta	Global Positioning System Satellite.
Sep. 9, 1992	GPS-15 (Block II)	Delta	Global Positioning System Satellite.
Nov. 22, 1992	GPS-16 (Block II)	Delta II	Global Positioning System Satellite.
Dec. 18, 1992	GPS-17 (Block II)	Delta II	Global Positioning System Satellite.
Feb. 3, 1993	GPS-18 (Block II)	Delta II	Global Positioning System Satellite.
Mar. 30, 1993	GPS-19 (Block II)	Delta II	Global Positioning System Satellite.
May 13, 1993	GPS-20 (Block II)	Delta II	Global Positioning System Satellite.
Jun. 26, 1993	GPS-21 (Block II)	Delta II	Global Positioning System Satellite.
Aug. 30, 1993	GPS-22 (Block II)	Delta II	Global Positioning System Satellite.

[a] Does not include Department of Defense satellites that are not individually identified by launch.

APPENDIX B-2

U.S.-Launched Scientific Satellites, 1987-Sep. 1993

Date	Name	Launch Vehicle	Remarks
Mar. 25, 1988	San Marco D/L	Scout	International satellite to study Earth's lower atmosphere.
Nov. 18, 1989	COBE	Delta	Measurement of cosmic background.
Feb. 14, 1990	LACE	Delta II	Low-powered atmospheric compensation experiment, for DoD.
Feb. 14, 1990	RME	Delta II	Second payload, relay mirror experiment satellite, for DoD.
Apr. 5, 1990	PEGSAT	Pegasus	Chemical release experiment satellite for NASA and DoD.
Apr. 25, 1990	Hubble Space Telescope	Space Shuttle	Long-term astronomical observations.
June 1, 1990	ROSAT	Delta II	Measurement of x-ray and extreme ultraviolet sources.
Jul. 25, 1990	CRRES	Atlas/Centaur	Chemical release experiment.
Apr. 7, 1991	Compton Gamma Ray Observatory	Space Shuttle	Measurement of celestial gamma-rays.
Sep. 15, 1991	Upper Atmosphere Research Satellite	Space Shuttle	Measurement of Earth's atmosphere and ozone layer.
Jun. 7, 1992	Extreme Ultra-violet Explorer	Delta II	Spectroscopic and wide-band observations over the entire extreme ultraviolet spectrum.
Jul. 3, 1992	Solar, Anomalous and Magnetospheric Particle Explorer	Scout	Investigation of cosmic rays and other phenomena of space physics.
Jul. 24, 1992	Geotail	Delta II	Investigation of geomagnetic tail region of the magnetosphere.
Aug. 2, 1992	Eureka-1	Space Shuttle	Research in the fields of material and life sciences.
Mar. 30, 1993	SEDS I	Delta II	Comparison of actual tether dynamics with model.
Apr. 11, 1993	SPARTAN-201	Space Shuttle	Study solar wind and sun's corona.
Jun. 26, 1993	Plasma Motor Generator	Delta II	Demonstrate ability of tether to generate electrical current in space.
Sep. 13, 1993	ORFEUS-SPAS	Space Shuttle	Study very hot and very cold matter in universe.

U.S.-Launched Space Probes, 1975-Sep. 1993

Date	Name	Launch Vehicle	Remarks
Aug. 20, 1975	Viking 1	Titan IIIE-Centaur	Lander descended, landed safely on Mars on Plains of Chryse, Sept. 6, 1976, while orbiter circled planet photographing it and relaying all data to Earth. Lander photographed its surroundings, tested soil samples for signs of life, and took measurements of atmosphere.
Sept 9, 1975	Viking 2	Titan IIIE-Centaur	Lander descended, landed safely on Mars on Plains of Utopia, July 20, 1976, while orbiter circled planet photographing it and relaying all data to Earth. Lander photographed its surroundings, tested soil samples for signs of life, and took measurements of atmosphere.
Jan. 15, 1976	Helios 2	Titan IIIE-Centaur	Flew in highly elliptical orbit to within 41 million km. of Sun, measuring solar wind, corona, electrons, and cosmic rays. Payload had some West German and U.S. experiments as Helios 1 plus cosmic-ray burst detector.
Aug. 20, 1977	Voyager 2	Titan IIIE-Centaur	Jupiter and Saturn flyby mission. Swung around Jupiter in July 1979, arrived Saturn in 1981,going on to Uranus by 1986, Neptune by 1989.
Sept. 5, 1977	Voyager 1	Titan IIIE-Centaur	Jupiter and Saturn flyby mission. Passing Voyager 2 on the way, swung around Jupiter in Mar. 1979, arrived at Saturn in Nov. 1980, headed for outer solar system.
May 20, 1978	Pioneer Venus 1	Atlas-Centaur	Venus orbiter, achieved Venus orbit Dec. 4, returning imagery and data.
Aug. 8, 1978	Pioneer Venus 2	Atlas-Centaur	Carried 1 large, 3 small probes plus spacecraft bus; all descended through Venus atmosphere Dec. 9, returned data.
May 4, 1989	Magellan	Space Shuttle	Venus orbiter, achieved Venus orbit Aug. 10, 1990, returning radar image of surface.
Oct. 18, 1989	Galileo	Space Shuttle	Planetary exploration spacecraft, composed of probe to enter Jupiter's atmosphere and orbiter to return scientific data.
Oct. 6, 1990	Ulysses	Space Shuttle	Solar exploration spacecraft, to explore interstellar space and the Sun.
Sep. 25, 1992	Mars Observer	Titan III	Planetary exploration spacecraft to study the geology, geophysics, and climate of Mars.

APPENDIX C

U.S. and Russian Human Spaceflights, 1961-Sep. 1993

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 3-person crew.
Voskhod 2	Mar. 18, 1965	Pavel I. Belyayev Aleksey A. Leonov	1:2:2	First extravehicular activity (Leonov, 10 min.).
Gemini 3	Mar. 23, 1965	Virgil I. Grissom John W. Young	0:4:53	First U.S. 2-person flight; first manual maneuvers in orbit.
Gemini 4	June 3, 1965	James A. McDivitt Edward H. White, II	4:1:56	21-min. extravehicular activity (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 2 orbiting spacecraft (Gemini 8 with Agena target rocket).
Gemini 9-A	June 3, 1966	Thomas P. Stafford Eugene A. Cernan	3:0:21	Extravehicular activity; rendezvous.
Gemini 10	July 18, 1966	John W. Young Michael Collins	2:22:47	First dual rendezvous (Gemini 10 with Agena 10, then Agena 8).
Gemini 11	Sept. 12, 1966	Charles Conrad, Jr. Richard F. Gordon, Jr.	2:23:17	First initial-orbit docking; first tethered flight; highest Earth-orbit altitude (1,372 km.).
Gemini 12	Nov. 11, 1966	James A. Lovell, Jr. Edwin E. Aldrin, Jr.	3:22:35	Longest extravehicular activity 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. 3-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 2 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.
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.

APPENDIX C
(continued)

U.S. and Russian Human Spaceflights, 1961-Sep. 1993

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Apollo II	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 wiThuot 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 ervice 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 demonstrated pinpoint landing capability and continued human exploration.
Soyuz 10	Apr. 22, 1971	Vladimir A. Shatalov Aleksey S. Yeliseyev Nikolay N. Rukavishnikov	1:23:46	Docked with Salyut 1, but crew did not board space station launched Apr. 19. Crew recovered Apr. 24, 1971.
Soyuz 11	June 6, 1971	Georgiy T. Dobrovolskiy Vladislav N. Volkov Viktor I. Patsayev	23:18:22	Docked with Salyut 1 and Soyuz 11 crew occupied space station for 22 days. Crew perished in final phase of Soyuz 11 capsule recovery on June 30, 1971.
Apollo 15	July 26, 1971	David R. Scott Alfred M. Worden James B. Irwin	12:7:12	Fourth human lunar landing and first Apollo "J" series mission, which carried Lunar Roving Vehicle. Worden's inflight EVA of 38 min. 12 sec was performed during return trip.
Apollo 16	Apr. 16, 1972	John W. Young Charles M. Duke, Jr. Thomas K. Mattingly II	11:1:51	Fifth human lunar landing, with Lunar Roving Vehicle.
Apollo 17	Dec. 7, 1972	Eugene A. Cernan Harrison H. Schmitt Ronald E. Evans	12:13:52	Sixth and final Apollo human lunar landing, again with roving vehicle.
Skylab 2	May 25, 1973	Charles Conrad, Jr. Joseph P. Kerwin Paul J. Weitz	28:0:50	Docked with Skylab 1 (launched uncrewed May 14) for 28 days. Repaired damaged station.
Skylab 3	July 28, 1973	Alan L. Bean Jack R. Lousma Owen K. Garriott	59:11:9	Docked with Skylab 1 for more than 59 days.
Soyuz 12	Sept. 27, 1973	Vasiliy G. Lazarev Oleg G. Makarov	1:23:16	Checkout of improved Soyuz.
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 ASTP configuration.
Soyuz 17	Jan. 10, 1975	Aleksay A. Gubarev Georgiy M. Grechko	29:13:20	Docked with Salyut 4 and occupied station.

APPENDIX C
(continued)

U.S. and Russian Human Spaceflights, 1961-Sep. 1993

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Anomaly	Apr. 5, 1975	Vasiliy G. Lazarev Oleg G. Makarov	0:0:20	Soyuz stages failed to separate; crew recovered after abort.
Soyuz 18	May 24, 1975	Petr I. Klimuk Vitaliy I. Sevastyanov	62:23:20	Docked with Salyut 4 and occupied station.
Soyuz 19	July 15, 1975	Aleksey A. Leonov Valery N. Kubasov	5:22:31	Target for Apollo in docking and joint experiments of ASTP mission.
Apollo	July 15, 1975	Thomas P. Stafford Donald K. Slayton Vance D. Brand	9:1:28	Docked with Soyuz 19 in joint (ASTP) experiments of ASTP mission.
Soyuz 21	July 6, 1976	Boris V. Volynov Vitaliy M. Zholobov	48:1:32	Docked with Salyut 5 and occupied station.
Soyuz 22	Sept. 15, 1976	Valery F. Bykovskiy Vladimir V. Aksenov	7:21:54	Earth resources study with multispectral camera system.
Soyuz 23	Oct. 14, 1976	Vyacheslav D. Zudov Valery I. Rozhdestvenskiy	2:0:6	Failed to dock with Salyut 5.
Soyuz 24	Feb. 7, 1977	Viktor V. Gorbatko Yury N. Glazkov	17:17:23	Docked with Salyut 5 and occupied station.
Soyuz 25	Oct. 9, 1977	Vladimir V. Kovalenok Valery V. Ryumin	2:0:46	Failed to achieve hard dock with Salyut 6 station.
Soyuz 26	Dec. 10, 1977	Yury V. Romanenko Georgiy M. Grechko	37:10:6	Docked with Salyut 6. Crew returned in Soyuz 27; crew duration 96 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 wiThuot a crew.
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	Sept. 18, 1980	Yury V. Romanenko Arnaldo Tamayo Mendez	7:20:43	Docked with Salyut 6. Tamayo was first Cuban to orbit.
Soyuz T-3	Nov. 27, 1980	Leonid D. Kizim Oleg G. Makarov Gennady M. Strekalov	12:19:8	Docked with Salyut 6. First 3-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.

U.S. and Russian Human Spaceflights, 1961-Sep. 1993

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Space Shuttle Columbia (STS 1)	Apr .12, 1981	John W. Young Robert L. Crippen	2:6:21	First flight of Space Shuttle, tested spacecraft in orbit. First landing of airplane-like craft from orbit for reuse.
Soyuz 40	May 14, 1981	Leonid I. Popov Dumitru Prunariu	7:20:41	Docked with Salyut 6. Prunariu first Romanian cosmonaut to orbit.
Space Shuttle Columbia (STS 2)	Nov. 12, 1981	Joe H. Engle Richard H. Truly	2:6:13	Second flight of Space Shuttle, first scientific payload (OSTA 1). Tested remote manipulator arm. Returned for reuse.
Space Shuttle Columbia (STS 3)	Mar. 22, 1982	Jack R. Lousma C. Gordon Fullerton	8:4:49	Third flight of Space Shuttle, second scientific payload (0SS 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 Soviet 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 2 commercial satellites (SBS 3 and Anik C- 3); first flight with 4 crew members. EVA test canceled when space suits 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.
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 2 commercial satellites (Anik C-2 and Palapa B-1), also launched and retrieved SPAS 01; first flight with 5 crewmembers, 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 6 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-41B)	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 (MMU) 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-II.

U.S. and Russian Human Spaceflights, 1961-Sep. 1993

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
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-41C)	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 LDEF-l, 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 extravehicular activity.
Space Shuttle Discovery (STS-41D)	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. non-astronaut.
Space Shuttle Challenger (STS-41G)	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 of 7 crew members, including first flight of two U.S. women and one Canadian (Garneau).
Space Shuttle Discovery (STS-51A)	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-51C)	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-51D)	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-51B)	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-51G)	June 17, 1985	Daniel C. Brandenstein John O. Creighton Shannon W. Lucid John M. Fabian Steven R. Nagel Patrick Baudry Sultan bin Salman bin Abdul-Aziz Al-Saud	7:1:39	Eighteenth STS flight. Three communications satellites. One reusable payload, Spartan-l. First U.S. flight with French and Saudi Arabian crewmen.

APPENDIX C
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U.S. and Russian Human Spaceflights, 1961-Sep. 1993

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Space Shuttle Challenger (STS-51F)	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-51I)	Aug. 27, 1985	Joe H. Engle Richard O. Covey James D. van Hoften William F. Fisher John M. Lounge	7:2:18	Twentieth STS flight. Launched three communications satellites. Repaired Syncom IV-3.
Soyuz T-14	Sept. 17, 1985	Vladimir Vasyutin Georgiy Grechko Aleksandr Volkov	64:21:52	Docked with Salyut 7 station. Viktor Savinykh, Aleksandr Volkov and Vladimir Vasyutin returned to Earth Nov. 21, 1985, when Vasyutin became ill.
Space Shuttle Atlantis (STS-51J)	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.
Space Shuttle Challenger (STS-61A)	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-61B)	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 communications satellites. First flight of Mexican astronaut (Neri Vela).
Space Shuttle Columbia (STS-61C)	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 communications satellite. First member of U.S. House of Representatives in space (Bill Nelson).
Soyuz T-15	Mar. 13, 1986	Leonid Kizim Vladimir Solovyov	125:1:1	Docked with MIR space station on May 5/6 transferred to Salyut 7 complex. On June 25/26 transferred from Salyut 7 back to MIR.
Soyuz TM-2	Feb. 5, 1987	Yury Romanenko Aleksandr Laveykin	174:3:26	Docked with MIR space station. Romanenko established long distance stay in space record of 326 days.
Soyuz TM-3	July 22, 1987	Aleksandr Viktorenko Aleksandr Aleksandrov Mohammed Faris	160:7:16	Docked with MIR space station. Aleksandr Aleksandrov remained in MIR 160 days, returned with Yury Romanenko. Viktorenko and Faris returned in Soyuz TM-2, July 30 with Aleksandr Laveykin who experienced medical problems. Mohammed 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	Jun. 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.

APPENDIX C
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U.S. and Russian Human Spaceflights, 1961-Sep. 1993

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
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.
STS-26	Sept. 29, 1988	Frederick H. Hauck Richard O. Covey John M. Lounge David C. Hilmers George D. Nelson	4:1	Twenty-sixth STS flight. Launched TDRS 3.
Soyuz TM-7	Nov. 26, 1988	Aleksandr Volkov 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.
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.
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.
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.
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	Sept. 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.
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.
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.
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 Long-Duration Exposure Facility (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.
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.

U.S. and Russian Human Spaceflights, 1961-Sep. 1993

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
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 astronaut.
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.
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.
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	175:01:52	Docked with MIR space station. Toyohiro Akiyama returned Dec. 10, 1990, with previous MIR crew of Gennady Manakov and Gennady Strekalov.
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.
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 (UK)	144:15:22	Docked with MIR space station. Helen Sharman first from United Kingdom to fly in space. Crew of Viktor Afanasyev, Musa Manarov, and Helen Sharman returned May 20, 1991. Artsebarskiy and Krikalev remained on board MIR, with Artsebarskiy returning Oct. 10, 1991, and Krikalev doing so Mar. 25, 1992.
STS-40	Jun. 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.
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).

APPENDIX C
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U.S. and Russian Human Spaceflights, 1961-Sep. 1993

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
STS-48	Sept. 12, 1991	John Creighton Kenneth Reightler, Jr. Charles D. Gemar James F. Buchli Mark N. Brown	5:8:28	Forty-third STS flight. Launched Upper Atmosphere Research Satellite (UARS).
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.
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.
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 in the TM-14 spacecraft.
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).
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.
STS-50	Jun. 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	Jul. 27, 1992	Anatoly Solovyov Sergei Avdeyev Michel Tognini (France)	189:17:43[a]	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 space craft on 1 February 1993.

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[a] Figures supplied by Marcia S. Smith, Congressional Research Service, Library of Congress, based on information in Tass.

U.S. and Russian Human Spaceflights, 1961-Sep. 1993

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
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-nineth STS flight. Deployed Tethered Satellite System-1 and Eureka-1.
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 (Japan)	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.
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.
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.
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[a]	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.
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.
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.

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[a] Figures supplied by Marcia S. Smith, Congressional Research Service, Library of Congress, based on information in Tass.

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U.S. and Russian Human Spaceflights, 1961-Sep. 1993

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
STS-57	Jun. 21, 1993	Ronald J. Grabe Brian J. Duffy G. David Low Nancy J. Sherlock Peter J. K. Wisoff Janice E. Voss	9:23:46	Fifty-sixth STS flight. Carried Spacelab commercial payload module and retrieved European Retrievable Carrier in orbit since August 1992.
Soyuz TM-17	Jul. 1, 1993	Vasiliy Tsibliyev Aleksandr Serebrov Jean-Pierre Haignere	196:17:45[a]	Docked with Mir space station July 3. Haignere returned to Earth with Soyuz TM-16. Serebrov Tsibliyev landed in TM-17 space craft after end of fiscal year on Jan. 14, 1994.
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.

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[a] Figures supplied by Marcia S. Smith, Congressional Research Service, Library of Congress, based on information in Tass.

APPENDIX D

U.S. Space Launch Vehicles

					Max. Payload (kg)[d]			
Vehicle	Stages: Engine/Motor	Propellant[a]	Thrust (kilonewtons)[bc]	Max. Dia x Height (m)	185-Km Orbit	Geosynch. Transfer Orbit	Sun-Synch. Orbit[e]	First Launch[f]
Scout G-1				1.14x22.90	255[g] 210[e]	54	155	1979, G-1 1960,X-1
	1. Algol IIIA	Solid	414.8 (SL)	1.14x9.40				
	2. Castor IIA	Solid	267.2	0.79x6.31				
	3. Antares IIIA	Solid	80.8	0.76x3.51				
	4. Altair III	Solid	25.8	0.51x1.48				
Pegasus				6.71x15.04[h]	380 280[e]	—	210	1990
	1. Orion 50S	Solid	580.5	1.28x8.88				
	2. Orion 50	Solid	138.6	1.28x2.66				
	3. Orion 38	Solid	35.8	0.97x1.34				
Delta II (6920, 6925)				2.44x38.20	3983 2943 [e]	1447[i]	2413	1989, -6920 [1960, Delta]
	1. RS-270/B	LOX/RP-1	921.0 (SL)	2.44x38.20				
	Castor IVA (9)	Solid	432.0 (SL)	1.01x11.16				
	2. AJ10-118K	N_2O_4/A-50	42.9	2.44x5.97				
	3. Star 48B[i]	Solid	67.2	1.25x2.04				
Delta II (7920, 7925)				2.44x29.70	5039 3819 [e]	1819[j]	3175	1990, -7920 [1960, Delta]
	1. RS-270/C	LOX/RP-1	894.4 (SL)	2.90x26.09				
	Hercules GEM (9)	Solid	440.0 (SL)	1.01x12.95				
	2. AJ10-118K	N_2O_4/A-50	42.9	2.44x5.97				
	3. Star 48B[j]	Solid	67.2	1.25x2.04				
Atlas E				3.05x28.1	820[e] 1860[ek]	—	910[k]	1968, E [1958, B]
	1. Atlas: MA-3	LOX/RP-1	1739.5 (SL)	3.05x21.3				
Atlas I				3.05x45.6	5900	2375	—	1990, I [1966, Atlas Centaur]
	1. Atlas: MA-5	LOX/RP-1	1954.0 (SL)	3.05x22.16				
	2. Centaur I: RL10A-3-3A (2)	LOX/LH_2	73.4	3.05x9.14				
Atlas II				3.05x49.3	6580 5510[e]	2610	4300	1991, II [1966, Atlas Centaur]
	1. Atlas: MA-5A	LOX/RP-1	2110.0 (SL)	3.05x24.9				
	2. Centaur II: RL10A-3-3A (2)	LOX/LH_2	73.4	3.05x10.05				
Atlas IIA				3.05x49.3	7280 6170[e]	2745	4750	1992, IIA [1966, Atlas Centaur]
	1. Atlas: MA-5A	LOX/RP-1	2110.0 (SL)	3.05x24.9				
	2. Centaur II: RL10A-4 (2)	LOX/LH_2	92.5	3.05x10.05				
Titan II				3.05x42.9	1905[e]	—	—	1988, II SLV [1964, II Gemini]
	1. LR-87-AJ-5 (2)	N_2O_4/A-50	1045.0	3.05x21.5				
	2. LR-91-AJ-5	N_2O_4/A-50	440.0	3.05x12.2				

APPENDIX D
(continued)
U.S. Space Launch Vehicles

					Max. Payload (kg)[d]			
Vehicle	Stages: Engine/Motor	Propellant[a]	Thrust (kilonewtons)[bc]	Max. Dia x Height (m)	185-Km Orbit	Geosynch. Transfer Orbit	Sun-Synch. Orbit[e]	First Launch[f]
Titan III				3.05x47.3	14515	4990[l]	—	1989, III
	0. Titan III SRM (2) (5-1/2 segments)	Solid	6210.0	3.05x27.6				
	1. LR87-AJ-11 (2)	N_20_4/A-50	1214.5	3.05x24.0				
	2. LR91-AJ-11	N_20_4/A-50	462.8	3.05x10.0				
Titan IV				3.05x47.3	17700	6350[m]	—	1989, IV
	0. Titan IV SRM (2) (7 segments)	Solid	8000.0	3.05x34.1	14110[e]			
	1. LR87-AJ-11 (2)	N_20_4/A-50	1214.5	3.05x26.4				
	2. LR91-AJ-11	N_20_4/A-50	462.8	3.05x10.0				
Space Shuttle[n]				23.79x56.14[h]	24900[o]	5900[p]	—	1981, Columbia
	1. SRB: Shuttle SRB (2)	Solid	13616.0(SL)	3.70x45.46				
	2. Orbiter/ET:SSME (3)	LOX/LH_2	1668.7(SL)	8.41x47.00 (ET) 23.79x37.24[h] (orbiter)				
	3. Orbiter/OMS: OMS engines (2)	N_20_4/MMH	118.8	23.79x37.24[h]				

Notes

[a] Propellant abbreviations used are as follows:
A-50 = Aerozine 50 (50% Monomethyl Hydrazine, 50% Unsymmetrical Dimethyl Hydrazine)
LH_2 = Liquid Hydrogen
LOX = Liquid Oxygen
MMH = Monomethyl Hydrazine
N_20_4 = Nitrogen Tetroxide
RP-1 = Rocket Propellant 1 (kerosene)
Solid = Solid Propellant (any type)

[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] 37.7° launch from Wallops Flight Facility, VA.

[h] Diameter dimension represents vehicle wing span.

[i] Applies to Delta II-6925 version only.

[j] Applies to Delta II-7925 version only.

[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 (SRBs) fire in parallel with the Space Shuttle Main Engines (SSMEs), which are mounted on the aft end of the Shuttle Orbiter Vehicle (OV) and burn fuel and oxidizer from the External Tank (ET). SRBs stage first, with SSMEs continuing to fire. The ET stages next, just before the orbiter attains orbit. The Orbiter Maneuvering Subsystem (OMS) is then used to maneuver or change the orbit of the OV.

[o] 280 x 420 km. orbit.

[p] With Inertial Upper Stage (IUS) or Transfer Orbit Stage (TOS).

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

***SOURCE OF DATA:* David H. Burks, Senior Engineer, Science Applications International Corporation, Washington, DC.**

APPENDIX E-1A

Space Activities of the U.S. Government

HISTORICAL BUDGET SUMMARY—BUDGET AUTHORITY

(in millions of real-year dollars)

Fiscal Year	NASA Total	NASA Space[a]	Defense	Other	Energy	Commerce	Interior	Agriculture	NSF	DOT	EPA	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	...	...	...	0.6	...	...	1,808
1962	1,825	1,797	1,298	200	148	51	...	...	1.3	...	...	3,295
1963	3,673	3,626	1,550	259	214	43	...	...	1.5	...	...	5,435
1964	5,100	5,016	1,599	216	210	3	...	...	3.0	...	...	6,831
1965	5,250	5,138	1,574	244	229	12	...	...	3.2	...	...	6,956
1966	5,175	5,065	1,689	217	187	27	...	...	3.2	...	...	6,970
1967	4,966	4,830	1,664	216	184	29	...	...	2.8	...	...	6,710
1968	4,587	4,430	1,922	177	145	28	0.2	0.5	3.2	...	...	6,529
1969	3,991	3,822	2,013	141	118	20	0.2	0.7	1.9	...	...	5,976
1970	3,746	3,547	1,678	115	103	8	1.1	0.8	2.4	...	...	5,341
1971	3,311	3,101	1,512	127	95	27	1.9	1	2	...	...	4,741
1972	3,307	3,071	1,407	97	55	31	5.8	2	3	...	...	4,575
1973	3,406	3,093	1,623	109	54	40	10.3	2	3	...	...	4,825
1974	3,037	2,759	1,766	116	42	60	9.0	3	2	...	...	4,640
1975	3,229	2,915	1,892	107	30	64	8.3	2	2	...	...	4,914
1976	3,550	3,225	1,983	111	23	72	10.4	4	2	...	...	5,320
TQ*	932	849	460	31	5	22	2.6	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	178	59	98	10	8	2	...	...	7,244
1980	5,240	4,680	3,848	160	40	93	12	14	2	...	...	8,689
1981	5,518	4,992	4,828	158	41	87	12	16	2	...	...	9,978
1982	6,044[b]	5,528	6,679	234	61	145	12	15	2	...	...	12,441
1983	6,875[c]	6,328	9,019	242	39	178	5	20	...[d]	...	...	15,589
1984	7,248	6,648	10,195	293	34	236	3	19	...	...	...	17,136
1985	7,573	6,925	12,768	474	34	423	2	15	...	...	...	20,167
1986	7,766	7,165	14,126	368	35	309	2	23	...	...	...	21,659
1987	10,507	9,809[e]	16,287	352	48	278	8	19	...	1	...	26,448
1988	9,026	8,302	17,679	626	241	352	14	18	...	1	...	26,607
1989	10,969	10,098	17,906	440	97	301	17	21	...	3	1	28,444
1990	13,073	12,142	15,616	383	79	243	31	25	...	4	1	28,141
1991	14,004	13,036	14,181	562	251	251	29	26	...	4	1	27,779
1992	14,316	13,199	15,023	619	223	327	34	29	...	4	2	28,841
1993	14,323	13,077	14,106	553	165	324	33	25	...	4	2	27,736

[a] Excludes amounts for air transportation (subfunction 402).
[b] Includes $33.5 million for unobligated funds that lapsed.
[c] Includes $37.6 million for reappropriation of prior year funds.
[d] NSF funding of balloon research transferred to NASA.
[e] Includes $2.1 billion for replacement of shuttle orbiter Challenger.
*Transit Qtr

SOURCE: Office of Management and Budget.

APPENDIX E-1B

Space Activities of the U.S. Government

BUDGET AUTHORITY IN MILLIONS OF EQUIVALENT FY 1993 DOLLARS
(adjusted for inflation)

Fiscal Year	GDP Inflator to 1993 $	NASA Total	NASA Space	Defense	Other	Energy	Commerce	Interior	Agriculture	NSF	DOT	EPA	Total Space
1959	4.8255	1,597	1,259	2,364	164	164	0	0	0	0	0	0	3,788
1960	4.7737	2,501	2,205	2,678	206	205	0	0	0	0	0	0	5,089
1961	4.7302	4,560	4,380	3,850	324	322	0	0	0	3	0	0	8,555
1962	4.6472	8,481	8,351	6,032	931	688	237	0	0	6	0	0	15,314
1963	4.5671	16,775	16,560	7,079	1,181	977	196	0	0	7	0	0	24,820
1964	4.5011	22,956	22,578	7,197	972	945	14	0	0	14	0	0	30,747
1965	4.4040	23,121	22,628	6,932	1,075	1,009	53	0	0	14	0	0	30,635
1966	4.2755	22,126	21,656	7,221	929	800	115	0	0	14	0	0	29,806
1967	4.1336	20,528	19,965	6,878	892	761	120	0	0	12	0	0	27,736
1968	3.9842	18,276	17,650	7,658	705	578	112	1	2	13	0	0	26,012
1969	3.7937	15,141	14,499	7,637	534	448	76	1	3	7	0	0	22,670
1970	3.5986	13,480	12,764	6,038	415	371	29	4	3	9	0	0	19,217
1971	3.4207	11,326	10,608	5,173	435	324	94	6	3	8	0	0	16,217
1972	3.2510	10,750	9,984	4,574	314	179	102	19	5	9	0	0	14,872
1973	3.0974	10,550	9,581	5,027	337	168	123	32	6	8	0	0	14,945
1974	2.8777	8,739	7,938	5,082	333	120	173	26	9	5	0	0	13,353
1975	2.6176	8,453	7,631	4,954	279	77	169	22	6	5	0	0	12,864
1976	2.4306	8,630	7,840	4,821	270	57	174	25	9	6	0	0	12,931
TQ*	2.3464	2,186	1,993	1,080	73	11	52	6	2	1	0	0	3,145
1977	2.2489	8,586	7,737	5,424	294	49	204	21	14	5	0	0	13,455
1978	2.0908	8,489	7,575	5,725	328	72	215	20	16	5	0	0	13,628
1979	1.9238	8,841	7,754	5,840	341	113	189	19	16	5	0	0	13,935
1980	1.7646	9,247	8,259	6,791	282	70	163	21	24	4	0	0	15,332
1981	1.6017	8,839	7,996	7,732	253	65	139	20	25	4	0	0	15,981
1982	1.4907	9,009	8,240	9,956	349	90	215	18	23	3	0	0	18,545
1983	1.4312	9,840	9,057	12,908	346	56	254	7	29	0	0	0	22,311
1984	1.3709	9,936	9,114	13,976	401	47	324	4	27	0	0	0	23,491
1985	1.3205	9,999	9,144	16,860	626	45	558	3	20	0	0	0	26,629
1986	1.2824	9,959	9,188	18,115	472	44	396	3	29	0	0	0	27,776
1987	1.2455	13,086	12,217	20,285	439	59	346	9	23	0	1	0	32,940
1988	1.2018	10,848	9,978	21,247	752	289	422	16	22	0	2	0	31,977
1989	1.1500	12,614	11,613	20,592	506	112	346	20	24	0	3	1	32,711
1990	1.1027	14,415	13,388	17,219	422	87	268	34	28	0	4	1	31,030
1991	1.0581	14,817	13,793	15,004	595	266	266	31	28	0	4	1	29,392
1992	1.0269	14,701	13,554	15,427	636	229	336	35	30	0	4	2	29,616
1993	1.0000	14,323	13,077	14,106	553	165	324	33	25	0	4	2	27,736

*Transit Qtr

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		
	1991 actual	1992 actual	1993 estimated	1991 actual	1992 actual	1993 estimated
NASA	13,036	13,199	13,077	13,351	12,838	13,092
Defense	14,181	15,023	14,106	14,432	14,437	13,779
Energy	251	223	165	251	223	165
Commerce	251	327	324	266	298	308
Interior	29	34	33	29	33	33
Agriculture	26	29	25	26	29	25
Transportation	4	4	4	4	4	4
EPA	1	2	2	1	2	2
TOTAL	27,779	28,841	27,736	28,360	27,864	27,408

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		
	1991 actual	1992 actual	1993 estimated	1991 actual	1992 actual	1993 estimated
NASA[a]	968	1,117	1,246	1,017	1,122	1,212
Defense[b]	6,149	7,366	7,601	6,793	6,790	7,165
Transportation[c]	2,300	2,681	2,532	1,691	2,099	2,378
TOTAL	9,417	11,164	11,379	9,501	10,011	10,755

[a] Research, Development, Construction of Facilities, Research and Program Management.

[b] Research, Development, Testing, and Evaluation of aircraft and related equipment.

[c] Federal Aviation Administration: Research, Engineering, and Development; Facilities, Engineering, and Development.

SOURCE: Office of Management and Budget.

APPENDIX F-1

The White House

Office of the Press Secretary

FOR IMMEDIATE RELEASE

Thursday, June 17, 1993

STATEMENT OF THE PRESIDENT

At a time when our long-term economic strength depends on our technological leadership and our ability to reduce the deficit, we must invest in technology but invest wisely, making the best possible use of every dollar. That's why I asked for a review of NASA's space station program. Concerns over rising costs and mismanagement raised serious questions about a program vital to our technological leadership. I instructed NASA to redesign the space station program in a way that would preserve its critical science and space research, and ensure international cooperation, but significantly reduce costs and improve management.

NASA has met that challenge, offering a plan that will substantially reduce costs to taxpayers, improve management, preserve research, and allow the United States to continue to work with its international partners and keep its international commitments. That was the conclusion of an outstanding panel of independent experts who carefully reviewed NASA's proposals. And, that is my conclusion as well, after thoroughly considering their report and recommendations. It will take not just a redesign of the space station, but a redesign of NASA itself.

I am calling for the U.S. to work with our international partners to develop a reduced cost, scaled-down version of the original Space Station Freedom. At the same time, I will also seek to enhance and expand the opportunities for international participation in the space station project, so that the space station can serve as a model of nations coming together in peaceful cooperation. Finally, I will be directing NASA to implement personnel reductions and major management changes to cut costs, reduce bureaucracy, and improve efficiency. The National Performance Review team, led by Vice President Gore, has been essential in working with NASA to develop these management proposals. We are going to redesign NASA at the same time that we redesign the space station.

To make maximum use of our investments and meet the scientific goals we have set, the specific design we will pursue will be a simplified version of Space Station Freedom recommended by the review panel. We will work with Congress, NASA and our international partners during the next ninety days to made the very best use of this design. The details of the proposal will be delivered to Congress within the next few days. I have asked Dr. John Gibbons, my Science and Technology Advisor, to transmit a letter to NASA with more detailed instructions for implementing this decision.

The redesigned program will capitalize on the investments we have already made. However, with its deep cuts in future development and operations costs, this redesigned program will save more then $4 billion over the next 5 years, compared with our assessments of what the real costs of funding the planned Space Station Freedom would have been. Over the two-decade life of the program, these savings will grow to more than $18 billion.

There is no doubt that we are facing difficult budget decisions. However, we can not retreat from our obligation to invest in our future. Budget cuts alone will not restore our vitality. I believe strongly that NASA and the space station program represent important investments in that future, and that these investments will yield benefits in medical research, aerospace and other critical technology areas. As well, the space station is a model of peaceful international cooperation, offering a vision of the new world in which confrontation has been replaced with cooperation.

In making this announcement today, I want to recognize the extraordinary efforts of all those involved. Vice President Gore, and Dr. Gibbons assembled an outstanding team of experts, led by Dr. Charles Vest, President of MIT, who assessed several cost-saving options prepared by NASA. This review included not only the design of the space station, but also the structure and management of NASA itself. Their work and the work of all those at NASA involved in this project, has been invaluable.

SPACE STATION REDESIGN DECISION REDUCES COSTS, PRESERVES RESEARCH, ENSURES INT'L COOPERATION

WASHINGTON—President Clinton today (6/17) announced he is recommending a scaled-down version of the Space Station Freedom that will significantly reduce costs to taxpayers, preserve critical research, ensure international cooperation, and mean a major redesign of America's space agency as well.

The redesigned space station will save an estimated $18 billion over the projected two decade life of the program, with more than $4 billion in savings in the next 5 years due to decreased development, operations, and management costs.

"At a time when our long-term economic strength depends on our technological leadership and our ability to reduce the deficit, we must invest in technology but invest wisely, making the best possible use of every dollar," President Clinton said in a statement announcing his decision.

"I instructed NASA to redesign the space station program in a way that would preserve its critical science and space research and ensure international cooperation but significantly reduce costs and improve management. NASA has met that challenge," the President said, announcing that he is proposing a scaled-down version of the Space Station Freedom recommended by an expert panel that reviewed NASA's redesign proposals.

President Clinton said the Administration would work with Congress, NASA, and America's international partners during the next 90 days to make the very best use of the simplified design, an option based on the Space Station Freedom and recommended by the expert panel assembled to review NASA's proposals for the redesign of Space Station Freedom.

"I am calling for the U.S. to work with our international partners to develop a reduced cost, scaled-down version of the original Space Station Freedom. At the same time, I will also seek to enhance and expand the opportunities for international participation in the space station project so that the space station can serve as a model of nations coming together in peaceful cooperation. Finally, I will be directing NASA to implement personnel reductions and major management changes to cut costs, reduce bureaucracy, and improve efficiency," the President said. "We are going to redesign NASA as we redesign the space station."

President Clinton cited the involvement of the National Performance Review team, led by Vice President Gore, in working with NASA to develop proposed management changes.

Ninety days ago, President Clinton asked NASA to review the Space Station Freedom program to confront rising costs and management problems. NASA's proposals were reviewed by a team of experts, led by Dr. Charles Vest, President of MIT, assembled by Vice President Gore, and Dr. John Gibbons, the President's Science and Technology Advisor. The option chosen by the President was one of the options recommended by the Vest panel.

The White House

Office of the Vice President

EMBARGOED FOR RELEASE
UNTIL 10:45 A.M. EDT
THURSDAY, SEPTEMBER 2, 1993

REMARKS BY THE VICE PRESIDENT IN SIGNING CEREMONY WITH PRIME MINISTER CHERNOMYRDIN OF RUSSIA

Room 450, Old Executive Office Building

The Prime Minister and I have worked hard over the past two days to bring to life the vision first sketched by President Clinton and President Yeltsin at their summit in Vancouver: it is time to leave behind the vestiges of the Cold War and reach for a new partnership between the United States and Russia.

No where will this partnership be so keenly felt as in the area of high-technology cooperation. Each of our countries spent the Cold War years pouring our resources into competition. So much was achieved, but at such a high cost. Now, we can work together to advance a joint agenda in energy and space, science and technology, using our cooperation to keep costs down, husband our limited resources and work together for our mutual benefit.

Turning forty years of competition into a future of cooperation is no easy task. Our Presidents agreed at Vancouver that high-level attention would be needed to jump-start our cooperation, and their agreement was the genesis of this commission. Prime Minister Chernomyrdin and I have focused fully on beginning the jump-starting process during our two days here in Washington. Our aim is to broaden the U.S.-Russian partnership so that it encompasses not only security and foreign policy concerns, but also the evolution of an economic partnership for the future.

Nothing pleases me more than the results that we already see emerging, especially the agreements on space cooperation that we have signed here today. Everyone remembers the great firsts that each of our space programs achieved. Sputnik l, the first human-made satellite, electrified the world when it was launched on October 4, 1957. We were equally excited when Yury Gagarin became the first human being to fly in space in 1961. Then came the great period of lunar exploration with the U.S. Apollo program and, on the Russian side, the Luna probes.

But the agreements that we signed here today, as much as they owe to the accomplishments of that competitive era, most clearly have their roots in the Apollo-Soyuz rendezvous and docking in July 1975. It was through this project that Russian and American space scientists and engineers, astronauts and cosmonauts first began to work together. I am very pleased to have here today General Tom Stafford and General Alexei Leonov, who flew together on that pathbreaking mission. Gentlemen, would you stand to be recognized?

The future holds more of what the Apollo-Soyuz project foretold: close work together to minimize costs and cut the time needed to do projects while achieving more than would otherwise have been possible. Let me review briefly for you the agreements that we have signed relating to space: first, the commercial launch agreement, which will give Russia access to the international launch services market; second, a joint statement on space cooperation, which defines a phased approach for cooperation on human space flight. This statement embraces the potential for cooperation on a truly international Space Station if technical and partnership considerations are met. Finally, two joint statements, one on environmental monitoring and space science and the other on aeronautics, will help us to set a broad strategy for cooperation in global environmental change as well as in the design of future aircraft.

Dan Goldin, our NASA Administrator, and Yury Koptyev, Director of the Russian Space Agency, will have much to do in coming months to nail down the agenda of our joint work. I know, however, that they relish the task, and we will stand ready to help.

In many ways, the agreements on space that we signed today represent the leading edge of what we are striving to accomplish, Russia and the United States together: from broad market access for Russian high-technology goods to long-term projects to work together in complex, productive ways.

At the same time, I would like to take special note of an agreement signed today that puts an important issue behind us: the Memorandum of Understanding on the Missile Technology Control Regime. By committing to adhere to the guidelines of the MTCR, Russia isshowing its readiness to be a responsible partner in the sale of high-technology goods and services. This is a welcome and important step, and I would like to recognize the hard work of Under Secretary of State Davis and Deputy Prime Minister Shokhin in bringing it to pass.

But space is not all we have worked on during this meeting. We also had an exceptionally productive series of discussions on energy matters: gas, oil and nuclear energy, as well as our efforts, on both sides, to deal with barriers to trade and investment. In this, I think the Prime Minister will agree with me when I say that we owe much to the experience and suggestions that the American business community has brought to us during these sessions. We really welcome the input of business, and expect to work directly with companies through the joint U.S.- Russian Business Development Committee chaired on the U.S. side by Commerce Secretary Brown and on the Russian side by Deputy Prime Minister Shokhin. Ultimately, it will be the American business community and not just the American government, that supplies the capital and technology Russia needs to continue its long-term reforms.

I would like to outline a few of our accomplishments on the energy side: we will be working closely with Russia and our own business communities to complete the many U.S. private sector oil and gas deals that are ready to go. We were able, I'm pleased to say, to agree to two specific projects relating to the private sector. In one, the Overseas Private Investment Corporation will provide $28 million in guaranty and insurance support for Texaco's $80 million oil well restoration project in Western Siberia. In another, OPIC and the Russian State Investment Corporation are together supporting a new Investment Fund, managed by Paine Webber. These investments — $50 million from OPIC and $25 million from Russia — are for a private investment fund that is a model for the joint cooperation that we are trying to achieve.

We will work very hard to expand our energy trade and investment. We have agreed that each of our governments will name an ombudsman — one American and one Russian — who will work full time to identify and overcome obstacles to specific investment and trade projects. At the same time, Energy Secretary O'Leary will be working with her counterpart, Minister Shafrannik, to define new policies that will encourage cooperation in energy.

Finally, we agreed to launch an important joint study on nuclear reactor safety issues. This study will add to the fund of knowledge that has been accumulated in the past few years and will help us to plan the most productive areas for joint work on nuclear safety issues. I especially appreciate the Prime Minister's personal commitment to enhance the safety of his nation's nuclear plants.

The Prime Minister and I have agreed in the course of our meetings that the commission should specifically focus its work on two other very important subjects: the environment, and science. We will be organizing two groups to carry forward these agendas, and will see their first inputs at our next commission meeting, which will take place within the next few months. The Prime Minister has invited me to visit Russia this fall, and I look forward to doing so.

In conclusion, I would like to extend my thanks to the many people on both the U.S. and Russian side who have made this meeting possible. Mr. Prime Minister, if its beginning foretells the future, this Commission will be one of the most productive engines that we have to propel us forward into new areas of cooperation and partnership. I welcome the challenge, as I know you do, and I heartily look forward to working with you.

The White House

Office of the Vice President

FOR IMMEDIATE RELEASE September 2, 1993

Joint Statements on Space Cooperation, Aeronautics and Earth Observation

Vice President Al Gore and Russian Prime Minister Victor Chernomyrdin issued three joint statements today in the areas of space and aeronautical cooperation. Through our high-technology partnership, the U.S. and Russia will work to realize new technological advances, productivity gains and cost savings. These joint statements create a framework and a strategy for cooperation in these important high-technology areas.

Joint Statement on Cooperation in Space

In a joint statement signed at the conclusion of the first meeting of the U.S.-Russian Joint Commission on Energy and Space, Vice President Gore and Prime Minister Chernomyrdin agreed to combine our considerable experience and resources in space to carry out a large-scale program of scientific, technical, and technological research. Both sides agreed that significant mutual benefits could be achieved through cooperation in space science and exploration activities.

Through the joint statement, the U.S. and Russian have agreed to begin the first phase of space cooperation immediately. This phase will expand cooperation involving the U.S. Space Shuttle and the Russian Mir Space Station. A second phase will provide an interim human-tended space science capability, by utilizing a Mir module with a U.S. laboratory module and the U.S. Space Shuttle. It also will provide practical experience in the use of different transportation systems, performance of complex construction and assembly efforts, and command and control.

All planned U.S.-Russian space cooperation programs are interconnected and have the common goal of creating an effective space-based scientific research complex earlier and with less cost than if undertaken separately. The United States and Russia are convinced that a unified Space Station can offer significant advantages to all concerned, including current U.S. partners — Canada, Europe and Japan. The U.S. and Russia will jointly develop a detailed plan of activities for such a Space Station. This plan will serve as the basis for early review and decision within each government and as the basis for consultation with their current international partners.

Joint Statement of the Development of Cooperation in Environmental Observations from Space and Space Science

The Vice President and Prime Minister Chernomyrdin agreed that the U.S. and Russia will examine the enormous potential and mutual benefit of expanding cooperation in environmental observations from space and in space science. The joint statement highlights the importance each country attaches to bilateral and multilateral cooperation in the fields of space-based Earth observation, environmental monitoring and space science and the benefits to be gained from such cooperation by both sides.

To advance U.S.-Russian partnership in this area, we will conduct a joint study to determine the feasibility of cooperative programs in environmental observations from space and in space science. The study will be conducted by NASA, the National Oceanic and Atmospheric Administration (NOAA), and the Russian Space Agency, under the auspices of the 1992 U.S.-Russian Space Cooperation Agreement. It is to be completed by November 1, 1993.

Joint Statement on Cooperation in Aeronautical Sciences

The Vice President and Prime Minister Chernomyrdin agreed that the U.S. and Russia will undertake new cooperation in the area of fundamental aeronautical sciences. To this end, the U.S. and Russia will negotiate a Memorandum of Understanding (MOU) on Cooperation in Aeronautical Sciences between NASA and the Russian State Committee for Defense Industries (Roskomoboronprom).

Later this month, a delegation of NASA specialists will travel to Russia to meet with Russian officials and visit technical institutes which may be involved in the agreed-upon activities. The delegation will identify specific projects and joint research activities of mutual interest and discuss the potential establishment of a U.S.-Russian Joint Working Group in Aeronautical Sciences to manage the cooperative relationship. It is expected that these negotiations will be completed in time to allow the new agreement to be signed and enter into force by November 1, 1993.

FACT SHEET

Joint U.S.-Russian Energy and Investment Agreements

Vice President Gore and Russian Prime Minister Chernomyrdin, co-chairs of the U.S.-Russian Joint Commission on Energy and Space, signed several important agreements today at the end of their two-day meeting to promote greater U.S.-Russian cooperation in energy and space. These agreements represent our joint intention to strengthen economic cooperation and significantly increase trade and investment, especially in energy-related projects. The agreements will also help to bolster Russia's move to privatize major areas of its economy and increase joint cooperation between our two governments, as well as our private sectors.

The Overseas Private Investment Corporation (OPIC) announced two major projects for Russia, demonstrating the Administration's commitment to further assist Russia's efforts to implement economic reforms. OPIC President Ruth R. Harkin and Deputy Prime Minister Aleksandr Shokhin signed the first-ever U.S.-Russian Investment Fund. This $100 million project will support the privatization process in Russia and provide substantial equity investment to new, emerging businesses. The fund is expected to generate over five times the initial amount of investment in the Russian economy, roughly half a billion dollars, while also creating investment opportunities for U.S. businesses. OPIC will provide a $50 million loan guarantee with Paine Webber, who will manage the fund, and the Russian Government has agreed to contribute $25 million.

OPIC signed an additional agreement providing $28 million in loan guarantees and insurance for Texaco's $80 million project to restore oil wells in Russia's Western Siberia region. The Administration is hopeful this and similar efforts will help the Russians to begin rebuilding their energy sector by restoring and increasing vital oil exports.

A Memorandum of Cooperation in the Field of Fossil Energy, signed by Secretary of Energy O'Leary and the Russian Minister of Fuels and Energy Yuriy Shafranik, will facilitate cooperation in fossil energy development. Through this agreement the U.S. and Russia will work jointly in four major areas: to identify improved technologies for supplying residential and industrial energy needs; to develop environmental remediation technologies by transferring U.S. know-how and technology which may improve Russia's environmental protection measures; to conduct joint research and development for improving the production and distribution methods of non-nuclear energy sources; and to provide recommendations to commercialize and privatize Russian facilities.

EXIMBANK and the Russian Ministry of Finance signed a memorandum of understanding that will lead to an expansion of the range of exports to Russia currently financed by EXIMBANK. Signed by EXIMBANK Chairman Kenneth D. Brody and Russian First Deputy Minister of Finance Andrey Vavilov, the memorandum outlines the principles to be included in a Project Finance Agreement currently under negotiation which would allow EXIMBANK to expand the scope of trade relations between the U.S. and Russia to new oil and gas projects, as well as projects in other promising sectors. We believe this is one of many steps the Russians have taken to demonstrate their continued commitment to promote market reform and encourage further privatization.

United States-Russian Joint Commission on Energy and Space

Joint Statement on the Development of Cooperation in Environmental Observations from Space and in Space Science

Having reviewed the status of the Agreement between the United States of America and the Russian Federation Concerning Cooperation in the Exploration and Use of Outer Space for Peaceful Purposes dated June 17, 1992, the Parties agree that it would be mutually beneficial to examine expanded cooperative activities in Environmental Observations from Space and in Space Science.

Given the particular importance to Russia and the United States of their current efforts to understand the scientific basis for global environmental change and to conduct scientific exploration to expand human understanding of the origin and nature of the solar system and universe, the parties consider further cooperation in this area as most important and consistent with the interests of both Russia and the United States, as well as the entire international community.

With this in mind, the U.S. and Russia will ask the Joint Working Groups established under the 1992 Space Cooperation Agreement to initiate a study to define and determine the feasibility of cooperative programs in Environmental Observations from Space and in Space Science. This joint study shall be pursued in accordance with the following principles:

- joining on a mutually beneficial basis the resources, and the scientific and technical potential and experience of Russia and the United States in Environmental Observation from Space and Space Sciences;

- committing to the full and open sharing of civil space-based and in situ data for the purposes of Environmental Monitoring and Global Change Research;

- working with current international partners (in coordination mechanisms such as the Committee on Earth Observation Satellites), and bilaterally in the U.S.-Russian Joint Working Groups on Solar System Exploration, Astronomy and Astrophysics, Solar-Terrestrial Physics, Earth Sciences, Mission to Planet Earth (including the Subgroup on Operational Satellites Systems and Data Exchange), and Space Biomedical and Life Support Systems, and consistent with existing international obligations assumed by each of the Parties:

- seeking to expand U.S.-Russian cooperation in Environmental Observations from Space and in Space Science with a goal to increase international cooperation to minimize cost, decrease duplication, and increase the scope and effectiveness of research in these disciplines.

The Parties hereby instruct the National Aeronautics and Space Administration, the Russian Space Agency, the National Oceanographic and Atmospheric Administration, the Russian Federal Hydrometeorological and Environmental Monitoring Service, the Ministry of Environmental Protection and Natural Resources of the Russian Federation, the Russian Academy of Sciences, and other relevant entities to undertake, in pursuance of this Joint Statement, the planned studies that will define development of the specific projects involving both countries' firms and organizations, being guided by the above principles and provisions and by existing agreements of both nations with their international partners, with a completion date for the studies not later than November 1, 1993.

United States-Russian Joint Commission on Energy and Space

Joint Statement on Cooperation in Space

Having reviewed the status of the Agreement between the United States of America and the Russian Federation Concerning Cooperation in the Exploration and Use of Outer Space for Peaceful Purposes dated June 17, 1992, the Parties note with satisfaction past agreement on the following: the flight of a Russian cosmonaut on the Space Shuttle System in 1993 and 1994, and American astronauts on the MIR station, the docking and a joint flight of these two space complexes in 1995. These activities are consistent with the national space programs of both countries and the overall development of a spirit of trust, partnership, and long-term political and scientific and technological cooperation between Russia and the United States.

Based on the agreement reached at a meeting of the U.S. and Russian Presidents in Vancouver on April 3-4, 1993 and June 17, 1992, the Parties see great promise and mutual benefit through cooperation in space science and exploration activities.

Given the particular importance for Russia and the U.S. of their respective efforts in developing a new generation of orbital stations for scientific and technological progress and human activities in space, the Parties regard further cooperation in this area as most important, and consistent with the interests of both Russia and the U.S. as well as the broader international community.

With this in mind it is the intent of the U.S. and Russia to undertake a cooperative human space flight program. Interim investigation has already indicated potential advantages-of joint cooperative activities in a truly international space station program. The parties intend to pursue such cooperation in accordance with the following principles:

- joining on a mutually beneficial basis the resources and the scientific, technological, and industrial potentials of Russia and the U.S. in space activities to carry out a large-scale program of scientific, technical, and technological research;

- working with each of our current partners, and in accordance with earlier international obligations assumed by each of the parties under the Freedom and MIR projects:

- operating in an orbit which is accessible by both U.S. and Russian resources;

- utilizing compatible service systems, enhancing reliability of the station and increasing the flexibility of transportation and technical maintenance:

- performing activities under cooperative programs on mutually beneficial terms, and including on a contract basis the procurement of individual systems and units or the provision of services.

The first phase of our joint programs begins immediately and is designed to form a basis for resolution of engineering and technical problems. This initial phase encompasses an expansion of our bilateral program involving the U.S. Space Shuttle and the Russian MIR Space Station. The MIR will be made available for U.S. experiments for up to two years of total U.S. astronaut stay time. The number of Space Shuttle flights and the length of crew stay time will depend upon the details of the experiments to be defined by November 1, 1993. During phase one, the use of the Russian modules "Priroda" and "Spektr," equipped with U.S. experiments, could undertake a wide-scale research program. These missions will provide valuable in-orbit experience in rendezvous, docking, and joint space-based research in life sciences, microgravity, and Earth resources. It will bring to reality performance of large-scale space operations in the future. The Parties consider it is reasonable to initiate in 1993 the joint development of a solar dynamic power system with a test flight on the Space Shuttle and MIR in 1996, the joint development of environmental control and life support systems, and the joint development of a common space suit.

Subsequent joint efforts on the second phase will be directed to the use of a Russian MIR module of the next generation, in conjunction with a U.S. laboratory module and the U.S. Space Shuttle. This facility would provide an interim human-tended space sciences capability where significant scientific experimentation can take place in a microgravity environment and also provide practical experience gained out of the use of different transportation systems (including the U.S. Space Shuttle and the Russian Proton), performance of complex construction and assembly efforts and command and control process of orbital structure of considerable complexity. Successful implementation of this phase could constitute a key element of a truly international space station.

It is envisioned that the U.S. will provide compensation to Russia for services to be provided during phase one in the amount of $100 million dollars in FY 1994. Additional funding of $300 million dollars, for compensation of phase one and for mutually agreed upon phase two activities, will be provided through 1997. This funding and appropriate agreements will be confirmed and signed by no later than November 1, 1993. Other forms of mutual cooperation and compensation will be considered as appropriate.

All the above programs are mutually connected and are considered as a single package, the main goal of which is to create an effective scientific research complex earlier and with less cost than if done separately. The parties are convinced that a unified Space Station can offer significant advantages to all concerned, including current U.S. partners, Canada, Europe, and Japan.

The precise planning process and organization of drafted phases of joint activity will give the opportunity to benefit both countries through expanded cooperative efforts on the space station project.

The Parties hereby instruct NASA and RSA, in pursuance of this Joint Statement, to develop by November 1, 1993, a detailed plan of activities for an international space station. This will serve as the basis for early review and decision within each government and as the basis for consultations with the international partners. Upon conclusion of the process of government approval and consultation, appropriate implementing agreements will be signed. NASA and RSA will include within the plan overall configuration, volumes, and forms of contributions and mutual compensation for Russian and U.S. activities.

FACT SHEET

U.S.-Russian Commerical Space Launch Agreement

Vice President Gore and Prime Minister Chernomyrdin signed an agreement today between the United States and the Russian Federation regarding commercial space launch services. The agreement opens the international commercial space launch market, hitherto limited to U.S., European and Chinese launch service providers, to Russia. The Russian space launch industry, with its strong performance record, should find a ready market for its services. We also believe this agreement is a first step toward Russian entry into other high-technology international markets.

The agreement establishes basic rules for the commercial space launch market concerning government involvement in such areas as subsidies, marketing inducements and corrupt business practices. Russian commercial space launch providers will be able to compete for contracts to launch up to eight telecommunications satellites, in addition to the INMARSAT 3 satellite, to geosynchronous earth orbit for international customers until December 31, 2000. Up to four launches may be of two satellites, and these may be counted as one, if the parties mutually agree that market conditions warrant such treatment. Russia will also be able to provide three launches (of seven satellites each) to low earth orbit for the Iridium system. Russian proposals for additional launches to low earth orbit will be reviewed by the parties and decided by mutual agreement as this unpredictable market segment develops.

The agreement obligates Russia to charge prices for its launch services comparable to Western prices for comparable services. Prices more than 7.5 percent below the lowest Western bid for launches to geosynchronous earth orbit would trigger consultations in which the Russians would need to explain why such a price was comparable to Western prices.

Other provisions of the agreement include information exchange, a mid-term review, annual consultations on its operation and urgent consultations on bids suspected of being out of compliance with the agreement. An "anti-bunching" provision prevents more than two launches under the agreement in a 12-month period. The agreement requires the U.S. to exercise "best-efforts" to issue export licenses for operations under the agreement, but the U.S. reserves its right to deny export licenses or impose sanctions when required under U.S. law. The parties may terminate the agreement by mutual consent.

FACT SHEET

U.S.-Russian Missile Export Controls Agreement

Vice President Gore and Prime Minister Chernomyrdin signed a Memorandum of Understanding on Missile-Related Exports today, at the conclusion of the inaugural meeting the U.S.-Russian Joint Commission on Space and Energy. The agreement illustrates our mutual commitment to promoting non-proliferation and effective export controls. It provides a strong foundation upon which we will continue to build our partnership with Russia in space cooperation and other areas of mutual interest.

The U.S. and Russian reached an agreement on missile export controls on July 15. This agreement cleared the way for an expanded partnership on proliferation issues and in space cooperation. In the Memorandum of Understanding (MOU), Russia agreed to conduct its missile-related exports according to the criteria and standards of the multilateral Missile Technology Control Regime (MTCR). This formal commitment on the part of Russia met a major objective of the U.S. and the 22 other members of the MTCR. We also reached an understanding on the disposition of Russia's cryogenic rocket engine contract with India. We expect a final arrangement on this issue to be reached by the beginning of next year.

Russia's commitment to abide by the criteria and standards of the MTCR is a welcome and important step that shows its readiness to be a responsible partner in the sale of high-technology goods and services.

United States-Russian Joint Commission on Energy and Space

Joint Statement on Cooperation in Aeronautical Sciences

The United States and the Russian Federation have agreed in principle to undertake new cooperation in the area of fundamental aeronautical sciences.

As part of the U.S.-Russian Joint Commission on Energy and Space, co-chaired by Vice President Gore and Prime Minister Chernomyrdin, the two sides agreed to take concrete steps to complete the framework for new cooperative research in fundamental aeronautical sciences, utilizing the complementary capabilities, facilities and talents of each side.

The Commission agreed that cooperation will take place through a variety of mechanisms, including cooperative scientific research projects, cooperative utilization of test facilities and test articles, jointly-sponsored scientific conferences, symposia and workshops, and exchanges of data, information and documentation. Areas that were noted as particularly promising included hypersonic research, transition and turbulence, thermal protection system materials, chemically reacting flows, and composite structures and materials, including computational modelling.

In order to arrive at a concrete agreement on the framework for cooperation in fundamental aeronautical sciences, the Commission agreed that a delegation of specialists from the National Aeronautics and Space Administration will travel to Russia during the month of September 1993 for the purpose of holding technical discussions, with ROSKOM OBORONPROM. These discussions will be for the purpose of identifying specific projects and joint research activities to be pursued over the next several years between the two countries. The delegations will also discuss the establishment of a U.S.-Russian Joint Working Group in Aeronautical Sciences to manage the cooperative relationship.

The Commission also agreed that following the September 1993 meeting of technical specialists, representatives will meet in Washington, D.C., for negotiations on the text of a Memorandum of Understanding on Cooperation in Aeronautical Sciences between the National Aeronautics and Space Administration and ROSKOM OBORONPROM. It is expected that these negotiations will be completed in time to permit the new agreement to be signed and enter into force by November 1, 1993.

Glossary

AAS	Advanced Automation System
AASE	Airborne Arctic Stratospheric Expedition
ABM	Anti-Ballistic Missile
ACARS	Arinc Communications Addressing and Reporting System
ACDA	Arms Control and Disarmament Agency
ACRIM	Active Cavity Radiometer Irradiance Monitor
ACRV	Advanced Crew Return Vehicle
ACT	Advanced Composite Technology
ACTS	Advanced Communications Technology Satellite
Ada	A programming language used by the DoD
ADAS	AWOS Data Acquisition System
ADEOS	(Japanese) Advanced Earth Observing Satellite
ADP	Advanced Ducted Propeller; Automated Data Processing
AEM	Animal Enclosure Modules
AESOP	ARGOS Environmental Shipboard Observer Platform
AFB	Air Force Base
AFSC	Alaska Fisheries Science Center
AFSCN	Air Force Satellite Control Network
AFTI	Advanced Fighter Technology Integration
AFW	Active Flexible Wing
AGFS	Aviation Gridded Forecast System
AGRHYMET	AGRiculture, HYdrology, and METeorology
AIDA	Arecibo Initiative on Dynamics of the Atmosphere
AIDS	Acquired Immune Deficiency Syndrome
AKM	Apogee Kick Motor
albedo	The ratio of the amount of electromagnetic radiation reflected by a body to the amount incident upon it
ALEXIS	Array of Low Energy X-ray Imaging Sensors
ALOHA	Airborne Lidar and Observations of Hawaiian Airglow
AMASS	Airport Movement Area Safety System
AMOS	Air Force Maui Optical System
AMSC	American Mobile Satellite Corporation
anechoic	Neither having nor producing an echo
angle of attack	The acute angle between the chord of an airfoil and its direction of motion relative to the air, often referred to as "alpha"; when an airfoil's angle of attack exceeds the one that provides maximum lift, it goes into a stall, losing airspeed and potentially, the capability of the pilot to control the airplane
AOA	Angle of Attack
APCG	Advanced Protein Crystal Growth
APE-B	Auroral Photography Experiment-B
APM	Ascent (or Atmospheric) Particle Monitor
APT	Automatic Picture Transmission—a low-cost ground terminal for receiving data from polar orbiting satellites, developed by NASA
ARFF	Aircraft Rescue and Firefighting

Arinc	Aeronautical Radio, Inc
ARPA	Advanced Research Project Agency (formerly Defense Advanced Research Project Agency)
ARS	Agricultural Research Service
ARTCC	Air Route Traffic Control Center
ASAT	Anti-Satellite
ASD	Aircraft Situation Display
ASF	Area Sampling Frames
ASI	Acronym for the Italian Space Agency
ASOS	Automated Surface Observing System
ASR	Airport Surveillance Radar
ASRM	Advanced Solid Rocket Motor
ASTP	Advanced Space Technology Program; Apollo-Soyuz Test Project
Astro	Astronomy Observatory
astronomical unit	A measure for distances in space, equal to the mean distance of the Earth from the sun, i.e., 93,000,000 miles (149,599,000 kilometers)
ATIS	Automatic Terminal Information Service
ATLAS	Atmospheric Laboratory for Applications and Science
ATMS	Advanced Traffic Management System
ATN	Aeronautical Telecommunications Network
ATP	Advanced Turboprop
Auto GCAS	Automatic Ground Collision Avoidance System
AVHRR	Advanced Very High Resolution Radiomet
AWOS	Automated Weather Observing System
AXAF	Advanced X-ray Astrophysics Facility
baseband processor	A computer processor similar in function to a telephone switching office
BATSE	Burst and Transient Source Experiment
BBXRT	Broad Band X-Ray Telescope
BIMDA	Bioserve ITA Materials Dispersion 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.
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.
BMD	Ballistic Missile Defense
BMDO	Ballistic Missile Defense Organization, formerly SDIO
canard	An aircraft or aircraft configuration having its horizontal stabilizing and control surfaces in front of the wing or wings
carbon-carbon	In one application, an improved form of disk brakes featuring carbon rotors and carbon stators in place of the beryllium formerly used
CASA	Controller Automation Spacing Aid
CASS	Computer Aided Stratification and Sampling
Cassini	A Saturn Orbiter/Titan Probe
CAT	Clear Air Turbulence
CCAFS	Cape Canaveral Air Force Station
C-CAP	CoastWatch-Change Analysis Program
CCDS	Center for the Commercial Development of Space

CCL	Commodity Control List
CCSDS	Consultative Committee for Space Data Systems
CD-ROM	Compact Disk-Read Only Memory
CEDAR	Coupling, Energetics, and Dynamics of Atmospheric Regions
CEES	Committee on Earth and Environmental Sciences
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFD	Computational Fluid Dynamics
CGMS	Coordination Group for Meteorological Satellites
CELLS	Controlled Ecological Life Support System
CEOS	Committee on Earth Observations Satellites
CEPS	Center for Earth and Planetary Studies
CFC	Chlorofluoro-carbon
CGF	Crystal Growth Facility
CGMS	Coordination Group for Meteorological Satellites (formerly, the Coordination of Geostationary Meteorological Satellites group)
CINC	Commander-in-Chief
CIP	Capital Investment Plan
CIRA	Cooperative Institute for Research in the Atmosphere
CIRRIS	Cryogenic Infrared Radiance Instrumentation for Shuttle
CIS	Commonwealth of Independent States, a grouping of now independent states formerly part of the Soviet Union
CITE	Cargo Interface Test Equipment
CLAES	Cryogenic Limb Array Etalon Spectrometer
CMC	Center for Macromolecular Crystallography (at the University of Alabama at Birmingham)
CNES	Acronym for the French Space Agency
COARE	Coupled Ocean-Atmosphere Response Experiment
COBE	Cosmic Background Explorer
COMET	COMmercial Experiment Transporter
COMPTEL	Compton Telescope
COPUOS	(U.N.) Committee on the Peaceful Uses of Outer Space
COSMIC	Computer Software Management Information Center
cosmic rays	Not forms of energy, like X-rays or gamma rays, but particles of matter
COSPAS	A Soviet satellite used for search and rescue
COSTR	Collaborative Solar-Terrestrial Science
CRAF	Comet Rendezvous Asteroid Flyby
CRDA	Converging Runway Display Aid
CREAM	Cosmic Radiation Effects and Activation Monitor
CRO	Chemical Release Observation
CRRES	Combined Release and Radiation Effects Satellite
CRS	CoastWatch Regional Site
CSA	Canadian Space Agency
cryogenic	Very low in temperature
CSCC	Concurrent Supercomputing Consortium
CTAS	Center-TRACON Automation System
CTR	Civil Tiltrotor
CTV	Cargo Transfer Vehicle
CWG	Council Working Group (of INMARSAT)

DARPA	See ARPA
dB	Decibel
DBS	Direct Broadcast Satellite
DCS	Data Collection System
DE	Directed Energy
Dem/Val	Demonstration/Validation
DLC	Diamond-Like-Carbon
DMSP	Defense Meteorological Satellite Program—DoD's polar orbiting weather satellite system
DNA	Defense Nuclear Agency
DoC	Department of Commerce
DoD	Department of Defense
DoE	Department of Energy
DoI	Department of Interior
DOLILU	Day-of-Launch I-Load-Update
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
DST	Defense and Space Talks
EAFB	Edwards Air Force Base
ECS	EOSDIS Core System
EDFE	EVA Development Flight Experiments
EDMS	Emissions and Dispersion Modeling System—an EPA-approved computer model for the assessment of air quality around airports
EDO	Extended Duration Orbiter
EDOMP	Extended Duration Orbiter Medical Program
EFM	Enhanced Fighter Maneuverability
EGRET	Energetic Gamma Ray Experiment Telescope
EHF	Extremely High Frequency, between 30,000 and 300,000 megacycles per second
EIS	Environmental Impact Statement
electromagnetic	A collective term for all known radiation spectrum from the shortest-waved gamma rays through x-rays, ultraviolet, visible light, infrared waves, to radio waves at the long-waved end of the spectrum
ELV	Expendable Launch Vehicle
EMAP	Environmental Monitoring and Assessment Program
EMSL-LV	Environmental Monitoring Systems Laboratory in Las Vegas, NV—part of the EPA
enthalpy	The heat content of a system undergoing change
envelope	The operational parameters within which an aircraft can fly
EO-ICWG	Earth Observations-International Coordination Working Group
EOS	Earth Observing System—a series of satellites, part of the Mission to Planet Earth, being designed for launch beginning near the end of the decade to gather data on global change
EOSDIS	EOS Data and Information System
EOSAT	Earth Observation Satellite Company
EPA	Environmental Protection Agency

EPIC	Environmental Photographic Interpretation Center
EPIRB	Emergency Position-Indicating Radio Beacons
EPM	Enabling Propulsion Materials
EPRI	Electric Power Research Institute
ERBE	Earth Radiation Budget Experiment
ERBS	Earth Resources Budget Satellite
ERIM	Environmental Research Institute of Michigan
EROS	Earth Resources Observation System
ERS	European Space Agency Remote Sensing Satellite
ERTS	Earth Resources Technology Satellite
ESA	European Space Agency
E-scan	Electronically scanned
EUMESAT	European Organization for the Exploitation of Meteorological Satellites
EURECA	European Retrievable Carrier
EUVE	Extreme Ultraviolet Explorer
EVA	Extra-vehicular Activity
F	Fahrenheit
FAA	Federal Aviation Administration
FAEED	FAA Aircraft Engine Emissions Database, which contains emissions factors for various aircraft engines and data correlating engines to specific aircraft
FAS	Foreign Agricultural Service
FASA	Final Approach Spacing Aid
FAST	Fast Auroral Snapshot
FBW/FBL	Fly-by-wire/fly-by-light
FCCSET	Federal Coordinating Council on Science, Engineering, and Technology
FDF	Flight Dynamics Facility
Floquet theory	A method of solving a second-order differential equation
FLTSATCOM	Fleet Satellite Communications System
FRED	FAA Research Electromagnetic Database
FSAR	Final Safety Analysis Report
FTS	Flight Telerobotic Servicer
fuel cladding	A coating designed to contain fission products released in nuclear fuel
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	Cosmic rays with energy levels as high as tens rays of billions of electron volts and velocities approaching the speed of light
gamma rays	The shortest of electromagnetic radiations, emitted by some radioactive substances
GAS	Get Away Special
GBI	Ground Based Interceptor
GCDIS	Global Change Data and Information System
GD	General Dynamics
GDR	Geophysical Data Records
GEM	Geospace Environment Modeling
geoid	The figure of the Earth as defined by the geopotential surface that most nearly coincides with mean sea level over the entire surface of the planet's contiguous bodies of water

Geosat	Geodetic and Geophysical Satellite
Geostar	A private firm providing a satellite tracking service
geostationary	Travelling about Earth's equator at an altitude of at least 35,000 km and at a speed matching that of Earth's rotation, thereby maintaining a constant relation to points on Earth
geosynchronous	geostationary
GETSCO	General Electric Technical Services Co Inc
GFO	Geodetic/Geophysical Follow-on (program)
GFS	Generic Flight System
GGS	Global Geospace Science
GGSF	Gas-Grain Simulation Facility
GHRS	Goddard High Resolution Spectrograph
GHz	Gigaherz (one billion cycles per second)
GIS	Geographic Information System
GLITeC	Great Lakes Industrial Technology Center
GLONASS	(Soviet) Global Navigation Satellite System
glove	In relation to laminar flow control, a suction device employing tiny, laser-drilled holes to draw off turbulent air and produce a smooth (laminar) flow of air over an aircraft's wing
GMDSS	Global Maritime Distress and Safety System
GMT	Greenwich Mean Time
GOES	Geostationary Operational Environmental Satellite
GPALS	Global Protection Against Limited Strikes
GPHS	General Purpose Heat Source
GPS	Global Positioning System
GRO	Gamma Ray Observatory
ground effect	The temporary gain in lift during flight at very low altitudes due to the compression of the air between the wings of an airplane and the ground
GSA	General Services Administration
GSFC	Goddard Space Flight Center
GTS	Global Telecommunications System
GVI	Global Vegetation Index
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.
HALOE	Halogen Occultation Experiment
HANG	High Alpha Nose-down Guidelines
HAPS	Hydrazine Auxiliary Propulsion System
HARV	High Angle-of-Attack Research Vehicle
HAX	Haystack Auxiliary Radar
HDTV	High Definition Television
HEAO	High Energy Astronomy Observatory
HESP	High-Energy Solar Physics
HIDEC	Highly Integrated Digital Electronic Control
high-alpha	High angle of attack
high-bypass engine	A turbo-engine having a by-pass ratio of more than four to one, the by-pass ratio being the proportion of air that flows through the engine outside the inner case to that which flows inside that case

HIRF	High Intensity Radiation Field
HIRIS	High Resolution Imaging Spectrometer
HLFC	Hybrid Laminar Flow Control
HPCC	High Performance Computing and Communications
HRDI	High Resolution Doppler Imager
HSCT	High Speed Civil Transport
HST	Hubble Space Telescope
HUT	Hopkins Ultraviolet Telescope
hypersonic	Faster than Mach 4; the borderline between high speed and hypersonic is somewhat fuzzy but lies at about that velocity
IBSS	Infrared Background Signature Survey
ICAO	International Civil Aviation Organization
ICBM	Intercontinental Ballistic Missile
ICE	International Cometary Explorer
IELV	Intermediate ELV
IEOS	International Earth Observing System
IFL	Interfacility Fiber Optic Link
IFM	Internal Fluid Mechanics
IFR	Instrument Flight Rules
IHPTET	Integrated High Performance Turbine Engine Technology
I-Lab	(FAA) Integration and Interaction Laboratory
IMI	Inner Magnetosphere Imager
IML	International Microgravity Laboratory
IMO	International Maritime Organization
IMP	Interplanetary Monitoring Platform
INF	Intermediate-Range Nuclear Forces (Treaty)
INM	Integrated Noise Model—a computer tool for simulation of aircraft noise
INMARSAT	International Maritime Satellite (Organization)
INTELSAT	International Telecommunications Satellite (Organization)
interferometry	The production and measurement of interference from two or more coherent wave trains emitted from the same source
IOC	Initial Operational Capability
ionosphere	That region of the Earth's atmosphere so named because of the presence there of ionized atoms in layers that reflect radio waves and shortwave transmissions
IPMP	Investigations into Polymer Membrane Processing
IPOMS	International Polar Orbiting Meteorological Satellite Group
IR	Infrared
IRAS	Infrared Astronomy Satellite
IRT	Icing Research Tunnel
ISAC	Intelsat Solar Array Coupon
ISAMS	Improved Stratospheric and Mesospheric Sounder
ISAS	(Japanese) Institute of Space and Astronautical Science
ISB, TW/AA	Improved Space-Based, Tactical Warning/Attack Assessment (formerly, Follow-on Early Warning System—FEWS—a successor to DSP)
ISO	International Organization for Standardization
ISTP	International Solar-Terrestrial Program
ISY	International Space Year (1992)

ITA	Instrumentation Technology Associates
ITO	International Test Organization
ITP	Integrated Technology Plan
ITU	International Telecommunication Union, an intergovernmental organization founded in 1865 that became a specialized agency of the United Nations in 1947
ITWS	Integrated Terminal Weather System
IUE	International Ultraviolet Explorer
IUS	Inertial Upper Stage
IV&V	Independent Validation and Verification
IWG	Intersessional Working Group (of INMARSAT)
JEM	Japanese Experiment Module
JGOFS	Joint Global Ocean Flux Study
Josephson effect	The radiative effect associated with the passage of electron pairs across an insulating barrier separating two superconductors
Josephson junction	The weak connections between superconductors through which the Josephson effects occur
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
Ka-band components	Components to receive and transmit a new, high radio frequency
KaBLE	Ka-band Link Experiment
KAO	Kuiper Airborne Observatory—a C-141 Starlifter at Ames Research Center, equipped with a 0.97-meter telescope
KE	Kinetic Energy
Kelvin	Temperature scale in which absolute zero is 0° and water freezes at 273.16°
KSC	Kennedy Space Center
Ku-band	Radio frequencies in the 11-12 gigaherz range
kWe	Kilowatts of electrical (power)
LAGEOS	Laser Geodynamic Satellite
laminar	Of fluid flow, smooth, as contrasted with turbulent; not characterized by crossflow of fluid particles
Landsat	Also known as ERTS, a series of satellites designed to collect information about the Earth's natural resources
LANL	Los Alamos National Laboratory
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
LEAP	Lightweight Exo-Atmospheric Projectile
LEO	Low Earth Orbit (100 to 350 nautical miles above the Earth)
LEOEX	Low Earth Orbit Experiment
LEX	Leading Edge eXtension
LFC	Laminar Flow Control
LfA	Laboratory for Astrophysics
Lidar	Light radar
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
lift/drag ratio	The ratio of the lift to the drag of any body, especially an airfoil; it is the measure of the aerodynamic effectiveness of the wing or airfoil

lightsats	Light-weight satellites
LiH	Lithium hydride
LLWAS	Low Level Windshear Alert System
Loran	Long-range navigation—a two-dimensional, pulse-synchronized radio navigation system to determine position through pulse-time differencing from a master compared to two slave stations; it uses the frequency band 1.7 to 2.0 megacycles.
Loran-C	A Loran system that uses transmission at 100 kilocycles; the C stands for Cytac.
LOX	Liquid oxygen
low by-pass engine	A turbo-engine having a by-pass ratio of less than four to one—see high by-pass engine
low-Earth orbit	An orbit of the Earth some 100 to 350 nautical miles above its surface
LWIR	Long-Wavelength Infrared
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° F and at sea level, for example, Mach 1 = approximately 741 mph or 1,192 kilometers per hour.
Mach	See M
MACSAT	Multiple Access Communications Satellite
magnetosphere	The region of the Earth's atmosphere where ionized gas plays an important role in the dynamics of the atmosphere 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, radio and television communication
mbps	megabits per second
MBR	Mars Balloon Relay
MCC	Mission Control Center
MCS	Maritime Communications Subsystem
MELV	Medium ELV
Mesopause	The layer of the Earth's atmosphere with the lowest temperature
MESUR	Mars Environmental Survey Mission
Meteosat	Meteorological satellite
MIDEX	Middle-Class Explorer
MILSATCOM	Military Satellite Communications
MLS	Microwave Limb Sounder
MMD	Mean Mission Duration
MO	Mars Observer
MOA	Memorandum of Agreement
MODE	Middeck 0-Gravity Dynamics Experiment
Mode C transponder	A radar beacon receiver/transponder capable of reporting the attitude of the aircraft aboard which it is installed
MOD-RTG	Modular Radioisotope Thermoelectric Generator
MOU	Memorandum of Understanding
MSS	Multispectral Scanner Sensors; Mobile Satellite Service
MSTI	Miniature Sensor Technology Integration

MTCR	Missile Technology Control Regime
MTD	Maneuver Technology Demonstrator
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 upon it
NAPP	National Aerial Photography Program
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NASCAP	NASA Charging Analysis Program
NASCOM	NASA Communications network
NASDA	(Japanese) National Space Development Agency
NASM	National Air and Space Museum
NASP	National Aero-Space Plane
NASS	National Agricultural Statistics Service
Navier-Stokes (equations)	Three equations that describe conservation of momentum for the motion of a viscous, incompressible fluid; developed in the nineteenth century by French engineer Claude-Louis-Marie Navier and English physicist Sir George Gabriel Stokes, who made the final derivation of the equations
NCAR	National Center for Atmospheric Research
NCC	Network Control Center
NCDC	National Climatic Data Center
NDVI	Normalized Difference Vegetation Index
NERVA	Nuclear Energy for Rocket Vehicle Applications—a program from 1961-72 to develop a nuclear rocket for post-Apollo missions
NESDIS	(NOAA) National Environmental Satellite, Data, and Information Service
NETSTAR	Network System for TV and Radio
neutron star	Any of a class of extremely dense, compact stars thought to be composed primarily of neutrons; see pulsar.
NGDC	National Geophysical Data Center
NHC	National Hurricane Center
NIH	National Institutes of Health
NIST	(DoC) National Institute of Standards and Technology
NIXT	Normal Incidence X-ray Telescope
NMC	National Meteorological Center
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration, also the designation of that administration's sun-synchronous satellites in polar orbit
NODC	National Oceanographic Data Center
nominal	Functioning as designed
NOS	National Ocean Service
NOx	Any of several compounds of nitrogen and oxygen, including nitrogen oxide
NRAO	National Radio Astronomy Observatory
NSCAT	NASA Scatterometer
NSCORT	NASA Specialized Center of Research and Training
NSF	National Science Foundation
NSSFC	National Severe Storms Forecast Center
NST	Nuclear and Space Talks

NTB	National Test Bed
NTF	National Test Facility
NTI	National Technology Initiative
NTIA	(DoC) National Telecommunications and Information Administration, the Federal Government's radio spectrum manager, which coordinated the use of LEO satellite networks like those for LANDSAT, NAVSTAR GPS, the Space Shuttle, and TIROS with other countries of the world
NTTC	National Technology Transfer Center
NUDET	Nuclear Detonation
NWS	National Weather Service
OACT	(NASA) Office of Advanced Concepts and Technology
OASC	(DoC) Office of Air and Space Commercialization
OCTW	Optical Communications Through the Shuttle Window
OLR	Outgoing Longwave Radiation
OMDP	Orbiter Maintenance Down Period
on-orbit	In orbit
order of magnitude	An amount equal to 10 times a given value; thus if some quantity was 10 times as great as another quantity, it was an order of magnitude greater; if 100 times as great, it was larger by 2 orders of magnitude.
ORFEUS-SPAS	Orbiting and Retrievable Far and Extreme Ultraviolet Spectrometer-Shuttle Pallet Satellite
OSC	(NASA) Office of Space Commerce; Office of Space Communications
OSL	Orbiting Solar Laboratory
OSSE	Oriented Scintillation Spectrometer Experiment
OSTP	Office of Science and Technology Policy
out-of-ground	See "ground effect" effect
OV	Orbiter Vehicle
PAMRI	Peripheral Adapter Module Replacement Item
PAM	Payload Assist Module
PARE	Physiological and Anatomical Rodent Experiment
PCG	Protein Crystal Growth
PEACESAT	Pan-Pacific Education and Communication Experiments by Satellite
PEM	Particle Environment Monitor
petrology	The science that deals with the origin, history, occurrence, structure, and chemical classification of rocks
piezoelectricity	The property exhibited by some asymmetrical crystalline materials that, when subjected to strain in suitable directions, develop polarization proportional to the strain
pitch-pointing	The pointing of an aircraft with respect to its pitch (its angular displacement about an axis parallel to the aircraft's lateral axis, that is, movement of the nose up or down)
pixels	Short for "picture elements," which provide image resolution in vidicon-type detectors
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
plastic media	A method of removing paint from aircraft skins blasting by propelling them with plastic beads
PLS	Personnel Launch System
PMS	Physiological Monitoring System
POAM	Polar Ozone and Aerosol Measurement
POES	Polar-orbiting Operational Environmental Satellites
polar orbit	The path of an Earth satellite that passes near or over the North and South Poles
PRA	Probabilistic Risk Assessment
PRC	People's Republic of China
PROSPER	PROgramme SPot Et Radar (the SPOT and radar program)
PSC	Performance Seeking Control
PSCN	Program Support Communications Network
PSE	Physiological Systems Experiment
Pu-238	A Plutonium isotope
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.
PVO	Pioneer Venus Orbiter
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
RAH	Reconnaissance Attack Helicopter
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
R&D	Research and Development
R&T	Research and Technology
RAWS	Remote Automatic Weather Station
RCRA	Resource Conservation and Recovery Act
real-time	Immediate, as an event is occurring
Resin Transfer Molding	A process for the fabrication of composite parts for aerospace vehicles in which a dry preform of reinforcements is placed in a mold, resin is infused by vacuum or pressure, and the part is cured in the mold
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 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.
RFI	Request for Information
RFP	Request for Proposal

RME	Radiation Monitoring Equipment
RMP	Rotorcraft Master Plan
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
Rover	After 1955, a program to develop a nuclear rocket, renamed NERVA in 1961
RSA	Russian Space Agency
RTG	Radioisotope Thermoelectric Generator
RTTC	Regional Technology Transfer Center
RTTM	Real Time Thrust Measurement
SAIN	Satellite Applications Information Notes
SAM	Shuttle Activation Monitor
SAMPEX	Solar, Anomalous, and Magnetospheric Particle Explorer
SAMS	Space Acceleration Mapping System
SAO	Smithsonian Astrophysical Observatory
SAREX	Shuttle Amateur Radio Experiment
SARSAT	Satellite Aided Search and Rescue Program
SBIR	Small Business Innovation Research
SBUV	Solar Backscatter Ultra-Violet (spectral radiometer)
SCS	Soil Conservation Service
SDI	Strategic Defense Initiative
SDIO	See BMDO
SEALAR	Sea Launch and Recovery
Seasat	Experimental oceanic surveillance satellite launched June 27, 1978; it demonstrated that much useful information about the ocean could be obtained through satellite surveillance
SeaWIFS	Sea-Viewing Wide Field Sensor
SEDS	Small Expendable Tether Deployable System
SEI	Space Exploration Initiative
SEM	Space Environment Monitor
S-GCOS	Space-based Global Change Observation System
Sgr A*	Sagittarius A*, a small but very luminous radio source located at the very center of the spiral Milky Way galaxy
SHARE	Space Station Heat Pipe Advanced Radiator Element
SIMMOD	Simulation Model
SLBM	Submarine-Launched Ballistic Missile
SMEX	Small Explorer
SIRTF	Space Infrared Telescope Facility
SLAR	Side-Looking Airborne Radar
SLC	Space Launch Complex
SLS	Space Life Sciences Laboratory or Spacelab Life Sciences
SLV	Space Launch Vehicle
SNOTEL	SNOWpack TELemetry
SOFIA	Stratospheric Observatory for Infrared Astronomy
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
SOLSTICE	Solar/Stellar Irradiance Comparison Experiment
SOLTIP	SOLar connection to Transient Interplanetary Processes
Space Test Program	A program in existence since 1965 in the DoD to test hardware in space and study the space environment
SPAS	Shuttle Pallet Satellite
SPEAR	Space Power Experiment Aboard Rocket
SPOT	Satellite Pour l'Observation de la Terre (satellite for the observation of the Earth)
SPPD	Signal Processing Packaging Design
SRA	Systems Research Aircraft
SRAM	Static Random Access Memory
SRL	Space Radar Laboratory
SRM&QA	Safety, Reliability, Maintainability, and Quality Assurance
SRMU	Solid Rocket Motor Upgrade
SSAAC	Space Science and Applications Advisory Committee
SSBUV	Shuttle Solar Backscatter Ultraviolet (spectrometer)
SSCE	Solid Surface Combustion Experiment
SSME	Space Shuttle Main Engine
SSM/I	Special Sensor Microwave/Imager
SSM/T	Special Sensor Microwave/Temperature
SSRT	Single Stage Rocket Technology (Program)
SST	Sea Surface Temperature
stall	A loss of lift by an aircraft or airfoil resulting from insufficient airspeed or excessive angle of attack, resulting in a drop of the aircraft's nose
START	Strategic Arms Reduction Treaty
STDN	Spaceflight Tracking and Data Network
STEP	Solar Terrestrial Energy Programme
STGT	Second TDRSS Ground Terminal
STEP	Space Test Program Experimental Platform
STME	Space Transportation Main Engine
STOL	Short Takeoff and Landing
STORM-FEST	Storm-Fronts Experiment Systems Test
STOVL	Short Take-off and Vertical Landing (Aircraft)
STRV	Space Technology Research Vehicle
STS	Space Transportation System, also used together with a mission number such as STS-55 to designate a particular Space Shuttle mission
STV	Space Transfer Vehicle
SunRISE	Radiative Inputs of the Sun to Earth
sunspot	A vortex of gas on the surface of the sun associated with stray local magnetic activity

SUPER	Name for a survivable solar-power subsystem demonstrator
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 luninosity ranging from 10 million to 100 million times that of our sun
SUSIM	Solar Ultraviolet Spectral Irradiance Monitor
SWAS	Submillimeter Wave Astronomy Satellite
TAAS	Terminal Advanced Automation System
TASS	Terminal Area Surveillance System
TBM	Theater Ballistic Missile
TCAS	Traffic Alert and Collision Avoidance System
TDLS	Tower Data Link Service
TDP	Telemedicine Demonstration Project
TDRS	Tracking and Data Relay Satellite
TDRSS	TDRS System
TDWR	Terminal Doppler Weather Radar
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
TIMED	Thermosphere-Ionosphere-Mesosphere Energetics and Dynamics
TIROS	Television and Infrared Operational Satellite
TM	Thematic Mapper
TNA	Thermal Neutron Analysis
TOGA	Tropical Ocean Global Atmosphere
TOMS	Total Ozone Mapping Spectrometer
TONS	TDRSS Onboard Navigation System
TOPEX	Ocean Topography Experiment
TOPS	Toward Other Planetary Systems
TOS	Transfer Orbit Stage
TOVS	TIROS Operational Vertical Sounder
TPCE	Tank Pressure Control Experiment
TPOCC	Transportable Payload Operations Control Center
TR	Thrust-reversing
TRACON	Terminal Radar Approach Control
tribology	The study of the interaction of sliding surfaces with respect to friction, wear, and lubrication
TRMM	Tropical Rainfall Measuring Mission
TSS	Tethered Satellite System
TV	Thrust-vectoring
TVCS	Thrust Vector Control System
UARS	Upper Atmosphere Research Satellite
UFO	UHF Follow-on
UHF	Ultra High Frequency, any frequency between 300 and 3,000 megacycles per second
UIT	Ultraviolet Imaging Telescope
UMS	Urine Monitoring System

UNEP	United Nations Environment Program
USAF	U.S. Air Force
USCINCSPACE	Commander-in-Chief, U.S. Space Command
USDA	U.S. Department of Agriculture
USGCRP	U.S. Global Change Research Program
USML	U.S. Microgravity Laboratory; U.S. Munitions List
USMP	U.S. Microgravity Payload
USTR	Office of the U.S. Trade Representative
UTTR	Utah Test and Training Range
UV	Ultraviolet
UVCS	Ultraviolet Coronal Spectrometer
VAFB	Vandenberg Air Force Base
VAS	Visible-and-Infrared-Spin-Scan-Radiometer Atmospheric Sounder
VCS	Voice Command System
very high frequency	Any radio frequency between 30 and 300 megacycles per second
VFC	Vortex Flow Control
viscosity	Resistance to flow or change of shape under pressure
VISSR	Visible and Infrared Spin-Scan Radiometer—an instrument on NOAA's GOES-7 satellite
VLBA	Very Long Baseline Array, a set of 10 radio telescopes in the continental U.S., Hawaii, and St. Crois
VLBI	Very Long Baseline Interferometry
VLSI	Very Large Scale Integration
VoA	Voice of America
V/STOL	Vertical/Short Takeoff and Landing
VSRA	V/STOL System Research Aircraft
WARC	World Administrative Radio Conference
WEFAX	Weather Facsimile
WGD	(CEOS) Working Group on Data
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
WINDII	Wind Imaging Interferometer
WMO	World Meteorological Organization
WSGT	White Sands Ground Terminal
WSMC	Western Space and Missile Center
WSMR	White Sands Missile Range
WSP	Windshear Processor
WSTF	White Sands Test Facility
WUPPE	Wisconsin Ultraviolet Photopolarimeter Experiment
x-rays	Radiations of very short wavelengths, beyond the ultra-violet in the spectrum
XTE	X-ray Timing Explorer

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