Aeronautics and Space Report of the President

Fiscal Year 1991 Activities

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Fiscal Year 1991 Activities

1992
National Aeronautics
and Space Administration
Washington, DC 20546

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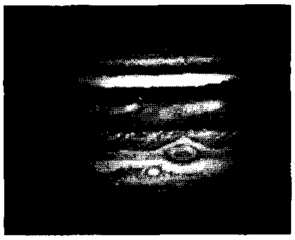
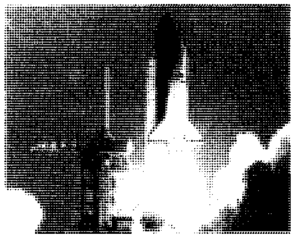
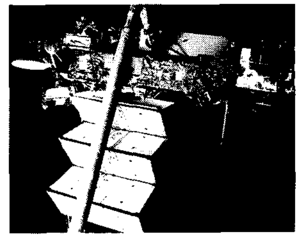
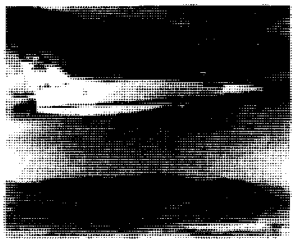
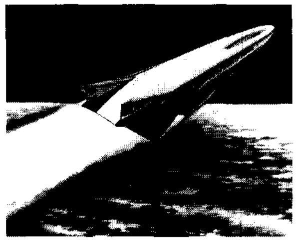
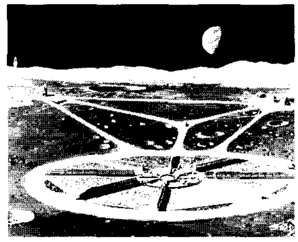







Executive Summary

Note: The National Aeronautics and Space Act of 1958 directed that the annual Aeronautics and Space Report 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, which is consistent with the budget period now used in federal government programs. The Administration will seek to work with Congress to amend the National Aeronautics and Space Act of 1958 accordingly.

Fiscal Year 1991 was a significant one for U.S. aeronautics and space efforts. It included eight Space Shuttle missions and six successful launches by the Department of Defense (DOD). The Shuttle missions included the first such mission to focus on astrophysics and the first dedicated to life sciences research. They also included a satellite launched from the Orbiter to study the unexplored polar regions of the Sun and another to collect astronomical data from gamma ray sources. Still another Shuttle mission launched a satellite to study global atmospheric change affecting our own planet. In related areas, the Department of Commerce (DOC) and other Federal agencies have likewise pursued studies of such problems as ozone depletion and the greenhouse effect. Also here on Earth, many satellites launched in FY 1991 and earlier provided vital support for the successful prosecution of Operations Desert Shield and Desert Storm to force Iraq to evacuate Kuwait. And in the aeronautical arena, efforts have ranged from the further development of the National Aero-Space Plane to broad-ranging research and development that will reduce aircraft noise and promote the increased safety of flight. In these and a great variety of other ways discussed below, the budgets for aeronautics and space—distributed among 14 different Federal agencies—have promoted significant advances in the nation's scientific and technical knowledge that promise to improve the quality of life on Earth by increasing scientific understanding, expanding the economy, improving the environment, and defending freedom.

National Aeronautics and Space Administration

Space Flight

In the area of Space Flight, the National Aeronautics and Space Administration (NASA) added a new Orbiter named Endeavour in May to the three active orbiters already in its fleet, and it did so on schedule and within budget. During the course of FY 1991, the Agency successfully completed eight Space Shuttle missions. In addition to improvements included in the design of Endeavour, NASA continued to incorporate modifications to the fleet, such as improved brakes and an improved auxiliary power unit. Some of the modifications contribute toward an Extended Duration Orbiter with a 16-day mission capability. NASA also made significant progress in work on an Advanced Solid Rocket Motor.

In cooperation with its international partners, NASA continued to develop and deploy hardware for use on Shuttle missions. For example, it made use of Spacelab carrier system hardware on the Astro-1 and Space Life Sciences-1 (SLS-1) missions. Spacelab is a reusable science observatory and laboratory flown in the Shuttle payload bay and developed by the European Space Agency. Another example of cooperatively developed hardware was the Tethered Satellite System (TSS), a facility for deploying a satellite connected by a tether to the Shuttle for distances up to 62 miles. TSS is a cooperative program between NASA and the Italian Space Agency, and the system became integrated with the Spacelab hardware during 1991.

Besides Shuttles, NASA also successfully launched two Expendable Launch Vehicles (ELVs) from the West Coast in 1991, a National Oceanic and Atmospheric Administration (NOAA) polar meteorological satellite on a United States Air Force (USAF) provided Atlas-E in May, and a USAF radiation-experiment payload on a Scout launcher in June. As part of the national policy to use a mixed fleet so as to assure access to space, NASA signed several contracts during the year for commercial ELV support, bringing to 32 the number scheduled for launch under such contracts.

In addition to conducting launches, NASA also pursued a variety of advanced program developments focused on improving U.S. space launch capabilities. One such effort initiated in 1991 is the New Launch System, a joint program with DOD. The objective of this program is to develop a launch system with reduced operating costs and improvements in reliability, responsiveness, and mission performance.

Work also continued on Space Station Freedom, a program to establish a world-class laboratory in low Earth orbit that would enable scientists to conduct a variety of life-science and materials-science experiments in the microgravity environment of space. NASA restructured the program during FY 1991 to fit within new 6-year budget guidelines provided by Congress. It completed the preliminary design review of the program, reducing the weight, power, and extravehicular-activity maintenance requirements of the Station, and it implemented the recommendations of the Advisory Committee on the Future of the U.S. Space Program as they applied to the Space Station. Other accomplishments of the program during FY 1991 included validating the solar array design for the Station, testing a prototype control moment gyro, and completion of testing for the Station's environmental control and life support system.

Finally, NASA continued to work with its international partners on the Space Station project—Europe, Canada, and Japan. Early in the fiscal year, the Space Station partners concluded an agreement on the design of payload racks to allow commonality throughout the separate laboratories (of the U.S., Europe, and Japan) to permit easy exchange and operation of research equipment. Also during the year, the four partners rehearsed the process of developing 5-year plans for Station operations and use, among other joint and cooperative activities, such as the agreement signed in 1991 with the Italian Space Agency for provision of two mini-pressurized logistics modules and potential provision of a minilaboratory in exchange for more Italian use of the Space Station.

Space Science and Applications

NASA continued its activities in the area of Space Science and Applications with the launches of the Ulysses, the Compton Gamma Ray Observatory, and the Upper Atmosphere Research Satellite (UARS), plus the flights of the Astro and Space Life Sciences missions, among others. The Ulysses mission, launched from the Space Shuttle on October 6, 1990, collected scientific data on the previously unexplored polar regions of the Sun. The Compton Observatory, deployed into Earth orbit from the Space Shuttle Atlantis on April 7, 1991, has excited astronomers with the number and surprising nature of the gamma ray sources it has detected, including quasars, powerful solar flares, supernovae, and many other high-energy pulsing sources, during its short lifetime in orbit.

UARS, launched aboard Space Shuttle Discovery on September 12, 1991, was the first mission in a long-term international program to study global change—in this case, specifically atmospheric chemistry, energy balance, and dynamics. As such, the mission underscored NASA's commitment to uncover the fundamental knowledge of our own planet and thereby to improve the quality of life for all people on Earth through the Agency's Mission to Planet Earth, of which UARS was the first major flight element.

The Astro-1 observatory flew on Space Shuttle Columbia in a nine-day mission during December 1990. Equipped with three ultraviolet telescopes and one x-ray telescope, it was the first Shuttle mission to study astrophysics. Analogously, SLS-1 was the first Shuttle mission dedicated to life sciences research. It revealed new, unexpected information, and a number of new techniques and procedures employed on the mission provided a new standard of scientific excellence for space research.

Among other achievements in this area during FY 1991, the Galileo spacecraft flew by Earth and the Moon in December 1990, providing spectacular views of our home planet and constituting the first encounter of a planetary spacecraft with that home planet. Despite aberrations in its primary mirror, during 1991 the Hubble Space Telescope continued to produce outstanding scientific results—collecting new evidence on the dynamic evolution of stars and making detailed observations of Mars, Saturn, Pluto, and Jupiter. Magellan, launched in 1989, completed its first 243-day mapping cycle of Venus on May 15, 1991. The second cycle began immediately, and by September 1991 the spacecraft had successfully mapped over 90 percent of the planet's surface. And finally, as FY 1991 ended, the Japanese/U.S. Solar-A mission that successfully launched on August 30, 1991, was making measurements of the Sun throughout the current peak of the solar activity cycle.

These are just some examples of how, as space science and applications programs open new vistas of knowledge, the possibilities for human exploration and habitation of space expand. Pushing the frontiers of knowledge and capability contributes to the realization of one of mankind's most compelling aspirations—to explore and understand more of the cosmos.

Space Research and Technology

The mission of the Space Research and Technology program is to provide both technology for future space missions and a base of research and technology capabilities to serve all national space goals. The program consists of two complementary parts: the research and technology (R&T) base program and the focused technology programs. Because the focused programs are committed to meeting the needs of the user community, they have been structured into five technological thrusts: Space Science, Planetary Surface, Space Platforms, Transportation, and Operations. This approach has proved most useful in managing the Space R&T program and facilitating the transfer of technology to user organizations of NASA and the aerospace community.

Significant progress was made in 1991 in each of the principal thrusts. For example, in Space Science the Magellan ground image processing system produced the remarkable images of the planet Venus that we have seen during the past year. The accomplishments of Space Science technology also included the demonstration of a diode-pumped, two-micron solid state laser. This laser was being researched as a potential candidate for use in NASA's Mission to Planet Earth program to better understand the complex and dynamic natural and man-made forces that interact to create weather and climate. In the Planetary Surface area, researchers developed and demonstrated a semi-autonomous navigation system for unmanned wheeled planetary rovers and tested the vehicle on a 100-meter test course.

With regard to Space Platforms, results obtained from the Long Duration Exposure Facility (LDEF), retrieved in January 1990 after five and a half years in space, will provide the "bench-mark" for design data bases for spacecraft that will have to be maintained in the low-earth orbit environment. In the area of Transportation, the program developed an advanced manufacturing process that could greatly decrease the time and cost of fabricating rocket engine combustion chambers for the Space Shuttle Main Engine. And finally, in the Operations thrust enhancements in computer systems improved the quality of flight decision making and the cost effectiveness of Space Shuttle Mission Control Operations.

Commercial Programs

During FY 1991, NASA continued to expand cooperative efforts with U.S. industry to encourage private investment in commercial applications of space technology. Technologies of NASA's Centers for the Commercial Development of Space were in the experimental phase but showed promise for maturing commercially within the next decade. In addition, NASA expanded its partnership with industry by signing new agreements for industrial space research, commercial space transportation, and the development of space infrastructure. NASA's Office of Commercial Programs (OCP) has assumed responsibility, in cooperation with U.S. industry, for managing technological and experimental programs that contribute to development of innovative commercial communications satellite services. Finally, to gauge progress in its Small Business Innovation Research (SBIR) program, NASA queried 61 of 250 SBIR contractors and identified 88 products that had already or soon would become commercially available. In short, OCP provided a focus for stimulating involvement by the U.S. private sector in civil space activities.

Exploration of the Moon and Mars

During 1991 NASA made significant progress toward developing a strategy for the Space Exploration Initiative (SEI), President Bush's challenge to return to the Moon and to explore Mars. An independent panel of government, industry, and academic experts presented a report outlining four candidate architectural options for lunar and Mars exploration that will serve as the foundation for detailed studies and ultimately lead to specific missions of exploration. Concurrently, internal studies continued to identify and address key long-term issues in mission design and operations, requisite technology development, and life sciences research. These activities continued to involve a range of Federal agencies, reflecting the national character of SEI.

Space Communications

The Office of Space Communications is responsible for meeting requirements critical to NASA's aeronautics and space flight missions. These include: spacecraft operations and control centers; flight dynamics and trajectory analyses; spacecraft tracking; frequency spectrum management; and applied research and development of new technology. When viewed as a unit, space communications activities are one leg of an interdependent triad that is absolutely essential to this nation's space program. Space communications functions, while often less visible, are no less vital than the other triad legs—the payloads and the space transportation systems that carry them to their destinations. Mission success is possible only when all triad elements meet their performance requirements.

The Space Communications functions are categorized as the Space Network, the Ground Networks, Communications and Data Systems, and Advanced Systems. The Space Network is the most complex, highly sophisticated tracking system in the world to date. This network provides tracking and communications for Earth-orbital and suborbital missions. The Ground Networks provide Earth-based tracking and data acquisition capabilities for all NASA planetary and deep space missions and many of those in Earth orbit.

The Communications and Data Systems are the vital links between the ground stations and the users. Communications are provided to link remote tracking stations with mission control and data processing facilities, and for administrative services such as facsimile, teleconferencing, and data sharing for NASA centers and Headquarters. The Data Systems provide data processing and mission control operations for numerous programs.

Advanced Systems specialize in research and development efforts focused on technological advances in telecommunications, electronic micro-circuitry, and computer sciences. The Advanced Systems efforts are only in areas where the needed technology is not being developed by industry or other agencies.

In 1991, the Space Network experienced its highest level of utilization while operating at a proficiency rating in excess of 99.8 percent. The increased frequency of Space Shuttle flights, the Gamma Ray Observatory, the Upper Atmosphere Research Satellite, and the Hubble Space Telescope were the major contributors to this heavy workload and the beneficiaries of the high proficiency level. The fifth Tracking and Data Relay Satellite (TDRS-5) was launched aboard STS-43 in August 1991. The on-orbit checkout of the spacecraft was highly successful and accomplished in record time. The on-orbit TDRSS constellation, linked to the ground by the White Sands Ground Terminal (WSGT) in New Mexico, provided continuous communications coverage to customers for over 85 percent of each orbit.

Major accomplishments of the Deep Space Network (DSN) included navigation, telemetry, and command activities for: Magellan's mapping of Venus's surface; Galileo and its successful encounter with the asteroid Gaspara; and Ulysses, the joint NASA/ESA mission on its journey to explore the polar regions of the Sun.

The Mission Control program successfully provided the control and performance analyses of numerous unmanned Earth-orbiting spacecraft. For example, Hubble Space Telescope operations were successfully initiated through a newly developed mission control and data capture facility.

The Advanced Systems program enabled the realization of improved performance and higher efficiency of operations through the introduction of new technology. Through the improvements in spaceborne communications equipment and ground receiving facilities, capabilities for reception of data from deep space missions have increased by a factor of a trillion over the lifetime of NASA.

Safety and Mission Quality

Recognizing the inherent risks and uncertainties involved in "frontier" ventures such as space exploration, NASA continued to give high priority to operational safety and quality. In FY 1991, as the use of statistical or quantitative analysis increased, probabilistic risk assessment became an integral part of several program areas.

Aeronautics Research and Technology

In implementing its program in aeronautics, NASA continued to pursue six key thrusts. The Subsonic Transport thrust focused on developing technology that would increase the productivity, affordability, and competitiveness of U.S. commercial transport aircraft. The focus of the High Speed Transportation thrust is to resolve critical environmental issues and establish the technological foundation for economical, high-speed air transportation. Goals in the research program focused on atmospheric effects, airport community noise, sonic boom, and enabling propulsion technologies. NASA's High-Performance Aircraft research program was structured to develop and mature technologies having important military applications.

The Hypersonics and Transatmospheric research program was an integrated, multidisciplinary thrust aimed at building fundamental technical understanding of the physical phenomena controlling airbreathing hypersonic vehicles. Research focused on developing technologies required for a new generation of aerospace vehicles, including the X-30 National Aero-Space Plane, that would be capable of hypersonic cruise in the atmosphere, single-stage-to-orbit operations using airbreathing primary propulsion, and horizontal takeoff and landing.

The Critical Disciplines thrust was pursuing revolutionary advances in the basic sciences necessary for the design and operation of next-generation aeronautical systems. Finally, in the conduct of aeronautical research and technology programs, NASA used a unique complement of high-value experimental wind tunnels, many of which were more than 30 years old at the end of FY 1991. In its sixth thrust, NASA has embarked on a multi-year program of revitalization to modernize and refurbish these Critical National Facilities.

Department of Defense

During FY 1991, the U.S. Air Force successfully launched two Titan IVs, including the first from Vandenberg Air Force Base, CA, three Delta IIs, and two Atlas Es. The DOD used three NASA Shuttle launches to support its programs. Space Transportation System (STS) flight 38 successfully launched a classified payload; STS-39 carried the Air Force Space Test Program 1, P-675, and the Infrared Background Signature Survey; and STS-40 successfully deployed Space Life Sciences Laboratory-1. In addition, the Defense Advanced Research Project Agency (DARPA) conducted the second successful test flight of the Pegasus air-launched space booster on July 17, 1991, placing seven small Ultra High Frequency (UHF) communications satellites into low-Earth orbit. Further, the Air Force and NASA formulated a program called the New Launch System during FY 1991 to satisfy the nation's space launch requirements in the next century. Another activity of the DOD in the space arena was a vigorous research effort to develop the Global Protection Against Limited Strike (GPALS) system in five different areas including sensor and interceptor technology.

Among numerous other space-related activities of the DOD during FY 1991 were many successful uses of satellites to support Operations Desert Shield and Desert Storm in the Middle East. Two UHF Multiple Access Communications Satellites launched by DARPA in May 1990 supported the 2nd Marine Aircraft Wing in those operations from August 1990 through April 1991. The Defense Satellite Communications System provided 95 percent of the inter-theater, long-haul communications between the continental U.S. and the Saudi Arabian-Iraqi theater and 80 percent of the intra-theater communications in support of ground (tactical) mobile forces engaged in Desert Shield/Desert Storm. The Navstar Global Positioning System was also critical to these operations by providing a means of navigation in the featureless desert; it guided warships, tank columns, artillery rounds, aircraft, and cruise missiles. Critical as well to the successful prosecution of the war against Iraq was the Defense Meteorological Satellite Program, including a third satellite launched in December 1990. Finally, an upgraded Defense Support Program, including a new satellite (DSP-I) launched in November 1990, was invaluable in detecting Iraqi SCUD missiles and providing warning data to allied forces.

There were also numerous aeronautical activities during FY 1991. Among them was further development of the National Aero-Space Plane, with the not-yet-fully-designed X-30 envisioned as a manned aerospace vehicle powered by ramjet/supersonic combustion ramjet engines to be fueled by liquid or slush hydrogen. Also, during the year the B-1B achieved all of its baseline requirements except for the defensive avionics suite, and the B-2 Advanced Technology Bomber continued its flight testing at Edwards Air Force Base, with tests exploring over 90 percent of its operational envelope. The C-17 airlift aircraft underwent its first flight from Long Beach to Edwards AFB, CA, in September 1991 after the first test aircraft had completed the assembly process in December 1990.

In other aeronautical developments, the X-29 Advanced Technology Demonstrator showed the viability of forward-swept, aero-elastically tailored, composite wings; digital control of a 35 percent statistically unstable aircraft; and excellent stability and longitudinal control resulting from the synergisms of its integrated technologies. The F-15 Short Takeoff and Landing/Maneuver Technology Demonstrator achieved successful short landings in crosswinds and on a wet runway among other accomplishments in FY 1991. The F-22, previously known as the Advanced Tactical Fighter, completed the demonstration/validation part of its development in July 1991 and entered the engineering manufacturing and development phase in August. On April 5, 1991, the Army selected Boeing/Sikorsky as the contract team for the new Comanche light helicopter. And the joint DARPA/Navy effort with Germany to develop the X-31A Enhanced Fighter Maneuverability aircraft achieved numerous milestones in FY 1991, including first flight in October and an airworthiness test in January.

Department of Commerce

The Department of Commerce (DOC) continued to have four components involved in space activities. The National Oceanic and Atmospheric Administration (NOAA), through its National Environmental Satellite, Data, and Information Service (NESDIS), was responsible for the operational polar-orbiting and geostationary satellites, and there will be prototype instruments on NASA's Earth Observing System (EOS) that are expected to be used subsequently on NOAA's polar satellites. Concern developed during 1991 about the quality of instruments on the follow-on models of the geostationary satellite; therefore, contact continued with foreign satellite groups to plan for contingencies. Meanwhile, satellite-derived products continued to be used by the nation's weather and climate services both for routine operational forecasting and for analysis and forecasting of severe storms and hurricanes. FY 1991 brought increased use of satellite information from the Advanced Very High Resolution Radiometer (AVHRR), the Visible and Infrared Spin-Scan Radiometer (VISSR), and from GOES (Geostationary Operational Environment Satellite)-Tap, a program enabling users to acquire high-quality satellite imagery over telephone data circuits.

CoastWatch, the operational program providing environmental information alerts to coastal areas, expanded with the initiation of the CoastWatch-Change Analysis Program (C-CAP), an information system for coastal land cover and habitat change. There were several new projects in the Climate and Global Change Program. The COSPAS/Satellite Aided Search and Rescue Program (SARSAT) and Pan-Pacific Education and Communication Experiments by Satellite (PEACESAT) programs—both international activities—continued, the latter in concert with the National Telecommunications and Information Administration (NTIA).

The Office of Space Commerce (OSC), the Department's newest space-related group, had five main responsibilities in FY 1991: coordinating space-related issues, representing the Department on the National Space Council, acting as industry's advocate at the Federal level, participating in international trade negotiations on space, and encouraging the export of U.S. space technology.

DOC's National Telecommunications and Information Administration (NTIA) maintained its activity on international committees and working groups and with foreign satellite groups. It continued its part in the World Administrative Radio Conference (WARC), completing a series of international meetings in preparation for WARC-92. NTIA also participated in meetings in preparation for the joint meeting of the International Maritime Organization and the International Maritime Satellite Organization. Planning and preparation continued for experiments on NASA's Advanced Communications Technology Satellite. And NTIA continued to study millimeter wave frequencies for use in Earth-space communications.

The National Institute of Standards and Technology (NIST), formerly the National Bureau of Standards, participated in space-program support that included spectrograph calibration on the Hubble, scientific and technical design on several future NASA satellites, various vacuum studies for space application, development of a robotics system to build and maintain Space Station Freedom, and the development and testing of extreme cold-temperature flowmeters.

In the area of high-performance aerospace materials, NIST was studying the physics and chemistry of combustion, performance of heat exchangers, use of composite materials, and alloy solidification. In space sciences research, several of NIST's studies in FY 1991 were astronomical in nature, some were low gravity studies, and others were in the areas of plate tectonic motion and the Earth's rotation. NIST's atmospheric sciences research included: studies of ozone and greenhouse effects, various chemical studies including chloroflourocarbons, and the development of a computer code for calculating quantities of electrons and protons in aluminum shieldings of spacecraft. In commercial space support, NIST was engaged in the study of methods and techniques for micro-gravity application and of crystal growth in space as well as participation in government and private groups involved in the commercial development of space.

Department of Energy

The Department of Energy (DOE) has the mission of providing nuclear power sources for NASA space missions. Such power units have permitted spectacular missions such as the Voyager flyby of Neptune and the Apollo scientific work on the lunar surface. In March 1990, DOE was added to the National Space Council in recognition of its over 30 years' experience in and contribution to the nation's space program. The Department's space efforts have focused on its treaty verification mission and on supporting DOD and NASA space requirements. This has included research and development of space nuclear power and propulsion, strategic defense, and space exploration. In addition, new roles are emerging in space exploration, global climate change, and space technology for the Department that will enable DOD, NASA, and the commercial sector to capitalize on the scientific and technological capability resident in the Department's national laboratories, such as in remote sensing, renewable energy, life sciences, manufacturing and science, and education. To formalize DOE's growing relationships, it has signed memoranda of understanding (MOUs) on space nuclear reactors, space exploration, and space technology. Future MOUs are anticipated as emerging problems become defined.

The Radioisotope Thermoelectric Generator (RTG) program developed and built devices that directly convert heat from the radioisotope Plutonium-238 to electric power. Progress included the successful launch of the RTG-powered Ulysses spacecraft; completion of life testing of the General Purpose Heat Source-RTG qualification unit after 54,588 test hours; and various actions intended to upgrade and initiate the restart of RTG production facilities to meet NASA's RTG requirements for the Comet Rendezvous Asteroid Flyby and Cassini missions.

The SP-100 Space Reactor program was developing a versatile, fully qualified space reactor power system to provide electrical power in the range of tens to hundreds of kilowatts for future NASA and DOD missions. In FY 1991 DOE made significant technical progress in the areas of thermoelectric cell development for power conversion, fuel pin materials, and design of a viable radiation shield.

The Thermionic Fuel Element Verification program was intended to resolve issues enabling thermionic power conversion to be a viable technology for future space reactor systems. Activities in FY 1991 consisted of lifetime testing of components in accelerated and real time environments. An additional DOE responsibility was providing sensors to scan for nuclear detonations in Earth's atmosphere and in space. Such sensors, aboard Global Positioning System spacecraft and other satellites, are used to monitor nations' compliance with nuclear test treaties, to monitor nuclear proliferation, and to meet military needs in the event of nuclear war.

To provide a focus within the Department for space policy and inter- and intra-agency coordination of DOE space-related activities, the Secretary in May 1991 named a Special Assistant for Space and directed the formation of an Office of Space in October 1991. These organizational changes will strengthen the Department's ability to support the space research and development needs of the civil, national security, and commercial sectors.

Department of the Interior

The Department of the Interior used data acquired by satellite and aircraft sensors to inventory natural resources and monitor changes on lands under its management. It also maintained an active program of research and technique-development in remote sensing. In 1991, the Department continued to archive, process, and distribute Landsat and Advanced Very High Resolution Radiometer satellite data. The National Aerial Photography and Side-Looking Airborne Radar programs acquired data over priority U.S. areas. Major land-management applications of remote sensing included land-use and land-cover mapping, vegetation mapping, wetlands mapping and inventory, wildfire mapping and monitoring, and irrigated-lands inventory. Hydrologic applications included snow-cover mapping and monitoring and modeling of reservoir surface water parameters. Oceanographic applications included monitoring of marine mammal migration. Geologic applications included multispectral data analysis, underground and surface coal mine monitoring, and radar data applications. Planetary studies included archiving of data from the Magellan mission and study of data from the Galileo encounter of the Earth and Moon. Cartographic applications included shaded relief mapping, satellite image mapping, and studies using the Global Positioning System. Global change research included studies of snow and ice; monitoring desertification; land-cover characterization; and baseline studies for monitoring global change in the Arctic. Work continued on development of the Global Land Information System to provide access to land-related, remotely sensed, and earth-science data; to produce and distribute regional, continental, and global land data sets; and to support the NASA Earth Observing Data and Information System. International programs operated in Africa, the Middle East, Latin America, and Antarctica.

Department of Agriculture

During fiscal year 1991, agencies of the U.S. Department of Agriculture (USDA) extended their operational use of remotely sensed data from space platforms as a source of information for agricultural assessment and resource management in such areas as water quality, vegetative health, disease and insect infestations, and the effects of natural disasters. A broad-based research program, using data from aircraft and space satellites, continued to provide essential background on procedures for operational applications.

Federal Communications Commission

The Federal Communications Commission granted authority to the Communications Satellite Corporation (Comsat) to participate in the successful launches of the first International Maritime Satellite (INMARSAT) Organization's second generation satellites, the F-1 on October 30, 1990, the F-2 on March 8, 1991, and the fourth International Telecommunications Satellite (INTELSAT) Organization's VI series satellite, the F-5, on August 14, 1991. INTELSAT has also contracted with NASA for a shared STS mission in April 1992 to rescue the INTELSAT VI satellite that failed to achieve geosynchronous orbit. Six U.S. domestic satellites launched during FY 1991.

In March of 1991, the U.S., Bahamas, Costa Rica, the Dominican Republic, and Eastern European countries not members of INTELSAT agreed at the Board of Governors meeting to use the Pan American Satellite-1 (PAS-1) satellite for international public switched services comprised of not more than 100 sixty-four kilobit per second equivalent circuits.

On June 28, 1991, the Commission granted the Orion Satellite Corporation's request for final authority to construct, launch, and operate two Ku-band international satellites. In August 1991, the Commission granted conditional authority to Alpha Lyracom, doing business as Pan American Satellite, to construct, launch, and operate a hybrid satellite (PAS-4). In September 1991, the U.S. and the United Kingdom received INTELSAT approval of consultation for two satellites to be operated by Columbia Communications.

The Qualcomm Corporation received authorization to operate an additional 20,000 mobile-user units (bringing its total number to over 40,000) for its two-way mobile data communications network. Canada and the United States agreed to permit cross-border roaming of certain mobile satellites without regard to normal U.S.-Canada border obligations. In September 1991, the Commission issued a Notice of Proposed Rulemaking to reallocate frequencies in the 137-138 megaherz (MHz), 148-150.5 MHz, and 399.9-401 MHz bands for a low-Earth orbit satellite service.

Department of Transportation

Federal Aviation Administration

Within the Department of Transportation (DOT), the Federal Aviation Administration (FAA) conducted a growing research and development program to support its mission of ensuring the safety and efficiency of civil aviation. The first annual Capital Investment Plan provided a comprehensive blueprint for modernizing the national system of air navigation and air traffic control. Accomplishments in this complex effort included initial deployment of the first element of the Advanced Automation System being developed to attain the greatly upgraded air traffic control capabilities needed for future demand. Other examples of progress included Aircraft Situation Display system expansion to facilitate nationwide air traffic flow and the New York area approach control facility's achievement of the ability to track 2,800 aircraft simultaneously.

The FAA's actions addressing a wide spectrum of safety issues included monitoring deployment of the airborne Traffic Alert and Collision Avoidance System and work to increase its capabilities. Among the many other safety-related programs were publications of a national human factors research plan, aircraft drop tests to obtain data on crashworthiness, and experiments on protecting aircraft against turbine engine rotor failure.

The FAA broadened the scope and increased the pace of its civil aviation security research program during FY 1991. It began construction of a unique new laboratory that will permit investigation of the full range of explosives detection technology. Another example of the numerous ongoing projects was investigation of structural hardening to improve the ability of aircraft to survive inflight explosions.

The Agency's effort to increase national airport capacity included programs to safely expedite aircraft surface movement and to improve the all-weather utility of parallel and converging runways. The use of data link for Pre-Departure Clearance proved a highly successful innovation. Efforts to combat weather hazards included beginning development of three new services to help improve forecasts and alerting. The FAA also continued research aimed at realizing the full civil potential of rotorcraft and tiltrotors.

Commercial Space Transportation

The U.S. commercial space transportation industry and the Department of Transportation's Office of Commercial Space Transportation (OCST) have made impressive progress in the three years since the first DOT-licensed U.S. commercial launch took place. A total of 18 successful U.S. commercial launches have occurred. They reflect a growing and diverse industry, including international business and foreign government customers, communications satellite and suborbital research payloads. According to the latest DOT Commercial Launch Manifest, issued in October 1991, at least 32 more commercial launches are expected to take place in the next few years.

Other important highlights for the year include issuance of operators' licenses to McDonnell Douglas, General Dynamics, and Orbital Sciences Corporation; completion of studies on commercial launch infrastructural needs; and forecasts for the launch industry. In addition, OCST issued final rules pertaining to user fees. Finally, OCST continued to monitor developments in the world commercial market and advocated U.S. policies to strengthen the competitive position of U.S. launch firms in the world market.

Environmental Protection Agency

The U.S. Environmental Protection Agency (EPA), primarily through its Environmental Monitoring Systems Laboratory in Las Vegas, NV, with assistance from its Atmospheric Research and Exposure Assessment Laboratory in Research Triangle Park, NC, routinely conducted research and provided technical support using remote sensing as part of an overall environmental monitoring program. The Agency used large-scale aerial photography to develop site characterization data during the remedial investigation and feasibility study part of 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. Aerial photography and satellite data also 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. In addition, it was using and developing (with NASA support) light detection and ranging systems to monitor urban plumes and emissions sources as well as to measure ozone, sulfur dioxide, and particulates. Finally, it was using a geographic information system for data integration and analysis in support of many of its programs.

National Science Foundation

The National Science Foundation (NSF) continued to be the principal supporter of academic research in ground-based astronomy and atmospheric sciences. Major events in the astronomical sciences during FY 1991 included the use of sensitive new detectors at Kitt Peak National Observatory to obtain spatially resolved images of quasi-stellar objects. These images revealed new features. Astronomers also obtained new results on the distribution of galaxies and distances to these galaxies. These seemed to indicate a lack of homogeneity in the distribution of matter in the universe. At the National Astronomy and Ionosphere Center, astronomers identified the first near-Earth metal asteroid, probably originating in the asteroid belt between Mars and Jupiter. Also, new measurements obtained at Kitt Peak National Observatory indicate that the age of the universe may be 12.5 billion years or less. This estimate differs from calculations of the age of older stars, which indicate that they are about 15 billion years old.

In the upper atmospheric sciences, the Coupling, Energetics, and Dynamics of Atmospheric Regions (CEDAR) program sponsored two major campaigns that significantly increased our knowledge of both the dynamics and the structure of mesospheric and lower thermospheric regions of the atmosphere—a difficult region to observe and thus often nicknamed the "ignorosphere." The Geospace Environment Modeling (GEM) program, which concentrates on the magnetosphere, began development of three-dimensional numerical simulations of oscillations produced by solar wind perturbations in that outer-plasma region of the atmosphere.

Smithsonian Institution

The Smithsonian Institution has contributed to national space goals through research conducted at the Smithsonian Astrophysical Observatory (SAO) in Cambridge, MA, and at the Center for Earth and Planetary Studies (CEPS) and the Laboratory for Astrophysics at the National Air and Space Museum (NASM) in Washington, DC. NASM's exhibits, lectures, and educational programs have also contributed significantly to the public understanding of space research. In addition, SAO has conducted programs designed to improve pre-college science instruction and has served as the North American gateway for SIMBAD, the international astronomical data base. In 1991 NASA selected SAO to operate the data archiving and analysis center for the Advanced X-ray Astrophysics Facility now planned for launch in 1999. NASA has already performed successful tests on the two largest mirrors in this unusual x-ray telescope. A high-resolution imaging camera built by SAO for the Roentgen Satellite made detailed observations of x-ray objects selected from the observatory's initial all-sky survey. Data on hundreds of other cosmic x-ray sources produced earlier by the Einstein (High Energy Astronomical Observatory-2) satellite were made available in CD-ROM format to all qualified scholars at no cost. Among the many results from the continuing analysis of this Einstein data was the discovery of an unusual x-ray arc associated with a gravitationally lensed quasar. A rocketborne SAO-IBM telescope made high-resolution x-ray images of the Sun's corona on the day of the total solar eclipse. And Hubble Space Telescope's observations of the ring structure around Supernova 1987A in the Large Magellanic Cloud made possible the most precise calculation to date of the distance to another galaxy.

Department of State

The Department of State, through its Bureau of Oceans and International Environmental and Scientific Affairs, works with NASA on all international and foreign-policy aspects of American space programs and participates in National Space Council deliberations on major policy issues. During 1991, State supported Space Shuttle activities by providing a direct link to U.S. embassies in countries with emergency landing facilities. It negotiated new agreements in this area with The Gambia, Morocco, and Spain.

The Department's Bureau of International Communications and Information Policy represents U.S. interests in the International Telecommunications Satellite Organization (INTELSAT) and the International Maritime Satellite Organization (INMARSAT). INTELSAT successfully launched the remaining two of its five VI-series satellites in 1991, one on August 14 and the other on October 29. INMARSAT repositioned one of its satellites in October 1990 to provide increased capacity in its heaviest traffic routes over the Atlantic Ocean and to provide seamless coverage throughout the globe except in extreme sections of the South and North Poles. And among its other activities, in February 1991 INMARSAT awarded a contract to the General Electric Astro Space Division to serve as prime contractor for four INMARSAT-3 satellites scheduled for launch in 1994-1995; then in the fall of 1991 it received bids from five organizations for the launch of third-generation satellites, with a decision on the bids expected for April 1991.

Arms Control and Disarmament Agency

The United States Arms Control and Disarmament Agency (ACDA) has played a role in space policy and research because of its arms control mandate. During FY 1991, ACDA officers were engaged in negotiations with representatives of the Soviet Union in the Defense and Space Talks in Geneva. The Strategic Arms Reduction Treaty was signed in July 1991, and negotiations on Defense and Space continued throughout the year. Also, during the year ACDA was the lead U.S. agency at multilateral discussions on space arms control at the Conference on Disarmament in Geneva and at the First Committee meetings of the United Nations General Assembly. ACDA is represented at National Space Council meetings when arms control issues are discussed. In addition, ACDA is a member of the Arms Control Policy Coordinating Committee and the Nonproliferation Policy Coordinating Committee; the charters of both committees include references to arms control issues related to space.

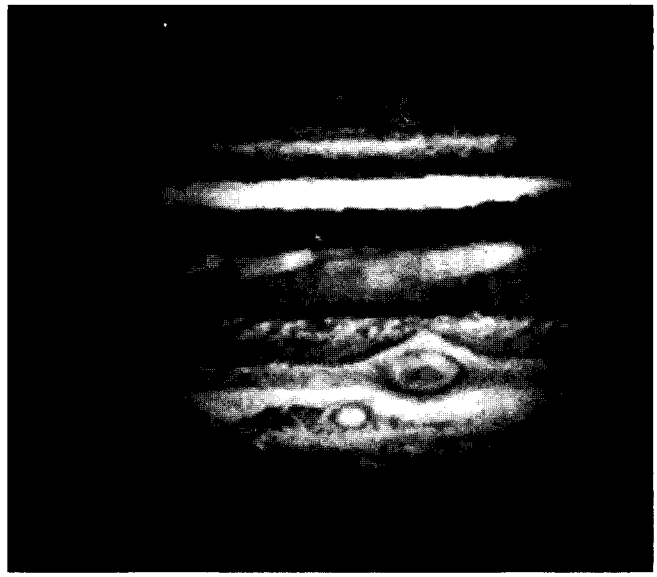
United States Information Agency

The United States Information Agency (USIA), using a wide variety of media to publicize U.S. activities to foreign audiences, was uniquely equipped to tell the world about NASA's progress in space sciences and exploration. In FY 1991, USIA's Voice of America provided live coverage of the Space Shuttle launches and other coverage of a variety of missions in English and 44 foreign languages. USIA's Press Division provided news and feature stories on the Shuttle missions and the discoveries made by the Magellan spacecraft orbiting Venus. The Publications Division distributed five articles on the space program to 70 USIA posts overseas, including photographs of Venus from the Magellan spacecraft, and several USIA publications in Russian, English, French, and Arabic carried articles on U.S. space efforts. Finally, in close cooperation with NASA, USIA's Television and Film Service used its WORLDNET satellite system to deliver extensive information on the space program in a variety of formats. Every NASA mission received extensive coverage. During the past fiscal year, WORLDNET produced nine programs on space and space-related topics for journalists and scientific writers in Europe, Asia, Latin America, Africa, and the Pacific Ocean nations. In addition, the USIA Newsfile produced over 70 individual two- to three-minute clips for placement on overseas television networks. The "Science World" series, composed of 15-minute segments, devoted over a dozen features to NASA activities, while six teleconferences with NASA officials and scientists reached experts in Brazil, Mexico, Honduras, and Thailand.

National Aeronautics and Space Administration

The National Aeronautics and Space Administration (NASA), established in 1958, continued to be responsible for planning, conducting, and managing civilian research and development activities in aeronautics and space. Other Federal agencies, state, local, and foreign governments, plus educational institutions and private industry, also share in NASA's programs.

NASA's mission continued to reflect the intent of Congress in creating the Agency—to explore space for peaceful purposes with international cooperation, for the benefit of all humankind. Technological advances have resulted in significant economic and social benefits for the United States and other nations; they remain a significant catalyst for national pride, progress, and achievement. The continued success of NASA's programs will allow the United States to maintain its leadership in aeronautics and space.



This photo of Jupiter was taken by the wide field planetary camera on NASA's Hubble Space Telescope. This picture is as sharp as the Voyager pictures taken in 1979. Detailed comparison with the Voyager pictures shows that a totally different cloud structure has formed over the past 12 years.

Space Science and Applications

NASA's Office of Space Science and Applications was responsible for planning, directing, and evaluating that part of the overall NASA program that has the goal of using the unique characteristics of the space environment to conduct a scientific study of the universe, to understand how the Earth works as an integrated system, to solve practical problems on Earth, and to provide the scientific and technological foundation for research that will support expanding the human presence beyond Earth orbit into the solar system. Scientific disciplines within the Office of Space Science and Applications included astrophysics, solar system exploration, earth science and applications, space physics, life sciences, and microgravity science and applications.

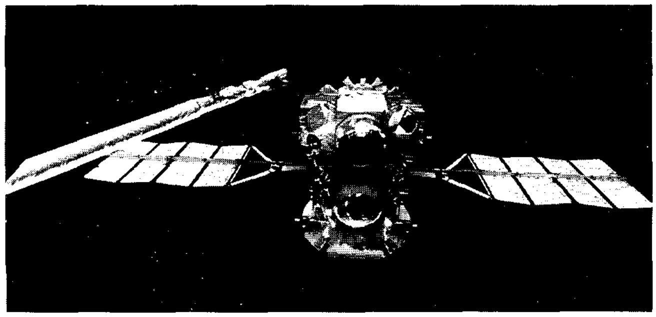
Astrophysics

The 1990s promise to be a "decade of discovery" for astronomers and NASA's Astrophysics program, using telescopes in space, in aircraft, and on the ground to answer fundamental questions about our universe. The NASA Astrophysics program was making unprecedented discoveries, exploring questions about the nature of the cosmos including: the origin and evolution of the universe; the laws of physics that govern the universe; and the birth of galaxies, stars, planets, and ultimately life itself. Research in these areas required observations at wavelengths absorbed by Earth's atmosphere and therefore had to be conducted from space-borne and airborne observatories. The Astrophysics program was centered around a series of space observatories, supported by a research base of instrument developments, suborbital research activities, data analyses, and theoretical studies.

The three great observatories—the Hubble Space Telescope (HST) launched in April 1990, the Compton Gamma Ray Observatory (GRO) launched in April 1991, and the Advanced X-ray Astrophysics Facility (AXAF) expected to launch in the late 1990s—will provide significantly improved sensitivity and resolution over their respective regions of the electromagnetic spectrum. Definition studies for the Space Infrared Telescope Facility (SIRTF), the fourth great observatory, continued in 1991. Meanwhile, smaller spacecraft in the Intermediate-and Explorer-class series were being used for exploration, all-sky surveys, specific studies, or unique investigations that complimented the great observatories. As part of the suborbital program, rockets, balloons, and aircraft have provided means to make preliminary observations, conduct selected low-cost investigations, test instrumental concepts and technologies, and train the next generation of scientists and engineers how to develop instruments for future space missions.

Hubble Space Telescope. NASA's first great observatory, the Hubble Space Telescope, marked its first anniversary of successful scientific operations in April 1991. During 1991, the Hubble Space Telescope continued to produce outstanding scientific results—collecting new evidence on the dynamic evolution of stars called "Blue Stragglers;" revealing new structure and detail in stars, star clusters, and galaxies; and making detailed observations of planetary weather patterns and interesting features on Mars, Saturn, Pluto, and Jupiter. Work on Hubble's second-generation instruments, which were being designed to correct errors in the telescope's primary mirror and thus end its spherical aberrations, plus preparations for the planned Space Shuttle servicing mission, both continued at a vigorous pace during 1991.

Compton Gamma Ray Observatory. The second of NASA's great observatories, the Compton Gamma Ray Observatory, deployed into Earth orbit from the Space Shuttle Atlantis on April 7, 1991. The first satellite to provide all-sky mapping of the universe at gamma ray energies, it was officially renamed the Arthur Holly Compton Gamma Ray Observatory in honor of the Nobel Prize-winning American physicist in September. Since its launch, the Compton Observatory has excited gamma ray astronomers with the quality of the data that it has collected on a variety of gamma ray sources, including quasars, powerful solar flares, supernovae, and high-energy pulsing sources. All four of the scientific instruments were performing at or above expectations. The Compton Observatory's comprehensive study of gamma ray sources and its discoveries to date have provided unprecedented information on the location and nature of some of the most mysterious and powerful objects in the universe. As an example, the Observatory has revealed



The second of NASA's Great Observatories, the Compton Gamma Ray Observatory, deployed into Earth orbit from the Space Shuttle Atlantis on April 7, 1991.

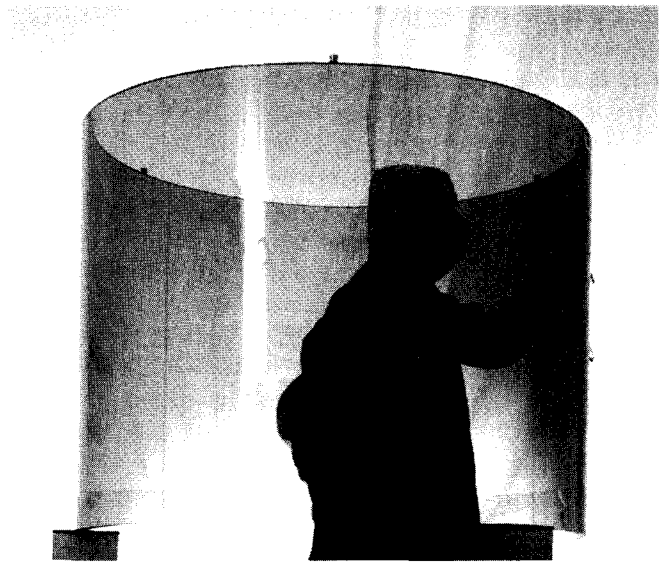
a uniform distribution of the sources of gamma ray bursts, requiring a total revision of existing theories of this enigmatic phenomenon. Another major discovery was the detection of extremely intense high energy gamma ray emission from the quasar 3C279 that, at the time of its observation, was the brightest object in the universe. Based on the performance to date, NASA anticipated that the Compton Observatory would provide scientists with a wealth of unique data and information on celestial objects during its projected 2-5 year lifetime.

Advanced X-ray Astrophysics Facility. The Advanced X-ray Astrophysics Facility (AXAF) will be the third of NASA's four proposed orbiting great observatories. AXAF will complement the observations made by the Hubble and Compton Observatories and will study stellar structure and evolution, large scale galactic phenomena, active galaxies, quasars and cosmology in the x-ray part of the electromagnetic spectrum. In 1991, NASA successfully completed development of the first and largest pair of AXAF's mirrors. In September 1991, NASA achieved a major milestone in the program with the successful test and x-ray calibration of the first set of AXAF's six mirror pairs. The capability of AXAF's mirrors, measured in terms of angular resolution, has been proven to be 10 times better than those on any other x-ray telescope ever flown. Progress was also made with plans for AXAF's Science Support Center to serve both national and international scientific communities, with the contract selection of the Smithsonian Astrophysics Observatory in Cambridge, MA, to provide this support. AXAF was being developed for launch in 1998 aboard the Space Shuttle.

Space Infrared Telescope Facility. The fourth of the great observatories, the Space Infrared Telescope Facility (SIRTF), will provide an enormous increase in capability for infrared astronomy, completing observatory coverage for the four major regions of the electromagnetic spectrum. SIRTF, a cryogenically cooled observatory in high earth orbit, will be capable of detecting planets around nearby stars, studying infant solar systems, identifying young and distant galaxies, and extending the cosmic distance scale out to several billion light years. Concept and definition studies continued in 1991. Once approved, SIRTF will build on the scientific results as well as the engineering heritage from the other important scientific satellites, including the Cosmic Background Explorer (COBE).

Cosmic Background Explorer. Through observations made by the Cosmic Background Explorer (COBE), launched in November 1989, astronomers have mapped the distribution of nitrogen throughout our whole galaxy for the first time. COBE's all-sky survey, and additional maps of carbon and dust, has provided quantitative information that may enable scientists to understand better the heating and cooling processes that take place throughout the Milky Way. The data to date have shown that key building blocks of life—carbon and nitrogen atoms—are widespread in our galaxy. The COBE spacecraft continued to return useful scientific data more than one year after completion of its primary mission objectives and the first all-sky survey in 1990.

Stratospheric Observatory for Infrared Astronomy. The proposed Stratospheric Observatory for Infrared Astronomy (SOFIA) is a joint study being conducted by NASA and the Federal Republic of Germany. In 1991, the space science community endorsed SOFIA as an essential investment in the education and training of future space scientists. A 2.5-meter-class airborne observatory (i.e., 2.5 meters in diameter) within a modified Boeing 747 aircraft, SOFIA will succeed the extremely successful Kuiper Airborne observatory. Once approved, SOFIA will assure frequent access to space and provide up to 200 flights per year for an estimated 65 science teams.



One of the Advanced X-ray Astrophysics Facility (AXAF) mirrors being cleaned and inspected prior to packaging and shipping. Each container was specifically designed for a particular optic. Each mirror was sealed in several layers of plastic covering. The packages were purged with nitrogen to protect the optical surfaces from atmospheric contamination.

Roentgen Satellite. A cooperative flight project with the Federal Republic of Germany and the United Kingdom, the Roentgen Satellite (ROSAT) successfully completed its all-sky survey of the universe in the light of x-rays in January 1991. NASA provided the High Resolution Imaging Detector and Delta II launch vehicle for the mission. In February, the Explorer-class satellite (see below) began the pointed phase of its planned observations, with major U.S. participation through the Guest Observer program. Data processing for guest observations began in August. During phase two, the science program continues with approximately one celestial target pointing per day. Nine hundred light years from the Sun and beyond the disk of the Milky Way, U.S. astronomers have made a significant early discovery providing evidence that hot gas from an ancient supernova may form a giant halo around our galaxy.

Astro-1. The Astro-1 observatory flew on the Space Shuttle Columbia during a 9-day mission in December 1990 to observe some of the most active objects in the universe. The mission was the first to use a Shuttle for the study of astrophysics. Three ultraviolet telescopes and one x-ray telescope mounted on a pallet in the Shuttle cargo bay made hundreds of observations.

Explorer Program. The Explorer program was designed to provide frequent access to space for smaller-sized science satellites. With an emphasis on technical innovation and scientific exploration, Explorer missions have made discoveries that dramatically changed our understanding of the near and distant universe. In 1991, progress continued in developing the Delta-class Explorer missions, while planning took shape to increase the number of flight opportunities by selecting missions in the Small Explorer (SMEX, see below) and Middle-class Explorer (MIDEX) categories.

Extreme Ultraviolet Explorer. In 1991, development continued to support the launch of the Extreme Ultraviolet Explorer (EUVE) in early 1992. EUVE will explore the window in the electromagnetic spectrum between ultraviolet radiation and x-rays—the extreme ultraviolet. Recent technological and scientific advances will enable the EUVE to make observations of distant stars, collecting important information about their age, temperature, chemical composition, and energy level. Once launched, EUVE will conduct a 2-phased mission, in the first 6 months mapping the entire sky to determine the position, brightness and temperature of extreme ultraviolet (EUV)-emitting objects, then studying individual targets for the remainder of the mission, estimated to last at least 12 months.

X-ray Timing Explorer. The X-ray Timing Explorer (XTE) continued development work in 1991. XTE will study cosmic x-ray sources and timing phenomena, enabling scientists to investigate physical events under extreme conditions around black holes, quasars, and highly magnetized neutron stars. XTE was planned for a 1996 launch on a Delta II expendable launch vehicle.

Small Explorers. The Small Explorer missions continued their development in 1991 for launch in the early and mid-1990s, including the Solar Anomalous Magnetospheric Particle Explorer (SAMPEX), the Submillimeter Wave Astronomy Satellite (SWAS), and the Fast Auroral Snapshot Explorer (FAST). SAMPEX will be launched on a Scout launch vehicle in 1992 to study solar flares. SWAS will make pointed and survey observations of dense galactic molecular clouds, looking for water and other important molecules in interstellar space. FAST will examine the electrodynamic causes of auroral displays.

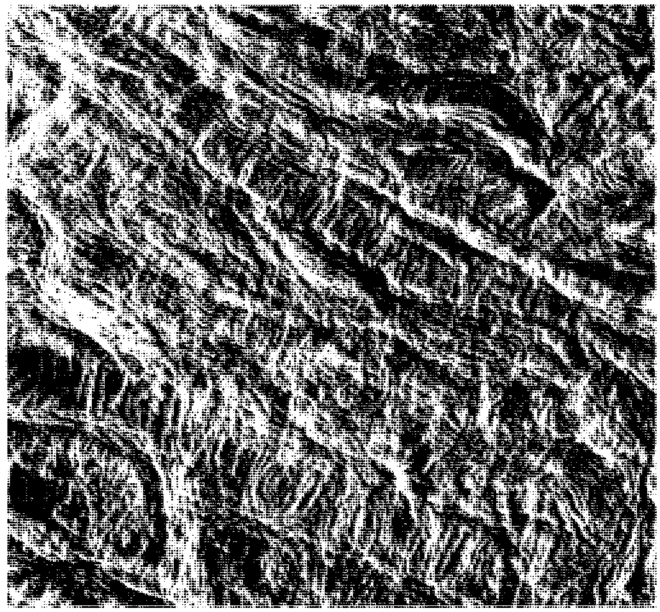
Solar System Exploration

NASA's Solar System Exploration program conducted research to determine the present nature of the solar system, its planets, moons, and primitive bodies (asteroids and comets). It also sought to identify and locate other planetary systems in various stages of formation, in order to understand how the solar system and its objects formed, evolved, and (in at least one case) produced environments that could sustain life. The program was responsible for comparative planetology, studies undertaken to better understand Earth by determining the general processes that govern all planetary development and by understanding why the "terrestrial" planets of the solar system are so different from each other. Other exploration missions have served to establish the scientific and technical data base for undertaking major human endeavors in space, including the survey of near-Earth resources and the characterization of planetary surfaces.

Spacecraft missions to achieve these objectives used an evolutionary approach, beginning with flyby reconnaissance missions. The first-generation missions have been succeeded by more complex missions (orbiting spacecraft, landing stations, and sample returns) that have provided increasingly detailed and specialized information. The spacecraft missions have been supported by an essential foundation of ground-based activities, including mission operations and data analysis, scientific research and analysis, and advanced program studies.

Pioneer Missions. Pioneer 10 and 11 (as well as Pioneer 6, 7, and 8) continued during FY 1991 to collect valuable data about the fields, particles, and plasma waves of the outer solar system. In flight for nearly 20 years, Pioneer 10 and 11 remained in working order, with most of their scientific instruments continuing to function well. They continued to explore the far edges of the solar heliosphere, remaining on their journey beyond our solar system in opposite directions. Pioneer 10 was expected to have enough power to continue operating until late 2001, while Pioneer 11 was expected to exhaust power in late 1995.

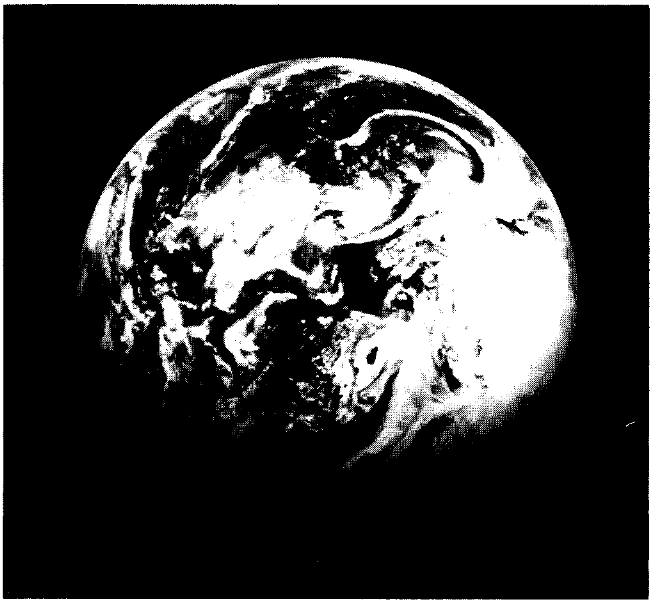
Pioneer Venus Orbiter. After more than a decade of operations, the Pioneer Venus Orbiter (PVO) continued to collect important scientific data from its orbit around Venus. PVO was continuing its studies of the chemical and physical processes of Venus' upper atmosphere, especially its interaction with the solar wind. Scientists recently reported that their analysis of PVO data indicated that Venus may have lightning similar to that on Earth. These scientists analyzed radio signal data obtained from PVO during the period 1979 to 1990. These data implied that there is as much or even more lightning within the thick, high-cloud layers of the cloud-shrouded planet as there is on Earth. The physical properties of the solid and liquid particles in the Venusian clouds, as well as temperatures and atmospheric pressure, also appear similar to those in Earth clouds. PVO is scheduled to exhaust its available fuel in late 1992. Before it enters the Venusian atmosphere and burns up, the remaining fuel will be used to control the orbit's orientation and altitude to maximize the data obtained about the planet's atmosphere.



This mosaic is a photograph of a portion of Alpha Regio in the Lavinia region of Venus as taken by the Magellan spacecraft during its first mapping cycle. The terrain shows intense folding, faulting, shearing, compression, and extension. It appears that the region has undergone many episodes of horizontal motion.

Voyager Missions. During 1989, Voyager 2 passed beyond the orbit of Neptune and became the fourth spacecraft to travel beyond the outermost planet (joining Voyager 1 and Pioneer 10 and 11). During 1991, scientists reported on a study of data taken by the Voyager 1 spacecraft of Saturn's largest moon, Titan, during the Voyager 1 flyby in 1980. Scientists used these data to model the temperature structure and energy balance on Titan and discovered the existence of an anti-greenhouse effect on a solar system body for the first time. This effect was produced by a thick, organic haze in Titan's upper atmosphere that absorbed solar light but transmitted reflected infrared radiation. Also evident from the data was the existence of a traditional greenhouse effect. This study provided the first evidence for a greenhouse and anti-greenhouse effect existing simultaneously, in opposition with each other. This information may help in basic studies of the green-house effect here on Earth. Both Voyagers were headed at the end of FY 1991 toward the outer boundary of the solar system in search of the heliopause, the region where the Sun's influence wanes and the beginnings of interstellar space can be sensed. The Voyagers will be the first spacecraft to pass through this region, which is thought to exist somewhere from 5 to 14 billion miles from the Sun. The Voyager spacecraft have enough electrical power and thruster fuel to operate at least until 2017. By that time, Voyager 1 will be 12.4 billion miles and Voyager 2 will be 10.5 billion miles from the Sun, respectively.

Magellan. Magellan's mission, since its launch in May 1989, has been to completely map the planet's surface features and to explore the surface topography and interior structure of Venus through the use of high resolution radar mapping, altimetry, microwave radiom-



This image of the Earth was obtained by the Galileo spacecraft on December 11, 1990, when the spacecraft was about 1.3 million miles from the Earth. South America is near the center of the picture, and the white, sunlit continent of Antarctica is below. Picturesque weather fronts are visible in the South Atlantic, lower right.

etry, and through the precise measurement of Venus' gravitational field. Magellan completed its first 243-day mapping cycle on May 15, 1991. The second cycle, to map the remainder of the planet and investigate any changes since the first cycle, began immediately. By September 1991, Magellan had successfully mapped over 90 percent of the planet's surface. Data received from the Magellan spacecraft revealed geological features unlike anything seen on Earth. One area observed was what scientists call "crater farms," a collection of numerous impact craters formed when aster-oids collided with the planet, while another area was covered by a checkered pattern of closely spaced fault lines running at right angles. Most intriguing were indications that Venus may still be geologically active, though much less so than Earth. Magellan also discovered what is believed to be the largest channel in the solar system, measuring over 4,200 miles long. This new information will add substantially to our understanding of Venus, building on the information provided by the earlier Pioneer Venus Orbiter, Arecibo observations (see below), and the Russian Venera investigations.

Galileo. Galileo, the first direct study of the solar system's largest planet, began its 6-year trip to Jupiter on October 18, 1989. During its 22-month encounter with Jupiter, the Galileo instruments will conduct detailed studies of the entire Jovian system, including the planet, its ring, and its four major moons: Io, Ganymede, Callisto, and Europa. The Galileo spacecraft also will investigate the structure and physical dynamics of the planet's magnetosphere. The second planetary mission to be launched from the Space Shuttle, Galileo had a trajectory toward Jupiter that was designed for three planetary gravity-assist swingbys (one of Venus and two of Earth), which will provide it with the necessary velocity to reach the solar system's largest planet in late 1995. In December 1990, the Galileo spacecraft flew by Earth and the Moon, providing spectacular views of our home planet. This flyby constituted the first encounter of a planetary spacecraft satellite with Earth. Galileo was continuing its journey toward Jupiter as the year ended, with an encounter with the asteroid Gaspra scheduled for October 1991, to be followed by a second flyby of Earth in late 1992.

Ulysses. The Ulysses mission, launched from the Space Shuttle with the assist of an inertial upper stage on October 6, 1990, is an international cooperative mission developed by NASA and the European Space Agency (ESA). The Ulysses spacecraft was designed to collect scientific data on the previously unexplored polar regions of the Sun. Instruments on the spacecraft will be used to make detailed measurements of the Sun's corona, the origin and acceleration of the solar wind in space, and the composition and acceleration of energetic atoms from the Sun in solar flares and violent solar events. To accomplish its mission, the spacecraft must leave the ecliptic plane, the plane in which the Earth orbits the Sun. At year's end, Ulysses was on its way to Jupiter, where it will use the immense gravity of the largest planet in the solar system to propel itself out of the ecliptic plane toward the Sun's southern pole. Ulysses will overfly the high southern solar latitudes in mid-1994 and the northern latitudes in mid-1995. The mission will be completed in late 1995.

Mars Observer. The Mars Observer (MO) mission was being developed for a fall 1992 launch aboard a

Titan III expendable launch vehicle/transfer-orbit-stage combination. Mars Observer is a single spacecraft that will be placed in a near-polar orbit around Mars to conduct the first long-term U.S. study of Mars as a planet. Instruments on the spacecraft will map and study the entire surface and atmosphere of Mars for a full martian year (687 Earth days). These observations will determine the planet's global chemical and mineral surface composition and will provide a thorough exploration of Mars's gravitational field, topography, and magnetic field. MO also will study the circulation of Mars's atmosphere and determine the distribution, abundance, and sources of dust and volatile materials over a complete seasonal cycle. MO will begin its 2-year mapping mission in late 1993 after insertion into Martian orbit. In addition, Mars Observer is being designed to conduct a Mars Balloon Relay (MBR) experiment in cooperation with the Soviet Union and France. The MBR antenna system will relay data and increase the yield of high-resolution imagery obtained from balloons to be deployed on Mars by the Soviet Union's Mars-94 mission, whose two spacecraft will arrive at Mars in late 1995.

CRAF/Cassini. Two missions, the Comet Rendezvous Asteroid Flyby (CRAF) and Cassini (a Saturn Orbiter/Titan Probe), form the CRAF/Cassini Program. CRAF/Cassini will be the first in a series of planetary missions whose common objective is to explore prim-itive bodies and the outer solar system, with the ultimate goal of understanding the origin of our solar system and life itself. CRAF has two main objectives: a close flyby of at least one large asteroid and a multiyear rendezvous with the short-period comet, Kopff. A cooperative international mission, it is scheduled for a 1995 launch aboard a Titan IV rocket. Cassini will be the second mission to use the Mariner Mark II spacecraft and is a joint endeavor with the European Space Agency. Named in honor of the Italian/French astronomer who discovered four of Saturn's moons, Cassini will conduct a comprehensive scientific investigation of the Saturnian system, including the planet's rings, moons, and the fields and particles in its magnetosphere. An ESA-provided probe, named Huygens, will make in situ measurements of the atmosphere of Titan, Saturn's largest moon, while the orbiter will make close flybys of a number of the planet's other satellites. Cassini will build on the Galileo and CRAF missions by flying by at least one asteroid and Jupiter en route to Saturn. A comparison of data from Galileo and Cassini will attempt to determine similarities and differences between the Jovian and Saturnian systems. Cassini is scheduled for launch in the spring of 1996 aboard a Titan IV expendable launch vehicle, arriving at Saturn in late 2002.

Research and Analysis. In 1991, the Research and Analysis program continued to support active scientific research in several important disciplines, including planetary astronomy, planetary atmospheres, planetary materials and geochemistry, and planetary geology and geophysics. Most of the efforts in this area were focused on university-based research groups and training new scientists. These activities supported the Solar System Exploration program by developing and maintaining the research base and scientific instrumentation necessary for future missions. These efforts have provided effective analysis and long-term use of mission data and have generated exciting research results that cannot be obtained from flight missions alone.

Advanced Programs. Advanced programs support essential studies for planning future planetary missions. In 1991, progress was made on several mission concepts, including work on the Lunar Observer mission. The Space Science and Applications Advisory Committee (SSAAC) recommended several new missions for study during its strategic planning workshop held July 29-August 2, 1991. These new missions included: (1) Toward Other Planetary Systems (TOPS), a new program to use interferometric techniques to locate planetary systems around other stars; (2) the Neptune Orbiter and Pluto Flyby missions, to explore separately the two most distant planets within our solar system; (3) Mars Environmental Survey Mission (MESUR), a follow-on to Mars Observer that will consist of a series of small Mars-lander spacecraft to study the Martian environment; and, (4) the Discovery program, a series of Explorer-class missions to examine issues in planetary science.

Space Physics

Space Physics program objectives included understanding the Sun as a star, as an influence on Earth, and as the dominant source of energy, plasma, and energetic particles in the solar system; understanding the interactions between the solar wind and solar system bodies, including Earth and other planets; understanding the nature of the heliosphere, in its steady state as well as dynamic configuration; and understanding the origin, acceleration, and propagation of solar and galactic cosmic rays. The health of the space physics discipline depended on maintaining a mix of major, moderate, and small missions, the suborbital program, a Guest Investigator Program, and significant increases supporting research and technology.

Combined Release and Radiation Effects Satellite Program. NASA and the Department of Defense (DOD) were joint participants in this program to study the space environment that surrounds Earth and the effects of space radiation on modern satellite electronic systems. The Combined Release and Radiation Effects Satellite (CRRES) carried an array of active experiments including chemical releases and a complement of sophisticated scientific instruments to accomplish these objectives. The first chemical release experiment, conducted in September 1990, successfully proved the theory of critical velocity ionization. In 1991, three CRRES chemical release campaigns successfully concluded. Two high-altitude campaigns in January and February studied the response of the space environment to injection of artificial clouds of charged particles. The experiments were focused specifically on whether it is possible to stimulate auroral phenomena artificially. In July and August 1991, a series of experiments over the Caribbean investigated the effects of artificial ion clouds on the electric-ally conducting ionosphere layers and sought to trace the geometry of electric and magnetic fields. These three campaigns concluded the chemical release experiments planned for the CRRES spacecraft. All 24 canisters have been ejected and released their chemicals as planned. The spacecraft continued, however, to collect data from the DOD experiments.

International Solar-Terrestrial Physics Program. The International Solar-Terrestrial Physics (ISTP) program is an effort to draw on the resources of a worldwide scientific community to make a concentrated and coordinated study of the interactions in the Sun-Earth system and to extrapolate this knowledge to the other planets and to the universe beyond. The ISTP embraced the Global Geospace Science (GGS) program and the Collaborative Solar-Terrestrial Science (COSTR) program. The GGS program is designed to study geospace as an interconnected, interactive system using a fleet of spacecraft, including the NASA Wind and Polar satellites scheduled for launch in late 1992 and mid-1993, respectively; the Japanese/NASA Geotail mission scheduled for launch in mid-1992; and the Combined Release and Radiation Effects Satellite extended mission (see 1989-90 report). The Wind mission will provide measurements on solar wind input into the magnetosphere, and the Polar mission will provide measurements of energy input to the polar ionosphere. The Geotail mission will characterize the energy stored in the Earth's geotail and mid-magnetosphere region including measurements in the tail plasma sheet and measurements of plasma entry and transport in the magnetosphere boundary layer. During 1991, the instruments for GGS were manufactured and assembled; spacecraft development was continuing. Also in 1991, the U.S. delivered its portion of the Geotail instruments to the Japanese Institute of Space and Aeronautical Sciences for integration and test. The ground system for GGS was installed in 1991 and work was progressing at year's end for the preparation and installation of software. The COSTR program included the Solar and Heliospheric Observatory (SOHO) and Cluster missions. This program will be a cooperative venture between NASA and the European Space Agency. The SOHO mission will take remote measurements of the Sun and in situ measurements of the solar wind abundance to characterize the structure of the solar interior and the dynamics of coronal plasma. The Cluster mission will perform three-dimensional studies of the microphysical properties of different plasma states in the Earth's magnetosphere. In 1991, engineers completed the majority of critical design reviews for the SOHO and Cluster instruments, and structural models were delivered. Planning for U.S. operations of the SOHO spacecraft continued in 1990 and 1991.

Orbiting Solar Laboratory. The Orbiting Solar Laboratory (OSL) will be a free-flying satellite in a near-polar orbit. The spacecraft will fly in a sun-synchronous orbit along the line separating the Earth's day side from its night side with its instruments pointing sunward. OSL will carry five major instruments that will observe the Sun in visible light, and at ultraviolet, extreme ultraviolet, and x-ray wavelengths. The OSL will provide the means with which to study the origin and evolution of features leading to solar flares and solar variability, which have profound effects on Earth's upper atmosphere. The understanding gained from these observations will also make an important contribution to our ultimate ability to predict the occurrence of energetic solar particle events that will pose health hazards to astronauts en route to and from or at the Moon and Mars. The OSL, therefore, will serve as the first critical step in determining the observations to be made by a network of solar monitoring stations that can provide early warning of solar events. Advanced Phase B studies of OSL occurred in early 1991. Having been brought to maturity by mission studies by the end of FY 1991, OSL awaited a new start in the future.

Solar-A Program. The Japanese/U.S. Solar-A mission, successfully launched on August 30, 1991, took measurements of the Sun throughout the current peak of the solar activity cycle . NASA provided the soft x-ray telescope, the most complex of the four instruments aboard the Japanese Solar-A spacecraft, subsequently renamed Yohkoh ("sunbeam"). The Solar-A mission was investigating high-energy phenomena on the Sun through x-ray and gamma ray observations. It will make the first simultaneous hard and soft x-ray images of solar flares. The spacecraft was operating according to plan as the year ended, and NASA's instrument had been activated and was returning excellent preliminary scientific data.

Tethered Satellite System. The Tethered Satellite System (TSS), a cooperative program between NASA and the Italian Space Agency (ASI), was scheduled for a spring 1992 launch. NASA was responsible for the TSS deployer and systems integration, while Italy was building the satellite; both were providing scientific investigations. The objectives of the TSS will be to determine and understand the electromagnetic interaction between the tether/ satellite/Space Shuttle system and the ambient space plasma, to investigate and understand the dynamic forces acting upon a tethered satellite, and to develop the capability for future tether applications on the Space Shuttle and Space Station Freedom (see below). On its first flight, the satellite will be deployed on a conducting tether above the Space Shuttle to a distance of 20 kilometers (km, approximately 12 miles). During 1991, all experiments, the Italian spacecraft, and the TSS deployer arrived at Kennedy Space Center for integration.

Explorer Program. The International Cometary Explorer (ICE) and the Interplanetary Monitoring Platform (IMP)-8 continued during FY 1991 to collect scientific information. ICE was collecting data on solar coronal mass ejections and IMP-8 was studying solar modulation of cosmic rays, solar wind/magnetosphere coupling, solar wind dynamics, and magnetospheric dynamics. IMP-8 remained critical to the support of deep-space missions such as Ulysses, Pioneer, and Voyager and has become the primary monitor of solar activity during the new maximum period. Dynamics Explorer was officially retired by NASA on February 28, 1991. The spacecraft, which acquired the first global images of the Aurora, performed in space and collected data for nine years. Two small Explorers, the 1992 Solar, Anomalous, and Magnetospheric Particle Explorer and the 1994 Fast Auroral Snapshot Explorer, were in development (see above). Spacecraft integration for SAMPEX began in 1991. The four particle detectors aboard SAMPEX will measure electron and ion composition of solar energetic particles, anomalous cosmic rays, and galactic cosmic rays. Scheduled for launch near solar maximum during 1992, SAMPEX will be able to observe at least one major flare event and several smaller flare events.

Suborbital Program. Scientific experiments in space could often be performed inexpensively through the use of sounding rockets or balloons, allowing project teams to design, build, and fly experiments within a period of 1 to 2 years. The quick turnaround time not only allowed for major scientific results but also served very effectively as a means of training graduate students and young scientists and engineers for advanced experimental research.

NASA can support 30-40 sounding rocket launches annually. Fiscal year 1991 was an active year for sounding rocket experiments. In November 1990, two sounding rockets launched within 20 minutes of each other to capture images of the same solar flare. In this highly difficult and unusual procedure, soft x-ray images of the flare and data showing surprisingly broad ultraviolet spectra lines were obtained. In May 1991, a sounding rocket carried out a test of technology when it carried aloft a telescope using the newly developed, multilayer-coated, extreme ultraviolet grating. This telescope obtained spectra with an optical efficiency superior to those of other telescopes by a factor of six. Also, sounding rocket observations were made in conjunction with the total solar eclipse on July 11, 1991. Launched at the precise time of total eclipse in Hawaii, a telescope developed by the Smithsonian Astrophysical Observatory and IBM obtained soft x-ray images of coronal structures against the bright disk of the Sun. These images provide a unique comparison for the visible light images of the corona off the limb of the Sun obtained by ground observations.

NASA continued to maintain the capacity to launch 40-50 scientific balloons annually. In December 1990, a long-duration balloon flight successfully occurred in Antarctica. The 9-day flight with high energy particle and photon sensors was the longest balloon flight sustained at an altitude of over 120,000 feet. This significant new capability in the scientific balloon program was the product of a joint NASA/National Science Foundation effort.

Advanced Studies. During 1991, NASA conducted intense preliminary definition studies for a number of smaller, low-cost missions. Activities were especially intense for the Thermosphere-Ionosphere-Mesosphere Energetics and Dynamics (TIMED) mission, which will carry the first comprehensive space borne investigation of the physical and chemical processes acting in the terrestrial mesosphere and lower thermosphere/ionosphere. A TIMED Science Definition Team began operations in December 1990, and planning continued in 1991, preparing TIMED for a possible FY 1994 new start. In 1991, definition studies began for a number of missions, including the High-Energy Solar Physics (HESP) mission, which will study solar high-energy astrophysics and solar flares; the Grand Tour Cluster mission, which will provide the first comprehensive study of the micro- and mesoscale processes of the magnetosphere; and, the Inner Magnetosphere Imager (IMI) mission, which will obtain the first global images of the Earth's magnetosphere and component regions.

Earth Science and Applications

The Earth Science and Applications program conducted broad, space-based scientific studies of the Earth system. It sought to understand its component parts and their interactions, how they functioned, and how they may be expected to change over time. Almost all of NASA's Earth Science and Applications program continued to contribute to the Mission to Planet Earth initiative. This initiative is the NASA contribution to the U.S. Global Change Research Program (USGCRP), coordinated by the Committee on Earth and Environmental Sciences through the Office of Science and Technology Policy. The programs of Mission to Planet Earth are planned and coordinated to contribute to the scientific objectives outlined by the USGCRP. Mission to Planet Earth includes near-term flight missions, the Earth Probes program, in situ and aircraft observations, research and analysis programs, a comprehensive data system, interdisciplinary science and modeling efforts, an education program, and the Earth Observing System (EOS). These continued to involve not only NASA efforts but extensive cooperation and coordination with scientific and governmental organizations from around the world.

Earth Observing System (EOS). The Earth Observing System was designed to make comprehensive, long-term measurements of various aspects of the Earth system. EOS is a critical element of the Mission to Planet Earth program. The EOS program was included in the FY 1991 budget as a new start. In January 1991, 11 instrument investigations that will monitor the Earth's surface, radiation budget, and atmospheric properties were confirmed for flight on the first EOS-A series spacecraft. At the same time, NASA also confirmed the 29 EOS interdisciplinary investigations that are criti-cal to the science objectives of the program. NASA decided to delay the confirmation of EOS-B instruments until late 1992 to conduct a review of potential spacecraft configurations that would satisfy the EOS-B series science requirements. After evaluating the science requirements for the EOS-B series, NASA issued a Request for Information (RFI) to industry in late May 1991, soliciting alternative concepts and approaches to the implementation of the EOS-B series.

There was significant progress on the EOS Data and Information System (EOSDIS) during FY 1991. The first major EOSDIS development product will be the Version 0, a prototype system that connects a set of distributed users of science to specific existing data systems and selected data sets to test system design and inte-gration, and to enable early research efforts in support of the USGCRP. Meetings during the year sought to develop and adopt the approach to be taken to implement Version 0. The Version 0 development process that was under way supported on-line capability by 1994. NASA released an RFI on EOSDIS in October 1990 that produced a large number of comments and suggestions. After incorporating these comments, NASA released a Request for Proposal (RFP) for the EOSDIS Core System (ECS) contract in July 1991. A contract award was expected in late 1992. This award date supports an operational core system by 1996-97.

The EOS Science program provides support for interdisciplinary investigations, algorithm development for facility and principal investigator instruments, and coordination with field campaigns necessary for validation and refinement of algorithms. The EOS Investigator Working Group, which provides guidance and advice concerning all major scientific issues relevant to the mission, met twice during FY 1991. In June 1991, it selected an additional 61 students to receive global change fellowships through a program designed to encourage the next generation of global change researchers.

International cooperation continued through meetings of the Earth Observations International Coordination Working Group (EO-ICWG) and its subgroups. The EO-ICWG was coordinating the payload planning for polar spacecraft from NASA, European Space Agency, and the Japanese Space Agency (NASDA), as well as addressing other elements of mission planning.

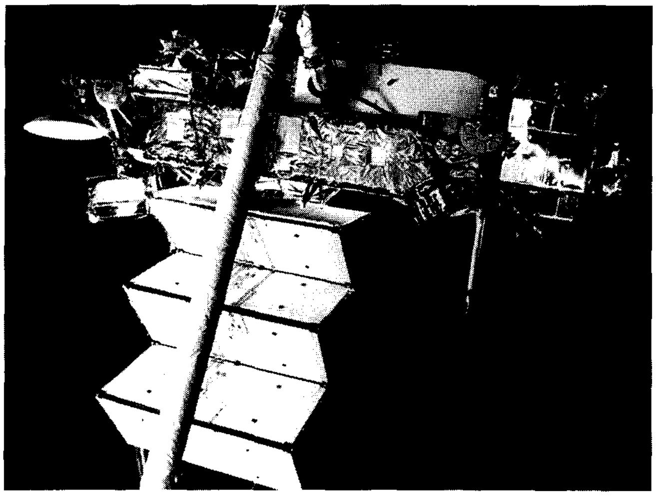
In 1991, due to budgetary constraints, emerging launch vehicle options, and other factors, NASA reevaluated its planning for the EOS program. NASA asked the IWG to prioritize the EOS science objectives and to study how required measurements could be acquired using various spacecraft types and sizes. The reconfiguration process was scheduled to be completed for inclusion in the President's FY 1993 budget submission.

In late September 1991, the EOS Engineering Review Advisory Committee released its report concerning the implementation of the EOS program. The Committee considered the most critical issues facing the EOS program, including budget, scientific priorities, sensor capabilities, and spacecraft and launch vehicle options. The Committee encouraged NASA to proceed with EOS using smaller spacecraft, to foster greater cooperation with other agencies, and to conduct an additional review of its implementation planning for the EOSDIS core system.

Ozone Observations, Research and Assessments. During FY 1991, NASA continued its broad program aimed at improved understanding of the nature of ozone depletion and the ozone layer. A Solar Backscatter Ultraviolet (SBUV) instrument flew on the Shuttle in October 1990 and August 1991 to gather on orbit data needed to calibrate direct ozone measurements by the Total Ozone Mapping Spectrometer (TOMS, see below) and other NASA and National Oceanic and Atmospheric Administration (NOAA) satellite instruments. NASA researchers confirmed that the ozone hole over Antarctica was as severe in 1990 as in previous years. In addition, researchers at NASA's Goddard Space Flight Center (GSFC) reprocessed nearly 12 years of measurements of total column ozone from the TOMS instrument aboard the Nimbus-7 satellite. These indicated that the ozone depletion over the northern mid-latitudes—including the United States—was approximately twice as severe as originally reported based on uncorrected data. NASA scientists will also be making substantial contributions in updating the *Scientific Assessment of Stratospheric Ozone* prepared under the auspices of the United Nations Environment Program (UNEP) and the World Meteorological Organization (WMO). All three assessments will be completed and distributed to the participating governments by January 1992, 6 months in advance of the review of the Montreal Protocol on Substances that Deplete the Ozone Layer. (See also coverage below.)

Climate Research. NASA researchers participated in the global research effort to study and understand the global consequences of the oil well fires that resulted from Iraqi actions during the war in the Persian Gulf. In addition, NASA researchers using aircraft and satellite data began studying the global effects of the eruption of the Mount Pinatubo volcano in the Philippines in June 1991.

Upper Atmosphere Research Satellite. The Upper Atmosphere Research Satellite (UARS) was the first mission in the long-term international program to study



The Upper Atmosphere Research Satellite (UARS) was photographed by the Discovery astronauts as the solar array deployed with the satellite attached to the manipulator arm. UARS represents the same advance in the environmental monitoring of Earth as does the Arthur Holly Compton Observatory for astrophysics.

global change. UARS, launched September 12, 1991, aboard Space Shuttle Discovery, was designed to study atmospheric chemistry, energy balance and dynamics. UARS will help establish the comprehensive data base needed to understand the depletion of stratospheric ozone, a component of the atmosphere critical to protecting life from harmful ultra-violet radiation. It will also assist our understanding of the effects of human activity on the atmosphere and lay the foundation for a broader study of the upper atmosphere's influence on climate and climatic variations. UARS included 10 instruments, all of which were operational. Several of these are precursors to instruments for the Earth Observing System.

TOPEX/POSEIDON. TOPEX/POSEIDON will be a joint U.S. (NASA) and French (CNES) mission to study global ocean circulation. Ocean circulation has a direct impact on regional climates. It also plays a key role in global climate through the absorption of carbon dioxide, an atmospheric constituent that contributes to global warming. The mission is comprised of highly accurate radar altimeters on a precisely tracked satellite that will observe sea-surface topography. The data will enable the study and more accurate modeling of oceanic circulation and heat transport, and its interaction with the atmosphere. TOPEX/POSEIDON is a precursor to the altimetry instruments that will be included in the Earth Observing System. In 1991, the TOPEX/POSEIDON instruments were delivered, and the development of the spacecraft neared completion. Delivery of the fully integrated satellite for launch is expected in the spring of 1992. TOPEX/POSEIDON will be launched from the Kourou launch site in French Guiana on an Ariane IV unmanned launch vehicle.

Earth Probes. A New Start in FY 1991, the Earth Probes program consisted of a series of small- and moderate-sized missions that will address highly focused problems in Earth science. Earth probes will provide a pre-EOS start/continuation of long-term data sets and will capture measurements that are not possible with EOS or other instrument suites. Each instrument has a specific purpose, providing critical measurements of a particular phenomenon but requiring a unique orbit or configuration not available from other EOS precursor missions. Earth Probes were composed of the Total Ozone Mapping Spectrometer, the NASA Scatterometer (NSCAT), and the Tropical Rainfall Measuring Mission (TRMM).

Total Ozone Mapping Spectrometer. The Total Ozone Mapping Spectrometer instrument has measured total ozone concentrations. The TOMS instrument flown on Nimbus 7 has provided continuous data on changes in global ozone since 1978. This data was instrumental in discovering the ozone hole over the Antarctic. TOMS also provided data on lower stratosphere/tropopause dynamics. In August 1991, a TOMS instrument flew aboard a Soviet Meteor-3 unmanned launch vehicle. The instrument was operating nominally. TOMS instruments were also scheduled to fly in 1993 aboard a U.S. small expendable launch vehicle, and in 1995 on the Japanese Advanced Earth Observing Satellite (ADEOS), both as part of the Earth Probes program. Contractors were selected in 1990 for the instruments, in 1991 for the spacecraft, and development began before the year ended.

NASA Scatterometer. The NASA Scatterometer is an instrument that will measure ocean surface wind velocity and provide data on air-sea interactions. NSCAT will be part of the Japanese Advanced Earth Observing Satellite payload, scheduled to be launched on an H-II launch vehicle in 1995. In 1991, development of NSCAT hardware continued. The Preliminary Design Review for the overall ADEOS mission occurred in Japan in September 1991.

Tropical Rainfall Measuring Mission. The Tropical Rainfall Measuring Mission will measure diurnal variation of precipi-tation and evaporation in the tropics, providing insight as to how substantial rainfall affects global climatic patterns. TRMM is a joint venture with Japan and will be launched on the H-II launch vehicle in the late 1990s. In 1991, Phase B definition studies for TRMM ended, and design and development began.

Sea-Viewing Wide Field Sensor. The Sea-Viewing Wide Field Sensor (SeaWIFS) is an instrument that will acquire high quality global ocean color measurements. This information is important to understanding biogeochemical processes, climate change and oceanography. Planned as a precursor to the Earth Observing System, SeaWIFS will serve as a follow-on to the Coastal Zone Color Scanner that flew aboard Nimbus-7 in 1978. SeaWIFS is being developed commercially, with a contract in place for the provision to NASA of data. The owner of the satellite will build and operate the instrument and retain rights to sell the data to other clients. SeaWIFS data may be of particular commercial interest because it can be used to pinpoint the locations of large concentrations of fish that feed on observable phytoplankton. Development of SeaWIFS began in May 1991. It is expected to be launched in the summer of 1993.

Operational Meteorological Satellites. NASA supported the National Oceanic and Atmospheric Administration's operational geostationary and polar weather satellite program, managing satellite procurement and arranging for launch and on orbit checkout. Under this arrangement, NASA then turned the satellites over to NOAA for operation. NOAA-D, replacement for the NOAA-10 polar orbiting satellite in operation since September 1986, launched in May 1991. NOAA-I, replacement for NOAA-11, underwent final testing during FY 1991. NOAA-I will be ready for launch as early as February 1992 and will be flown as it is needed. Since the failure of the Geostationary Operational Environmental Satellite (GOES)-6 in January 1989, the tracking of severe storms near the United States has been provided by a single satellite, GOES-7 (launched in February 1987). GOES-I, the next satellite in the series, is planned for launch in 1993. During 1991, development of the GOES-I instruments continued, and the GOES-I spacecraft development reached completion. Both the instruments and the completed spacecraft began thermal vacuum testing. Integration and subsequent testing of the GOES-I satellite is expected to begin in early 1992. (See the coverage below under NOAA.)

Airborne Arctic Stratospheric Expedition II. The 1991-1992 Airborne Arctic Stratospheric Expedition (AASE II) involved an extended aircraft campaign designed to investigate the Arctic polar stratosphere over the complete annual lifetime of the northern hemisphere polar vortex. This is a period in early winter when polar stratospheric clouds are most likely to form. The AASE II consists of five or six 2-week data-gathering phases planned to take place between October 1991 and April 1992. It expected to employ the NASA ER-2 research aircraft and the NASA DC-8 "flying laboratory." AASE II was being staged from Fairbanks, AK, during October 1991, with the base of operations shifting to Bangor, ME, for the remainder of the mission (ending April 1992).

Life Sciences

Basic research in life sciences was predicated upon the goals of ensuring the health, well-being, and productivity of humans in space; developing an understanding of the effects of gravity upon living systems; expanding the understanding of origin, evolution, and distribution of life in the universe; and promoting the application of research in life sciences to improve the quality of life on Earth. The program encompassed basic and applied research, plus clinical practice. The core space life sciences program comprised ongoing programs, enhancements to the research base, small and moderate missions, and Space Station Freedom use and support.

Space Life Sciences-1. Space Life Sciences Laboratory (SLS)-1, the first Space Shuttle mission dedicated to life sciences research, launched on June 5, 1991, for a 9-

day mission. While previous flight investigations have characterized gross physiological changes in space, research on SLS-1 was primarily devoted to understanding the underlying biological processes and mechanisms of adaptation to microgravity and readaptation to Earth's gravity. The Shuttle crew conducted 18 primary investigations, along with a greater number of secondary investigations, on themselves as well as upon rodents and jellyfish. Preliminary results from the SLS-1 investigations indicated that the experiments not only achieved their objectives but revealed new, unexpected information.

Operationally, as well as scientifically, the mission was an outstanding success. SLS-1 provided more life sciences data than any previous mission. The crew employed a number of new techniques and procedures, including tracers for measuring fluid volumes, state-of-the-art automated cardiopulmonary tests, and many measurements that were never before made in flight, establishing a new standard of scientific excellence for space life sciences research.

Several of the more dramatic findings included: (1) evidence that the body begins to adapt to microgravity earlier than expected and that the nervous and endocrine systems play a significant role in regulating that adaptation; (2) new insights into the ways in which the circulatory and renal systems participate in reducing the fluid content of the body in space, which will cause a refinement of ground-based models; and (3) the puzzling finding, resulting from an assessment of pulmonary functions, that regional differences in the lung ventilation and blood flow, previously thought to be a gravity effect, still exists in weightlessness.

Extended Duration Orbiter Medical Program. The Extended Duration Orbiter Medical Program (EDOMP) was designed to develop medical countermeasures to the effects of microgravity and other features of life in orbit for Space Shuttle missions of 10 days and longer. The EDOMP has two phases: extension of missions to 13 days, and then to 16 days. The main areas to be investigated are the capability of the crew for a safe landing, unaided and timely egress, and a safe spacecraft environment. The knowledge acquired will feed into the overall data base to support more advanced missions on Space Station Freedom. The first extended duration (13-day) Shuttle flight was planned for the United States Microgravity Laboratory mission scheduled for mid-1992.

Space Physiology and Countermeasures. The Space Physiology and Countermeasures program was responsible for studying the physiological changes and deconditioning resulting from space flight and for developing predictive models, methods, and countermeasures. The experimental results from SLS-1 have advanced our knowledge about the effects of space flight on humans. In 1991, NASA and other agencies developed plans for all biomedical disciplines included in the program. Meanwhile, the Fourth Meeting of the U.S.-U.S.S.R. Joint Working Group on Space Biology and Medicine had occurred in September 1990, and NASA was participating in the Interagency "Decade of the Brain" program. A workshop on the musculoskeletal effects of space flight was held jointly by NASA and the National Institute of Musculoskeletal and Skin Disease in October 1990. NASA selected the University of Rochester as its Specialized Center of Research and Training (N-SCORT) for Environmental Health. The Radiation Health program sponsored a workshop in 1991 that explored new directions in radiation health research. NASA plans to establish an N-SCORT for Radiation Health in 1992.

Centrifuge Facility. During 1991 NASA completed Phase B studies for the Centrifuge Facility to be used on Space Station Freedom. The Centrifuge was expected to be the single most important research facility for space life sciences. This facility will provide controlled levels of artificial gravity (between 0 and 2 gs) for experiments using plant and animal subjects. Engineers were designing it to separate the effects of weightlessness from other environmental factors. The Phase C/D Request for Proposals is expected to be released in April-June 1992, with the contract to be awarded in November 1992-January 1993. A memorandum of understanding between NASA and the Italian Space Agency is expected to be signed in October 1991. It would allow ASI to build a minilab to house the Centrifuge Facility on Space Station Freedom. If an agreement cannot be reached, the Centrifuge Facility will be housed in a node of the Space Station.

Cosmos. Cosmos is a joint U.S.-U.S.S.R. program including U.S. investigators who have conducted life sciences investigations aboard unmanned Soviet biological satellite missions. Since the biosatellite program began over 15 years ago, the U.S. has participated on seven missions and flown experiments involving plants, insects, rodents, fish, and rhesus monkeys. Life sciences participated in the Cosmos Biosatellite Symposium (August 1991) in Leningrad, which reviewed all the results from the Cosmos missions to date. Negotiations were under way at the end of FY 1991 for a mission in late 1992.

Controlled Ecological Life Support Systems. The goal of the Controlled Ecological Life Support System (CELSS) program is to design and construct a biologically-based, regenerative support system that could reduce the need for costly resupply from the Earth. Experiments accommodated by the CELSS Test Facility on Space Station Freedom are expected to permit the systematic development of the capability to control, monitor, and evaluate the growth of crops in a closed system in space. A laboratory version of a "salad machine" for the provision of fresh vegetables on Space Station Freedom has operated successfully on Earth. The effects of lighting and temperature on crop growth were being investigated in a Crop Growth Research Chamber, while the CELSS Breadboard Project continued to investigate the effect of full-scale simulation of conditions in space on different plant crop yields.

Operational Medicine. The Operational Medicine Program provided for medical care and support for Space Shuttle crews before, during, and after space flight. Follow-up exams and longitudinal studies were part of the ongoing program in health maintenance. The primary goals of the program were to identify and anticipate potential health problems, develop preventive and therapeutic procedures, and establish research priorities to address biomedical challenges. Other areas of activity included the development of medical standards for astronaut selection and retention and the definition of requirements for advanced health care systems, protocols, and procedures for long-duration space missions.

Telemedicine Spacebridge. The initial goal of the Telemedicine Spacebridge was to provide expert medical consultation, in real time, to the medical personnel of Armenia and Ufa, in the U.S.S.R., to help them address two major disasters—an earthquake in 1988 and a gas explosion in 1989. The Spacebridge became the first example in history of the use of a system of satellite communications in support of systematic, long-term, multidisciplinary collaboration between the medical personnel of two nations. Both the U.S. and U.S.S.R. have reaffirmed their common interest in developing an experimental telemedicine program both within the framework of the bilateral agreement on space and for the good of the international medical community, especially in the areas of manned space flight and disaster relief. Both countries have agreed to further explore the financial and technological requirements for reestablishing a telemedicine capability between American and Soviet medical institutions.

Space Biology. The Space Biology program is aimed at understanding the effects of gravity on plants and animals at the most fundamental levels and providing basic knowledge of biological processes through experimentation in microgravity. An active flight experimental program continued with a study of circadian rhythms in space in the fungus *Neurospora*, conducted on STS-32 in 1990, and an experiment investigating muscle metabolism in rats on STS-48 in September 1991. Space Biology experiments in the neuroscience, musculoskeletal, and cell biology areas were key parts of the highly successful SLS-1 investigations performed in the summer of 1991. Flight experiments will continue with studies in plant phototropism and gravitropism, plant and bone cell culture, and plant reproduction scheduled for flight in 1992.

Exobiology. Current research in the Exobiology Program has addressed the hypothesis that life is a natural consequence of the origin and evolution of stars and planets. The Gas-Grain Simulation Facility (GGSF) will accommodate experiments in exobiology on Space Station Freedom. Several ground-based studies have been selected and will begin in 1992; these will lead to the development of the GGSF. The Search for Extra-terrestrial Intelligence (SETI) Microwave Observing Project, a 10-year program to probe our galaxy for radio signals of possible extraterrestrial origin, is scheduled to begin operation with prototype systems in 1992. A primary activity for this project in 1992 will be to continue building and testing the operational systems in preparation for their later deployment.

Biospheric Research Program. This program used ground- and space-based studies to understand how biological processes and planetary properties affect one another and how human activities affect this interaction. Research emphasis during 1991 was on biogeochemical cycling, particularly the global production of greenhouse gases from biological sources in wetlands, temperate and tropical forests. In the temperate forest research project, investigators were studying experimentally controlled burns to quantify greenhouse gas and particulate production. The Global Monitoring Disease Prediction Project sought to identify potential sites of malarial outbreaks and to develop a model, using remote sensing, that will establish the links between the presence of malaria-bearing mosquitos and certain environmental conditions.

Microgravity Science and Applications

During the past year, the Microgravity Science and Applications program has experienced an exciting period of intense experimental activity looking forward to, and preparing for, three focused microgravity science missions during 1992. The program has used the unique attributes of the space environment to conduct research in three primary areas: fundamental science, materials science, and biotechnology. In space, the absence of gravity-induced phenomena, such as buoyancy-driven convection, sedimentation, and hydrostatic pressure, provides a unique opportunity to study many physical processes and materials. Involved disciplines include fluid dynamics and transport phenomena, combustion, materials science, and biotechnology. In 1990 and 1991, the microgravity payloads flown on Space Shuttle flights focused on protein crystal growth and combustion experiments. In addition, work continued on the development of experiments and hardware to be flown on upcoming 1992 Spacelab flights, such as the International Microgravity Laboratory, the United States Microgravity Laboratory, and the United States Microgravity Payload.

Protein Crystal Growth. The Protein Crystal Growth (PCG) Facility flew aboard Space Shuttle missions STS-37, STS-43, and STS-48 in 1991 (see below). Results of the experiments will help refine methods for growing high-quality crystals in micro-gravity and will help define the commercial potential for this process. Protein crystals grown in microgravity are often larger and more defect-free than crystals grown on Earth. Protein crystals are used to determine the three-dimensional molecular structure of proteins through the use of x-ray diffraction analysis. Determination of protein structures is an area of tremendous scientific and commercial importance.

Combustion Experiment. It is also extremely important to understand how a flame spreads in microgravity, especially because of the importance of fire-safety in the spacecraft. However, notwithstanding the issue of fire-safety, many of the complex physical and chemical processes of combustion can be more readily understood in the absence of buoyancy and particle settling, such as the processes of radiation and diffusion. The Solid Surface Combustion Experiment, which measured the rate of a flame spreading in thin paper samples, flew successfully on STS-41 in October 1990; STS-40 in June 1991; and STS-43 in August 1991. The experiment will fly several more times with paper samples and with thicker slabs of Plexiglass to explore the influence of ambient atmospheric pressure.

Ground-Based Research. Ground-based research facilities, such as drop towers and aircraft, play an important role in microgravity-science investigations. Extensive testing occurs in these facilities before committing to costly experimentation. In 1991, numerous investigations in fluid dynamics and transport phenomena, combustion, and materials science took place at the Lewis Research Center. Studies at the Marshall Space Flight Center focused on materials science and containerless processing. These facilities allow wider access to microgravity by the research community, including hands-on student involvement in microgravity research.

Space Flight Facility Development. In 1991, NASA continued to support the development of over 30 experiments flown on the Shuttle. The hardware being developed included both investigator-specific and multiuser apparati. Several of the multiuser facilities were precursors to the six facilities that are planned for Space Station Freedom. These include the Space Station Furnace Facility, the Modular Containerless Processing Facility, the Advanced Protein Crystal Growth Facility, and the Fluid Physics/Dynamics Facility. This is an evolutionary approach to Space Station use that will allow NASA to benefit from on orbit experience gained on Shuttle flights.

Flight Systems

The flight systems program managed Spacelab missions and plans for scientific use of Space Station Freedom.

Spacelab Flight Program. During FY 1991, two Spacelab missions flew on the Shuttle—Astro-1 and Space Life Sciences-1 (see above)—and extensive preparations occurred for several other Spacelab flights scheduled for FY 1992. In early 1992, more than 200 scientists from 13 countries will collaborate with NASA on the first International Microgravity Laboratory (IML), which will carry life and microgravity sciences payloads to study how life forms adapt to weightlessness and how materials behave when processed in space. Preparations were also under way at year's end for the Atmospheric Laboratory for Applications and Science (ATLAS) missions, the first of which will fly in the spring of 1992. The ATLAS missions will measure, over the 11-year solar cycle, the long-term changes in the total energy radiated by the Sun, the variability in the solar spectrum, the effect of the Sun's radiation on Earth's upper atmosphere, and the global distribution of key molecular species in the middle atmosphere. Using 11 instruments, scientists will conduct 12 investigations in atmospheric science, solar physics, space plasma physics, and astronomy.

The U.S. Microgravity Laboratory (USML), the first in a series of missions dedicated to microgravity research, was a pressurized Spacelab module scheduled to fly in 1992. It will be followed soon after by the U.S. Microgravity Payload (USMP), which will consist of pallet-mounted instruments. Preparations were also in work for a joint microgravity mission with Japan, known as Spacelab J, scheduled for late FY 1992.

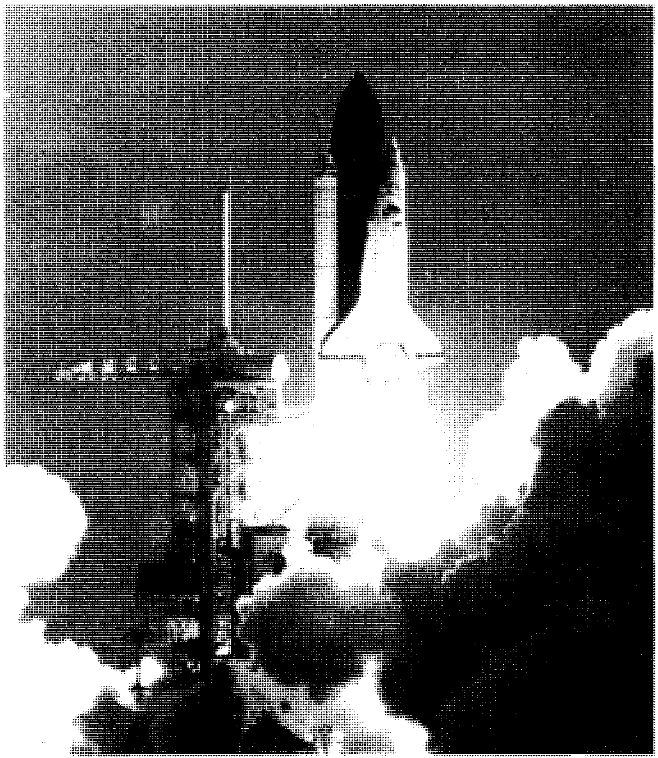
Space Station Activities. During 1991 NASA conducted accommodations analyses and Phase A concept studies for numerous experiment facilities planned for Space Station Freedom. (See above for coverage of Phase B definition studies for a Life Sciences Centrifuge Facility.) The feasibility and costs required to divert payloads from the third planned U.S. Microgravity Laboratory (USML-3) to take advantage of early opportunities aboard the Station were also being examined. The Crystal Growth Facility (CGF), Advanced Protein Crystal Growth (APCG) experiments, Combustion Research experiments, and the Space Acceleration Mapping System (SAMS) were identified as technically feasible and scientifically productive "transition payloads." Supporting engineering and accommodations studies will occur in the coming year. NASA also established requirements for development of capabilities at NASA Field Centers to support payload integration, ground processing, and flight operations. As a result of the restructuring of the Space Station, the Office of Space Science and Applications and the Office of Space Flight reduced the Station's capability to support external, attached payloads. The investigations previously selected for these payloads were being evaluated for alternative missions as FY 1991 ended or had already been deselected.

Space Transportation

As part of NASA's mission, derived from the President's National Space Policy, the Office of Space Flight was responsible for developing space transportation capabilities, carrying out space flight operations, and planning for men and women to work in space. In addition, the Office continued to support future scientific and human exploratory missions in the solar system and the permanent presence of human beings in space. It has also assisted in the commercialization of space and the privatization of space transportation systems.

The Space Shuttle

Orbiter. The Space Shuttle's primary purpose is to transport people and cargo into low-Earth orbit (100 to 350 nautical miles above the Earth). As of the end of the year, there were four active orbiters: Columbia, Discovery, Atlantis, and Endeavour. Each orbiter could accommodate a flight crew of up to seven people. Typical missions have ranged from four to nine days in duration, with crews numbering from five to seven. The newest



Kennedy Space Center, FL—The Space Shuttle Discovery heads skyward at 7:47 a.m. EDT, October 6, 1990, carrying the Ulysses spacecraft on its journey to reveal the mysteries of the Sun.

orbiter, Endeavour (OV-105), joined the fleet on schedule and within budget in May 1991. Its first flight, STS-49, was scheduled for April 1992. Changes made to this vehicle included a drag chute, improved nose wheel steering, and the capability to upgrade easily to an extended duration orbiter configuration.

In addition to work on Endeavour, several modifications were in the process of being incorporated into the fleet. Among the improvements were an upgraded general purpose computer, new carbon-carbon brakes, an improved auxiliary power unit, a fixed-orifice oxygen flow control valve, and a redesigned helium-system regulator. These and other improvements will help to enhance the orbiter fleet's performance and safety margins. The historical data trend on in-flight anomalies has already shown continued improvement.

Work continued in 1991 on the Extended Duration Orbiter program to provide up to a 16-day mission capability. NASA was modifying Columbia for this capability and constructed Endeavour in such a way that the option for extended duration could easily be implemented. Modifications that enable extended missions include the addition of a new cryogenic pallet containing four tank sets of oxygen and hydrogen for additional power generation, a regenerative carbon dioxide removal system, an improved waste management system, and increased stowage. Extended missions will be approached incrementally with 10- and 13-day flights prior to the first 16-day extended duration orbiter flight. During 1991, several missions included data-gathering experiments in support of the first 13-day mission planned for June 1992.

A special crew transport ground vehicle has been added to the program to gain rapid access to the crew upon landing so that medical tests can be performed before readjustment to the Earth's environment.

FY 1991 Shuttle Missions. NASA successfully completed eight Space Shuttle missions during fiscal year 1991. The missions included STS-41, STS-38, STS-35, STS-37, STS-39, STS-40, STS-43, and STS-48. STS-41 (Discovery) was a four-day mission, launched on October 6, 1990, from the Kennedy Space Center, FL. The primary objective of the mission was the deployment of the Ulysses spacecraft. This probe's primary mission, in turn, will be to study the environment of the Sun. (See above, Space Science and Applications.) The orbiter landed safely at Edwards Air Force Base (AFB), CA, on October 10, 1990.

The next mission, STS-38 (Atlantis), launched on November 15, 1990. The 5-day flight was a classified Department of Defense mission. The orbiter landed safely on November 20, 1990, at the Kennedy Space Center.

The last flight of calendar year 1990 was STS-35 (Columbia). Columbia lifted off on December 2, 1990. The highlight of the mission was the successful use of the Astro-1 ultraviolet telescope (see above). Columbia returned safely to Edwards AFB on December 10, 1990.

The first launch of calendar year 1991, STS-37 (Atlantis), occurred on April 5, 1991. The 6-day mission's primary objective was the deployment of the Gamma Ray

Observatory (see above). Atlantis returned safely to Edwards AFB on April 11, 1991.

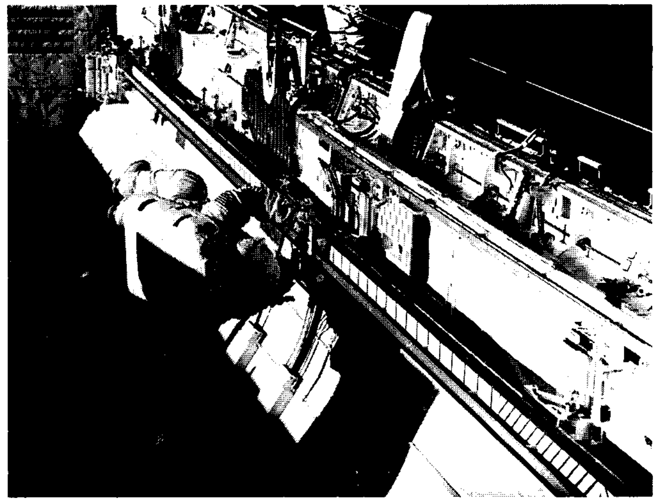
The next mission, STS-39 (Discovery), launched on April 28, 1991. Its primary mission involved supporting the Strategic Defense Initiative by observing the spectral signature of several plasma and gas sources in the upper atmosphere and in the orbiter's exhaust plume. On May 6, 1991, Discovery landed safely at Kennedy Space Center.

STS-40 (Columbia) launched on June 6, 1991, from Kennedy Space Center. Also known as Space Life Sciences (SLS-1), it was the first Spacelab mission devoted exclusively to life science research (see above). Columbia returned safely to Edwards AFB on June 14, 1991.

STS-43 (Atlantis) launched from Kennedy Space Center on August 8, 1991. The 9-day mission deployed a Tracking and Data Relay Satellite (TDRS-E). The TDRS satellites provide communication and data links between Earth and spacecraft such as the Space Shuttle. On August 11, 1991, Atlantis returned safely to the Kennedy Space Center.

Discovery flew the final shuttle mission of fiscal year 1991. STS-48 launched on September 12, 1991. The primary objective of the 6-day mission was the deployment of the Upper Atmosphere Research Satellite (UARS, see above). Discovery returned safely to Edwards AFB on September 18, 1991.

Space Shuttle Main Engine. The Space Shuttle Main Engine (SSME) program continued its active test program in 1990 and 1991. Some 112 ground tests totaling more than 43,000 seconds took place in support of its development, certification, and flight programs during 1990. During the first nine calendar months of 1991, there were 80 tests for a total of 26,523 seconds. This increased the total since January 1986 to 541 tests for just over 200,000 seconds with a renewed emphasis on reliability, safety, and life enhancements. In 1991, the alternate turbopump began engine-level development tests for fleet implementation in FY 1994, and the redesigned high pressure fuel turbopump was certified for flight use. In addition, during FY 1991 the Technology Test Bed Program, which furnishes NASA with critical basic propulsion research and technology capability, initiated testing on the highly instrumented SSME to characterize engine internal operating environments for advanced SSME designs.



On-board STS-37—Astronaut Jerome (Jay) Apt, STS-37 mission specialist, participates in a lengthy extravehicular activity in Atlantis' cargo bay. Astronauts Apt and Jerry L. Ross evaluated translation devices that could be predecessors of hardware to be used on Space Station Freedom. Here, Apt moves along a beam on a device called a Tether Shuttle.

Solid Rocket Booster. The Solid Rocket Booster continued to perform without significant problems in eight flights during FY 1991. There were two static test firings of motors manufactured before the Challenger accident, performed to qualify a new source of rayon material as well as design improvements in the motor nozzle. A limited development effort was continuing to improve the design, including redesign of the igniter seals for added safety margin and to improve manufacturing processes to minimize defects.

Advanced Solid Rocket Motor. The Advanced Solid Rocket Motor program made significant progress during FY 1991 in both motor design and in facility construction. NASA released drawings for manufacture of the first motor case that incorporated bolted field joints and welded factory joints. It selected a specific formulation for the propellant and activated a pilot plant for the propellant's continuous mix and cast process. It conducted two 48-inch diameter subscale-motor static-firing tests to evaluate nozzle and insulation materials. It obtained environmental permits for all construction sites, and site preparation at Yellow Creek manufacturing plant at Iuka, MS; the Stennis Space Center at Bay Saint Louis, MS; and the Michoud Assembly Facility at Slidell, LA, neared completion. Construction at Yellow Creek has begun with foundation emplacement for the motor case preparation building. Finally, the National Research Council completed an assessment of the program plans for quality assurance and testing.

Shuttle Systems Integration. Development of a Day-of-Launch I-Load-Update (DOLILU) System started early in 1990 and proceeded throughout 1991. The DOLILU considers the actual winds on launch day and updates the software that directs the optimum trajectory during ascent of the Space Shuttle. In so doing, it will reduce structural loads during ascent, thereby providing a higher probability of launch and an expected reduction in launch delays and launch holds.

A Critical Design Review, safety and hazard analyses, a series of demonstration tests, seven operational simulations, and a Design Certification Review generated confidence in DOLILU. It was certified for flight use in August 1991. On September 12, during the countdown for STS-48, unusually strong winds aloft were measured in the hours leading up to launch. A launch hold was prevented since the DOLILU trajectory update was ready and put into use on the very first flight for which it was available that day.

DOLILU was continuing to be used in parallel with existing ascent guidance commands to compare its ability to generate trajectories that are safer than currently available in the face of actual launch day winds. NASA expected the DOLILU system to provide the prime I-Load trajectory software starting early in 1992.

Expendable Launch Vehicles

1991/1992 Launches. NASA successfully launched two missions from the West Coast in 1991, a NOAA polar meteorological satellite on a United States Air Force (USAF)-provided Atlas-E in May and a USAF radiation experiment payload on a Scout launcher in June. Seven missions were scheduled as of the end of the year for launch in 1992, beginning with the Extreme Ultraviolet Explorer aboard a USAF procured Delta II; another NOAA polar meteorological satellite in February; the Solar, Anomalous and Magnetospheric Particle Explorer on a Scout in June; followed by two launches of commercially procured Delta II's to support the launches of the Japanese/NASA cooperative Geotail payload and the Wind spacecraft. The Mars Observer spacecraft was expected to begin its journey to Mars aboard a commercially procured Titan III vehicle using a commercial Transfer Orbit Stage (TOS). NASA's Expendable Launch Vehicle (ELV) flight rate for 1993 and beyond was expected to average approximately five to seven launches per year.

NASA's use of commercial ELV services made significant progress this year. The Agency signed a contract for commercial launch services in November 1990 with McDonnell Douglas for three firm Delta II launches to support the Geotail, Wind and Polar missions targeted for launch in 1992 and 1993. The contract also includes an additional 12 optional launch services, which will enable NASA to support future science missions requiring Delta launch services without the need for individual procurement actions. This contract approach has provided NASA the economic benefits associated with a quantity buy while providing the launch service contractor with a stable business base. NASA signed a similar contract in September 1991 for seven firm Pegasus launches and three optional launches with Orbital Sciences Corporation for support to NASA's small explorer program. NASA also signed a contract with General Dynamics in April 1991 for Atlas IIAS launch services to support the NASA/ESA cooperative Solar Heliospheric Observatory mission scheduled for launch in July 1995. At year's end, NASA had 32 missions scheduled for launch under commercial ELV service contracts.

In an effort to maximize low cost flight opportunities, NASA initiated a secondary ELV payload program in 1991. The purpose of this program was to increase the utility of each ELV launch by identifying and using any excess capacity on those missions beyond that required for the primary payload. NASA had four secondary payloads currently scheduled for launch aboard Delta IIs. The first secondary payload, the Diffuse Ultraviolet Experiment, was scheduled to be launched aboard the Geotail vehicle in July 1992. The next three scheduled secondary payloads were targeted for flight aboard USAF Delta IIs in 1992 and 1993.

NASA's activities over the past year have demonstrated the Agency's strong commitment to a balanced, mixed fleet launch strategy using both the Space Shuttle and unmanned expendable launchers, in accordance with national policy established following the Challenger accident.

Upper Stages

Inertial Upper Stage. The USAF-developed Inertial Upper Stage (IUS) rocket successfully transported two payloads launched from the Space Shuttle in low earth orbit to the payloads' final destinations. The Ulysses spacecraft launched in October 1990 into an interplanetary trajectory, and a TDRS launched into a geosynchronous orbit later in August 1991. NASA planned use of two additional IUSs in 1993 and 1995 to complete the TDRS constellation.

Transfer Orbit Stage. The commercially developed Transfer Orbit Stage (TOS) was scheduled to make its first flight in September 1992 aboard a commercially procured Titan III carrying the Mars Observer spacecraft. Qualification and mission integration activities continued throughout 1991. Orbital Sciences Corporation, manufacturer of the upper stage, developed the TOS for use on both the Space Shuttle and ELVs for those missions that require an extra boost to place the payload in its final orbit. The second flight of the TOS is scheduled to transport NASA's Advanced Communications Technology Satellite from the Space Shuttle in early 1993. At the end of FY 1991, there were no other identified NASA missions for the TOS.

Spacelab Flight Program

During 1990 and 1991, two Spacelab missions (Astro-1 and Space Life Sciences-1) were successfully completed. Three Spacelab module missions and two Spacelab pallet missions were planned for FY 1992. The three module missions were the International Microgravity Laboratory (IML), the United States Microgravity Laboratory (USML), and a microgravity mission with the Japanese, called Spacelab-J. The pallet missions planned for FY 1992 included the first of a series of Atmospheric Laboratory for Applications and Science missions and the first Tethered Satellite System (TSS) mission (see above and below). Integration of experiment and carrier systems hardware was well under way at the end of FY 1991 at Kennedy Space Center in preparation for these missions.

Tethered Satellite System

The Tethered Satellite System (TSS) is a Shuttle-based facility for deploying a satellite connected by a tether to the Shuttle for distances up to 62 miles, as discussed in part above. In 1991, the integration of the deployer system with the Spacelab hardware was completed. Mission planning and integration of the flight experiments with the deployer/Spacelab system was nearing completion at the end of FY 1991.

Advanced Programs

Advanced Programs activities focus on future space transportation concepts and related operations plus on-orbit space systems. The scope of Advanced Programs includes concept definition (Phase A), systems definition (Phase B), and advanced development efforts to demonstrate emerging technology for application in existing as well as future transportation systems. The Civil Needs Data Base (CNDB)—a compilation of civil space-mission needs from 1990 to 2010—is a key tool for advanced program planning. Following are some of the studies and advanced development activities currently under way in Advanced Program Development.

New Launch System. The New Launch System (NLS) is a joint DOD/NASA program to develop a new launch capability to meet civil and military space needs. This program is responsive to the direction of the National Space Council to greatly improve national launch capability, reduce operations costs, and improve launch system reliability, responsiveness, and mission flexibility. The new launch system will provide a range of lift capabilities from medium to heavy-lift and to facilitate evolutionary change as requirements evolve and new technology becomes available. The design will use some existing components from the Shuttle and existing expendable rockets in order to expedite initial capability and reduce development costs. While initially unmanned, the NLS will be defined as "human-ratable" in the future. The program, which was in the definition phase at the end of the fiscal year, was being planned for a first flight in FY 2002.

NASA and the DOD first received direction from the National Space Council to develop the New Launch System on April 16, 1991. During the remainder of FY 1991, they set a number of milestones for the program, including the first firing of the Space Transportation Main Engine (STME) by the end of 1996, the delivery of the first set of flight engines for the STME in 1999, and the delivery of the common core pathfinder vehicle in 1999. On April 16, 1991, NASA announced that it had awarded three 10-month study contracts, each valued at $500,000, to support the definition of the New Launch System. The new contractors were Lockheed Missiles and Space Co., Sunnyvale, CA; McDonnell Douglas Corp., Huntington Beach, CA; and TRW, Redondo Beach, CA.

During 1991 NLS developers established the program baseline, defined the basic elements of the program, and produced an overall cost estimate. They performed a level zero flight environment analysis for the baseline vehicle in order to validate the design and performance of the NLS-1 and NLS-2 vehicles. From a hardware standpoint, the primary focus was on the propulsion system technology. In the course of the year, a 25 kW prototype electro-mechanical actuator was built and tested; a single piece thrust chamber was cast; a 40K thrust injector design was tested; and hydrostatic bearings for the liquid oxygen turbopump were also tested. (For further details, see coverage below in the section devoted to NLS in the DOD section of this report.)

Cargo Transfer Vehicle. The Cargo Transfer Vehicle (CTV) is planned as the orbital transfer element of the NLS. This unmanned stage is intended to boost payloads from the NLS delivery orbit to the Space Station. The CTV definition studies were in progress at year's end. The schedule for design and development of the CTV is planned to coincide with the NLS schedule.

Future Manned Transportation System. Studies were continuing to examine options for assured human access to space in the future, including potential replacement of the Shuttle. The primary focus of the manned transportation activity has been on the Personnel Launch System (PLS) concept and a two-way personnel transportation system discussed in December 1990 by the Advisory Committee on the Future of the U.S. Space Program. Planners have placed relatively minor emphasis upon the Advanced Manned Launch System concept. A study, initiated in 1991 by a NASA/industry team, examined transportation needs, requirements and architectural issues for future manned space activities.

Advanced Upper Stages. Concepts for high performance space transfer vehicles (STVs) to support scientific and exploration missions beyond low-Earth orbit continued to be examined. Since the President's statement in 1989 affirming the goal of manned missions to the Moon and to Mars, the STV studies have been focused to provide support for that goal. Two parallel contractor study teams were in the process of defining STV concepts for the delivery of cargo and humans to the lunar surface. These studies were also considering commonality with upper stage requirements for the NLS. Trade studies for mission scenarios, vehicle concepts, and use of advanced technology were being coordinated with the development of advanced launch vehicles to provide cost-effective capability and operational flexibilities for the nation's space transportation system.

Advanced Space Systems. Activities focused on advanced space systems included hardware development, flight demonstrations, satellite servicing, tether applications, and orbital debris. Advanced developmental projects applied existing technology to flight hardware for use on the Shuttle, other NASA spacecraft, and for satellite servicing.

In 1991, advanced development work continued on an automated fluid interface system, a flight-support-system servicing aid tool, and a superfluid helium coupler. Flight demonstrations of the Voice Command System and the Optical Communications Through the Window System were successfully carried out on STS-41 and STS-43, respectively. These demonstrations provided on-orbit experience with voice command of the Shuttle's closed circuit television cameras and of high-rate and fiber-optic communications through the aft flight deck window between the pressurized area of the Shuttle and the payload bay.

Preparatory work on the Superfluid Helium On-

Orbit Transfer Demonstration planned in early 1993 has already yielded many cryogenic management techniques that can be used on the Advanced X-ray Astrophysics Facility, the Space Infrared Telescope Facility, and other spacecraft. Phase B procurement for the Satellite Servicer System Flight Demonstration, on the other hand, was terminated following cancellation of the Orbital Maneuvering Vehicle.

Orbital Debris. The population density of man-made orbital debris in space at both low-Earth and geostationary orbits has been growing as a direct result of an expanding space launch rate. In recent years, spacefaring nations have been increasingly concerned that orbital debris could pose a hazard to future space missions—possibly to unacceptable risk levels early in the 21st century. NASA has devoted a considerable effort over the years toward understanding the orbital debris environment and its trends. Using up-to-date models of the debris environment, the Agency has performed hazard analyses for space programs and has instituted protective measures to assure a high probability of safe and reliable space operations.

In 1991, NASA updated its space debris population density model, baselined for the Space Station Freedom design and hazard analyses, with new data from debris measurements and hypervelocity testing. In addition, it has made significant progress during the past year in the collection, processing and analysis of orbital debris data using the Haystack Radar at MIT/Lincoln Laboratory. These data provided the first statistically significant comparison with the Kessler orbital debris flux model in the critical size regime between 0.5 centimeters (cm) and 10 cm of debris diameter. Two computer models for processing the Haystack Radar data were developed and implemented. The first model estimated ability to detect the debris passing through the "parked" radar beam. The second model related the radar cross section of the debris to its physical size. The early measurements from the Haystack radar indicated that the measured detection rates were 30-100 percent higher than predicted by the Kessler model in the important 350-450 kilometer (km) altitude band. This will be determined further as additional data are processed. Moreover, NASA has funded the U.S. Air Force to begin construction of the Haystack Auxiliary Radar (HAX) to be used for continued observations of orbital debris during the remainder of the 1990s.

The U.S. held discussions for the first time in 1991 with representatives of the People's Republic of China (PRC) on the problems associated with orbital debris. We specifically discussed with the PRC the impact of the December 1990 explosion of its Long March 4A third-stage rocket and the implications of a similar event for the future debris population. Consultations continued during 1991 on the modeling and mitigation of orbital debris with Europe, Japan, and the Soviets. In late 1991, the U.S. negotiated a protocol with the Soviets that will lead to an exchange of unclassified catalogs of space objects published in each country and of materials (witness samples) that have been exposed to space and returned, together with the analysis of these materials. These exchanges and discussions will continue to expand our knowledge and understanding of the orbital debris environment. In addition, they will lead toward the development of coordinated plans to reduce the continued proliferation of orbital debris.

Space Station Freedom

The aim of the Space Station Freedom program is to establish a world-class laboratory in low-Earth orbit enabling scientists to conduct a variety of life and materials science experiments that will take advantage of the microgravity environment of space. The program was being developed by three each of NASA Field Centers, prime contractors, and international partners. The Space Station Program Office in Reston, Virginia, coordinated technical aspects of the program.

In spite of technical and budgetary challenges in 1991, the Space Station Freedom project made progress on several fronts. The three most significant of these were: completing the preliminary design review, which included efforts to reduce weight, power, and EVA (Extravehicular Activity) maintenance requirements; restructuring the program to fit within new 6-year budget guidelines provided by Congress; and implementing recommendations made by the Advisory Committee on the Future of the U.S. Space Program. Although each of these developments was important in and of itself, taken together they represent a solid step forward at a pivotal juncture in the Space Station Freedom program.

The program consisted of two steps: "man-tended" capability and "permanently manned" capability. Even in its early stage, Space Station Freedom was expected to have several times more research capability than any previous orbiting facility—U.S. or Soviet. It will be the largest and most sophisticated orbiting laboratory ever built and operated, and its designs will retain the ability to be upgraded as requirements dictate and funding allows. The program currently is examining an assured crew recovery capability in the permanently manned phase of the program to ensure crew safety.

One of the greatest advantages Freedom will hold over other orbiting facilities will be its ability to provide substantially more electrical power to its users. This will allow significantly more research equipment, some with unique high power requirements, to be operating at any one time. Power available to the users will initially be 11 kilowatts (kW) and will be at least 30 kW by the permanently manned phase. This is roughly ten times that of Skylab and Spacelab and more than double the power available for science on the Soviet space station Mir.

During the man-tended stage of the program, the free flying time on Space Station Freedom will offer an excellent environment to conduct untended research on materials, such as crystal growth experiments. While the Shuttle is docked and crew are present, materials science will continue along with the addition of life sciences research. At permanently manned capability, the space Station will provide full support to life sciences with addition of long-duration stay times and a 2.5 meter centrifuge. It will also continue to support microgravity research. During the man-tended phase, the Space Shuttle will fly three utilization (research) flights and up to four assembly flights per year. The Space Station design can accommodate a follow-on phase including additional capability to increase crew size from four to eight and power to 75 kW. This phase would use the New Launch System if it is available.

Program Accomplishments

In fiscal year 1991, the program's three prime contractors assembled several development test articles. These test articles are used to evaluate component design integrity and the manufacturing process. Although test articles will not become actual flight elements, their designs are very similar or identical to flight elements. Completion of the testing of these articles represents the final design stage prior to the critical design review. At this point, designs will be approximately 90 percent complete and significant development testing will have been accomplished.

Production of the photovoltaic cells for the Space Station power generation system was well under way. The solar array design was validated during 1991 in a test series equal to 10 years of in-orbit thermal cycles. The first engineering model battery arrived and began long-term cycling tests. Also, tests successfully demonstrated the ability to interrupt current levels at 160 volts direct current, a higher voltage than achieved in any previous spacecraft. Fabrication of the verification article for airlock welding procedures also began during 1991, and an early version of the Space Station data management system was delivered to test designs of related Space Station subsystems. Another development test article having to do with a prototype control-moment gyro was fabricated and subjected to testing. Additionally, engineers completed comparative testing on the environmental control and life support system, allowing initial development of hardware that will be used for flight qualification of the system.
Several Space Station-related flight experiments took place on board the Space Shuttle in 1991. An EVA flight experiment concerned three design concepts to move astronauts and equipment along the Space Station truss structure. Additionally, the crew successfully tested a Space Station radiator design to evaluate fluid dynamics in weightlessness.

International Partners' Activities

Early in fiscal year 1991, NASA successfully completed an agreement with the Space Station Freedom international partners—the European Space Agency, the Canadian Space Agency, and the National Space Development Agency of Japan—on the design of payload racks to allow use of common racks throughout all three laboratories on the Station. This agreement benefits the U.S. as well as each individual partner by allowing easy exchange and operation of research equipment. Each laboratory will provide standard interfaces, standard interface options, and module-specific interfaces for payload racks. The synergy of equipment use will increase the efficiency of the entire Space Station manned base and significantly enhance overall program flexibility.

All the international partners continued to move forward in their respective programs. Each played key roles in both the program preliminary design review and the restructuring assessment. The Japanese completed program requirements reviews on the second and third Japanese Experiment Module's (JEM) safety and product assurance as well as the operations and utilization requirements aspects of the program. The Europeans received new proposals for their polar orbiting platform, the Attached Pressurized Module and its Man-Tended Free Flyer. They also conducted a program requirements review covering all aspects of their program. Canada completed its interim preliminary design review of the Mobile Servicing System, as well. Additionally, for the first time, NASA and the international partners met jointly to discuss plans and programs for the evolution of Space Station Freedom. Also, NASA signed an agreement in 1991 with the Italian Space Agency for provision of two mini-pressurized logistics modules and potential provision of a mini-laboratory in exchange for more Italian use of the Space Station.

Utilization and Operations

Progress was made during 1991 in accommodating utilization payload requirements. The Space Station program assessed and approved requirements for externally mounted experiments and the accommodation of a 2.5-meter life sciences centrifuge. Early plans for the Station now include an 8-flight Utilization Sequence for the man-tended phase. These utilization flights will involve up to 13-day Shuttle missions for payloads installed in the U.S. Lab and on the Station preintegrated truss.

Utilization and operations capability of Space Station Freedom and associated ground support capabilities were better defined at the end of FY 1991 than ever before. The Functional Control Documents that described ground systems functions, such as payload integration and operations, command and control, ground processing, and crew training, were extensively reviewed and baselined. The Network Program Requirements Document that identified the communication and data transfer capabilities required to effectively support the Space Station Control Center, Payload Operations and Integration Center, and other program and user facilities was also baselined. Early in the year, participants approved formal joint program management plans as well.

Also in 1991, a multilateral exercise of the Space Station payload and systems strategic planning activities occurred. The four partners rehearsed the process of developing 5-year plans for Station operations and use. The rehearsal provided significant insight into how the partners will plan for Station operations and utilization. Development of the first official Consolidated Operations and Utilization Plan was expected to begin soon after the beginning of FY 1992.

The partners presented the status of user accommodations on the restructured Station to the Space Station Science and Applications Advisory Subcommittee and to commercial and technological users during 1991. Information about Space Station utilization and potential benefits to users, industry, teachers, students, and the general public will be widely distributed as well.

Safety and Mission Quality

Recognizing the inherent risks and uncertainties in "frontier" ventures such as space exploration, NASA continued during FY 1991 to accord high priority to operational safety and quality. Thus, in the course of the year, the Office of Safety and Mission Quality expanded its oversight of NASA programs. The goal of mission quality was to achieve 100% mission or operational success. Ensuring quality for current and future missions was a function of the combined efforts of the safety, reliability, maintainability, and quality assurance (SRM&QA) disciplines.

Assurance oversight entailed Safety and Mission Quality personnel working closely with program managers and engineers to develop SRM&QA policy and requirements for NASA programs. Affected personnel then implemented these criteria throughout each phase of program development and operation. For significant (critical) program issues, assurance engineers conducted independent analyses to evaluate or devise preventive or corrective measures. In FY 1991, the Office addressed a wide range of assurance-related program issues. A representative cross-section of these areas included risk analysis, human factors, advanced technology requirements, trend analysis, software assurance, and supplier quality.

Mission Safety

The primary objective of mission safety was to minimize risks through early identification and resolution of problems, hazards, or adverse trends. In FY 1991, as the use of statistical or quantitative analysis techniques increased, probabilistic risk assessment (PRA) became an integral part of several program areas. For example, a PRA performed on the 8-foot-high temperature wind tunnel at the Langley Research Center in FY 1991 revealed significant risk factors involved in tunnel operation and identified mitigative measures to keep risk within acceptable limits. Further, PRA-based methods as applied to selected Advanced Solid Rocket Motor design trade-off issues and other possible applications in the Space Shuttle program were under consideration as the year ended.

The Mission Safety Evaluation Report, which Safety personnel prepared for each Space Shuttle flight, exemplified the role of the Safety organization in identifying, assessing, documenting, and resolving program issues. In 1991, this report became a primary tool for communicating results of qualitative risk analyses on a permission basis to the Associate Administrator for Safety and Mission Quality and key Shuttle program managers. Data compiled prior to each launch included safety evaluations of any problem, concern, anomaly, and issue that could adversely impact the risk baseline. For each factor identified, the report specified the safety criteria and the rationale for risk acceptance or rejection.

Mission Quality

In FY 1991, the Office of Safety and Mission Quality strengthened its role in identifying significant programmatic SRM&QA issues in the areas of mission definition/mission requirements, system and subsystem design, and hardware performance or validation. Engineers from Safety and Mission Quality, assigned to each program element, supported all major milestone reviews and programmatic decisions. Over 70 special studies addressed systems engineering issues for the missions flown in FY 1991. Assurance oversight entailed working with the programs to ensure that adequate program planning occurred and appropriate resources were allocated to meet SRM&QA requirements.

Senior managers used the findings from independent system assessments and trend analyses conducted by engineers in specific disciplines to mitigate high risks and resolve safety and quality problems or concerns. In addition, the Office of Safety and Mission Quality provided support to the Administrator for internal quality management initiatives and functioned as the prime focus for the Agency's external quality and productivity initiatives in FY 1991, such as the George M. Low Trophy for Excellence and Productivity Improvement, established but not yet awarded during the fiscal year. (George M. Low became the Deputy Administrator of NASA in 1969 after a distinguished career in which he had been responsible for the Mercury and Gemini programs and later the Apollo program both in Washington, D.C., and at the Manned Spacecraft Center in Houston, TX—later the Johnson Space Center. He served as Acting Administrator of the Agency in 1970-71.)

Diverse Challenges

Areas of concentration for Safety and Mission Quality ranged from high-profile programs such as the Shuttle to less visible (but still vitally important) issues such as small supplier assistance. Based on NASA's reliance on contractors and suppliers, the quality of the goods and services provided to the Agency must be reviewed constantly. While there is a natural tendency to focus on the large-scale hardware manufacturers, the Office recognized that small suppliers were just as integral to NASA programs. In FY 1991, the Associate Administrator for Safety and Mission Quality was instrumental in establishing a NASA small supplier quality assurance program to assist firms in identifying and meeting the Agency's hardware requirements.

A major challenge continued to be the determination of next-generation assurance requirements and contingency plans for future system hardware/software applications that may not have been obvious. In FY 1991, the Office established a Technical Standards Division to support the applied technologies required to design and build advanced hardware. The objective was to work with the appropriate NASA, industry, and the Department of Defense organizations to develop and upgrade standards for emerging and changing technologies.

Although technology-based programs traditionally have focused on hardware, the vital relationship between mission hardware and software was attracting industry attention. Particularly for flight-critical applications, software assurance has evolved into a notable program issue. Safety and Mission Quality engineers have been active in the ongoing planning for the Independent Validation and Verification (IV&V) facility that NASA has earmarked funds to build in FY 1992.

Commercial Programs

The mission of the Office of Commercial Programs (OCP) during FY 1991 continued to be the encouragement of private investment in commercial space and the facilitation of the application and transfer of existing technologies to U.S. industry. OCP encompassed a range of activities that provided a focus for addressing one of America's preeminent concerns—our ability to compete economically in the world environment.

Making Strides in Commercial Marketing

Historically, initiatives developed by private markets to meet their own needs have shown themselves to be many times more effective in expanding our nation's economy than have those that rely on the public sector as the investor and user. To develop commercial products and markets, NASA's Centers for the Commercial Development of Space (CCDSs) drew at the end of FY 1991 on the participation of 71 universities and 241 companies, in industries ranging from pharmaceuticals to fisheries. There were also 16 competitively selected consortia of university, industry, and government affiliates that performed industry-driven research on technologies with potential commercial applications during the year.

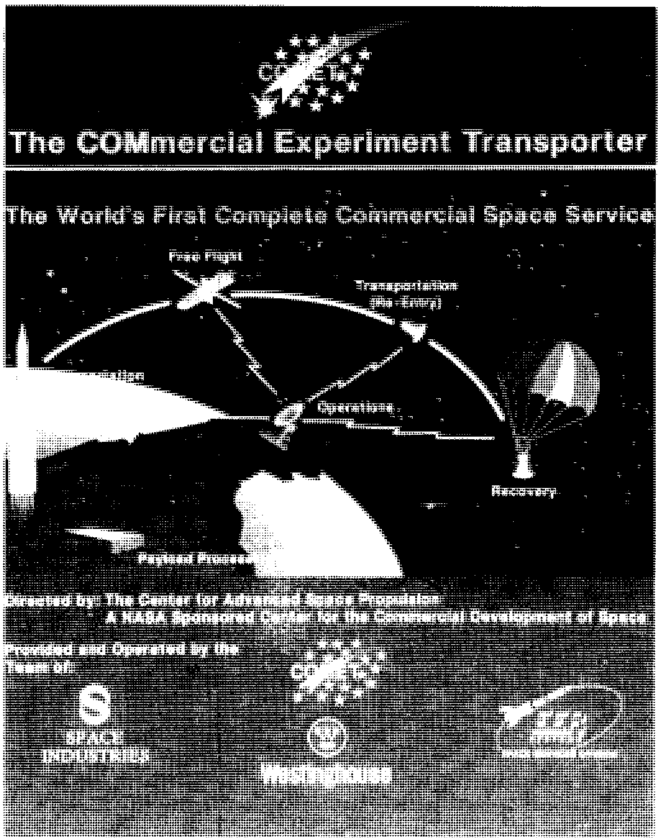
In promoting commercial products and markets, the CCDSs' strategy was twofold: to establish a technological and developmental base that could lead to new products and markets and to encourage the development of infrastructure and transportation industries that could directly contribute to the creation of these markets. As products and markets matured from a base in technology to actual development and growth, NASA expected that the necessary infrastructure and transportation would be maturing to support future commercial operations.

Already by the end of FY 1991 NASA funds, leveraged by those of industry, universities, and other state and Federal institutions, had yielded many accomplishments. By that time, the CCDSs had acquired 59 patents and 20 licensing/equity agreements for their research work; 113 technologies had transitioned to CCDS affiliates; and nine spinoff companies had formed to move product offsprings to the commercial market.

Sixty-one industry-driven technologies continued to be developed in FY 1991 to determine their commercial potential. Product developments were still in the experimental phase but showed great promise for maturing to commercial availability within the next decade. Zeolites that can be used as filters and catalysts, protein crystals for designing new and improved drugs, superconductors that increase computers' computational speed, and remote sensing systems for large-scale mapping and mineral exploration were just a few of the promising new products that illustrate the breadth of CCDS research.

The growth of this program can be measured in the number of experiments that flew from the beginning of the program in 1985 to the end of FY 1991: 1,041 drop tube/drop tower experiments, 60 Lear/KC-135 flights, 28 Space Shuttle flight tests, and 37 sounding rocket flight tests. Measured by these statistics, the program clearly has made great headway. But the real surge in transportation requirements will come as the CCDSs progress further in their research. Meeting their future transportation needs is a critical objective of the Office of Commercial Programs. Consistency and flexibility are needed to assure the successful development of these projects.

To match space transportation and support capabilities with anticipated growth in materials processing requirements, NASA continued in FY 1991 to fund a commercial sounding rocket program through the CCDS program. EER Systems, Inc. provided the Consort launch series with a fourth launch scheduled for the fall of 1991. The next series of sounding rocket launches, scheduled to take place early in 1992, will be provided by Orbital Sciences Corporation using the Prospector vehicle, which



Commercial Experiment Transporter (COMET), a system for launching and recovering space-borne experiments, scheduled to be launched in the fall of 1992 from Wallops Island, VA.

will give experimenters about 14 minutes of microgravity exposure for their payloads.

The CCDSs were also in the process at the end of the year of developing the Commercial Experiment Transporter (COMET), a system for launching and recovering space borne experiments. The CCDSs, which initiated the program, were totally responsible for overseeing system design, fabrication, and operations. EER Systems, Inc., Westinghouse Electric Company, and Space Industries, Inc. were the three primary industry contractors selected to provide key hardware and services for the COMET's development and operations. COMET was scheduled to be launched in the fall of 1992 from Wallops Island, VA.

As part of the CCDS's goal of providing cost-effective hardware for conducting experiments in space, NASA has contracted with SPACEHAB, Inc., to provide the services of a Commercial Middeck Augmentation Module for Space Shuttle operations. As a commercial customer of the contractor, NASA has leased space to provide flight research opportunities for the CCDSs and the cooperative agreement partners.

As FY 1991 ended, the Office of Commercial Programs was in the process of selecting at least one additional CCDS to specialize in the commercial development of advanced satellite communications technologies and other space-based telecommunications technologies. Establishment of the new CCDSs was anticipated for the fall of 1991.

New Cooperative Agreements

In FY 1991, NASA further expanded its partnership with U.S. industry by signing a 2-year technical exchange agreement with Autometrics, Inc., for analysis of high resolution and electronic still-camera imagery. Through digital data processing and data compression techniques, high-resolution pictures taken of the Earth, middeck experiments, and the payload bay by astronauts aboard the Space Shuttle could be sent back to Earth quickly and easily. Access to imagery generated by the process will enable researchers to perform real time analysis of natural disasters and other crises.

In July 1990, Orbital Sciences Corporation signed a 5-year support services agreement that gives Orbital Sciences Corporation access to NASA-owned launch facilities. The agreement, similar to those signed by the big three rocket manufacturers, will support the company's Pegasus and Taurus commercial launch programs.

During FY 1991, NASA signed a 2-year memorandum of under-standing with Technical and Administrative Services Corporation that allows the two parties to share research information associated with closed environmental systems. The two partners have mutual interests in development of hydroponic technology for life sustenance on space missions of long duration and for agricultural applications in hostile terrestrial environments.

Cooperative agreements such as these have provided technical assistance and access to launch facilities and services to support industrial space research, commercial space transportation, and the private development of space infrastructure and services. NASA has used these and other innovative agreements to help reduce the risks associated with commercial development of space.

A New Role in Enhancing Satellite Communications

The accomplishments of NASA in fostering the continuing leadership of U.S. industry in the highly visible and economically successful use of space technology for domestic and global telecommunications are well recognized. Plans call for the next major contribution in this field to occur in 1993 with the launch of the Advanced Communications Technology Satellite (ACTS). As NASA turns its attention to the development of a strong experimental program for ACTS and to the strategy for NASA's future activities in this vital area of technology, it will be important that NASA design its organization to assure that decisions regarding implementation of new technologies for telecommunications services be responsive to needs determined by industry as opposed to governmental push in specific directions. The Office of Commercial Programs will now manage NASA's programs for advanced technology, designed to contribute to the introduction of new and innovative communications satellite services and to the maintenance of U.S. leadership in the key technologies required to accomplish the services efficiently.

Specifically, NASA expects to do the following:

Establish one or more CCDSs to create an infrastructure for infusing NASA's technology into the satellite-based telecommunications industry.

Manage the ongoing radio science and support studies and communications data analysis.

Define and conduct an innovative and thorough experimental program for the ACTS mission based upon the specific interests of industry and in conjunction with industry-provided resources.

Manage an experimental program using mobile satellite resources.

Expanding Satellite Communications Capabilities

ACTS represents an important government contribution to satellite communications development and is expected to demonstrate the feasibility of a variety of technologies that will be incorporated into future operational satellites. The ACTS demonstration and experiment program and the verification of ACTS innovative technologies that are applicable to various satellite communications frequency bands hold the key to continued industry growth and improved customer service in the satellite communications field.

Future operational systems like ACTS could add a new dimension to communications services by combining the technologies of satellites and fiber optics. Although fiber systems offer excellent performance for point-to-point, high-volume "trunk" communications, advanced satellites will be competitive with fiber systems in capacity, cost performance, and reliability for point-to-point services, especially in rural and remote areas. More importantly, advanced satellite links have the capability of teaming with fiber systems to expand the communications capabilities of users who are not part of the main fiber backbone. Without satellite connections, these users would not have access to high-capacity transmission media.

Increasing User Capabilities

Technologies devised by the ACTS program are likely to narrow the gap separating the information services "haves" from the "have nots." Because of the wideband transmission needs associated with the information processing technologies that will be perfected in the 1990s, there is concern that these capabilities will be employed only by users in limited areas who are connected by fiber-optic cable. However, advanced communications satellites incorporating ACTS-validated technologies will expand the availability of wideband transmission and, subsequently, increase access to the services and advantages offered by the "Information Age."

Increasing Commercial Opportunities

Signs of ACTS technology being adapted to the commercial realm could already be seen in the United States as FY 1991 ended. Several of the technologies that will be flown on ACTS, including the baseband processor and Ka-band components, will be used commercially in future satellite systems. Recently, Motorola, Inc., one of the major contractors on ACTS, announced the introduction of its Iridium system, which will be based on 77 low-Earth-orbit communications satellites to provide global coverage for data and cellular telephone communications.

An Enriched Technology Transfer Structure

NASA missions have often been culminations of the latest technological advances in engineering, computers, materials, and dozens of other fields. These advances not only were critical to space exploration and aeronautical research, but they also provided valuable resources to industry, a primary customer of the Office of Commercial Programs. Companies, organizations, and institutions from coast to coast have been applying information provided by NASA's Technology Utilization program to solve problems on Earth.

NASA's Technology Transfer program is a continuum that begins from the moment a new technology is developed and concludes with the commercial application of a new or existing product or service by the private sector. Technology transfer has occurred primarily through two mechanisms: technology dissemination and applications projects. The cornerstones of the program have been the comprehensive data bases that incorporate not only NASA technology but also that of other Federal programs and the private sector, plus a distribution network that promotes these technologies and acts as a clearing house for the private sector seeking a solution to its technological needs.

The principal medium for disseminating all the new technologies has been an electronic data base (the "RECON" system) that is accessible to a very large and broad population. More selective but equally important media have been NASA publications, particularly *NASA Tech Briefs* and *Spinoff* magazines, that reach over 200,000 subscribers throughout the United States. The primary announcement mechanism for new technologies available to the private sector has been the monthly *NASA Tech Briefs*, a compendium of abstracts, announcements, and full articles on the newest, emerging technologies from the NASA research and development (R&D) programs. The periodical had a circulation of over 200,000 at the end of FY 1991, including individuals and commercial firms. Furthermore, an analysis of the "pass-along" readership of *NASA Tech Briefs* indicates an average of five readers for each copy, or over a million readers per issue.

Furthermore, the new series of Technology 2000 conferences has been designed to enhance U.S. industry's awareness of developing Federal technology in a more timely manner. On November 27-28, 1990, NASA held the first of these national conferences, Technology 2000, an exhibition highlighting transferrable technologies for industry. It attracted 2,500 attendees—75 percent from industry. NASA scientists and engineers presented over 90 technical papers describing new technological advances having commercial potential, and several papers focused on future NASA R&D missions, high-lighting possible emerging technologies that may be available for industrial use in the decade ahead. Additionally, over 160 companies, universities, and government agencies (including NASA) were represented in the exhibit hall.

Planning for the next conference, Technology 2001, was already under way in October 1991. The 1991 Technology 2001 Conference was held on December 3-5 in the San Jose Convention Center in California. NASA broadened participation to other Federal agencies and laboratories by inviting technical papers in five major fields of interest: advanced materials, computers and software engineering, advanced manufacturing, electronics, and biotechnology and life sciences. Technology 2001 attracted about 4,000 industrial executives and thus served as a national forum for governmental technology transfer.

To facilitate the close interaction between NASA's technology and the users, a network of Industrial Applications Centers began operation over 25 years ago. They have acted as clearinghouses and outreach centers for the NASA Technology Transfer program and supplemented the efforts of the various NASA laboratories. Many developments have taken place in the national technology transfer arena since the inception of the Industrial Applications Centers. For this reason, NASA has begun the process of restructuring, redefining, and renaming this network.

The new technology transfer structure included, as of the end of FY 1991, a National Technology Transfer Center (NTTC) in Wheeling, WV, and six Regional Technology Transfer Centers (RTTCs) aligned with Federal Laboratory Consortium regions to cover all 50 states. The

NTTC will provide managerial, analytical, and training capabilities for facilitating the national technology transfer process. The six RTTCs will identify needs specific to their regions, developing relationships with specific organizations and providing user referral services and data bases.

This new infrastructure will offer broader geographical coverage, establish linkages with the various states and local technology transfer programs, and act as a source for technology transfer from all Federal laboratories in the respective regions. NASA believes that this revised structure will foster greater participation than occurred in the past from Federal, state, and local governments and will reach a much larger business community.

NASA has recently signed a memorandum of agreement with the Federal Laboratory Consortium to disseminate other Federal laboratory software to industry through NASA's Computer Software Management Information Center (COSMIC). Plans for improving this facility include the development of an on-line capability that will enable COSMIC to enhance its software delivery capacity greatly and provide a more streamlined system for communications and software ordering. Such efforts should create a broader and faster capability at COSMIC for handling microsoftware products being developed more frequently today than ever before by NASA and other Federal laboratories.

NASA's direct support of technology application in 1991 helped to advance a range of industries from medicine to transportation. Through interaction with public and private sectors of the economy, projects have identified specific needs or problems and developed potential solutions through adaptation of aerospace-developed technologies.

Annually, there have been about 60 ongoing technology-applications projects at NASA's nine Field Centers. In nearly 20 years, over 500 applications projects have been completed. One new technology resulting from applications projects was a portable fetal heart rate monitor developed by the NASA Langley Research Center's Technology Utilization and Applications Office. Using NASA sensor technology, the device detected irregularities in the fetal heartbeat and consequently informed the mother of potential health dangers to the unborn child.

Another successful product, completed in 1990 by scientists at the NASA Lewis Research Center and Case Western Reserve University, was a computer software program for designing orthopedic implants that last up to 20 years—almost three times the current lifetime—because they are fitted to the patient.

Successful Products from Small Business Innovation Research

Small Business Innovation Research (SBIR) program objectives have included stimulating technological innovation in the private sector, strengthening the role of small business in Federal R&D programs, fostering and encouraging greater participation of minority and disadvantaged persons in technological innovation, and increasing private sector commercial development of innovations derived from Federal R&D.

Since 1983, the SBIR program has proved its value both to NASA and the high-technology small business community. The SBIR program, funded by a 1.25 percent set-aside from the annual NASA R&D budget, has increased small business participation in NASA's R&D activities and provided entrepreneurial firms the opportunity to develop and market innovative commercial products. Over the life of the SBIR program, more than 2,200 awards have been made to approximately 770 businesses. In FY 1991, NASA awarded 280 Phase I contracts for the initial definition of research and 125 Phase II contracts, separately competed, for the actual development of a project.

Final development and marketing of research results under this process uses private sector, not SBIR, funds. To gauge how well they have been progressing, NASA queried 61 of 250 SBIR contractors and, based on the information provided, was able to identify at least 88 products that have or will become commercially available. One representative example of a successful product emerging from an SBIR contract was the underwater photosynthesis profiler, developed by the San Diego-based Biospherical Instruments. The device can be used to monitor fisheries, water treatment plants, and reservoirs. NASA was also using it to validate satellite sensors.

In a separate project under way at the end of FY 1991, Daedalus Enterprises of Ann Arbor, MI, was completing work on a 3-year program aimed at developing a commercial remote sensing system for the fisheries industry. The product, when completed, will help the industry to deploy its fleets in waters that have high concentrations of marine life.

Yet another SBIR success can be found in Lightwave Electronics, a California-based company that, since receiving a Phase I contract in 1985, has sold some 400 ultranarrow linewidth lasers that can be used for fiber sensing, communications, and infrared interferometry.

To stimulate the interest of potential customers and markets and to encourage private contracts with small firms that have commercially viable products, in late 1990 the SBIR office published a catalog listing detailed information on the 88 products that have resulted from SBIR contracts. Thus far, the SBIR office has distributed more than 1,500 copies of the catalog through mailings and at the Technology 2000 Conference.

In addition, the SBIR office has been working to include these products in the data base network of NASA's Industrial Applications Centers. The New England Research Applications Center in Tolland, CT, has already integrated information on SBIR products in its data base system. Also, as part of its outreach program, the SBIR Office sent representatives to 16 conferences held in 1990 by Federal and state agencies as well as small business development organizations across the U.S. and participated in two Federal high technology conferences.

In short, NASA's Office of Commercial Programs has been active in a variety of areas to promote private investment in commercial space and to transfer existing technologies to U.S. industry. There remain many challenges, foremost among them being the organization of OCP's efforts into a program that fully develops commercial space markets and thereby strengthens U.S. industrial competitiveness.

Space Communications

The Space Communications functions are categorized as the Space Network, the Ground Networks, Communications and Data Systems, and Advanced Systems. The Space Network is the most complex, highly sophisticated tracking system in the world. This network provides tracking and communications for Earth-orbital and suborbital missions. The Ground Networks provide Earth-based tracking and data acquisition capabilities for all NASA planetary and deep space missions, and many of those in Earth-orbit. The Communications and Data Systems are the vital link between ground stations and the users. Communications are provided to link remote tracking stations with mission control and data processing facilities, and for administrative services such as facsimile, teleconferencing, telemail, and computer-to-computer data sharing for NASA Centers and Headquarters. The Data Systems provide data processing and mission control operations for numerous programs. The Advanced Systems specialize in research and development efforts focused on technological advances in telecommunications, electronic microcircuitry, and computer sciences. The Advanced Systems efforts are only in areas where the needed technology is not being developed by industry or other agencies.

Space Network

The Space Network provides tracking and communications service requirements to a variety of Earth-orbital missions demonstrating in dramatic fashion its versatility and functionality. During the past year, the Space Network accommodated a 4-fold increase in peak traffic over that provided 2 years earlier. Yet, services to the space mission were provided at a performance proficiency better than 99.8 percent. Increased frequency of Space Shuttle flights, the Gamma Ray Observatory, the Upper Atmosphere Research Satellite, and the Hubble Space Telescope were the major contributors to this heavy workload and the beneficiaries of the high proficiency level.

Key elements of the operational Space Network serving those spacecraft in Earth-orbit are: the Tracking and Data Relay Satellite System (TDRSS) spacecraft; the White Sands Ground Terminal (WSGT); the Goddard Space Flight Center's Network Control Center (NCC) and Flight Dynamics Facility (FDF), interconnected through the NASA Communications System (NASCOM).

Tracking and Data Relay Satellite System (TDRSS). On August 2, 1991, the fifth Tracking and Data Relay Satellite (TDRS-5) was successfully launched aboard STS-43. After a successful on-orbit checkout of this spacecraft in record time, it replaced TDRS-3 in the 174 degrees West position of the TDRS constellation. TDRS-3 was then moved to a central location and designated the on-orbit emergency backup spacecraft for the network. TDRS-1 remained on station at 171 degrees West to augment TDRS-5 during STS missions. Space Network customer requirements in the eastern hemisphere continue to be met by TDRS-4. The on-orbit TDRS constellation, linked to the ground by the White Sands Ground Terminal (WSGT) in New Mexico, provided continuous communications coverage to network customers for over 85 percent of each orbit.

Second TDRSS Ground Terminal (STGT). The STGT, located a few miles north of the WSGT, was initiated to eliminate a critical single point of failure. It is scheduled to be operational in mid-1993. Major accomplishments during this fiscal year included delivery of substantial quantities of automated data processing equipment, fabrication of the 19-meter antennae, and substantial testing of electronic subsystems. In addition two more space-to-ground links were added to the system design.

TDRS II (formerly called the Advanced Tracking and Data Relay Satellite System). In order to meet the continuing needs for satellite tracking and communications through the first decade of the 21st century, the Office of Space Communications initiated the TDRS II program. The three participating contractors completed the TDRS II Phase B study in December 1991. The principal objectives are to minimize life-cycle costs and technical risks, and to develop transition procedures for integration of new capabilities at the ground terminals without interfering with ongoing operations. The Phase C/D request for proposals is to be issued early in 1992.

Ground Networks

The mission of the Ground Networks is to provide Earth-based tracking and data acquisition capabilities to all NASA planetary and deep space missions and many of those in Earth-orbit. The Ground Networks also provide launch and emergency communications for the space transportation system and tracking and data acquisition services for aeronautics, balloons, and sounding rocket programs. The Ground Networks are comprised of the following elements: the Deep Space Network (DSN), the Spaceflight Tracking and Data Network (STDN), and a variety of facilities for the tracking and acquisition of data from aircraft, balloons, and sounding rockets.

The Deep Space Network (DSN). The DSN, managed by the Jet Propulsion Laboratory, consists of three deep space communications complexes located at Goldstone, CA; Madrid, Spain; and Canberra, Australia. This network has a world-class capability for receiving transmissions from spacecraft operating in our outer solar system and for performing the extremely accurate measurements necessary to navigate to the outer planets. Since its inception in 1958, the DSN has provided tracking and data services to over 30 space flight projects. All the planets of the solar system have been visited with the exception of Pluto. The capabilities of this network to communicate with and navigate spacecraft at distances beyond the Mars orbit are unique. The DSN routinely receives data originating from spacecraft over seven billion kilometers from Earth.

In 1991, the DSN provided navigation, telemetry, and command activities for: Magellan's mapping of Venus; Galileo and its successful encounter with the asteroid Gaspara; and Ulysses, a joint NASA/ESA mission on its journey to explore the polar regions of the Sun. The DSN continues to provide tracking and data acquisition for older spacecraft such as the Pioneer and Voyager series. One of the Pioneer spacecraft has been operating since 1965. The Voyagers, with their primary missions to explore the outer planets, are journeying in search of the heliopause, which marks the outer boundary of our solar system. Communication with many of these spacecraft will continue into the next century.

The unique capabilities of the DSN are also used to provide emergency tracking and command functions for both national and international spacecraft. Ground-based astronomical radar observations of near-Earth asteroids and comets also took place. This activity will continue to increase in future years as more emphasis is placed on detecting and observing objects that approach the Earth's orbit.

New capabilities continued to be implemented in the DSN in preparation for future planetary missions, such as Mars Observer, Cassini and Earth/Solar observations of the International Solar Terrestrial Physics (ISTP) program, which involves a series of spacecraft missions.

Spaceflight Tracking and Data Network (STDN). The STDN, managed by the Goddard Space Flight Center (GSFC), consists of three ground stations located at Merrit Island, FL; Bermuda; and Dakar, Senegal. The STDN provides communications for the preflight testing of the Shuttle with its integrated payloads, contingency communications throughout the Shuttle mission, and range safety functions for the Eastern Test Range.

Over the past 30 years, STDN has provided tracking and data acquisition to unmanned and manned space flight. Unmanned spacecraft have provided a myriad of Earth science observations ranging from global weather data to monitoring of the Earth's crustal dynamics. In FY 1991, the STDN primarily supported the Space Shuttle program with contingency voice, command, and telemetry communications for six Shuttle missions. In addition, it provided tracking and data acquisition communications for Earth-orbiting spacecraft incompatible with the TDRS-based Space Network. It also performed emergency tracking and command activities for other Earth-orbiting spacecraft.

Tracking and data acquisition activities for suborbital research activities require a variety of permanent and mobile facilities positioned throughout the world. These facilities capture, record, and process data from instrumentation packages on aircraft, balloons, and suborbital rockets. These systems contribute to basic research in aeronautics programs—such as flight dynamics, hypersonics, supersonics—and rotary winged aircraft as well as to astronomy, astrophysics, and Earth sciences.

In a typical year, the Ground Networks facilities will meet the requirements of over 1,600 flight research missions and approximately 75 balloon and sounding rocket launches. Future plans include enhancement of the mobile capabilities to satisfy requirements for limited-duration tracking and data acquisition for selected Earth-orbital spacecraft, such as the Small Explorer series of spacecraft.

Communications and Data Systems

In 1991, the Communications and Data Systems program continued to form the vital link between the data acquisition stations and the scientific customers and project facilities. The basic elements are: two communications networks; spacecraft mission control centers; data processing; and flight-dynamics computations.

Communications. The Communications Program provided two Agencywide communications networks. The real time space operations communications are provided by the NASA Communications (NASCOM) Network. This global network interconnects NASA's launch complexes, missions and network control centers, NASA's Field Centers, and NASA's international partners.

The NASA Select video service continues to broadcast Shuttle mission operations, as well as educational and public affairs events, with coverage to the continental U.S., Hawaii, Alaska, and the Pacific Basin.

NASA's nonoperational data delivery and administrative communications requirements are met by the Program Support Communications Network (PSCN). This network connects all NASA Field Centers, major contractors, scientific investigators, and it provides access to commercial network services. Among the capabilities of PSCN is an extensive video teleconference facility linking all NASA Field Installations and Headquarters.

NASCOM. In 1991, NASCOM began working with the General Services Administration (GSA) to transfer most voice/data and wideband services from dedicated point-to-point services to multiplexed dedicated transmission services using the FTS 2000 network. Reliability, availability, and technical specifications required by NASCOM will be retained through a negotiated "Assured Service Plan" between GSA and AT&T.

PSCN. PSCN completed the transition to FTS 2000 during FY 1991. An upgrade to the PSCN network will continue through FY 1992 in the area of packet switching prior to recompetition of the overall contract in FY 1993. Enhancements in the field of videoconferencing will also take place with the addition of high resolution graphics (1000-line resolution) in the network.

Mission Control. During 1991, the Mission Control Program provided the control and performance analyses of NASA's unmanned Earth-orbiting spacecraft. These control facilities perform the essential function of instructing the spacecraft to make observations and measurements.

A newly developed dedicated control center and data capture facility successfully initiated Hubble Space Telescope operations. This control center is the most complex developed to date for an automated satellite. It effectively handled the early on-orbit operations problems of HST by modifying the ground and spacecraft software to enable mission success.

In 1991, the Gamma Ray Observatory (GRO) satellite and the Upper Atmosphere Research Satellite (UARS) were launched. Our existing Multi-Satellite Operations Control Center and the Packet Processor Data Capture Facility successfully initiated operations of these two spacecraft.

During 1991, the data processing program captured space-acquired images and measurements from both manned and unmanned spacecraft. Engineers then converted the captured data to forms the science community can interpret and distribute to world-wide science facilities.

Flight dynamics computations for in-orbit, free-flyer spacecraft and Shuttle-attached payloads continued to supply the necessary trajectory analyses. Computational functions of the flight dynamics system were expanded to include GRO and UARS. In 1992 operations will begin for the Extreme Ultraviolet Explorer (EUVE) and Small Explorers.

Standards. During the past year, the Consultative Committee for Space Data Systems (CCSDS), for which the Office of Communications and Data Systems serves as NASA delegate and secretariat, and the International Organization for Standardization (ISO) joined forces in developing improved data system standards. These standards provide a mechanism for the space agencies of the world to work together on space missions. CCSDS proposed two technical recommendations as ISO Draft International Standards that were approved unanimously.

Advanced Systems

The Advanced Systems program enables the realization of improved performance and higher efficiency of operations through the introduction of new technology. The development efforts are focused in areas where the needed technology is not being developed by industry or other agencies.

This program has effected great improvements in spacecraft, tracking and command, reception of spacecraft data, ground communications, data handling, network and mission control.

Through the improvements in spaceborne communications equipment and ground receiving facilities, capabilities for the reception of data from deep space missions have increased by a factor of a trillion over the lifetime of NASA. Over the same period, the ability to determine the position of deep space mission spacecraft from the ground has increased by a factor of a hundred thousand. The performance and efficiency of data collection from Earth-orbiting satellites has been revolutionized by the operational TDRSS, which was first studied and conceptualized in the Advanced Systems program.

Long-Term Study and Development Efforts. Major gains for deep space and Earth-orbiting missions are largely the result of long-term study and development efforts in the Advanced Systems program. Research efforts during 1991 included studies of new modulation and coding schemes to allow higher data rates and new data compression techniques; new techniques for highly accurate navigation and tracking; improved human machine interfaces; and use of knowledge-based systems to augment the software development process and reduce the process cost.

Development efforts in 1991 were aimed at advances in both hardware and software. Among the significant accomplishments was completion of a new 34-meter antenna that is performing research on the use of higher frequencies for communications with future deep space missions. The use of higher frequencies will allow performance improvements that can be translated into smaller antenna apertures. Using a number of smaller antennas with increased performance lowers the cost of future networks, increases the scheduling flexibility, and improves system reliability. The first test of these higher frequencies will come with the experimental 32 GHz communications space-to-ground link on the Mars Observer spacecraft scheduled for a 1992 launch.

Also in 1991, specialized microcircuits employing VLSI technology for signal processing and various other applications such as signal acquisition, tracking, and communications were implemented in the development of future missions. The chips can be used for both spaceborne payloads and ground stations. A ground-based decoder (called the Big Viterbi Decoder) is being built for improved performance with the Galileo spacecraft in its approach to Jupiter in 1995. Development continues on advanced languages and scheduling systems for network control and resource allocation in both the Space and the Deep Space Networks. All of the above were being tested in an operational environment as 1991 ended. Another series of developments consisting of expert systems for fault monitoring, diagnosis, and operator assistance are being used in the COBE and GRO missions.

Aeronautics Research and Technology

Within NASA, the Office of Aeronautics and Space Technology (OAST) is responsible for the planning, advocacy, direction, execution, and evaluation of projects and research activities concerned with aeronautics research and technology. NASA's strategy for aeronautics research and technology represents a response to the challenges of the nation's aviation leadership and the opportunities for technological advances identified by the Office of Science and Technology Policy's (OSTP) 1985 report entitled *National Aeronautical R&D Goals: Technology for America's Future.* A second OSTP report in 1987, *National Aeronautical R&D Goals: Agenda for Achievement*, updated the earlier report and provided a detailed, 8-point action plan for coordinating the efforts of industry, academia, and the government to ensure that U.S. industry remains a viable competitor in the world aviation marketplace. Together these reports outlined national goals in the transatmospheric, supersonic, and subsonic flight regimes to focus high-leverage technological developments, and concluded with a broad strategy for revitalizing the nation's capacities for innovation in aeronautical research and technology. To implement this strategy, the Agency is pursuing six key thrusts:

> Subsonic Transports—to develop selected new technologies that will ensure the competitiveness of U.S. subsonic aircraft and enhance the safety and productivity of the National Airspace System.
>
> High-Speed Transport—to resolve the critical environmental issues and establish the technological foundation for an economical, next-generation supersonic transport.
>
> High-Performance Aircraft—to provide technological options for revolutionary new capabilities in future high-performance fixed and rotary wing aircraft.
>
> Hypersonics/Transatmospherics—to develop critical technologies for the X-30 National Aero-Space Plane and future hypersonic vehicles.
>
> Critical Disciplines—to perform fundamental research, investigate cross-cutting technology, and validate numerical simulation techniques to design and operate advanced aerospace systems.
>
> Critical National Facilities—to enhance, maintain and operate NASA's vital aeronautical research facilities.

The program itself is conducted at NASA research Centers located in California, Ohio, and Virginia. Each Center has unique facilities and research staff expertise that provide a significant national resource for the pursuit of new advances in aeronautical technology. All Centers conduct extensive in-house research using special facilities and equipment. In addition, each center conducts research in close coordination with other governmental agencies, universities, and industry.

The Ames Research Center at Moffett Field, CA, uses its unique capabilities in computational fluid dynamics and computer science applications to focus on the development of new analytical methods. Key items in the area of systems technology include hypersonic aircraft, propulsion/airframe integration, powered lift technology, and rotorcraft aeromechanics. The Center also has advanced aerodynamic testing and flight simulation facilities for validating analytical methods and conducting investigations of both small- and large-scale aeronautical configurations. Ames also conducts research in such areas as human factors, aircraft and air traffic control automation, flight dynamics, and guidance and digital controls. The National Full-Scale Aerodynamics Complex houses the world's largest wind tunnel, providing capability to conduct ground testing of full-scale and large-scale aircraft and their components. Additional wind tunnels offer unique test capabilities from the low subsonic to the hypersonic speed range.

The Dryden Flight Research Facility at Edwards, CA, is NASA's premier installation for aeronautical research and flight testing. Current research includes investigations in flight techniques and instrumentation, high angle-of-attack flight characteristics, laminar flow at supersonic speeds, and design methodologies for integrated flight and propulsion controls.

Propulsion is the primary focus of the Lewis Research Center in Cleveland, OH. The Center's research and technology expertise address four main thrusts:

aeropropulsion, space propulsion, space power, and space science and applications. The objective of the aeropropulsion thrust is to advance and strengthen aeropropulsion technology that will contribute significantly to the development of U.S. civil and military aircraft. NASA's research on aircraft icing and ice protection systems is being performed in the Lewis Icing Research Tunnel. Other areas of investigation include advanced turboprop systems, small turbine engine technology, high temperature composite materials, and advanced concepts for reduced engine noise and emissions.

The Langley Research Center in Hampton, VA, pursues research in fundamental aerodynamics and fluid mechanics, computer science, unsteady aerodynamics, human factors, and aeroelasticity. Aerodynamic testing to support the research in each of these areas is a major focus of the Center. In addition, the Center is a leader in structures and materials research with a primary focus on the development and validation of methods and research in structural analysis of airframe metallic and composite materials. Langley also conducts fundamental research on fault tolerant electronic systems and flight control. Other research areas include: advanced airborne windshear technology, simulation and evaluation of advanced operational aircraft systems, acoustics and noise reduction, and propulsion/airframe integration.

Applied Research and Technology

Applied research and technology activities carry new and innovative technology from the laboratory experiment into experimental and verification systems testing. These programs are organized into a specific vehicle-class focus to provide for the design, fabrication, and testing of multidisciplinary aeronautical systems. The overall goal of the systems technology programs is to reduce greatly the technical risks associated with integration of diverse disciplinary technologies into their ultimate applications.

Subsonic Transports

The overall goal of the subsonic transport program is to develop selected, high-leverage technologies and explore new means to ensure the competitiveness of U.S. subsonic aircraft and to enhance the safety and productivity of the National Aviation System. In recent experiments, radar and infrared sensors were flight evaluated on the NASA Transportation System Research Vehicle in a cooperative program with the Federal Aviation Administration (FAA) to develop and validate airborne windshear detection and avoidance systems technology. In other cooperative activities with the FAA, the two agencies have initiated field evaluation of the NASA-developed Center-Tracon Automation System (a concept to assist controllers in handling terminal area traffic) to meet future needs of Air Traffic Control in the airport terminal area.

A cooperative flight test with the Boeing Commercial Airplane Group has successfully achieved aircraft drag reduction using hybrid laminar flow control. Analysis of the performance improvements from this technology was under way at the end of FY 1991. Active noise control techniques, tested in models, have been shown to reduce fuselage interior noise levels by 12 decibels (dB). Increased emphasis has been placed on engine source noise reduction. Advanced composites materials technology for high-strength, light-weight structures is progressing on a broad front. Representative results have included fabrication of Resin Transfer Molding stitched composite structures that exhibit minimal reduction in compression strength due to thermal and moisture exposure.

Rotorcraft

NASA has established two key rotorcraft objectives. The first is to develop critical technologies for safe, economical and environmentally acceptable operation of advanced rotorcraft in the National Aviation System. The second key objective is to develop the technology for revolutionary new capabilities in future high-performance rotary wing aircraft.

Ongoing research under the first objective includes a recent joint NASA-Industry tail-rotor noise research program that resulted in the development of Sikorsky's quiet tail rotor design. Tilt-rotor noise research included a project with the XV-15 tiltrotor equipped with advanced-technology blades. A flight test program has been completed providing an extensive data base of acoustic measurements for validation of prediction code. Rotorcraft Icing research is being conducted to provide prediction capabilities leading to icing protection systems that will permit all-weather operations. Future commercial tiltrotor technology requirements are being studied, and a technology plan is being prepared for a potential enhanced tiltrotor technology program.

The second objective involves a joint program with the Army to conduct wind tunnel and flight testing with highly instrumented blades to investigate rotor structural limits during high speed maneuvers. A UH-60 Blackhawk is being used in the flight research program to provide the necessary data for the development of advanced technologies such as active control for improved maneuverability. Future high-leveraged technologies including Nap-of-the-earth (low-level) flight and increased agility are also being developed in cooperative programs with the Army.

High-Performance Aircraft

NASA's high-performance aircraft research program is an integral and critical part of the overall aeronautics program. The program is structured to develop and mature technologies with important military and civil applications.

Supermaneuverability. Achieving stable, maneuverable and controllable flight at angles-of-attack to 70 degrees—and beyond—relative to the free stream airflow offers dramatic improvements in military effectiveness. Collectively the technology is referred to as "supermaneuverability." Flight experiment, wind tunnel, and Computational Fluid Dynamics (CFD) data are being integrated to develop design criteria and methodologies for future high-performance aircraft in the areas of flight-validated aerodynamics, maneuver, and agility. Free-flying, powered wind tunnel models and simulation studies have demonstrated unprecedented high angle-of-attack capabilities, which were being verified in flight as the year ended.

Flight tests of the NASA/Navy F-18 High Angle-of-Attack Research Vehicle (HARV) with a Thrust Vector Control System (TVCS) installed were taking place at the end of FY 1991. The TVCS was developed to provide the HARV with additional control authority necessary for stable, maneuverable, and controllable flight at the previously mentioned angles of attack to 70 degrees and beyond. The TVCS provides up to 20 degrees of vectoring in both pitch and yaw axes. The first HARV flight with the TVCS activated was successfully completed on July 15, 1991. This aviation milestone was the first interrelated propulsion/flight control, multi-axis thrust-vectoring flight on a fixed wing aircraft.

In addition to ongoing flight research, a Navy F-18 was being tested in the Ames Research Center's 80- by 120-foot Low Speed Wind Tunnel. The results of this testing will permit the comparison of full-scale wind tunnel results with CFD solutions, subscale wind tunnel data, and flight research results. Future activities include the full three dimensional CFD modeling of the aircraft, full envelope expansion of the TVCS, ground and flight tests of aircraft forebody vortex generators for yaw control, and the integration of program results into flight-validated design criteria and methodologies for future highly agile, high-performance aircraft.

X-29 Program Status. The X-29 program was a joint program by NASA, the Air Force, and the Defense Advanced Research Projects Agency to investigate performance advantages and new options in configuration integration of forward swept wing fighter-class aircraft. Concurrently, researchers seized the opportunity to test several other emerging technologies of high potential. These include relaxed static stability; three-surface longitudinal control; aeroelastic-tailored, composite, thin supercritical wing; and digital flight control systems.

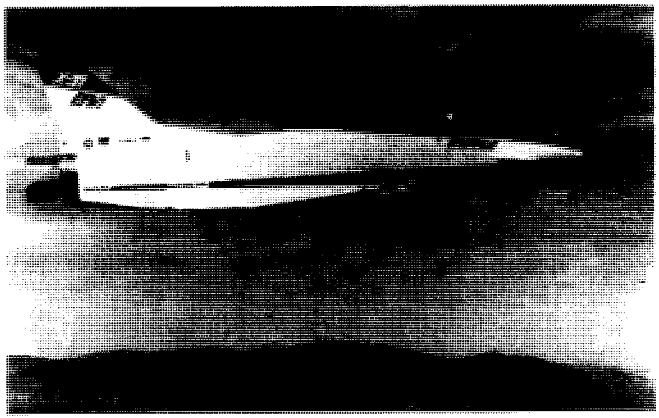
At the end of FY 1991, the X-29 program had been successfully completed. The final phase, the X-29 high-alpha program, completed the aerodynamic characterization using flow visualization and extended surface pressure instrumentation. During the X-29 high-alpha program, the aircraft successfully maneuvered to 45 degrees alpha and was flown pitch-only to 68 degrees alpha. One aircraft will be kept in flyable storage in order to maintain availability for potential follow-on research on this unique configuration.

X-31 Enhanced Fighter Maneuverability Flight Test Program. The X-31 Enhanced Fighter Maneuverability (EFM) program is a joint U.S.-German program. The Defense Advanced Research Projects Agency, Navy, NASA, and Air Force are the U.S. partners. NASA, along with the Navy and Air Force, will conduct the initial flight envelope expansion of the X-31 at the Dryden Flight Research Facility. After envelope expansion, X-31 flight testing will explore the tactical utility of the high angle-of-attack flight regime.

Short Take-off and Vertical Landing Aircraft. In 1991 the United States and the United Kingdom pursued a 3-year extension to the 5-year program for developing advanced Short Take-off and Vertical Landing (STOVL) technologies aimed at reducing the technological risk associated with the next-generation STOVL aircraft. The two countries exchanged research and technical data for key STOVL phenomena such as hot gas ingestion, augmentation by burning, jet plume/aircraft interactions, ground temperatures and noise, and integration of flight and propulsion controls. Research under the original agreement is essentially complete except for the flight and propulsion controls flight research. Another technological thrust was to develop airframe configurations that minimize hot gas ingestion from the propulsion system recirculation and the associated performance degradation. Analysis of the Lewis Research Center's 9- by 15-foot low speed wind tunnel results have identified aircraft design options for substantial reductions in the ingestion of hot gas. Studies and research under this effort have identified additional research needs for internal propulsion ducting and valving, hot gas ingestion and ground environment, vertical thrust nozzles, controls, and alternate approaches for thrust augmentation.

Supersonic Cruise

Studies conducted here and abroad continue to show that with sufficient technological development, future high-speed aircraft could be commercially competitive with subsonic aircraft and capture a significant portion of the growing long-haul intercontinental market, especially in the transpacific sector where travel is projected to quadruple by the turn of the century. However, environmental concerns regarding atmospheric impact, airport noise, and sonic boom present powerful private-sector disincentives at this time. NASA's High Speed Research program, initiated in FY 1990, is directed at resolving these issues and developing a technical basis for informed decisions by U.S. industry on high-speed aircraft development in the future. Strong foreign interest and investment in high-speed transport research only serves as a reminder that a share of this multibillion dollar future market will not be won without a concerted national research effort. By addressing the key technologies that will resolve the environmental barriers, NASA's High-Speed Research program is helping assure U.S. manufacturers are well prepared for this next plateau of transport sales competition. The program builds on NASA's extensive ongoing efforts in upper atmosphere research and previous experience in reducing aircraft emissions, noise, and sonic boom.



X-31 Enhanced Fighter Maneuverability flight test aircraft.

Atmospheric Research. The Atmospheric Research program involves two elements: long-term atmospheric assessment and low emission combustor research. The long-term atmospheric assessment is refining and adapting atmospheric models to evaluate potential global ozone depletion due to high-speed transport engine emissions in the lower stratosphere. The initial assessments show that operational flight corridors are possible that would produce less than 1 percent ozone loss if engine nitrogen oxide (NO_2) emissions could be reduced by a factor of 10 over current engines (to 5 grams equivalent NO_2 per kilogram of fuel burned).

Engine Emissions Research. To achieve this goal, NASA's low emission combustor research is developing and testing alternative methods for reducing or eliminating engine exhaust products that cause ozone depletion. The primary focus is to develop advanced technology combustor designs for low nitrogen oxide emissions. Progress to date is excellent with recent laboratory testing of two advanced combustion concepts having both demonstrated less than 5 grams equivalent

NO_2 per kilogram of fuel at simulated cruise operating conditions. (See above and below for other ozone-related coverage.)

Airport Noise Reduction. The airport noise reduction research for supersonic aircraft focuses on alternative engine cycles and jet noise suppression nozzles aimed at providing the technology to comply with Federal noise regulations (FAR 36 Stage 3 noise levels), the same levels required of today's quietest subsonic aircraft. This research includes anechoic chamber tests of advanced technology noise suppressor nozzle designs and development of aircraft high-lift aerodynamics and advanced operational procedures during takeoff and landing. During the past year, 12-18 dB noise suppression has been demonstrated in acoustic testing of 2 small mixer-ejector nozzle models, thereby showing significant potential for achieving the noise reduction goals.

Sonic Boom Research. The sonic boom reduction research addresses aircraft configurations aimed at reducing the sonic boom levels and also looks at human responses thereto in order to define the criteria for acceptability. The aircraft configuration research includes design analyses and wind tunnel testing of low sonic boom configurations, analysis and flight research on supersonic laminar flow control, and selected flight research efforts to verify the analyses and wind tunnel test results and evaluate atmospheric propagation effects and operational procedures. With respect to human response, recent testing of human subjects in a sonic boom simulator has been successful in developing a subjective noise metric for the relative acceptability of a wide range of aircraft pressure-disturbance signatures.

Engine Materials Research. To meet the challenge of environmental acceptability, both of the candidate low-NOx combustor concepts preclude the use of internal cooling now applied extensively in current aircraft combustors, thereby placing a severe demand on materials. Similarly, the length and mechanical complexity of the exhaust nozzles necessary for low noise levels will also require much lighter-weight, higher-temperature materials than currently available to be economically viable. Both requirements place a demand on material properties that cannot be met with today's technology. The FY 1992 Enabling Propulsion Materials augmentation to the program addresses these requirements by accelerating development of a new class of ceramic-based composite materials capable of operating uncooled to 3000 degrees Fahrenheit (F) for the combustor, and of high-temperature, high-strength intermetallic composites to reduce jet exhaust nozzle structural weight. As the development and introduction of new materials have historically required from 12 to 15 years, efforts on these new materials must start now to ensure their availability by 2005, the year when these new materials will be required. Early work will focus on advanced high-temperature fibers that are critical to both these composite-material systems.

Generic Hypersonics

The Generic Hypersonic program is a long-range endeavor that stresses fundamental understanding of the physical processes controlling flight and promotes new ideas. The program emphasizes research and technology development, primarily for slender air-breathing hypersonic vehicles that use highly integrated airframe/propulsion concepts; however, the scope is quite broad and includes various forms of accelerator and cruise aircraft, space and planetary vehicles, hydrogen and hydrocarbon fuel systems. The program also stresses technical issues as opposed to commitment to particular missions, and it advances high pay-off technologies, some of which have been identified by the National Aero-Space Plane (NASP) program (see below), as well as other aeronautics and space programs. Key problems exist in the areas of hypersonic boundary layers and high-speed transition, mixing and combustion at supersonic speed, real gas effects at high temperature, rarefied flows at high altitude, and high-specific-strength metal-matrix composite materials. The overriding objective of the program is to provide a capability to respond to the future mission and application needs of both NASA and the DOD.

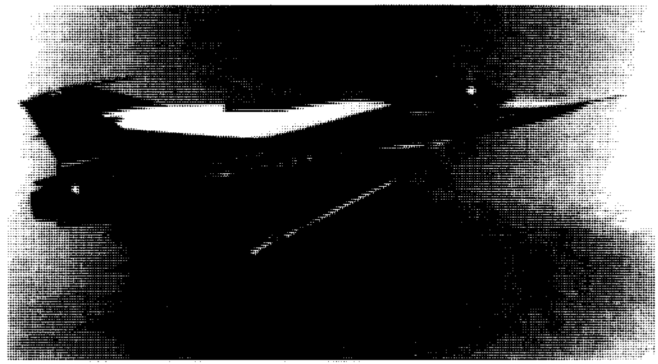
In addition to the classical disciplines, the program introduces new elements in the areas of technology-integration research, advanced instrumentation research, facilities research, and flight research. An important focus of this program will be the enhancement of overall hypersonic capability through activities in ground-based facilities research, flight experimentation, development of advanced nonintrusive flow-field instrumentation, multidisciplinary research addressing the highly coupled, complex interaction of integrated components, and the development of CFD algorithms of unprecedented accuracy.

Ames Research Center has conducted investigations in aero-heating, control concepts, lightweight ceramic matrix composites, and improvements to an arc-jet facility used to test and evaluate high-temperature insulation concepts. Langley's efforts consisted of the development of three-dimensional, nonequilibrium computational fluid dynamics flow field code; characterization of thin-gauge metallic substrate material formed by deposition; evaluation of waverider configurations with high lift/drag ratios; investigations of the effects of contaminants on supersonic-combustion ramjet combustion; and analysis of actively cooled structural concepts. Lewis' efforts focused on advanced high-speed propulsion inlet configurations, fundamental fuel/air mixing, and development of high-temperature reinforced composites.

NASA's expertise in hypersonic technology is being fully applied to the National Aero-Space Plane with the realization that its extremely broad range of technological needs challenges all disciplines. Future hypersonic vehicle concepts will be designed with the data base developed from the multidisciplinary technology of the generic hypersonic program.

Disciplinary Research and Technology

NASA's disciplinary research is aimed at establishing and maintaining a solid foundation of technology in the traditional areas of aerodynamics, propulsion, materials and structures, information sciences and human factors, and flight systems and safety. Research objectives include development and validation of computational methods for analysis and prediction of complex external and internal flows, structural mechanics, control theories and their interactions; development of design and validation methods for highly reliable, integrated, and interactive control of aerodynamics, structures, and propulsion systems; development of human-error tolerant, computer-aided piloting systems; development of design methodologies and life prediction modeling techniques for advanced high temperature materials; and development of a solid research base to enable new innovative concepts.

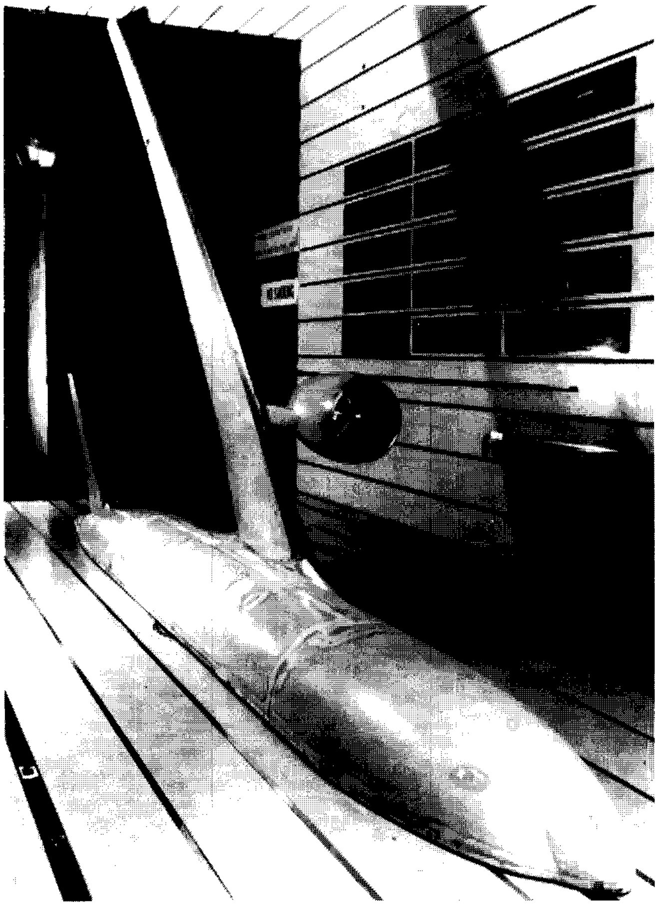


F-16XL flight test with supersonic laminar flow control test section glove.

Aerodynamics

The NASA aerodynamics effort provides the technology upon which vehicle advances can be made throughout all speed regimes and aerospace vehicle classes. Disciplinary research in aerodynamics has been structured in a program of closely integrated efforts in theoretical analyses, numerical simulation, wind-tunnel testing, instrumentation development, and flight research projects.

Fluid Physics Research. Fluid physics activities explore fluid mechanics phenomena theoretically, computationally, and experimentally. Emphasis has been placed on the development and validation of computational design tools, advancing the technologies of aerodynamics configuration surface modeling and grid generation, development of advanced testing methods of visualization both experimentally and computationally, and the investigation of viscous phenomena for accurate prediction of aerodynamic characteristics. These advanced and validated methods will be integrated into vehicle design through technology transfer to the aircraft industry. The continued efforts in transition and turbulence in terms of understanding, modeling, and direct simulation will provide improvements in prediction techniques for both transition and turbulence. The totality of this research in fluid physics continues to move toward achieving the goal of accurate design-analysis capabilities



Wind tunnel study of high Reynolds number transport wing design.

across the speed regimes for all types of aerospace vehicle configurations.

Computational Fluid Dynamics. NASA's CFD program is focused on the present and future technological needs of the aerospace community. These needs include: (1) developing faster and more efficient numerical algorithms to facilitate solutions of the full Navier-Stokes equations by large-eddy simulation/small-scale turbulence modeling; (2) developing advanced geometric techniques for complex, three-dimensional configurations; (3) improving understanding of the efforts of grid characteristics on solution accuracy, convergence, and stability; (4) enhancing computational capabilities through development and use of advanced computer architectures and expert systems concepts; and (5) developing improved methods for numerical simulation of aerothermodynamic flow phenomena associated with hypersonic cruise and maneuver vehicles, including real-gas chemistry. CFD techniques are now capable of accurately simulating full-flight configurations. Recently, NASA computed the complex flow field over an F-18 aircraft. These flow field computations display the vortex behavior and breakdown at high angles-of-attack and can cause buffeting of the vertical tail surfaces. The results compare very well with flow visualization photographs taken in flight of a testbed F-18 aircraft.

Hybrid Laminar Flow Control Flight Experiments. Hybrid Laminar Flow Control (HLFC) is a recently developed technique for maintaining low-drag flow on an aircraft wing by air suction near the leading edge and by contouring a special wing surface. Research has suggested that substantial reductions in aircraft drag can be realized by employing this technique. During 1990-1991 a cooperative research program involving NASA, Boeing, and the United States Air Force applied and flight tested an HLFC research section to a B-757 transport aircraft wing. The experiment established that HLFC operation for the wing mid-span is feasible. Researchers observed laminar flow back to 65 per cent of the wing chord, which extrapolates to a 6 percent reduction in total aircraft drag. In addition, the requirements for wing suction to maintain laminar flow proved to be considerably less than expected. Tests to further refine the feasibility of the technique were continuing at year's end. Engineers also tested laminar flow control (LFC) techniques at supersonic speeds on an F-16XL testbed aircraft. They maintained laminar flow to 26 percent chord in these initial tests, suggesting that LFC may be an applicable drag-reduction method across the speed range. Plans were under way at the end of the year to modify an F-16XL with a larger suction glove in an attempt to obtain laminar flow back to 60 percent chord at supersonic speeds.

Wind Tunnel Test Techniques. Research efforts were under way at the end of FY 1991 to explore the use of heavy gases for wind tunnel test media. These gases can provide high test Reynolds numbers at low dynamic pressures, reducing model loads and distortion. High-lift models are particularly susceptible to deformation at elevated dynamic pressures; yet precision tests of this nature are crucial in advanced transport development. These gases do not have the same compressibility and thermodynamic properties as air, and investigations will determine the feasibility of accurately adjusting the heavy gas test results to predict the aerodynamic characteristics in air. Recent instrumentation research has resulted in a photoluminescent paint technique that provides for real time sensing and visualization of surface pressures or test articles. This work promises to greatly reduce the difficulty and expense of obtaining static pressures. The method was also proven valid for the supersonic flight environment with experiments performed on an F-104 aircraft test fixture.

STOVL E-7A Tests. The E-7A program is part of an overall NASA effort in the development of STOVL technology (see related coverage above). Early tests of the full-scale powered model demonstrated acceleration and deceleration performance that enabled transition from hover to forward flight and back to hover in level flight. In 1991, initial tests at the Outdoor Aerodynamic Research facility sought to determine the hover performance without wind tunnel wall interference. The results demonstrated that the aircraft has adequate out-of-ground effect lift capability. These test efforts provided technological assurance toward the development and deploy-ment of a new class of supersonic STOVL combat aircraft in the United States.

Propulsion

Advanced propulsion technology is the key to realizing major improvements in performance for many new aeronautical-vehicle concepts. The current Propulsion System Technology Program is built upon a solid base of focused research in areas of Internal Fluid Mechanics (IFM), high-temperature materials, advanced control concepts, and new instrumentation techniques.

Discipline research in IFM has provided analytical tools necessary for describing complex flows in turbomachinery, high-speed inlets, exhaust nozzles and ducts, and chemically reacting flows in combustors. The research has shown that high-temperature materials, including nonmetallic ceramic matrix composites, can provide operational capability up to 3000 degrees F and are thus the key element in achieving high performance and reduced specific fuel consumption. Advanced control concepts, such as fiber-optic based controls, are aimed at providing increased safety and protection from electromagnetic interference and atmospheric phenomena, such as lightning. New instrumentation techniques not only provide accurate measurements of the fundamental properties of materials and fluids necessary to validate computational tools but also precisely monitor critical operating parameters of the propulsion system that have increasingly severe temperature and pressure environments.

Advanced Ducted Propeller. In a cooperative program, NASA's Lewis Research Center and Pratt and Whitney tested a 17-inch-diameter Advanced Ducted Propeller (ADP) at takeoff conditions in the Lewis 9- by 15-foot Low Speed Wind Tunnel. The simulated ultra-high-bypass-ratio model was run with a conventional, a mid-length, and a short inlet installed. Inlet duct and fan total pressures and temperatures and inlet surface static pressures were measured while the model was taken to high angle of attack. This parametric low-speed (Mach 0.2) testing indicated that the best high angle-of-attack performance was obtained with the short inlet duct configuration. Additional tests also confirmed that this ADP concept can generate required levels of reverse thrust. At year's end, NASA and contractor personnel were installing the model in the Lewis 8- by 6-foot Supersonic Wind Tunnel for Mach 0.8 performance tests.

High Efficiency Core. The high efficiency core program is specifically directed to provide the enabling technologies for achieving overall cycle-pressure ratios of 100:1 and peak temperatures of 3000 degrees F in advanced ultrahigh-bypass-ratio turbofan engines for the next generation (Year 2015) subsonic transport. Parametric cycle studies have provided the definition of technological needs for the high efficiency core program. Effort was under way at the end of FY 1991 to establish the optimum-configuration turbofan engine incorporating a high efficiency core.

High Speed Research. The high speed research program is focused to address critical environmental issues and provide enabling propulsion technology for economically viable, high-speed civil transports. A major technical challenge is the development of propulsion systems that will meet acceptable emission and noise standards and provide substantial reduction in fuel consumption while offering extended engine life at high, sustained operating temperature. (For a related program, see above under Applied Research and Technology.)

The engine emissions of primary concern are nitrogen oxides which, through a series of catalytic reactions, could adversely impact the Earth's protective ozone layer. Recently completed combustion experiments at the Lewis Research Center have demonstrated the potential of lean-premixed-prevaporized and rich, burn-quick, quench-lean-burn combustor concepts to achieve emission levels at or below the emission index goal of five grams of NOx/kilogram of fuel burned.

Aircraft noise and its propagation in and around airport communities continues to be a subject of significant concern. Technological development for supersonic transport noise reduction will combine propulsion-source noise reductions and the effects of improved lift-to-drag ratios on aircraft operations into an integrated program for reducing overall noise levels near airports. In 1991, the Langley Research Center completed source noise tests of single-flow generic nozzles (that is, circular, rectangular, elliptic). These tests quantified the noise reduction advantages of nonaxisymmetric jets. Approximately a 15 dB reduction in sound pressure level was achieved with a shock-free elliptic jet configuration as compared to a conventional circular nozzle exhibiting a typical strong-shock structure.

Generic Hypersonics. The generic hypersonics propulsion program focused on development of improved understanding of supersonic combustion processes. The program used advanced laser-based optical techniques to define and map temperature and species-concentration profiles for flow downstream of a transverse jet injecting hydrogen into a Mach 2 air stream. Also completed in 1991 were the first tests of a new, variable-geometry hypersonic inlet concept that demonstrated enhanced low-speed (Mach 2-3) mass capture while retaining high-speed (Mach 5) performance.

Materials and Structures

The performance gains for future civil and military vehicles depend on technological advances in new, strong, lightweight materials and innovative structural designs. Equally important, the lifetimes of current aircraft have been increasing. To ensure the current fleet remains safe, NASA and the FAA have begun an aging aircraft program to develop methods for quick and inexpensive inspection for corrosion and structural degradation; to examine the nature of fatigue in the materials in use today; to develop new crack and corrosion resistant materials and structures; and to develop analytical procedures for evaluating in-service aircraft and predicting their residual life.

Advanced Engine Structures. Materials and structures play an important role in the development of advanced turbine engines. New materials will permit the development of turboprop and turbofan aircraft with increased range and thrust and enable development of an economically and environmentally acceptable high-speed civil transport. The goal of the enabling-propulsion materials initiative is to make a quantum leap in the development of materials to withstand the stress and temperatures found in these engines. Tests of advanced engine-structures technology, completed this year on new magnetic bearings with increased load capacity and reduced fuel consumption, demonstrated a 5 percent fuel savings and 15 percent weight savings for turbofan engines.

Advanced Composites Technology. The advanced composites technology program emphasizes innovative fabrication concepts to make composites cost competitive. NASA selected an automated fiber placement process for a fuselage crown structure, then fabricated and tested panels to validate the concept. Compared to current aluminum technology, the tests demonstrated a potential 25 percent cost and a 40-50 percent weight savings.

Computational Structures Technology. At the current rate of improvement in computational power, the computers of the 1990s will be invaluable design tools. The computational structures technology program has been examining ways to exploit the evolving high-performance computers to increase the efficiency of the computer-analysis tools used to design novel structures employing advanced materials.

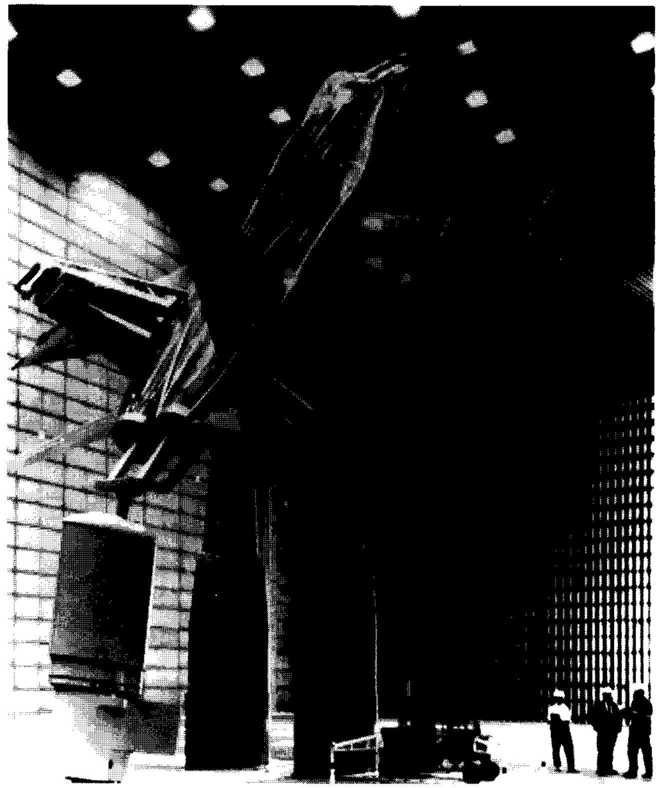
Tire Design. Recently, NASA distributed a national tire-modeling computer program to the tire industry. This analysis method performs detailed, three-dimensional tire design based on material and geometrical parameters. Coupled with the national data base for bias-ply, radial-belted and H-type tires, this program will allow superior tires to be designed so as to enhance aircraft safety during ground operations under adverse weather conditions.

Aircraft Noise Reduction. Noise has always been a concern. Not only is it bothersome to airline passengers; it fatigues the airframe. The final phase of the advanced turboprop interior flight program was under way at year's end. This program, a combination of predictive techniques and testing, is developing ways to reduce the noise in the aircraft cabin. One innovative technique of reducing cabin noise is the application of piezo-electric actuators to the fuselage, resulting in a reduction of cabin noise by an average of 12 dB.

Active Flexible Wing Program. High-performance aircraft encounter the severest loading conditions. Their control systems must therefore be more flexible and expected to perform a wide range of roles, exhibiting significant aerodynamic and structural interaction, than those of commercial aircraft. In 1991 NASA completed a wind tunnel program in which the control system was designed to actively control wing loads during a rolling maneuver. The modified aircraft exhibited significant load reduction during rapid roll maneuvers, and its operating envelop was increased in dynamic pressure by more than 20 percent.

Flight Systems

In each discipline area such as aerodynamics, structures, flight controls, and propulsion there exists a need to validate research through actual flight testing of new components and systems. In some instances, aeronautical research can only be performed or validated in flight. This in-flight validation has frequently been accomplished using high-performance aircraft as test platforms.



Full-scale F-18 undergoing high-angle-of-attack testing in the Ames 80x120-foot wind tunnel.

Aircraft Icing Research. NASA has been conducting tests jointly sponsored by the United States Air Force to define the capabilities on new low-power deicing systems for aircraft. Engineers using the Lewis Research Center Icing Research Tunnel (IRT) have evaluated eight concepts from six companies. The result has been an extensive data base of residual ice, shed-ice particle size, and power requirements. One of the important results of these studies has been the development of techniques that permit the recording and post-test analysis of ice-shedding events.

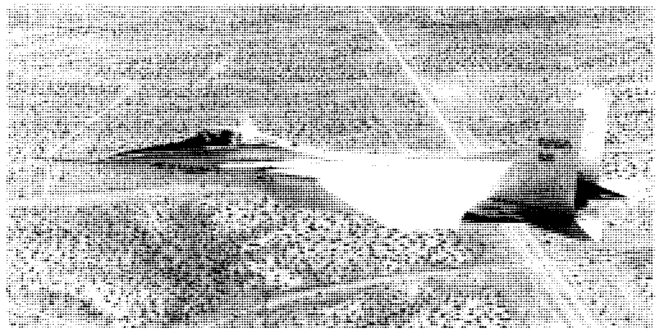
Engineering personnel at Lewis have developed a three dimensional ice-accretion computer code, LEWICE 3D, to permit the prediction of ice buildup on an actual airfoil, whereas past codes have been limited to two-dimensional shapes. Experimental ice shapes on a 30-degree swept wing in the IRT have shown excellent agreement with code predictions for icing times up to 7 minutes. This new code will lead to more realistic evaluations of the effects of ice on aircraft performance.

Lewis personnel have incorporated an electrothermal deicer computer code into the two-dimensional ice-accretion code, LEWICE. With this addition, the system can predict the effects of electrothermal deicer performance on ice shape and quantity, allowing designs and operating procedures to be optimized quickly and inexpensively.

Vortex Flap. NASA has completed aerodynamic and performance flight tests of the vortex flap fitted to the F-106B research aircraft. Tests have evaluated wing/flap pressure distributions, handling qualities, performance, and stability and control characteristics for the modified configuration under sub-sonic and transonic conditions. The flight test results have generally confirmed the predicted characteristics, and engineers presented a summary of these results at the NASA High-Angle-of-Attack Technology Conference in November 1990.

The results of the F-106 vortex flap flight experiment will provide validated design methods and computational fluid dynamics predictions to enable improved subsonic lift/drag performance for supersonic aircraft. At the design lift coefficient of 0.5, a 60 percent improvement in lift/drag was obtained. Applied to a High Speed Civil Transport (HSCT), this would permit reduction in engine power during climb-out after takeoff with significant noise reduction. In the case of a fighter aircraft, this would provide for increase in maneuvering "G" for a specific thrust setting. Preparation of the formal documentation for these results was in process as the year ended.

High Angle-of-Attack Technology Program. This comprehensive aerodynamics, flight dynamics, and control research program contains analytical, computational, wind tunnel, and flight research elements. The program has placed its emphasis on the acquisition of detailed, flight-validated data bases in high angle-of-attack environments (that is, to 70 degrees and beyond). A thrust vectoring control system installed on the test aircraft will enable extended pitch and yaw control. The system was



F-15 flight test of Highly Integrated Digital Electronic Control.

midway through envelope expansion at year's end; preliminary results indicated that it was producing predicted levels of control in-flight. Forebody vortex control devices, both mechanical and pneumatic, that enable yaw control at high angle of attack through the manipulation of forebody vortices, were in detailed design and test at the close of Fiscal Year 1991.

The detailed data base developed for the conventionally controlled F/A-18 aircraft was in the process of being extended using the thrust vectoring capability. Engineers have obtained data enabling comparisons between predicted and flight-measured aero-dynamic flow characteristics. Computational fluid dynamics techniques have been extended, allowing for the modeling of the full aircraft configuration at high angle of attack and sideslip for correlation to flight data. A retired Blue Angels F-18, installed in the Ames National Full-Scale Aerodynamic Complex Wind Tunnel, has begun to obtain high-fidelity wind tunnel data for correlation to subscale tests, CFD, and flight tests.

Flight Research of F-15 Aircraft. The NASA Performance Seeking Control (PSC) flight validation program began in 1990 at the Dryden Flight Research Facility using the F-15 Highly Integrated Digital Electronic Control (HIDEC) aircraft and will continue into 1992. PSC optimizes the engine controls and the aircraft flight controls in combination. Tests have demonstrated thrust increases in the 10 to 15 percent range at constant fuel flow for the subsonic conditions tested to date.

SR-71 Research Testbed Aircraft. By July 1991, three SR-71 aircraft had arrived at NASA's Dryden Flight

Research Facility. NASA's Dryden-based flight operations for pilot training began in July 1991 using the dual cockpit SR-71B trainer aircraft. Flight research experiments were being defined for these testbed aircraft as the year ended. The experiments identified to date primarily support the National Aero-Space Plane and NASA's High-Speed Research program. In August 1991, the SR-71B conducted sonic boom research flights. Other flights under consideration include investigation of an Optical Air Data System and an inlet-spike Flush Air Data System.

Supersonic Laminar Flow Control Research. NASA has conducted a cooperative laminar flow control flight test program using an active and passive glove attached to the left wing of an F-16XL aircraft. Rockwell International designed the glove and active boundary layer suction system for a military requirement. Results of this test in 1991 indicate significant laminar flow of the test glove airfoil can be achieved at low-unit Reynolds number supersonic flight conditions. Laminar flow sensitivity to angle-of-attack and sideslip were also investigated. Between 1992 and 1995, NASA plans to conduct extensive flight research of a new glove design. The new and larger active and passive glove will include an airfoil section and pressure distribution designed to achieve maximum laminar flow during supersonic cruise for the HSCT application. Development and delivery of validated methodologies for a high degree of HSCT supersonic cruise laminar flow is the goal of this program.

Information Science and Human Factors

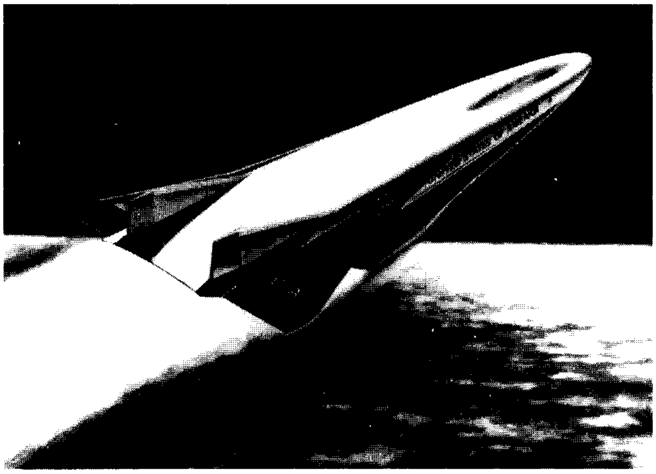
New missions that stretch piloting capability and integrated systems that demand high-speed computational processing are the challenges confronting the NASA Information Sciences and Human Factors program. The technologies emerging from this rapidly expanding field of science provide the key to understanding, controlling, and optimizing the new families of aeronautical vehicles.

Controls and Guidance. Controls and guidance research has been providing advanced technology to exploit concepts that dramatically improve the operational capabilities of civil and military aircraft. NASA has conducted the first airborne windshear flight experiment for detection and avoidance to evaluate radar clutter models and airborne infrared radar systems. The Federal Aviation Administration selected the Center-TRACON Automation System as the basis for the Terminal Air Traffic Control Automation program field evaluation. An F-18 High Angle-of-Attack Research Vehicle demonstrated automated testing techniques, along with multifunction test and analysis techniques, in an integrated computer environment. Further, researchers have completed the initial integration of heat transfer code and have developed enhanced actuator models for aeroservoelastic analyses to support hypersonics research.

Human Factors. Human factors research supports aeronautical research and technological development by providing new methods and tools to increase flight crews' capabilities to manage complex flight conditions. NASA researchers have developed and published a new concept of human-centered aircraft automation. The report describes rationale, concepts, and guidelines for the use of automation by flight crews. In other areas, there have been extensive tests of countermeasures to combat pilot fatigue during long flights, and simulator tests have demonstrated electronic display of procedural checklists.

High Performance Computing and Communications. NASA's High Performance Computing and Communications (HPCC) program participates in all four components of the Federal program in this area of endeavor. HPCC is focused on grand challenges through a vertically integrated program composed of: computational aerosciences, Earth and space sciences, and remote exploration and experimentation. The goal is to accelerate the development and application of high performance computing technologies in order to meet NASA's science and engineering requirements. In cooperation with other Federal agencies, NASA's program will deploy teraFLOPS computer capabilities essential for computational design of integrated aerospace vehicle systems and for predicting long-term global change, and it will enable the development of massively parallel techniques for spaceborne applications.

NASA's program is focused on bringing together interdisciplinary teams of computer scientists and computational physicists to develop these technologies within three vertically integrated projects that are unique to



Artist's concept of the X-30 National Aero-Space Plane.

NASA's missions. These technologies include applications algorithms and programs, systems software, peripherals, networking, and the actual high performance computing hardware. NASA plans to develop a suite of software tools to enhance productivity. These include: load balancing tools, run-time optimizers, monitors, and parallization tools, as well as data management and visualization tools.

NASA's role includes coordinating the *Advanced Software Technology and Algorithm* component for the Federal program; acquiring experimental hardware for testbeds in computational aerosciences, earth and space systems sciences, and remote exploration and experimentation; and supporting the development of the National Research and Education Network. NASA's considerable expertise in experimental parallel computer testbeds and small, scalable testbed systems will be used to demonstrate high performance computing technologies as a step toward full-scale computational capabilities.

National Aero-Space Plane

The National Aero-Space Plane (NASP) program, begun in 1986 as a joint venture by NASA and the DOD, has continued to be focused on key technologies for hypersonic cruise and single-stage-to-orbit flight using airbreathing primary propulsion. This program is currently progressing through a technology-development phase that relies on analytics and ground-based testing. The next program phase will require building and flight-testing a NASP experimental vehicle, the X-30. This vehicle will demonstrate numerous new technologies and explore phenomena that cannot be adequately simulated on the ground. The decision on whether to proceed to the X-30 will be made in 1993.

The five major contractors for NASP have integrated their work under a joint-venture partnership. Pratt & Whitney and Rocketdyne continued to advance propulsion-system technology, while General Dynamics, McDonnell Douglas, and Rockwell International were jointly responsible for the airframe and total vehicle integration. Government research centers and laboratories, the other part of the national team, were responsible for numerous technological tasks that span a wide range of disciplines.

Participating engineers have achieved progress in propulsion through both CFD and tests of both engine components and subscale engines. New data for improved engine concepts was gained in the Mach 4 to 8 range with special facilities for supersonic combustion ramjets. (These facilities use arc-heaters or combustion to preheat the inflow air, simulating shock-wave heating at the front of an actual hypersonic vehicle.) Tests at speeds up to Mach 17 defined the performance of advanced engine components, such as fuel injectors, as well as the chemistry of nozzle flows; advanced laser-based diagnostic tools yielded much of the data. CFD for internal flows was sufficiently advanced to apply to detailed engine design. Continued work on slush hydrogen fuel, a cryogenic mixture of solid and liquid hydrogen, has led to improvements in fuel production, storage, and handling for the projected X-30 aircraft.

The development of NASP structures has progressed to the testing of large-scale assemblies representative of parts of the final vehicle design. During 1991, for example, a fuel tank installed in a fuselage segment successfully endured harsh thermo-mechanical loads that simulated NASP flight profiles. Results of such tests contributed to the selection of graphite epoxy for the fuel tank and a titanium metal-matrix composite for the fuselage shell. Heat shields of baked carbon and panels cooled with internal flows of cold hydrogen will protect the parts of the fuselage shell that experience the most severe aerodynamic heating.

Advances in NASP aerodynamics have refined the X-30 configuration. Results of wind-tunnel tests have allowed better simulations of engine flows from takeoff through hypersonic speeds. Improvements in the use of CFD predictions include applications of new, more sophisticated mathematical models of hypersonic boundary-layers. This work has led to configuration refinements, such as a recontoured fuselage forebody as well as selection of the best nozzle shape.

Space Research and Technology

The Space Research and Technology program consists of a continuum of activities ranging from initial research conceptualization to the full-scale testing of prototype equipment in space. The program's mission is to provide both technology for future civil space missions and a base of research and technology capabilities to serve all national space goals. This mission includes identifying, developing, validating, and transferring technology to increase mission safety and reliability, reduce program development and operations cost, enhance mission performance, and enable new missions. In addition, the program provides the capability to advance technology in critical disciplines and respond to unanticipated mission needs. Activities include work that is performed by in-house staff at the NASA Centers, university researchers supported by NASA-funded grants and contracts, and industrial aerospace organizations under contract to NASA. The Office of Aeronautics and Space Technology manages and coordinates the work through a process that integrates the best available talent and capability in NASA, industry, and the universities into a national civil space research and technology program.

To accomplish its goals, the Space Research and Technology program is composed of two complementary parts: the research and technology (R&T) base program and the focused technology programs. The R&T base serves as the seed bed for new technologies and capability enhancement. Through the R&T base program, usually at a subscale level, scientists and engineers develop forecasts regarding the potential applicability, usefulness, and overall benefit associated with new technologies. These diverse efforts provide evolutionary advances in technology in all important space disciplines and technological breakthroughs that may revolutionize a technical discipline or mission concept. Once the potential applicability of a new capability is established, decisions are made to carry selective discoveries into focused technology. A key element of the space research and technology program is developing and sustaining a strong partnership with the university community. The goal of the university space technology research is to enhance and broaden the capabilities of the nation's engineering community through active research participation in the U.S. civil space program. The program is an integral part of the strategy to reinforce the space research and technology capabilities of the nation.

Focused development is initiated based on the identified and projected needs of both current and future space missions. The strategy is to provide a balanced, multidisciplinary program to meet these needs. Three focused programs have been initiated since 1988, the civil space technology initiative, the exploration technology (formerly called Pathfinder), and the in-space technology experiments program. In the focused programs, technologies are developed for specific applications, and products are delivered in the form of large-scale hardware technology demonstrations, software, and design techniques and methods. This technology development is the vital first step in providing the capability to improve our understanding of the planet Earth and in allowing us to move out from Earth and expand our presence into the solar system. Because the focused programs are committed to meeting the needs of the user community, they are structured into five technology thrusts: space science, planetary surface, space platforms, transportation, and operations. This five-thrust approach correlates well with the capabilities that will be needed for current and future missions and organizes the space research and technology program for alignment with future NASA or national technology needs. The program addresses requirements developed through an intensive and continuous dialogue with technology users from NASA, U.S. industry, and the academic community.

Significant progress was made in 1991 in each of the principal thrusts, and continuing efforts promise to show even greater results. Recent examples have included:

Space Science Technology Thrust

In the 1990 Report of the Advisory Committee on the Future of the U.S. Space Program, chaired by Mr. Norman

Augustine, science was identified as the fulcrum of the entire civil space effort. "Science," the committee said, "gives vision, imagination, and direction to the space program." The space science thrust is committed to developing advanced observation, information, spacecraft, and operations technologies that will maximize the return from NASA space and Earth science missions over the next 20 years.

The coming era will witness dramatic increases in the use of robotic spacecraft for space science missions, including Earth science, solar system science, astrophysics, space communications, and microgravity. These missions will advance our understanding of the Earth as a system; explore and characterize the planets in our solar system; study the complex interactions between the Sun and planetary magnetospheres; expand our understanding of the birth and formation of stars and stellar systems; search for evidence of planets around other stars; and contribute to our continued leadership in space.

The space science thrust is aimed at developing space-based instrument component and detector technologies to enable new space science measurements and space instrument support and observation technologies to maximize scientific returns from these missions. Areas of research in FY 1991 included direct detectors, submillimeter sensing, laser sensing, telescope optical systems, coolers and cryogenics, and sample acquisition, analysis, and preservation.

During FY 1991, space science technologies provided concrete examples of the benefits of technology investments on a number of crucial NASA missions. In support of space science missions in the early 1980s, the Office of Aeronautics and Space Technology developed the technology for the world's first large-swath, real time synthetic aperture radar ground processor. Capable of performing over 6 billion floating point operations per second, the system consists of 76 circuit boards containing over 27,000 integrated circuits with a capability to process data in real time. This technology became the heart of the Magellan ground image processing system, producing the remarkable images of the planet Venus that we have seen during the past year. The system has processed over 1500 orbits of Magellan data over the last year without major failure. Yet, without the initial investment in technology, this capability would not have been possible.

Technology provided by the space research and technology program was also critical to the development of Star Trackers used on the recent Astro-1 Space Shuttle mission in December 1990. (See above.) Star trackers are a special class of star sensors that image an area of the sky to provide precise star position data relative to a fixed line of sight. Based on charge-coupled device sensor technology, the Astro Star Tracker tracked objects over a 10,000:1 brightness range and allowed very accurate and stable position determination at any point within its field of view.

The Astro Star Tracker took on a vital role early in the mission when problems with the prime star trackers prevented the automated Instrument Pointing System from locking onto the operational guide stars. The Astro Star Tracker then became the primary means of target acquisition. The Shuttle crew was able to compare star positions acquired with the Astro Star Tracker with onboard small-field-of-view star maps and manually point the instruments to the science target with a joystick. Problems for the mission were compounded when the Shuttle's onboard digital display units failed. Star positions could then no longer be displayed to the crew. Ground support crews were able to resolve this glitch by identifying each star field acquired by the Astro Star Tracker in real time and issuing instructions to the astronauts who then manually repointed the telescopes. The mission manager stated that this capability was essential to the success of the mission.

The accomplishments of space science technology also included the demonstration of a diode-pumped two-micron solid state laser. This laser was being researched as a potential candidate for use in NASA's Mission to Planet Earth program to better understand the complex and dynamic natural and manmade forces that interact to create weather and climate. Two-micron laser research is motivated by numerous atmospheric remote sensing applications that require an efficient, long-life, eyesafe laser. Potential applications include both the measurement of global winds and atmospheric CO_2 concentrations. In the past year, researchers were able to demonstrate in 2.122 micron lasing at 30° Celsius (room temperature) with good efficiency. Additional experiments demonstrated for the first time both high efficiency and gain for the same laser amplifier. The laser obtained optical gains of 10 for low amounts of incident light. These accomplishments will enable eye-safe lidars ("light detection and ranging" laser radar) with greater range and sensitivity.

Transportation Technology Thrust

The transportation technology thrust is comprised of technologies enabling expansion of space transportation systems capabilities for future ambitious missions, including full studies of the Earth and its environment, robotic missions to explore the Solar System fully, and manned exploration of the Moon and Mars. It has included technologies that allow for evolutionary improvements in current transportation systems as well as technologies that provide the foundation for the development of major new transportation systems as needed. The goal has been to provide vehicle systems technologies that substantially improve safety and reliability, increase system availability and provide new capabilities, while reducing life-cycle costs.

This thrust is segmented into three technology areas: Earth-to-orbit transportation, space transportation, and technology flight experiments. Earth-to-orbit transportation is necessary to provide access to low-Earth-orbit. Space transportation, meanwhile, is focused on developing the critical technologies needed for transportation to, and return from, the Moon, Mars, and other planets and bodies in our Solar System. Technology flight experiments consist of efforts to develop, through space experimentation, information not available from ground-based research, and in some cases, to provide a technological validation that could not pragmatically be achieved otherwise.

Elements of research in FY 1991, included Earth-to-orbit propulsion, aerobraking, advanced cryogenic engines, autonomous landing, autonomous rendezvous and docking, cryogenic fluid systems, nuclear thermal propulsion, and the aeroassist flight experiment.

There were many significant accomplishments in FY 1991. The program developed an advanced manufacturing process that could greatly decrease the time and cost of fabricating rocket engine combustion chambers for the Space Shuttle Main Engine (SSME). The two major components comprising a typical combustion chamber are a structural outside jacket and an internal liner. An advanced low cost investment casting process was used in the fabrication of the outer structural jacket, and NASA developed promising construction methods for the internal liner fabrication. One method employed a technique of vacuum plasma spraying a copper alloy material onto the internal surface of the outer structural jacket to form the liner in which slots were milled to form coolant passages. Analyses suggest that an SSME main combustion chamber fabricated by these approaches would decrease the fabrication time to 50 weeks (instead of 150) and reduce the cost significantly. Although primarily aimed at the next generation of rocket engine developments, the application of these techniques to our current family of expendable launch vehicles or to the SSME itself is a distinct possibility.

In another area, researchers used advanced computational fluid dynamics techniques that will enable the design of turbines, pumps, and other rocket engine parts with higher operating efficiencies and greatly reduced dynamic loading. Using these tools for engine component design prior to the initiation of a flight hardware development program has the promise of greatly reducing program risk and cost. As an example, in FY 1991, the use of computational fluid dynamics tools in the design of a generic technology turbine stage permitted the use of a single instead of a two-stage turbine. This advance resulted in a turbine efficiency increase of 10 percent and a 55 percent reduction in the number of blades required. Analyses suggest that these design improvements would result in significant life-cycle cost savings for future engine developments, such as the SSME. This work is essentially laying the ground work for all future rocket engine turbopump designs.

Space Platforms Technology Thrust

The space platforms technology thrust is primarily concerned with providing the technology needed for future space platforms. This thrust seeks to provide technologies for the following mission classes: unmanned Earth orbiting platforms in low-Earth-orbit or geosynchronous Earth-orbit, manned Earth orbiting platforms (space stations), and deep-space platforms. The overall technological goal is to enhance future scientific, explorational, and commercial missions by providing lightweight and durable platforms. In addition, these platforms must have the capability to compensate for the vibrations and disturbances that structures experience in space. Once achieved, these advances will lead to reductions in spacecraft launch weight, increased lifetime, and reduced life-cycle costs by decreasing on-orbit maintenance and logistics resupply needs. Ongoing efforts at the end of FY 1991 included research in platform structures and dynamics.

This program made great strides in FY 1991. Researchers continued to analyze results obtained from the Long Duration Exposure Facility (LDEF), retrieved in January 1990 after 5 1/2 years in space. The preliminary findings of radiation investigators yielded a few surprises. The LDEF measurements of anomalous and ultra heavy cosmic rays were 6 times more sensitive than any other measurements that will be available this decade. In addition, beryllium 7 was discovered on the front surfaces of LDEF in quantities 1,000 times that predicted by atmospheric diffusion. An explanation of the presence of beryllium 7 on the surface of LDEF posited that it must have been first rapidly and efficiently transported to higher altitudes and then absorbed onto the surface of the spacecraft. Neither process had been expected. This data has contributed to the understanding of radiation issues and has improved the models used to develop Space Station Freedom (SSF) radiation protection requirements. Ultimately, this knowledge will result in significant weight savings for the Station.

In addition, materials data from LDEF will provide the "benchmark" for design data bases for spacecraft that will have to be maintained in the low-Earth-orbit environment. Some materials were encouragingly resistant to that environment. Protective techniques involving the coating of polymer materials with very thin metallic layers proved to be quite durable. Overall, most systems on LDEF worked well. No failures of electrical or mechanical systems that could be attributed to the low-Earth-orbit space environment have yet been detected. A variety of low cost electrical/electronic components were used successfully on the facility. Additionally, no evidence of cold welding has been detected to date.

Also during the past year, researchers used a computer program known as the NASA Charging Analysis Program (NASCAP) to model the electrodynamic environment that Space Station Freedom might encounter. Use of the program identified a potential problem from deleterious high-voltage interactions. Space Station solar cells are larger than standard solar cells and have a peculiar geometry. NASCAP determined that the floating potential of the cells in the space plasma resulted in a negative ground (about -140 volts) relative to the plasma. The magnitude of this voltage is high enough that the incoming positive ions in the plasma will hit with sufficient energy to "knock off" material from the Station (that is, sputtering will occur). Moreover, dielectric breakdown could occur (that is, the voltage is high enough that there would be arcing or breakthroughs of the anodized surface). The calculated arc rate is one arc every 2 seconds. If this occurred all surfaces would be denuded in 2 to 3 years. Awareness of this problem and quantitative predictions by NASCAP about its effect have permitted a solution to be devised to change the floating potential by either increasing the ion collection or decreasing the electron collection.

NASA is planning an array of ambitious science missions to explore the Solar System and better understand the Earth as an entire system. To make these missions possible, engineers need advances in the precision control of space structures that support sensitive scientific instruments. The key is to develop designs that compensate for the vibrations and disturbances that structures experience in space so that these instruments can acquire the data they need. In the past year, researchers have conducted initial ground test experiments which indicate that an increase in precision control of 20-30 percent is possible. In addition, analytical studies show significant improvements in precision pointing jitter (vibration) for large space antennas. These results hold the promise of reducing the jitter for antennas of 20 to 80 meter range by a factor of 500.

Planetary Surface Technology Thrust

The objective of the planetary surface technology thrust is to develop the critical technologies required for future Solar System exploration missions including establishment of a base on the Moon and manned exploration of the planet Mars. This effort will develop a broad set of technologies that will enable new and innovative capabilities, increase reliability, and reduce risk for human missions beyond low Earth orbit; reduce development and operations costs for long-term exploration efforts; and enhance performance for human and robotic missions.

As a partnership between NASA, industry, and academia, this thrust will enhance our nation's "cutting edge" in the highly competitive arena of aerospace technology. The focus of effort is on developing new technologies in several broad areas to enable future robotic and piloted Solar System exploration: space nuclear power, high capacity power, surface power and thermal management, planetary rovers, regenerative life support, radiation protection, extravehicular-activity systems, human factors in exploration, and exploration-technology analysis.

During FY 1991, there was progress in a number of key areas. In regenerative life support, researchers developed a systems analysis tool with the capability to perform rigorous system and technology trade-off analyses quickly and inexpensively. This modeling tool identifies the relative benefits of each technology without having to commit to costly hardware designs. It has been shown to be versatile for analyzing a wide variety of regenerative life support systems. This tool has proved useful in analyzing potential systems for both lunar and Mars base missions. These include carbon dioxide removal, carbon dioxide reduction, oxygen generation, potable water processing, hygiene water and human waste processing. These studies will support NASA's definition and evaluation of hybrid physical-chemical-biological life support systems for potential development.

This thrust also supports NASA's contribution to the SP-100 technology development program for space nuclear power. The program's objective is to develop and validate technology for nuclear reactor power systems in space that can produce tens to hundreds of kilowatts of electric power and be capable of 7 years of operational life at full power.

In FY 1991, the SP-100 Program, which is a joint NASA, Department of Defense, and Department of Energy endeavor, successfully completed development of uranium nitride fuel pellets for a generic 100-kilowatt-electric space reactor power system. Researchers also achieved the design goal of burn-up to 6 percent with prototypic fuel in representative fuel pins. In addition, the program successfully demonstrated the bonding of the fuel pin cladding to the rhenium liner. This liner is needed to protect the fuel pins from fusion gases. With these advances, the fuel pin design and fabrication process for the reactor is now complete. These were all critical steps toward bringing this technology to maturity for application in a lunar outpost in the next century. A mature lunar base will require nuclear power because the lunar nights are too long (approximately 14 Earth days) to make non-nuclear energy storage practical.

The past year has also witnessed a true watershed in robotics research. Researchers developed and demonstrated a semi-autonomous navigation system for unmanned wheeled planetary rovers and tested the vehicle on a 100 meter test course. This advance represented the first use of an autonomous navigation and control system for recognizing and traversing natural terrains without human teleoperation. For potential future unmanned missions to Mars, rovers will need onboard intelligence or semi-autonomous navigation systems to enable the machines to think and see for themselves under conditions of long communications delays. For manned missions, it offers the potential of freeing the astronauts for more creative tasks.

In another accomplishment, researchers developed and demonstrated a low-power, legged vehicle on extreme terrains. Known as Ambler, this system demonstrated extremely high mobility, with an ability to cross large obstacles while maintaining a low power profile. Legged systems provide realistic alternatives to wheeled rovers, which can be limited to benign terrains. These experimental robots will form the foundation for continuing development of mobile robotics software and navigation technologies to support future exploration of challenging but scientifically intriguing areas of both the Moon and Mars.

Operations Thrust

The objective of the operations technology thrust is to develop and demonstrate technology to reduce the cost of NASA operations, improve the safety and reliability of those operations, and permit new, more complex activities to be undertaken with robust and flexible support systems. This thrust is directed towards developing those technologies that offer potentially significant benefits in all of the major operational areas of the Agency, as well as in support of the U.S. commercial satellite industry.

The major operational areas of NASA are physical operations and activities in space, including flight operations and mission control for both manned and unmanned missions; ground support operations to process payloads, spacecraft, and launch vehicles (both pre- and post-flight); and those special operations that will be necessary to support activities on the surface of the Moon and Mars, as the Space Exploration Initiative unfolds. The technology program that responds to these needs is directed to those specific areas where the greatest needs exist, where the greatest impact can be made, and where U.S. industry is not expected to develop the required capabilities independently. Work was ongoing at year's end in telerobotics, artificial intelligence, in-space assembly and construction, and space data systems.

Automation and robotics activities received special emphasis with a number of significant accomplishments in 1991. Advances were made in real time data systems and automated structural assembly among other programs. By introducing state-of-the-art techniques in expert systems, software engineering, human/computer interfaces, and distributed systems, the Space Research and Technology program improved the quality of flight decision making and the cost effectiveness of Space Shuttle Mission Control Operations. As manned spacecraft missions and flight operations have increased in frequency and complexity, greater demands have been placed on flight controllers to perform more problem solving tasks. The goal of the real time data system is to relegate the repetitive, monotonous monitoring tasks in mission control to automated systems and free the flight controller to concentrate on the more challenging aspects of space flight such as schedule modifications and trouble shooting. In FY 1991, the Johnson Space Center added a number of real time expert systems into its Mission Control Center consoles. The principal mission benefits from the applications were improved data monitoring and more thorough analysis of fault data in a shorter period of time. By supplying this capability, real time data systems should produce much needed savings in manpower. As an example, the Mission Control Center (MCC) recently installed a data communications expert system for operating the flight recorders on board the Space Shuttle. Providing a color graphics display in order to be user friendly, this system monitors the flight recorder data for failures or errors. Once the system is complete, it will replace a data communications officer.

Real time data systems have resulted in other dramatically new capabilities. For example, by acquiring real time telemetry, these systems permit an animated view of the position of the Space Shuttle's Remote Manipulator System. Flight controllers who monitored the Remote Manipulator System traditionally had to determine the position of the robot arm by observing digital readouts of the angles of each of the arms joints. A combination of off line tools and mental gymnastics allowed operators to ascertain the arm's position. The new data system not only lowers the flight controller's workload but also allows the controller to view and thus prevent collisions between the Shuttle and payloads.

Advances were also made in the automated assembly of large space structures. This program focused on the actual automated assembly of a generic structural truss that is the basic element for both observation antenna and aerobrake configurations. Proposed space missions, both to and from Earth, require large structures to provide stiff and stable platforms for experimental measurements. This program conducted robotics research with the goal of making the construction of these platforms both practical and cost effective. In FY 1991, complete assembly and disassembly of a 102-member truss took place in a supervised autonomy, computer control mode. The reliability of the system was good and the test monitor was successful in correcting most operational errors. Operations have now been expanded to include the assembly of panels that are removed from a canister by the robot and attached to the truss during assembly.

University Space Research

In April 1988, NASA's Office of Aeronautics and Space Technology announced the competitive selection of nine University Space Engineering Research Centers. These university centers have supported NASA's goal of broadening the nation's engineering capability in order to meet the critical needs of the civilian space program. As stated in the August 1987 program notice, "these centers are expected to perform research and to develop technologies relevant to operational bases on the moon, to manned and unmanned operations to Mars, to space flight missions to other parts of the solar system, and to space flight operations in the future, such as envisioned by the National Commission on Space."

The centers foster creative and innovative concepts for future space systems while conducting focused research in one or more of the traditional space engineering disciplines and in cross disciplinary combinations. This effort enhances engineering education by directly involving students in space engineering research tied to future NASA mission needs. The centers promote the teamwork that technological systems problems demand and bring individuals from a wide range of engineering and scientific fields into a single research structure.

In FY 1991 the centers have already shown exciting technical and educational benefits. For example, the Mars Mission Research Center at North Carolina State University and North Carolina A&T University combined fragile carbon fibers with hardened resin to create strong, lightweight, damage-tolerant, heat resistant materials that may one day be used in the construction of a spacecraft for a mission to Mars. These materials, known as composites, are made by combining two or more elements to yield a final product that is much stronger than its parts. Using a technique known as three dimensional braiding and weaving, students are employing high tech fibers to make beams and cylinders for use as components in future heat shields and aerobrakes.

A team of faculty members and graduate students at the University of Cincinnati, meanwhile, was developing a series of microsensors to indicate the health of spacefaring vehicles. Since they fly into space repeatedly, being able to determine the condition of Shuttle components like the main engines is critical. These devices could monitor gas and liquid fuel flows inside a Shuttle engine and its associated support systems to ensure they are functioning properly. Advanced micromachining techniques make it possible to include valves, heaters, or even motors in a device with a diameter less than that of a human hair. The sensors are so small that even if one came loose, it would be like a speck of dust, having negligible impact on engine performance.

The potential spin-off applications of this technology are limitless. Researchers at the University of Cincinnati's Medical Center were already exploring their use in the care of premature infants as the year ended. A significant number of these infants suffer respiratory disorders. Many have to be connected to a ventilator around the clock. But setting the controls on the ventilator remains a relatively imprecise science. Improper oxygen levels and pressures can contribute to more severe problems, such as mental retardation. Researchers were thus studying the possibility of putting a microsensor inside the plastic tube inserted in a baby's trachea. Their work to date indicates that these microsensors can produce the information needed to improve premature infant care.

In-Space Technology Experiments Program

NASA's partnership with the university community also passed a major milestone when the first university flight experiment supported by the In-Space Technology Experiments Program flew aboard the Space Shuttle in September, 1991. Known as MODE for Mid-deck 0-gravity Dynamics Experiment, the project, developed by students and faculty at MIT, flight tested the influence of zero-gravity on the sloshing behavior of fluid in a tank and the vibration characteristics of truss structures in space. This experiment will help the Agency develop technologies that will compensate for the vibrations platforms encounter in space. The truss structure contained various components including a model of the Space Station solar array support structure. Astronauts used a device to excite vibrations within the structure as it floated in the Shuttle's middeck cabin. The knowledge gained from this experiment will be applicable to Space Station Freedom.

Another advance for the In-Space Technology Experiment program took place when the Tank Pressure Control Experiment rode aboard Atlantis on STS-43 in July 1991. This project demonstrated how cryogenic storage tank pressures can be controlled by actively mixing the fluids to eliminate temperature stratification. Transfer and control of very cold (cryogenic) fluids in microgravity for propulsion or power purposes is critical to plans for several future space efforts. The technology would allow lightweight cryogenic tanks to be used in advanced space projects, thus saving weight for additional payloads.

Integrated Technology Plan

The Advisory Committee on the Future of the U.S. Space Program, chaired by Mr. Norman Augustine, recommended in its final report that an Agencywide technology plan be developed by NASA with inputs from the associate administrators responsible for the major developmental programs. The recommendation was based on the analysis that "NASA has not been permitted to sustain an adequate level-of-effort program in space technology due in recent years to externally imposed budget reductions." In response to this recommendation, NASA's Office of Aeronautics and Space Technology has developed an Integrated Technology Plan (ITP) for the civil space program that entails substantial changes in the processes, structure, and the content of NASA's Space Research and Technology program. This plan will provide strategic direction for the space technology program. The major aspects of the planning process include employing a technology user driven process to establish program content, using well defined decision rules and evaluation criteria to establish program priorities, and creating an annual cycle for Space Research and Technology program planning, involving both user office participation and external review of proposed plans.

The ultimate measure of success in the Space Research and Technology program is the incorporation of a technology into an operational mission. The evolution of a technology from proof-of-concept, through validation in successively more realistic environments, to eventual development can be a complex and time-consuming process. The objective of the Space Research and Technology program is to facilitate this process and minimize the time required. Involving the technology "users" as early as possible in technology development is critical to achieving this goal. The Integrated Technology Plan focused on facilitating this involvement at the critical phases of technology development. Concurrent participation by technologists and mission developers in the selection and maturation of technologies should lead to a level of understanding and a sense of ownership that will improve all aspects of technology development and transition. In this way, all our future national space endeavors will be enhanced by an investment in NASA space research and technology.

Exploration of the Moon and Mars

During 1991, the Space Exploration Directorate made significant progress toward developing a strategy for planning and implementing the Space Exploration Initiative (SEI), President Bush's challenge to establish a permanent outpost on the Moon and explore Mars.

Synthesis Report

The Synthesis Group, an independent panel of government, industry, and academic experts chaired by former astronaut Lt. Gen. Thomas P. Stafford, USAF (Ret.), was established to assess and distill the results of the nationwide Outreach Program conducted in 1990. The Outreach Program solicited innovative ideas for lunar and Mars exploration from universities, industry, professional societies, Federal agencies, and the general public. Over 2,200 ideas reached the Synthesis Group. In June 1991, it released its report, "America at the Threshold," which made several recommendations for lunar and Mars exploration and outlined six exploration "visions" that formed the foundation for subsequent technical and programmatic recommendations. It also added to the body of policies and goals guiding the development of SEI. The six visions are to:

> Increase our knowledge of the Solar System and beyond;
>
> Rejuvenate interest in science and engineering;
>
> Refocus U.S. position in world leadership;
>
> Develop technology with terrestrial application;
>
> Facilitate further space exploration and commercialization; and
>
> Boost the U.S. economy.

In addition, the report identified over a dozen key technologies, ranging from nuclear propulsion to advanced life support systems, that would be required to achieve the nation's goals in space. The Synthesis Group also developed four explorational architectures—each a mixture of rationale, objectives, and technical approach—that should be considered as options for future explorational activities.

> Mars Exploration—The major objective of this architectural option was the first human exploration of Mars. The object of this exploration would be to address major scientific questions, including whether there was ever life on Mars. The emphasis of activities performed on the Moon would be preparation for the Mars missions, for example testing

surface power system technologies and life-support systems.

Science Emphasis for the Moon and Mars—This option features a range of scientific activities on both the Moon and Mars. Lunar science would include the installation of astronomical observatories, studies of lunar geology, and observations of the Earth's atmosphere. Scientific activities on Mars, in addition to addressing the question of past life on the planet, would include geology, climatology, and comparative studies designed to increase human understanding of our own planet, Earth, and its behavior.

The Moon-to-Stay and Mars Exploration—Here, the focus was on a permanent human outpost on the Moon, followed by missions to Mars. In addition to all of the scientific activities previously mentioned, a continuing presence on the lunar surface would enable us to conduct extensive biological and manufacturing studies in low gravity environments, as well as to assess the potential for using lunar and Martian resources.

Space Resource Utilization—This option emphasizes the use of natural resources found on the Moon and Mars. Such resources could be used locally to support subsequent exploration, for example the production of oxygen for life support and propellant, or for use on Earth, for example mining lunar Helium 3, a potential fuel for fusion reactors. This architecture might also include networks of satellites to collect and transmit solar power to Earth receiving stations, as well as missions to asteroids for purposes of mining their resources.

Strategy and Technical Studies

To provide a context for the Synthesis Report and lend coherence to space exploration efforts at NASA and other Federal agencies including the DOD and DOE, NASA developed a long term strategy for planning and implementing national exploration goals. Near term activities will focus on detailed analyses of architectural options with the goal of providing the President with recommendations for the first exploration "waypoint" or goal. This will be a significant technical and programmatic achievement in its own right, accompanied by identifiable benefits for exploration while maintaining maximum flexibility for planning and implementing future explorational missions.

The technical challenges associated with exploration, particularly human trips to Mars, are immense. In 1991, technical studies and analyses continued, building on past studies by NASA's Space Exploration Directorate (formerly the Office of Exploration). These studies focused on mission design, trajectory analysis, systems concepts, and implications for research and technology of lunar and Mars exploration. By conducting these types of studies, the Space Exploration Directorate could more effectively work with other NASA program offices, other Federal agencies, and industry to define exploration requirements and formulate an action plan that takes advantage of each group's unique capabilities, making the best use of limited resources available to meet the nation's exploration goals.

Interagency Cooperation

As a result of such studies, in 1991 NASA and the DOD signed a memorandum of understanding specifying those agencies' respective roles in the development of SEI. NASA and the National Science Foundation also signed a memorandum of agreement covering potential research activities in Antarctica that would benefit future SEI missions. Potential Antarctic analog activities include research into the effects of long-duration isolation and the conduct of scientific investigations in hostile environments. These new agreements build on the MOU signed by NASA and DOE in 1990.

Making Space Exploration Responsive to National Needs

In 1991, the Space Exploration Directorate made significant strides toward reaping early benefit from space exploration activities, particularly in the area of education. The highlight of the year's activities was the Education Strategy Planning Conference, held in June 1991 at the Johnson Space Center. NASA representatives from the Space Exploration Directorate and the Educational Affairs Division met in Houston with educators and representatives of industry to discuss strategies for maximizing the benefits of exploration for all levels of the educational system from kindergarten through postdoctoral study.

The primary objectives of the conference were to identify the ways in which space exploration in general, and SEI in particular, could contribute to meeting our national educational goals and to discuss the tools and mechanisms by which these contributions could be realized. In addition, the conference led to the establishment of an educational network for the Space Exploration Initiative, designed to foster future partnerships among academia, industry, and government.

Work also began in 1991 to enhance the benefits of SEI to the U.S. economy. The Space Exploration Directorate has been working with NASA's Industry Relations Division and the Office of Commercial Programs in this area. Preliminary efforts were focused on encouraging timely transfer of technology through government-industry-academia partnerships in SEI-related research and development programs.

Space Activities

Space Launch

Shuttle. The NASA Shuttle continued to support the DOD in Fiscal Year 1991 with a total of three launches. On November 15, 1990, STS-38 successfully launched a classified payload. Shuttle mission STS-39 lifted off on April 28, 1991 and carried the Air Force Space Test Program 1, P-675, and the Infrared Background Signature Survey (IBSS). On June 5, 1991, STS-40 launched the SLS-1 and successfully deployed it.

Titan. In FY 1991, the U.S. Air Force successfully launched two Titan IVs, including the first from Vandenberg Air Force Base (AFB), CA. Because of a reduction in satellite launch requirements, the Titan IV program was restructured in FY 1991. This restructure included the cancellation of another launch pad—Space Launch Complex 6 (SLC-6) at Vandenberg—and a slowdown in the production rate. At the end of FY 1991, two launch pads were in operation, one on each coast. A third pad was being constructed at Cape Canaveral Air Force Station (CCAFS), FL. When it is completed in 1993, the USAF will have the capability to launch up to six Titan IVs per year from Cape Canaveral and two from Vandenberg.

Medium Launch Vehicles

In FY 1991, the Air Force launched three Delta II carrying NAVSTAR Global Positioning System (GPS) satellites, in addition to providing launch support for four commercial launches. The Atlas II launch system was in development to meet the needs of the Defense Satellite Communication System (DSCS). The first Atlas II launch vehicle was brought to the new stand at SLC-36 at CCAFS, FL. At Vandenberg AFB, two Atlas E vehicles launched in support of the Defense Meteorological Satellite Program (DMSP) and the National Oceanic and Atmospheric Administration.

Small Launch Vehicle

Pegasus. The Pegasus booster is a 3-stage, solid-propellant, inertially-guided, winged launch vehicle. A conventional transport or bomber class aircraft carries it aloft to an altitude of about 40,000 feet where ignition of its first-stage motor occurs. The Defense Advanced Research Project Agency (DARPA) conducted the second successful test flight of the Pegasus air launched space booster on July 17, 1991. The launch mission placed seven small Ultra High Frequency (UHF) communications satellites, known as Microsats, into low earth orbit. DARPA developed these satellites under the LightSat initiative. The Armed Services will demonstrate them in military exercises. The Flight 2 Pegasus booster incorporated several enhancements, including a new monopropellant liquid for the stage known as Hydrazine Auxiliary Propulsion System (HAPS), weight saving modifications to the Flight Termination System, and the first ever experimental application of a Global Positioning System receiver on a launch vehicle. The incorporation of GPS for aided navigation (to complement the inertial navigation system), together with the HAPS liquid motor upper stage, will provide a precision orbit injection capability for future defense space missions. Knowledge and experience gained in DARPA's first two successful test flights of Pegasus was undergoing technical review at year's end, while the transition of this new state-of-the-art booster to the USAF was proceeding. The USAF awarded the Small Launch Vehicle contract to Orbital Sciences Corporation on June 4, 1991. That company offered an improved Pegasus capable of delivering 459 pounds to a 400 nautical mile circular orbit with a 90 degree injection.

Taurus. Progress in the development of the mobile Taurus, or Standard Small Launch Vehicle, continued this year. The Taurus is designed to be launched from unimproved areas and is expected to deliver a minimum payload of 1,900 pounds to a 400 nautical mile orbit. The Taurus Critical Design Review has recently been conducted, range coordination was continuing, and test firings were scheduled beginning in February 1992.

Future Launch Systems

New Launch System. In FY 1991, the USAF and NASA formulated the New Launch System (NLS) program. This program combines elements of the previous USAF Advanced Launch System program and NASA's Heavy Lift Cargo Vehicle program. Together, the USAF and NASA have devised an evolutionary approach to satisfying the nation's space launch requirements in the next century. The NLS program will develop a modular family of three expendable launch vehicles and the attendant infrastructure. The family of vehicles will share many components and parts, especially the Space Transportation Main Engine (STME). The STME is a 600,000 pound thrust class, liquid hydrogen/oxygen engine that is on the critical path for the program development. With the addition of this system in the next century, the DOD will have a fully operational, low-cost, and responsive space launch system for the nation.

SEALAR. The Navy was continuing its research on low cost, responsive, and flexible launch concepts with the system called SEALAR (Sea Launch and Recovery). The plan for SEALAR calls for the design of a fully reusable, two stage vehicle in order to achieve its low-cost goals. The at sea launch and recovery will provide a level of responsiveness, flexibility, and environmental acceptability that is very attractive; a small scale version of the SEALAR booster was being built as part of the Research and Development (R&D) program. During FY 1991, essentially all of the subsystems of the vehicle and its sea based support system were completed including tanks, engine assembly, pressurization system, avionics, recovery system, barge modification, and a ballast system. Integration and testing of these subsystems were occurring on a schedule that will result in a series of launches, recoveries, and relaunches starting in the spring of 1992. Because a low cost launch system would have great commercial potential, the Navy was studying a Cooperative Research and Development Agreement to transition this technology to the U.S. commercial sector, consistent with, and encouraged by, the National Commercial Space Policy.

Commercial Launch Activities. The Department of Defense continued to support the fledgling American commercial space launch industry in a number of ways. The Air Force space launch centers at Patrick and Vandenberg Air Force Bases have supported commercial programs with government supplied services, facilities, and expertise on a direct cost basis. Commercial space launch services are part of the Navy's Ultra High Frequency (UHF) follow-on program. The Navy has entered into a memorandum of agreement with Space Science Incorporated of America to conduct four sounding rocket flights at the Naval Ordnance Test Station, White Sands, NM. One launch was scheduled for FY 1992.

Space Operations

To support the growth in numbers of DOD and NASA space assets, the Air Force Satellite Control Network (AFSCN) was transitioning to its new command and control system, scheduled for full operational turnover in 1993. The new system is being installed at the Consolidated Space Test Center at Onizuka AFB, CA, to replace the current system and to provide dual-node interoperability. The command and control system was also being installed as the core for the new Consolidated Space Operations Center at Falcon AFB, CO. The AFSCN upgrade of its worldwide network of tracking stations started with a new automated remote tracking station at Falcon AFB in Colorado Springs, CO. Upgrading of all existing tracking stations will be completed by 1993.

Satellite Systems

Satellite on orbit mission capability improved, and data distribution to military users grew in volume and quality in FY 1991. This measure of merit for responsive DOD space operations has become increasingly relevant as research and development efforts in satellite survivability, mobile ground processing centers, and secure information distribution become integrated into the operational inventory. Following is the status of the various defense satellite programs as of the end of the year.

Defense Satellite Communications System (DSCS). The DSCS is the current long-haul, high-capacity communications system supporting worldwide command and control of U.S. armed forces. The system provided communications connectivity for: tactical warning and assessment information transfer; intelligence data transfer to processing segments from remote locations as well as overhead intelligence platforms; missile warning conference; survivable emergency action message dissemination to the launch control complexes; and command and control between the national command authority and all deployed military commanders. DSCS also supported other government agencies with wideband transmission connectivity. The DSCS was a five-satellite constellation with two reserves. On orbit satellites current at the end of FY 1991 were three DSCS IIIs located in the west Atlantic, east Atlantic, and east Pacific areas, and two DSCS IIs located in the west Pacific and Indian Ocean areas. The reserve satellites were one DSCS II and a DSCS III, launched in 1982. Three DSCS IIIs were scheduled for launch in 1992. The remaining stored satellites are scheduled for launch by 1997. The mean mission duration (MMD) of the DSCS II increased to 5 years on the final acquisition phase; however, some of these satellites continued to provide service beyond their MMD. The DSCS III had an MMD of 7 years and, while these satellites were far more complex than the DSCS IIs, they were expected to meet their MMD. The DSCS control segment provided semi-automated management of DSCS resources to maintain the satellite communications network in alignment with the needs of the operational commanders. Efforts continued to consolidate all DSCS operations centers under the Army Space Command. Contracts were also in place to move toward a contingency control capability in the period 1991-94. The DSCS ground segment consisted of a mix of strategic and tactical terminals. The strategic terminals ranged from small, 30 inch antennas supporting the National Emergency Airborne Command Post to fixed 60 foot antennas supporting major fixed facilities. The tactical terminals were ground mobile force equipment with 8 and 20 foot antennas, and Navy shipborne terminals equipped with 6 foot antennas.

In support of the Desert Shield/Desert Storm operations, the DSCS constellation and these terminals supported the tactical users of the DSCS and provided 95 percent of the inter-theater, long haul communications between the continental U.S., Saudi Arabia, and Iraq. In addition, DSCS provided over 80 percent of the intra-theater communications in support of the ground (tactical) mobile forces. To better support tactical ground mobile terminals during operations Desert Shield/Desert Storm, a DSCS II satellite was moved from the Indian Ocean satellite area by 109 degrees longitude between November 17 and December 19, 1991. Ultimately, this spacecraft, designated the Indian Ocean Reserve, supported the communications requirements of 48 terminals directly involved in the war-fighting requirements of the Commander-in-Chief, Central Command.

The strategic special users of DSCS enjoyed end-to-end, survivable communications connectivity. These users were equipped with anti-jam modems located at the ground terminals. Some of these modems have been modified to operate in both a jamming and nuclear-scintillated environment for the highest-priority critical users. These protected users were only accommodated on DSCS III satellites and assigned to specific channels in the satellites.

Milstar. Milstar, the cornerstone of the Department's MILSATCOM architecture, is a multichannel, EHF/UHF satellite communications system that will provide survivable, enduring, jam-resistant, and secure voice/data communications for the President, the Secretary of Defense, and the Commanders-in-Chief (CINCs) of the unified and specified commands, tactical and strategic forces, and other users. It will provide the worldwide command and control of U.S. strategic and tactical forces during all levels of conflict. The USAF is the lead service for the procurement of Milstar satellites, the dispersed mission control network, airborne terminals, and ground command post terminals. The Army and Navy also have terminal development and procurement programs.

During FY 1991 the program underwent a major restructure that will increase the tactical utility of the system and will decrease program life-cycle cost by approximately 25 percent. Major effects of the restructure include: (1) reduction of the satellite constellation by two satellites, (2) reduction of the number of mission control stations from 24 to 9, (3) reduction of the overall number of terminals from 1,721 to 1,467, (4) an increase in the number of Army tactical terminals from 330 to 607, and (5) the addition of a new medium-data-rate payload to the satellite with the terminal changes to optimize use of this 'significant' new capability.

In FY 1991 the first satellite achieved full integration and was in a period of intensive ground testing prior to an early 1990s launch. Fabrication of the second and third satellites continued. As part of the restructured program, the Air Force planned to start development in 1992 of a new, medium-data-rate payload that will be added to satellites beginning with satellite four. The terminal program continued in low-rate initial production of command post terminals. Major terminal milestones in FY 1991 included modification of a Strategic Air Command aircraft with a Milstar terminal and installation of a Strategic Air Command ground command-post terminal. The terminal program was preparing to initiate development of a compact terminal for bomber aircraft applications.

Navstar Global Positioning System. The Navstar Global Positioning System (GPS) is a space based radio-navigation system satisfying requirements for highly precise, worldwide, three- dimensional position, velocity, and timing data for military aircraft, ships, and ground personnel. The system consists of user, satellite, and control segments. The GPS satellites operate in inclined, semi-synchronous (i.e., 12 hour) orbits. At the end of FY 1991, GPS was still being deployed. When fully operational (1993), it will consist of a constellation of satellites that will provide continuous three-dimensional, worldwide coverage.

In 1991, approximately 64,000 DOD receiver terminals were on order or in use. The first two operational GPS satellites (Block IIA) launched during the year on Delta boosters. The control segment updates the satellite broadcasts, which provide positional accuracies to within 16 meters for military users and to 100 meters for civil users.

Initial deliveries of user equipment to all three armed services began in 1989. Installations were well along on many different ships and aircraft at the end of FY 1991. The then-existing mix of five developmental and eleven operational satellites provided worldwide, two-dimensional coverage at least 23 hours a day and worldwide, three-dimensional coverage at least 18 hours a day; the completed constellation of 24 satellites (21 active, 3 backups) will provide full-time, three-dimensional navigational information.

GPS was a key contributor to the success of Desert Shield/Desert Storm operations. As U.S. forces arrived in Saudi Arabia, they confirmed the fact that navigating in a featureless desert posed significant challenges. Because there were almost no man-made or natural features by which soldiers could confirm their positions, GPS served as the primary space-based navigation system.

GPS receivers were used throughout the theater, from navigating warships and tank columns to "locating the mess tent." GPS provided the grid coordinates for maps. The Air Force used GPS to guide aircraft to targets. At sea, GPS served to fix positions during mine clearing operations and to provide launch coordinates for GPS-equipped ships firing Tomahawk cruise missiles. The Army used GPS to maneuver units, keep them out of each other's fire, and fix positions of land mines. The Marines used GPS to set up artillery. Special Operations Forces employed GPS for many operations.

Because of immediate need for GPS receivers, U.S. and coalition forces were forced to rely on commercial equipment. Almost 90 percent of receivers used by U.S. forces were commercial, non-crypto capable. By March 1991, there were 4,490 commercial and 842 military GPS receivers deployed to the area of operations.

Defense Meteorological Satellite Program. In this program a third satellite, launched in December 1990, provided improved weather updates. The three-satellite Defense Meteorological Satellite Program (DMSP) provided timely, high quality, worldwide visible and infrared cloud imagery and other specialized meteorological, oceanographic, and solar geophysical data to support DOD strategic missions. DMSP also provided real time direct readout of local weather to ground- and ship-based tactical terminals supporting DOD forces worldwide. This system was particularly important during operations Desert Shield/Desert Storm. DMSP weather data provided real time support to the on-scene mission planners to direct the air war against Iraq. This was especially critical for proper employment of smart weapons. To meet urgent needs of mobile forces, the DMSP program procured six Rapid Deployable Imagery Terminals to get DMSP data real time to the mobile forces in-theater.

DMSP imagery significantly enhanced military planning during Desert Shield/Desert Storm and enabled the successful execution of operations during the worst desert conditions the Army has faced in combat since World War II in North Africa.

Defense Support Program. An upgraded Defense Support Program (DSP) satellite (DSP-I), the second in the series, launched in November 1990 on a Titan IV space launch vehicle. DSP-I will provide DOD with enhanced missile warning and surveillance capabilities and will include a second-color focal plane array and mission data message broadcast. The program's endurability/ survivability is provided by its mobile ground processing system, geosynchronous orbit, and satellite characteristics. In FY 1991, the DSP supported operations Desert Shield/Desert Storm by detecting Iraqi Scud missile launches and providing warning data to allied forces. Air Force planning was under way as the year ended for a DSP follow-on threat warning/attack assessment system, which will enter the demonstration/validation phase in FY 1992.

Space Technology

Hardened Space Electronics Program. The radiation-hardened electronics program of the Defense Nuclear Agency (DNA) has successfully demonstrated the design, fabrication, and technology transfer of very-large-scale integrated (VLSI) circuits. Significant progress in this advanced VLSI technology included the demonstration of a 256-kilobit static random access memory (SRAM) fabricated on advanced silicon-on-insulator material. During 1991, development of radiation-hard, one-million-bit SRAMs began. These SRAM devices, used in all space based computer systems, are immune to the degrading effects of trapped, high energy charged particles and random erroneous computer states caused by cosmic rays. The use of hardened electronics eliminates the need to remove power from space systems as they pass through the radiation belts.

In addition, hardened, power integrated circuits are considered essential components in advanced space systems. The DNA demonstrated high power integrated circuits that are immune to circuit burnout and gate rupture from high energy particles and cosmic rays. It also evaluated hard fiber-optic links to these power circuits. Progress has also been made in the transfer of immune-electronics technology to space systems through the joint DNA/NASA hardness assurance working group. The development of radiation test facilities, uniform test methods, and radiation test standards has increased the application of advanced electronics in space systems. For example, space systems such as Galileo, Voyager, TIROS-N, GPS, DMSP, and Mars Probe have employed hardened electronic circuits.

DARPA's Advanced Technology Initiatives. The major theme in DARPA's Advanced Space Technology Program (ASTP) has been the development of leading technologies to enhance the performance, capabilities, survivability, and accessibility of military space systems while simultaneously minimizing the size, weight, cost, and power consumption of these systems. The generic space technologies being pursued by DARPA will be applicable to both large and small defense satellites, and additionally they may benefit other sectors of government space endeavors (SDI, Earth Observing System, etc.) as well as strengthening our nation's commercial space sector. DARPA's significant accomplishments this year included technologies and studies to support the military satellite communications (MILSATCOM) architecture. DARPA developed a Dual Common Bus architecture with the objective of demonstrating the flexibility and cost-effectiveness of architectures that integrate both large and smaller satellites working in unison.

DARPA's efforts also focused on the critical Extremely High Frequency (EHF) satellite-communication area with an off-site meeting that gathered all the players to lay out the EHF technology program for the future as part of the Department's MILSATCOM architecture. This effort exploits enabling technology developments contained within ASTP's advanced technology initiatives.

Among other technology areas, the inflatable Torus Solar Array Technology project was yielding up to one-third more watts per kilogram than current arrays, with potential for even better performance. A Small Business Innovative Research (SBIR) project has determined a method of heat dissipation that can yield up to 200 percent improvement over current techniques. Spacecraft platform stability can be significantly enhanced through techniques developed as part of the ASTP's advanced technology initiatives. The Lightweight Reaction Wheel project was exceeding expectations by being able to rotate faster with less drag, thereby improving platform stability. A space-qualified miniature GPS receiver was scheduled to fly on several satellites in the next several years, giving them increased position accuracy.

Developments in the laser and laser filter area yielded promising results. An order of magnitude improvement occurred in filter efficiency with the cesium atomic resonance filter. It attained nearly 50 percent throughput, which would benefit satellite communications.

LightSat Initiative. The two store and forward UHF Multiple Access Communications Satellites (MACSATs) launched by DARPA in May 1990 were extensively exercised during their first year on orbit. These satellites provide global relay of messages, data, facsimile, and graphics. Most notably, these R&D satellites (originally intended solely for demonstrations in conjunction with military tactical exercises) served successfully in daily support of the 2nd Marine Aircraft Wing during Operations Desert Shield/Desert Storm. In addition to this major activity, which spanned the period August 1990 through April 1991, the MACSATs demonstrated their capabilities in a number of military exercises, including operations to recover data from unattended sensors and to deliver command information to those sensors plus support provided in remote regions of the Antarctic.

The launch of the Microsat constellation by the Pegasus on July 17, 1991, completed DARPA's first generation LightSat demonstration system. The seven Microsats then available provided radio relay service in the military UHF band, as well as limited capacity store and forward capability. Though small in size (7.5 inches high by 19 inches in diameter) and weight (less than 50 pounds), the Microsat is nonetheless a sophisticated small satellite featuring both analog and digital regenerative transponder capabilities, an all digital, fully autonomous attitude control system, and a miniature propulsion system for on orbit maneuvering. The armed services have employed the Microsats in applications such as ship to shore communications.

Laser Communications System. In FY 1991 DARPA conducted a successful field demonstration of the Laser Communication System technology, which could eventually be used for satellite-submarine communication. Specifically, the demonstrations included: the first medium power, diode-array-pumped, prime power efficient solid-state laser; over 33 million pulses from a solid-state laser without measurable energy degradation; a projected solid-state diode-array lifetime of greater than 10^{11} pulses; the first submarine-safe certified laser; a submarine-safe certified optical hull penetrator; the first two-way laser communications between an airplane and a submerged submarine; an initial assessment of link covertness; and the first submarine-initiated communications link. The completed field experiment and its associated technology demonstrations were an important step in establishing the feasibility of affordable, covert tactical submarine communications at reasonable depths and speeds.

Other Space Communications Applications. The Army's technology base efforts in exploiting space technology began to mature in FY 1991 and provided important contributions to the military success in Operations Desert Storm/Desert Shield. A space communications capability was pulled out of the technology base arena and "patched" into existing networks to provide early warning to the Patriot launch sites with a 3-4 minute warning prior to impact. Computer work stations developed to process commercial multi-spectral imagery from LANDSAT and SPOT were used extensively by Topographic Engineer Battalions deployed to Saudi Arabia. Technologies provided to Army units under the Army Space Exploitation Demonstration Program, such as Wrasse receivers (weather) and Global Positioning System (positioning), were used extensively by the Army during Desert Storm/Desert Shield.

Space Control

Kinetic Energy Anti-Satellite Weapon System. The Kinetic Energy Anti-Satellite (KE ASAT) Program is an effort to develop a near-term, surface-launched weapon system capable of non-explosive neutralization of satellites. The KE ASAT program is part of a national ASAT capability to include space- and ground-based surveillance sensors, battle management/command, control and communications elements, and both kinetic and, ultimately, advanced technology weapons, including directed energy.

In FY 1991, the KE ASAT program was restructured based on DOD budget reductions that resulted from an FY 1992 Secretary of Defense program review. Demonstration/validation activities in FY 1991 included a Systems Requirement Review, a continued technical risk reduction program including Weapons Control System prototype and booster optimization design review, and component tests to support resolution of engineering issues. A Joint Cost Operational Effectiveness Analysis started to address the overall KE ASAT system during the year.

As a complement to KE ASAT, the Army was continuing Directed Energy (DE) ASAT research and development to support U.S. Space Command's mission needs. The DE ASAT program also had to be refocused due to funding reduction to the Ground Based Free Electron Laser system. The High Energy Laser Test Facility completed a full aperture upgrade to the Mid-Infrared Advanced Chemical Laser/Sea-Lite Beam Director system. Research and development tests against terrestrial objects were successful, and the system may have a limited near term contingency capability to complement the KE ASAT system.

Strategic Defense Initiative. During the last year the Strategic Defense Initiative Organization (SDIO) performed vigorous research on the technology required to develop the Global Protection Against Limited Strike (GPALS) system and for potential follow-on systems. SDIO advances in astronautics and space involved the following five areas:

(1) ***Sensor Technology and Phenomenology***, where significant progress occurred in the detection, discrimination, acquisition, and tracking of targets. During 1990, two successful sounding rocket experiments showed that laser radars can be used for discrimination of targets up to 1,000 miles away. The Firepond laser radar performed precision measurements of deployment dynamics, images, and ranging of inflatable decoy targets launched from Wallops Island, Virginia and viewed at an 800-kilometer range. In the beam control area of component development, the program demonstrated an innovative, lightweight, mechanical system capable of assessing 50 targets per second. Additionally, several experiments improved our understanding of detection and discrimination of targets in space.

The Infrared Background Signature Survey (IBSS) and the Cryogenic Infrared Radiance Instrumentation for Shuttle (CIRRIS) were successfully launched during 1991, to observe and characterize the spectral and radiometric signatures of several space objects and natural phenomena. In the IBSS experiments, measurements of firings of the Shuttle main engines gathered data on the optical signature of rocket plumes. IBSS also measured the interaction of four neutral gases with the plasma and characterized the environment around the Shuttle payload bay. CIRRIS collected infrared background signatures of the earth's surface and atmosphere during the 1 week Shuttle mission. The IBSS and CIRRIS data combined with the data from the Space Infrared Imaging Telescope II Experiment provided the specific bands and processing techniques to limit the impact of the natural background on target acquisition.

Two experiments involved a STRYPI three-stage sounding rocket. The first experiment measured the successful acquisition, tracking, and imaging of ultraviolet (UV) rocket plumes from STRYPI thrusting boost segments. The UV Plume Instrument onboard the Low Power Atmospheric Compensation Experiment satellite provided the imaging. A second onboard experiment measured the intensity of UV emissions in the rocket plume and the aerodynamic bow shocks surrounding the vehicle.

During 1991, SDIO integrated the long-wavelength infrared (LWIR) focal plane arrays, optics, and on-array processors into the LWIR Advanced Technology Seeker to provide enhanced detection, tracking, and discrimination throughout all phases of flight for both ground- and space-based systems.

Also during 1991, SDIO conducted the ZEST flight test. During this experiment, tungsten dust was released 200 miles above the earth to investigate alterations of a sensor's field of view caused by cloud cover and to determine the ability of space-based sensors to locate objects flying through the cloud-like formations.

In 1991, SDIO calibrated data from the April 1990 launch of the EXCEDE III experiment and began its evaluation. This two- part rocket experiment excited the atmosphere with an electron beam while observing optical emissions in ultraviolet through infrared wavebands. Preliminary results confirmed some of our understanding of nuclear effects on the upper atmosphere, but they also identified significant and surprising anomalies. Analysis of data was continuing at the end of the year.

(2) ***Interceptor Technology***, where the Ground Based Interceptor (GBI) was developing and testing kinetic kill vehicles to intercept ICBM warheads in the exoatmosphere. In January 1991, GBI successfully intercepted a warhead in the presence of decoys with the Exoatmospheric Reentry Vehicle Interceptor Subsystem. GBI tests were planned through the end of 1991.

During the summer of 1991, SDIO and the U.S. Air Force Systems Command successfully completed the hover test of the highest performance kill vehicle yet developed for the SDIO's Lightweight Exo-Atmospheric Projectile (LEAP III) program. The half-meter long, 22-pound LEAP III flew as planned for 17 seconds with LEAP's high speed, on board computer in full control of the test flight. The projectile was propelled from its launch cradle to a height of approximately 13 feet within 1 second and held steady for five seconds. During this flight the LEAP's infrared sensor viewed a simulated missile plume target more than 100 meters away. The projectile then performed lateral movements with its high performance lightweight thrusters for 8 seconds, simulating the 5 g maneuvers it will need to execute to "leap" in front of the target during actual space engagements.

The second Brilliant Pebble flight experiment in April 1991 deployed a payload consisting of sensors, a computer processor, and an attitude control system at an altitude of 100 miles. The experiment successfully demonstrated the sensor's ability to acquire and track the solid rocket booster, do star tracking, and perform a series of attitude control maneuvers.

In the area of interceptor avionics technology, a high throughput, high density signal processing packaging design (SPPD) brassboard went through design, fabrication, and testing in FY 1991. This new SPPD weighs less than 75 grams in a volume less than 75 cm^3 with a throughput greater than 100 million operations per second. This SPPD represents a reduction in mass by a factor of 30 and an increased processor throughput by more than a factor of four over the existing technology. This new SPPD is now integrated with a micro-mechanical inertial guidance system with a weight of less than 30 grams to develop an advanced stellar navigation sensor.

(3) ***Simulation, Modeling, and Battle Management***, in which the SDIO has continued to be successful in integrating human resources with man-in-the-loop control in the development of the National Test Bed (NTB), a network of geographically distributed test facilities; connecting nodes of the Army, Air Force, and Navy; and national laboratories. The National Test Facility (NTF) serves as the operational hub of this integrated system of satellites and ground linked test facilities. In 1990 SDIO established a super computer at the NTF to perform modeling of U.S. Space Command's command operations. The NTB has successfully enhanced system simulation with increased level of details in tracking and correlation computations during simulation.

(4) ***Power and Power Conditioning***, in which design and testing of two survivable solar power subsystem demonstrators, called SUPER, met performance requirements and survivability specifications. To reduce battery mass for the SUPER program, a 16-cell sodium sulfur battery was completed. Experimental low-earth-orbit cells have been life-tested through approximately 4,000 charge/discharge cycles. The present test now includes 42 sodium sulfur battery cells.

Life cycle testing of thermionic fuel elements (TFEs) indicate a potential for a 7 year operational life for a multi-unit TFE to be used in a thermionic nuclear reactor. New thermionic reactor system technology was being developed as an alternate reactor project. Arrangements were being made as the year ended to purchase an unfueled Soviet TOPAZ II class reactor and test facilities for non-nuclear testing.

During 1991, SDIO continued one of the more innovative technologies embodied in the Space Power Experiment Aboard Rocket (SPEAR) program. The SPEAR program examines the use of low Earth orbit (LEO) space "vacuum" for electrical insulation. After a successful test in 1987 exposing two spheres charged to 44,000 volts in the LEO environment in a suborbital flight, SDIO tested the actual operation of a high voltage system in the order of 100,000 volts and a high current system of 500,000 amps using the simulated space vacuum to insulate the conductors. At the end of the year, design guidelines for the operation of electrical components (batteries, capacitors, transformers, switches, pulse forming network, etc.) were being documented and developed as proposed engineering guidelines for future SDI space system designers. This innovative insulation technique has the potential for major reductions in both weight and volume of high power electrical components and could be useful for Space Station Freedom. Another positive feature is that the proposed insulation, the space vacuum, is automatically "replenished" and does not deteriorate with time, or arc, as do solid, liquid, and enclosed gas insulators. A contract for SPEAR III, awarded in April 1991, had the primary objective of comparing the effectiveness of different spacecraft grounding techniques as a function of altitude in the LEO region, attitude relative to the geomagnetic field, and voltage levels between the payload and the space plasma. Other objectives include characterizing solar cell performance in spacecraft charging/discharging environment and examining the role of effluents in the grounding process. SPEAR III was scheduled for launch in January 1993 from Wallops Island.

(5) ***Materials and Structures***, in which SDIO continued to develop improved spacecraft components by doing vigorous research in structural lightweight composites, space environment effects, optical materials, superconductive materials, and diamond films. The most

important contributions in the materials area during the last year were: (1) the demonstration of survivable thermal control coatings and atomic oxygen protective coatings during orbit, (2) the firing of a lightweight, low cost booster nozzle showing that the carbon-carbon composite technology can be transitioned for advanced nozzle options, (3) the demonstration of superconducting Josephson-junction in analog-to-digital converters for infra-red (IR) focal plane array processing, which can be developed for improved target acquisition, tracking, and discrimination, (4) the fabrication of free-standing diamond-mask substrates for x-ray lithography, which has both a tremendous commercial and military market potential, and (5) the discovery of a new solid propellant oxidizer, ammonium dinitramide that, compared to conventional ammonium perchlorate propellant, has a higher specific impulse, is environmentally cleaner, and is not detonable.

In the material area, the program developed and was evaluating a housing for the LEAP hover test made of advanced thermoplastic composite materials. Finally, plans were proceeding in the development of the Space Active Materials Modular Experiments to provide an industry standard module for materials testing in the space environment.

Aeronautical Activities

Aircraft Programs

B-1B. During 1990-1991 the B-1B continued to improve on its capabilities. With the exception of the defensive avionics suite, the aircraft has achieved all of its baseline requirements, including the ability to fly low level at high subsonic speeds both at night and in weather. With regard to the defensive avionics, in February 1991 the B-1B successfully completed the ALQ-161 "core" flight test. The system demonstrated it will significantly improve the maintainability of the ALQ-161 system.

The B-1B successfully demonstrated its capability as a conventional bombing platform in July 1991. At that time, follow-on test and evaluation of the conventional capability with the Mk-82, 500 pound bomb was completed. During this test, the aircraft dropped eighty-four Mk-82s with an accuracy that was well within its specifications.

Air Force and contractor personnel discovered and solved a potentially serious engine problem in early 1991. There had been a problem with retention of the first-stage fan blades when one failed. The problem lay in the strength of the retainer ring that holds the blades in place. A team of Air Force and contractor personnel identified and solved the problem in less than 4 months at a minimal cost.

B-2 Advanced Technology Bomber. Throughout this year, the B-2 continued to make steady progress in its flight test program. Two more aircraft have joined the flight test team at Edwards Air Force Base, and by the end of the year the team had more than 300 hours of flight test time behind it. The most interesting development thus far was the determination that the extensive pre-testing done on the program appears to have paid off. Nearly all of the aircraft's performance has mirrored the engineering predictions.

During 1991 flight tests explored over 90 percent of the operational envelope. The test team completed one lifetime on the durability and damage tolerance test aircraft with no significant problems, and the static test article completed over 50 percent of its testing.

The aircraft successfully passed its first block of low observable tests, again matching or exceeding predictions. Late in the summer of 1991, during the second block of low-observable testing, a low-observable anomaly appeared. Aircraft performance did not meet predictions in a very narrow band of radar energy. The problem was being worked and several potential solutions were being analyzed as the year ended.

Air Vehicle-3, the first full avionics aircraft, has demonstrated in flight both the radar and the navigation system. It has worked various modes of the radar and has updated the inertial navigation system with the radar. The 1,500 hours of airborne testing of the avionics in a C-135 flying test-bed aircraft has made this possible.

C-17. The Air Force's C-17 is a newly-designed, air refuelable, airlift aircraft with intercontinental range. It is capable of routine operations onto 3,000-foot runways and austere airfields as well as airland/airdrop delivery of outsize cargo. The program was in the Engineering Manufacturing and Development phase of its development. it received low-rate initial production approval on January 18, 1989. Major events in FY 1991 were the completion and assembly of the first test aircraft in December 1990 and the first flight from Long Beach, CA, to Edwards AFB, CA, on September 15, 1991, initiating the 2 year flight test program.

Advanced Tactical Fighter (ATF) - F-22. The F-22 program, previously known as the Advanced Tactical Fighter, was developing the next generation Air Force fighter. As the F-15 follow-on, the F-22 was designed to penetrate high threat enemy airspace and support the air-land-sea battle forces with "first look, first kill" capability against a technologically advanced, numerically superior enemy. The F-22's improved capabilities will be made possible by significant technological advances in the areas of signature reduction, aerodynamic design, flight controls, materials, propulsion, sensors, and integrated avionics.

The F-22 completed the demonstration/validation (Dem/Val) portion of its development in July 1991 and entered the next phase, Engineering Manufacturing and Development, on August 2, 1991. The F-22 Dem/Val program demonstrated combined stealth and maneuverability with four flying prototypes in over 150 flight hours. The program also demonstrated supercruise, the ability to fly at supersonic airspeeds using intermediate power settings. Two airborne flying avionics laboratories, flying over 100 sorties, demonstrated that the radar, electronic combat, communication, navigation, identification, and infrared search and track systems were conceptually correct and technically feasible. Avionics integration was accomplished, and over one million lines of Ada computer code were designed, coded, and tested. The F-22 program ensures air superiority in the future. The schedule in effect at the end of FY 1991 called for the purchase of 648 aircraft.

Light Helicopter - Comanche. The Light Helicopter program, recently designated the Reconnaissance Attack Helicopter-66 (RAH-66) "Comanche," is developing the next generation Army aerial scout/attack helicopter to counter worldwide threats in the late 1990s and beyond. The Comanche exploits advances in propulsion, materials, electronics, and sensor technologies to provide day and night target acquisition capability and a helicopter capable of operating in high altitude and hot temperature environments with a full design payload, a capability not now widely available to the Army. Additionally, the Comanche will incorporate low observable signature reduction and other survivability improvements, such as advanced composite armor, to improve the effectiveness and survivability in future battlefield environments significantly.

During FY 1991, the Army made major decisions on the program. On April 5, 1991, it selected Boeing/Sikorsky, the "First Team," to develop and produce the Comanche helicopter. Also, by the end of FY 1991 the T-800 engine, which was undergoing final qualification tests, had accumulated approximately 11,000 test hours.

In January 1992, the Commanche program was restructured. Because of threat changes and the interim capabilities provided by other aircraft, the development program was extended to provide three aircraft prototypes and full-up proof of principle for avionics, the upgraded T-800 engine, and the Longbow system. The extension will also resolve aircraft weight and engine issues.

Aeronautics Technology Development

Pilot's Associate Program. The Pilot's Associate program applied many of the technologies being developed under the DARPA Strategic Computing Program to aid pilots in making decisions in combat. The Pilot's Associate was designed as a knowledge based system to be embedded in future avionics systems, both for new production and for retrofit to existing aircraft. The specific technologies being developed and applied include artificial intelligence, automated planning, advanced man-machine interface, and the supporting computer technology necessary for their implementation. Technological advances would provide the pilot of a single-seat fighter aircraft assistance in the highly dynamic and demanding environment of aerial warfare. The program includes increasingly challenging demonstrations in advanced flight simulators representative of the fighter aircraft of the mid-1990s.

In 1991, the program demonstrated a functional prototype of a Pilot's Associate supporting the air-to-ground mission in an advanced F/A-18 fighter. This prototype primarily supported the pilot during preparation and execution of the target acquisition and attack phases of the mission. Progress has also continued on development of air-to-air versions of the Pilot's Associate. Initial design and architecture were completed, and software was developed.

Application studies, completed for the F-16 and F/A-18, identified near-term opportunity for transition of mission planning and display management functions. A similar study began to evaluate a multicrew associate application for a Special Operations Forces transport aircraft.

National Aero-Space Plane. The National Aero-Space Plane was a Presidentially directed, joint DOD and NASA program. The objective is to develop and demonstrate the enabling technologies for an entirely new generation of hypersonic flight vehicles including space launch vehicles capable of single-stage-to-orbit operations with horizontal takeoff and landing and aircraft capable of long range hypersonic cruise within the atmosphere. Subject to revision by the National Space Council as to cost and feasibility, the requisite technologies will be integrated into the design and fabrication of an experimental research aircraft, the X-30, for flight test and demonstration. These demonstrated technologies would then provide the basis for follow on military and civil vehicles capable of: global unrefueled operation, reaching any point on Earth in less than two hours; providing routine "on demand" access to space; reducing payload-to-orbit costs by at least an order of magnitude; and flexibly based, rapid response space launch. Such NASP-derived aerospace systems would provide a revolutionary increase in civil and military capability.

While the X-30 design was not yet firm at the end of FY 1991, the X-30 was envisioned to be a manned aerospacecraft powered by ramjet/supersonic-combustion ramjet engines that will be fueled by liquid or slush hydrogen. It will have auxiliary rocket engines for final orbit insertion and maneuvering during orbit. The vehicle structure will be manufactured from advanced high strength, lightweight, heat resistant materials, and critical portions of the structure will be actively cooled with the super-cold hydrogen fuel before it is burned in the engine.

The NASP program has made solid progress. Component hardware fabrication and ground tests have produced impressive results. Among recent accomplishments of the program, it:

Completed the first airborne test of the external burning drag reduction concept.

Tested a titanium matrix composite fuselage section with integrated carbon epoxy cryotank to 1,300 degrees Fahrenheit.

Tested a subscale integrated engine (inlet combustor and nozzle) at NASA's Langley Research Center.

Completed first and second design cycles of the National Contractor Team's selected X-30 configuration.

Defined lines for airframe aerodynamic wind tunnel models based on the selected X-30 configuration.

Advanced Fighter Technology Integration. The Advanced Fighter Technology Integration (AFTI/F-16) program continued evaluation of advanced-technology integration in support of aircraft with the air-to-surface attack mission. This Air Force/balanced technology initiative program completed aircraft modifications in FY 1991 to incorporate: head steered forward looking infrared, helmet mounted displays, night vision goggle-compatible lighting, data link, and multiple digital terrain data based systems (automatic terrain following, ground collision avoidance, threat avoidance, route replanning, and terrain aided navigation) required for safe day/night, all weather, low altitude combat mission accomplishment. The total integration and automation of these systems, coupled with color pilot vehicle interface displays, is required to provide single seat fighters with the desired kill and survive capability for the air to ground combat scenario. Flight test of these technologies started in July 1991, gathering data on several key system components including: radar altimeter, pilot activated recovery system, low altitude radar autopilot, all terrain ground collision avoidance, and silent attack radar altimeter. Further flight testing was planned for FY 1992 subject to availability of funds.

X-29 Advanced Technology Demonstrator. This unique aircraft has demonstrated the viability of forward swept, aero-elastically tailored, composite wings; successful digital control of a 35 percent statically unstable aircraft; and excellent stability and longitudinal control derived from the synergism of the integrated technologies. The aircraft has pitch pointed up to 67 degrees angle of attack (AOA) and maneuvered in all axes up to 45 degrees AOA. It has demonstrated superb roll-rate performance—70 degrees per second at 30 degrees AOA and 200 knots calibrated airspeed. The X-29 high AOA flight tests at Edwards AFB, CA, have also yielded a wealth of data regarding agility and military utility. The performance of the X-29 in a rolling scissors basic flight maneuver matched or exceeded the F-18's performance, with the loaded roll capability at high AOA giving the X-29 the advantage over the F-18. Several different guest pilots flew the X-29 in FY 1991 and all of them commented on the X-29's high AOA controllability and roll rate capability. The X-29 program has already transitioned technology with agility data being used by the Advanced Tactical Fighter program and the high-g simulation group at Armstrong Laboratory. Extensive tail-buffet data was being put into the data base for DOD-wide use. Plans for FY 1992 include using the X-29 aircraft as a test bed for the Vortex Flow Control critical experiment, which will provide valuable data to the Air Force Multirole Fighter and F-16 upgrade program.

F-15 Short Takeoff and Landing/Maneuver Technology Demon-strator. The Air Force's F-15 Short Takeoff and Landing/Maneuver Technology Demonstrator (STOL/MTD) is a highly modified F-15B design with enhanced maneuver capability and STOL performance. Aircraft modifications included: pitch-axis thrust-vectoring/thrust-reversing (TV/TR) engine exhaust nozzles, full-authority canards, integrated flight and propulsion controls, and rough-field landing gear. The result has been an aircraft with additional control in the pitch axis and improved up-and-away performance. It is designed to take off and land on a 1,500 foot icy runway during 30 knot crosswinds with no external, ground based landing aids. The first flight with all modifications (including the two-dimensional nozzles) took place on May 10, 1989. STOL/MTD accomplishments in FY 1991 included: successful short landings in crosswind/wet runway conditions; touchdown dispersion tests that validated the landing precision benefits of the STOL/MTD's control laws, which use reverser vane thrust modulation to decouple airspeed and pitch attitude on landing approach; a nozzle software revision that resulted in a program-best landing of 1,366 feet; inflight surveys of the infrared signature properties of the two-dimensional TV/TR nozzles and demonstration of their potential to reduce vulnerability to IR threats; an evaluation of thrust reverser jet interaction with ground effects for NASA Langley; and a night, short landing demonstration combining the autonomous landing guidance system and thrust reversing nozzles for the first time.

X-31A Enhanced Fighter Maneuverability. The X-31A Enhanced Fighter Maneuverability (EFM) program is a joint DARPA/Navy effort with Germany to develop an experimental aircraft to explore the technical and military implications of dynamic post-stall maneuvers for close-in aerial combat. The participants in the program have fabricated and checked out two unique, low-cost flight vehicles and were supporting the conventional envelope expansion as the year ended. Milestones achieved in FY 1991 included:

First flight (Aircraft #1)	October 11, 1990
(Aircraft #2)	January 19, 1991
Airworthiness test complete	January 23, 1991
First government pilot evaluation	May 3, 1991
Flutter testing complete	July 18, 1991
5 g load limit	July 26, 1991
Thrust vector vane calibration	August 14, 1991
Maximum conventional AOA (30 degrees)	September 19, 1991

Dynamic, post-stall flight testing will occur next year at NASA's Ames-Dryden Flight Research Facility. An international test organization (with NASA, Navy, Air Force, U.S., and German prime contractors and German government participation) will perform those activities. Following the demonstration of safe flight in the post-stall regime, the aircraft will begin the final flight test phase to assess the tactical utility of the EFM technologies.

Space Systems

Satellite Systems

The National Oceanic and Atmospheric Administration (NOAA), through its National Environmental Satellite, Data, and Information Service (NESDIS), continued to operate its polar-orbiting and geostationary spacecraft for remote sensing of Earth's environment, collection and relay of data from in situ observing platforms, search and rescue, and sensing of the space environment. In full operation, the polar-orbiting system consisted of two NOAA spacecraft, one each in sun-synchronous morning and afternoon orbits at a nominal height of 850 kilometers. The geostationary system, called GOES for Geostationary Operational Environmental Satellite, lost the older of its two satellites, GOES-West, in January 1989. The remaining GOES spacecraft was subsequently moved to a more centralized geographic position and continued to function normally as the year ended.

Instruments carried by the polar-orbiting spacecraft included a Television-and-Infrared-Operational-Satellite Operational Vertical Sounder (TOVS) for profiling atmospheric temperature and moisture from Earth's surface to the top of the atmosphere; an Advanced Very High Resolution Radiometer (AVHRR) to obtain visible and infrared imagery; an Earth Radiation Budget Experiment (ERBE); a Solar Background Ultra-Violet (SBUV) sensor for measuring ozone distribution and concentration; a Space Environment Monitor for observing near-Earth, charged-particle spectra; a Canada/France-provided search-and-rescue package to detect and locate emergency distress signals; and a France-provided Data Collection System (DCS) to collect, relay, and pinpoint observations sensed by moving and stationary platforms such as buoys, balloons, and wildlife.

The instrument complement on the GOES satellite included a Visible-and-Infrared-Spin-Scan-Radiometer Atmospheric Sounder (VAS) for visible and infrared imaging and sounding; a space environment monitor; a search-and-rescue package; and a DCS to collect and relay observations from fixed stations such as river gauges, tide gauges, and anchored and drifting buoys. The communications systems onboard the GOES were also used to broadcast a weather facsimile (WEFAX) service, consisting of satellite pictures, weather charts, and other environmental information to properly equipped ground stations in the Western Hemisphere.

NOAA Series. The NOAA-9, NOAA-10, and NOAA-11 satellites continued to provide a polar-orbiting service throughout FY 1991. NOAA-9, launched in December 1984, operated in a standby mode providing limited Earth Radiation Budget Experiment and Solar Background Ultra-Violet data. NOAA-10, launched in September 1986, had provided the primary morning orbit coverage but was replaced in that role in September 1991, following operational checkout of the newest polar satellite, NOAA-12. NOAA-11, launched in September 1988, provided the primary afternoon orbit coverage. Finally, NOAA-12 successfully launched on May 14, 1991.

A feasibility study for a future series of polar-orbiting satellites began in 1991 and was supplemented with preliminary design studies for upgraded and improved sensors and instruments later in the year. The next generation of polar satellites after NOAA-K/M (see below), will involve the sharing of common interface instruments on U.S. and European polar orbiters, with Europe providing a series of morning polar spacecraft and NOAA continuing its afternoon polar series. NOAA and NASA were also continuing discussions with European counterpart agencies to determine how these instruments would be integrated and how their data would be exchanged.

GOES Series. Two GOES spacecraft have usually been in service at any one time. Their combined views have provided coverage that extended westward from near Africa to beyond Hawaii. In the mid-1980s, a launch failure destroyed a GOES satellite; thus, in 1989 when the GOES spacecraft failed in orbit (after providing long service) there was no spare to replace it. Since that time, a single satellite, GOES-7, has been providing double duty. It is positioned at 108 degrees west longitude to better observe winter storms in season and moved to 98 degrees west longitude in summer to improve coverage of Atlantic hurricane regions.

A new series of five GOES satellites, designated GOES-I, -J, -K, -L, and -M respectively, was in development as the year ended. The Space Systems Division of the Loral Corporation continued their development after it purchased the Ford Aerospace and Communications

Corporation, the original contractor. Work on the first two spacecraft of the series included instrument fabrication and testing.

The GOES-I/M development program has experienced significant technical problems, schedule delays, and cost increases. Launch of the first spacecraft, GOES-I, cannot occur before late 1993. GOES-7 is expected to continue in service through 1993. Because catastrophic failure of the sole operating GOES-7 satellite would pose a serious risk to detecting and tracking hurricanes and other severe storms, NOAA has asked for backup support from its European space partners in the Coordination Group for Meteorological Satellites (CGMS). (In the past, NOAA has loaned or offered its GOES satellites to other CGMS members for emergency backup.) As a result of these discussions, a European geostationary weather satellite will very likely be moved to a position over the U.S. east coast by the end of 1992.

The NESDIS unit at the Cooperative Institute for Meteorological Satellite Studies at Madison, WI, developed a system for evaluating the effect on products of problems associated with the forthcoming GOES-I imager and sounder. The system was used extensively to influence decisions regarding changes in specifications.

Landsat Series. Pursuant to the Land Remote Sensing Commercialization Act of 1984, the Earth Observation Satellite Company (EOSAT) has operated both the Landsat 4 and 5 remote-sensing satellite systems for NOAA since 1985.

The National Space Council undertook a policy review of the Landsat program during 1989. The Council recommended and the President approved a policy of ensuring continuity of Landsat-type data. EOSAT is continuing to manage the design and development of a Landsat 6 system, with the new satellite scheduled to be launched in 1992. A follow-on to Landsat 6 will be funded jointly by NASA and the DOD.

In 1991, 16 foreign ground stations received Landsat data. A ground station in Ecuador began operations in March 1991.

Search-and-Rescue Satellite-Aided Tracking. The international search-and-rescue, satellite-aided tracking service, COSPAS/SARSAT, provided by Canada, France, the United States, and the Soviet Union, continued to be responsible for saving over 200 lives per year, bringing the total number of lives saved through this program to over 1,800. International participation in COSPAS/SARSAT continued to grow. At least 29 nations were currently participating or had declared their intention to participate as FY 1991 ended.

Pan-Pacific Education and Communication Experiments by Satellite. In 1991, the Pan-Pacific Education and Communication Experiments by Satellite (PEACESAT) program reestablished a satellite telecommunications network for exchange of social, environmental, health, and educational information among the Pacific Island nations. The National Telecommunications and Information Administration (NTIA), another DOC component involved with space activities, was instrumental in setting up this network. Earth terminals funded by NTIA have been installed and PEACESAT service resumed in 71 territories and nations.

ARGOS. Service ARGOS, Inc., which has operated the U.S. processing center for the ARGOS Data Collection and Location System, focused its activities during FY 1991 on refining its services. The French Space Agency provided ARGOS instruments for collection, relay, and position-determination of observations from sensors on balloons, buoys, and the like for flight on NOAA polar-orbiting satellites. The NOAA-D satellite, launched in July 1991, included the ninth ARGOS instrument flown on NOAA satellites. In 1991 NOAA and CNES amended the current ARGOS memorandum of understanding to include flight of one additional ARGOS instrument on the NOAA-N spacecraft. Regarding services, Service ARGOS began development of new processing software for ARGOS environmental data that is put onto the World Meteorological Organization's Global Telecommunications System (GTS). This new processing will increase the amount and improve the quality of the data put onto the GTS.

Advanced Communications Technology Satellite. NTIA continued planning and preparation for experiments that will use the Advanced Communications Technology Satellite, which was being developed by NASA as a testbed for advanced communications technology studies and is now expected to be launched in early

1991. This technology effectively will put a high speed digital switch in the sky with the capability to establish megabit channels to hundreds of Earth stations within microseconds. This will allow the integration of satellite communication technology with other advanced communication system technologies such as optical fiber transmission, integrated services digital networks, and mobile and personal communication system services.

Satellite Operations and Support

Atmospheric Temperature and Moisture Soundings. The year 1991 marked the 12th year of operational atmospheric sounding production from NOAA's polar-orbiting satellite system. These soundings have been used by both the military and civilian meteorological communities as input to numerical weather forecast models. NOAA honored numerous requests for sounding data and science software/techniques, from both military and civilian researchers. Preparations were under way at the end of the year for the development of the next generation operational sounding system, which will implement new science needed for the NOAA-K satellite instrumentation (including an advanced microwave sounder). Like that from the NOAA satellite series, the data from the Special Sensor Microwave/Temperature (SSM/T) instrument onboard the Defense Meteorological Satellite Program (DMSP) polar-orbiter were operationally processed into soundings. The use of data from the Special Sensor Microwave/Imager (SSM/I) also onboard the DMSP spacecraft, combined with the SSM/T data, was being explored as an option for improving the soundings. Upgrading of the DMSP sounding science software to be consistent with that developed for NOAA satellites was in progress as the year ended. Products from the DMSP satellites are operationally archived and distributed under the shared processing agreement between NOAA and the Department of Defense—specifically the Navy and Air Force. Development of the next generation geostationary satellite series (GOES-I/M) sounding product processing system was under way at the end of FY 1991. This system will provide temperature and moisture sounding information for the NOAA National Meteorological Center's regional forecast models and images of atmospheric stability and moisture to the NOAA National Severe Storms Forecasting Center and the NOAA National Hurricane Center.

VAS Applications. GOES-7 Visible-and-Infrared-Spin-Scan-Radiometer data continued to be used operationally by all of the NOAA National Weather Service National Centers—the National Meteorological Center (NMC), the National Severe Storms Forecast Center (NSSFC), and the National Hurricane Center (NHC). NMC used imagery, VAS-CO2 slicing techniques, and moisture analyses in both its global forecast models and its national forecasting programs. The NSSFC used the GOES-7 water vapor channel to fine-tune locations and timing of outlooks and watch areas for severe weather. The NHC employed imagery and a special VAS-derived Deep Layer Mean (steering current) analysis in the monitoring and forecasting of hurricanes (including storms in the Atlantic, Gulf of Mexico, and Caribbean Basin) that affected the United States.

GOES-Tap. GOES-Tap, a program enabling users to acquire high quality satellite imagery over telephone data circuits, continued to expand. At the end of FY 1991, there were approximately 350 primary users and over 500 secondary users of GOES-Tap data. They consisted primarily of National Weather Service (NWS) field forecast offices but also included the Department of Transportation's Federal Aviation Administration, other civilian agencies (both state and Federal), the Department of Defense, private companies, universities, and the media. A significant number of high schools have also started receiving NOAA satellite images via GOES-Tap. GOES-Tap data consists of visible and infrared facsimile images from the GOES and NOAA satellites, Geostationary Meteorological Satellite (Japanese), and Meteosat (European) spacecraft. During 1991, NOAA continued to expand its suite of available NOAA polar satellite products accessible to the NWS field offices. In addition, high resolution polar imagery was now gridded with geopolitical boundaries and contained a machine-readable identification code.

Hurricane Operations. GOES continued to carry the major load in positioning and estimating the strength of tropical cyclones outside of the aircraft reconnaissance areas for the western Atlantic, Caribbean Sea, Gulf of Mexico, and the eastern Pacific. Meteosat supplemented GOES in the far eastern Atlantic Ocean. As a supplement to GOES-7 imagery, the National Hurricane Center continued to employ imagery from a Meteosat spacecraft located at 0 degrees west longitude. Additionally, NHC has begun to use imagery from a second Meteosat spacecraft, recently relocated to 50 degrees west longitude. The satellite provided continuous monitoring for early detection of change while the aircraft provided precise spot observations.

In the Eastern Hemisphere (that is, the western Pacific and Indian oceans), the NOAA polar orbiters provided the essential coverage for tropical cyclone monitoring. The NOAA data were being used to provide estimates of position and intensity for the U.S. Joint Typhoon Warning Center in Guam and for foreign meteorological services, as part of the World Weather Watch Program of the World Meteorological Organization (WMO).

NHC was using the Special Sensor Microwave/Imager wind and rain-rate algorithm to improve products. The SSM/I algorithm has provided estimates of wind radii for marine advisories as well as rain projections (when the tropical cyclones are expected to make landfall) for public advisories.

Satellite-Based Fire Alarms. The National Geophysical Data Center (NGDC) of the NOAA National Environmental Satellite, Data, and Information Service (NESDIS), in partnership with the National Park Service and Bureau of Land Management in the Department of the Interior (DOI), has contracted with NASA to develop a prototype operational system for using the NOAA Advanced Very High Resolution Radiometer for automated early detection of wildfires. Wildfires cause great loss of forests. Forest managers must decide which fires are constructive and which are destructive to overall forest development. The techniques developed under this program should assist managers in making such decisions. International organizations such as the United Nations Food and Agriculture Organization and other nations such as Italy have shown interest in this technology. NGDC's involvement will be reduced in October 1991. However, NGDC will continue to help the agencies in DOI evaluate a possible follow up to the project.

Volcano Hazards Support. GOES-7 and NOAA polar data continued to be used to define the horizontal and vertical extent of ash cloud, as well as the direction and speed of cloud movement. Although a few minor eruptions occurred during late 1990 and 1991 from the Redoubt Volcano in Alaska, the Mount Pinatubo eruption in the Philippines (although volcano and ash were not in U.S. controlled air space) emphasized the need for an expanded role of the United States to help detect, track, and forecast ash clouds. The First International Symposium, cosponsored by NOAA, on Volcanic Ash and Aviation Safety was held in Seattle, WA, during July 1991.

CoastWatch. Operational support of CoastWatch activities and products began in 1989. At the end of FY 1991 there were three regional CoastWatch sites providing operational support—in Beaufort, NC; Narragansett, RI; and Ann Arbor, MI. In 1991, development began for a CoastWatch site in Florida to serve the greater Caribbean.

NOAA's interagency Ocean Products Center provided the regional sites with operational products such as high resolution AVHRR satellite-derived sea surface temperature (SST) imagery, meteorological fields, and oceanographic information in near real time via the electronic delivery system known as the NOAA Ocean Communications Network.

A new satellite mapping capability called IMGMAP began operating in mid-1991. An improvement over an older, non-operational routine, IMGMAP provided superior coastlines, better land/sea tags, more accurate satellite-derived SST's, and most notably, the ability to remap high resolution satellite images automatically for each coastal state of the United States.

An inexpensive, personal computer based workstation has been developed to interactively display and analyze satellite and other environmental information that supported Federal, state, and local decision makers and researchers responsible for managing coastal living marine resources and ecosystems. The NOAA CoastWatch Archive and Access System, an optical mass storage system on-line at the National Oceanographic Data Center for near real time capture and retrospective availability and distribution of CoastWatch data and products, provided data management for the system.

CoastWatch-funded research efforts included water reflectance/turbidity studies in the Chesapeake Bay as well as in Albemarle and Pamlico Sounds; examination of phytoplankton "red tide" blooms; El Nino monitoring; coastal circulation analysis; and development of an ocean color index. As part of the CoastWatch program, the Change Analysis Program was developing a comprehensive, nationally standardized information system for land cover and habitat change in the coastal region of the United States. Satellite imagery, aerial photography, and surface level data will be interpreted, classified, analyzed, and integrated within a geographic information system. The program will delineate coastal wetland habitats and adjacent uplands and monitor changes in these habitats on a cycle of 1 to 5 years.

Program products will strengthen conceptual and predictive models and improve policy planning and analysis with respect to coastal resources. Operational protocols were being developed through a series of interagency workshops and meetings focusing on coastal emergent wetlands and adjacent uplands, submerged aquatic vegetation, and user products.

Strategic Environmental Assessment Program. This program, managed by the Office of Ocean Resources Conservation and Assessment of the National Ocean Service (NOS) used NOAA and NASA satellite data to produce analyses that describe the physical and biological conditions within estuaries, adjacent coastal waters, and the continental shelf. It acquired and analyzed satellite imagery to determine: the location, movement, and spatial extent of estuarine plumes and shelf/slope fronts; the interactions and exchanges of water between estuaries and coastal oceans; and the distribution and concentration of primary productivity zones. The analyses produced by the Strategic Environmental Assessment Program were used by Coastal Managers to help in the continued monitoring and assessment of the environmental context within which living marine resources must survive.

Fisheries Enforcement. In cooperation with the National Marine Fisheries Service (NMFS), NOS provided, on an experimental basis, satellite imagery and other environmental data to the NMFS Enforcement Offices in Sitka and Juneau, AK, and San Jose and Monterey, CA. These NMFS offices used the environmental informa-tion provided by NOS to determine the most likely location to search for illegal foreign fishing activity. Coast Guard surveillance aircraft and ships were guided to these locations and reported an increase in the number of at-sea apprehensions.

Aviation Applications. A color image display has been developed that shows the approximate thickness of fog and stratus clouds. It was based on the temperature difference of two GOES infrared channels. Such estimates are useful in determining the time required for fog to clear an airport terminal area. Preliminary data show the estimates to be accurate to about 100 meters. An effort is under way to determine the Northern Hemispheric distribution of clear air turbulence (CAT) based on monthly, seasonal, and annual averages of an index calculated from forecast winds aloft. Preliminary results have identified regions where CAT is relatively common. These compare favorably with pilot reports and the observation of turbulence signatures in satellite imagery.

Additionally, work was nearly completed at the end of FY 1991 on developing a new procedure for classifying mid-latitude winter cyclones in the Atlantic Ocean. Preliminary results showed significant improvement over existing techniques for estimating the central pressure of full-latitude storm systems. An expanded study addressing north Pacific storms was planned for 1991-92.

Precipitation. Improvements in the forecasting of heavy rainfall continued during FY 1991. Imagery from the GOES satellite was proving to be an excellent tool for quickly locating: mid-level systems associated with upward vertical motion; areas of relatively deep moisture; and unstable air masses. All of these are ingredients for producing thunderstorms, especially those associated with heavy rainfall. The presence of low level moisture can increase the rainfall efficiency from thunderstorms. When polar or subtropical moisture approaches or intersects tropical moisture, thunderstorms can develop, producing flash floods. Techniques employing microwave satellite data for monitoring global precipitation were quasi-operational at year's end. Automated techniques to estimate rainfall from infrared satellite data were also being developed to improve the forecasting of flash floods and to lead to better water management.

Aerosol Optical Thickness. Although experimental production of a measurement of aerosol optical thickness over global oceans began in July 1987, operational production began in January 1990 and continued at year's end. A cooperative project with the Navy in the

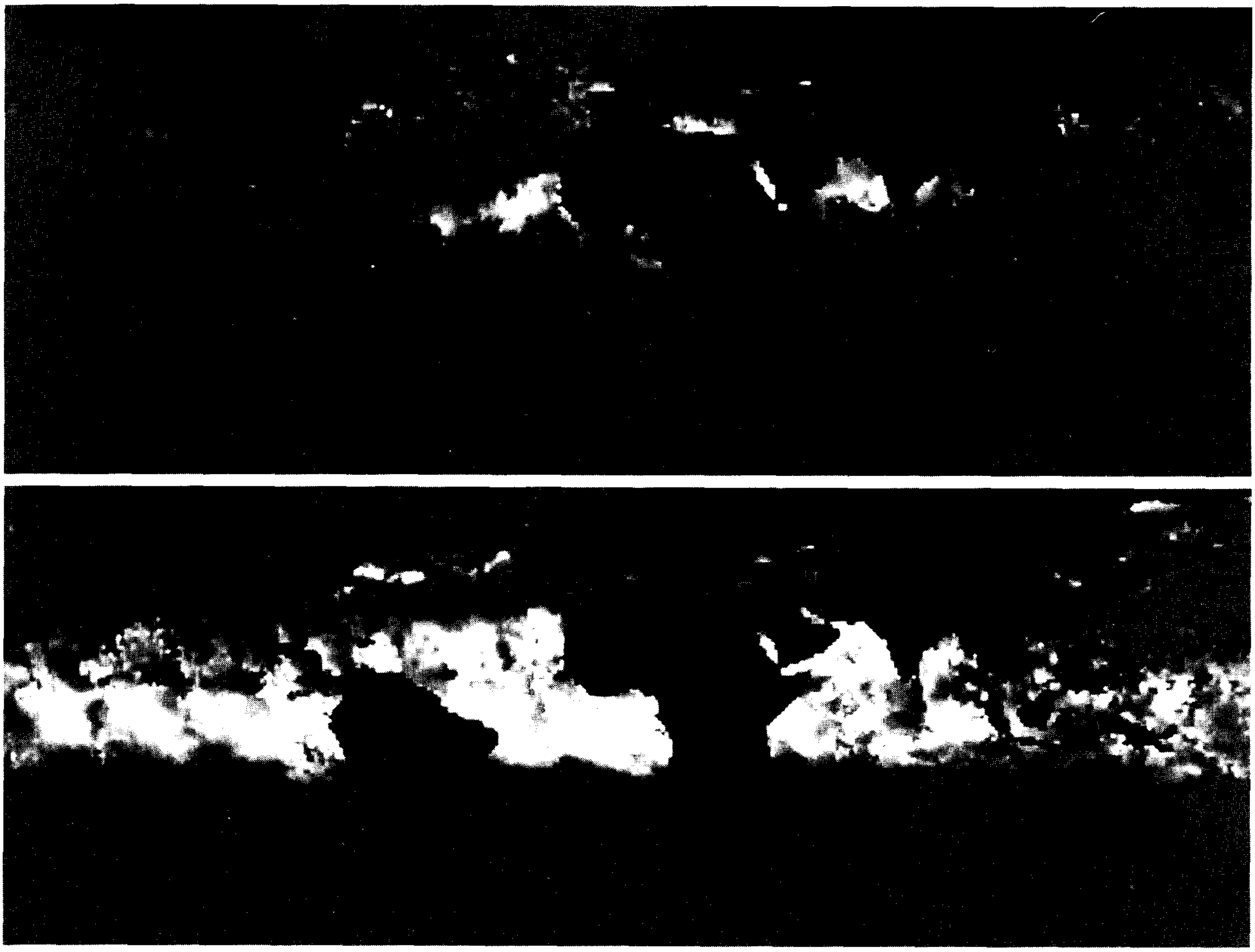


Figure showing the distribution of aerosol particles before and after the Mt. Pinatubo eruption. Top figure shows the situation one week before; bottom figure, five weeks after the eruption.

summer of 1990 resulted in an airdrop of drifting buoys in the eastern Atlantic off the coast of northwest Africa, an area where Saharan dust is prevalent. Close (time/location) matchups of the buoy and satellite data have enabled development of an aerosol correction algorithm for AVHRR-based daytime sea surface temperature retrievals.

The eruption of Mt. Pinatubo and the subsequent creation of a tropical belt of volcanic aerosol in the high stratosphere has been readily monitored by means of the weekly composite aerosol product. Five weeks after the eruption, the entire equatorial region, from 20 degrees South latitude to 25 degrees north latitude, was affected by the stratospheric aerosol particle layer generated by the eruption. This increase in reflected solar radiation could cause the Earth's surface temperature to decrease by up to 0.5 degrees Celsius over the next few years.

Satellite Applications Training. With increasing domestic and international awareness of the value of satellite information in weather and oceanographic analysis and forecasting, demand for training in satellite applications continues to grow. During the 1990-91 period, NESDIS has taught or coordinated almost 50 courses and workshops, training more than 1500 forecasters and others in the National Weather Service (NWS), Department of Defense, and overseas weather services and in weather-dependent agencies. A renewed focus on "training the trainer" has allowed thousands of additional forecasters to be trained by attendees at these NESDIS courses. Training topics included synoptic- and mesoscale analysis, heavy rainfall, water vapor imagery interpretation, numerical model initial analysis, tropical meteorology, oceanography, and agroclimatic applications.

NESDIS has completed its third self-study training module. Work was under way at year's end on a comprehensive script-slide training module on tropical cyclones, and the second volume of the "Workbook on Tropical Cloud and Weather Systems" was nearly completed. NESDIS, working with NWS and the University Center for Atmospheric Research, has nearly completed several interactive video-disc learning programs on severe storms and convection.

A technical report describing "Water Vapor Imagery Interpre-tation," also completed in FY 1991, comprehensively summarizes nearly 10 years of work designed to improve understanding of weather systems through water vapor imagery and can be used for self-study. The report's distribution included all of the NWS, and the DOD was reprinting it for distribution to its forecasting units.

The Service also printed nine Satellite Applications Information Notes (SAINs). These were designed to disseminate new satellite techniques to NWS operations staff in a timely manner. Aviation and heavy rainfall topics dominated this year's SAINs. However, several addressed polar orbiter imagery as well.

Space Environment Services. NOAA, in cooperation with the U.S. Air Force, has operated the Space Environment Services Center to provide forecasts, alerts, indices, and data describing disturbances in the space environment that may affect the operations of satellites, data systems, manned space missions, and defense reconnaissance sensors. The center continued to collect data in real time from the Space Environment Monitors on the GOES and NOAA satellites. These data were then combined with real time data from Department of Defense satellites and telescopes, Department of Interior geomagnetic field sensors, and from national and international facilities, to synthesize a running description of the state of the solar-terrestrial environment, especially disturbances that might adversely affect space activities. Means of distributing these data have included satellite broadcasts, computer-to-computer links, radio broadcasts, and a facsimile-based alert system. Substantial portions of the data were being preserved for future research by the NOAA National Geophysical Data Center. NOAA also engaged in research and development directed toward improved monitoring, better physical understanding, and improved forecasts, primarily through the Space Environment Laboratory.

Millimeter Wave Frequencies. The National Telecommunica-tions and Information Administration was continuing to study propagation effects at millimeter-wave frequencies on Earth-space paths. Measurement of these millimeter-wave characteristics, employing laboratory instruments, will allow NTIA to analyze higher level atmospheric effects on millimeter-wave system performance more effectively and will provide important results for the operations of space-based remote sensing systems.

Space Programs Support. Precisely synchronized Earth stations continued to be extremely important to NASA's Deep Space Net used for space navigation. Commerce's National Institute of Standards and Technology (NIST) has assisted the Jet Propulsion Laboratory in synchronizing NASA stations in the United States, Australia, and Spain.

The Hubble Space Telescope's High Resolution Spectrograph (HRS) has two hollow cathode calibration sources for on-board wavelength calibration using a platinum spectrum. The precise wavelengths of the platinum spectrum measured by NIST have been incorporated into the calibration codes for the HRS and are also used in calibrating the ultraviolet spectra obtained with the International Ultraviolet Explorer satellite and other space missions. Astronomers have been using the HRS for such studies of stellar atmospheres. One early study provided data that furnish one of the few critical tests of theories describing the first few seconds of the universe.

Synchrotron radiation at the NIST Synchrotron Ultraviolet Radiation Facility was being used as an absolute standard of spectral irradiance to calibrate spectrometer sensitivity. Users of this calibration service included scientists from government laboratories and academic institutions. A new detector, sensitive in the far ultraviolet and developed in conjunction with industry, had found several applications as of the end of FY 1991.

Astronomers at NIST were continuing to participate in the scientific and technical design of several future NASA scientific satellites, including the Advanced X-ray Astrophysics Facility, the Far Ultraviolet Spectroscopic Explorer, and the Space Telescope Imaging Spectrograph.

NIST has been supporting NASA's development of a leak- standards capability that will serve all of NASA's facilities. A large variety of space components and systems must either retain or exclude gases for continued proper functioning. NIST was also assisting in developing and calibrating vacuum instruments and techniques used to determine outgassing rates from space materials and satellite assemblies. Material outgassed from one component of a satellite was often readsorbed on other parts, obscuring optical components and detectors and causing catastrophic discharges in high density electronic assemblies. Prevention and evaluation of these phenomena require the kinds of quantitative measures of outgassing characteristics provided by the calibration.

NIST has also provided regular calibration support for vacuum instrumentation to almost all of NASA's facilities (five within the past year) and to numerous aerospace contractors. Each year, personnel from at least one NASA facility and several aerospace companies have participated in NIST's vacuum calibration training course. NIST was developing a terrestrial version of the control system that will be used in NASA's Flight Telerobotic Servicer (FTS). The FTS is a two-armed robot that will be used to build and maintain Space Station Freedom. As of the end of FY 1991, the robot was able to assemble Space Station hardware that connects the pieces of the station, using visually guided techniques.

Cryogenic flowmeters were being developed and tested for use in the fuel supply system of the Space Shuttle and the proposed heavy lift vehicle as well. NIST was studying new refrigeration systems to achieve higher reliability and greater efficiency in cryocoolers. It provided research, calibration services, and standards to allow quantitative analysis of gases used in Space Shuttle ground support systems.

Commercial Space Support

Office of Space Commerce. Established in December 1988 in the Office of the Deputy Secretary of Commerce, the Office of Space Commerce (OSC) has had five main responsibilities: (1) to coordinate space related issues, programs, and initiatives within the Department; (2) to represent the Department on the National Space Council; (3) to act as industry's advocate at the Federal level; (4) to participate in international negotiations on trade relating to space technology; and (5) to encourage the export of U.S. space technology except for sensitive items.

To coordinate space policy within the Department, OSC chaired the Space Commerce Coordinating Committee, a group composed of representatives from bureaus and agencies within Commerce that had an interest in space related issues. Typical issues include reviews of the Landsat Remote Sensing Commercialization Act and modifications to U.S. export regulations affecting space items. OSC is also leading an interagency study on the worldwide status of launch vehicle and satellite technologies.

As the Working Group representative on the National Space Council, OSC has participated in the development of specific statements of space policy, such as the National Launch Strategy, Commercial Space Policy Guidelines, and Commercial Space Launch Strategy. Representing the Department internationally, OSC has been involved in the negotiations for free and fair trade with respect to space launch services. OSC was working at year's end with the European Space Agency to establish guidelines for commercial competition in the international launch industry.

OSC supported the McDonnell Douglas sale of launch services to Indonesia; helped Hughes/General Dynamics obtain Export/Import Bank financing for the Telesat Canada project; and supported the Orbital Sciences Corporation's sale of launch services to Brazil. OSC has encouraged the formation of the U.S. Global Positioning Satellite Industry Council to coordinate industry input on export controls and has held discussions with industry on buying remote sensing data from lightsats.

Commercial Space Support and Technology Transfer. Members of the National Institute of Standards and Technology participated in a number of governmental and private groups related to the commercial development of space. These included the Secretary of Commerce's Commercial Space Advisory Committee, the National Security Council Space Policy Working Group, the National Academy of Sciences Microgravity Facilities Study, and the American Institute of Aeronautics and Astronautics-NASA Commercial Programs Strategic Plan Working Group.

NIST was developing methods and techniques for measurement of materials processing and research in the microgravity environment. In order to test these techniques, NIST was a participant in the first study by a NASA Center for the Commercial Development of Space on suborbital flight. The work was performed in association with the Consortium for Materials Development in Space at the University of Alabama, Hunstville, AL.

The Materials Microstructure Characterization Group at NIST was one of six research laboratories participating in the NASA Center for Commercial Crystal Growth in Space. The NIST part of the program involved characterization of vapor-grown cadmium-tellurium, nucleation and growth of zeolites, and solution growth of nonlinear optical materials. In these projects, the characteri-zation includes both Earth-grown and space-grown materials to permit a fundamental understanding of the quantitative differences in the processing-microstructure-property relationships of materials prepared on Earth and in space. This understanding was expected to lead to improvements in processing of materials, resulting in better and/ or unique properties for industrial applications.

Research Applications

The Climate and Global Change Program. NOAA was continuing with its program of producing and maintaining the continuity of climatological products from operational satellites. (For examples, see last year's report.)

In addition, NOAA has undertaken new activities to improve and expand its suite of high quality climatological data to meet the goals of the U.S. Climate and Global Change Program. These included:

An OPSAT '90 Conference—A conference on Operational Satellites: Sentinels for Monitoring Climate and Global Change. It examined the role of operational satellites in observing global climate systems and helped define the climatological variables obtainable from current and future satellites.

A Calibration Workshop—A Workshop on Radiometric Calibration of Satellite Sensors of Reflected Solar Radiation, hosted by NOAA. The calibration of the short-wave sensors is critical if these data are to be used for climatic studies. This workshop addressed the problem of obtaining the most accurate calibration of the visible and near-infrared sensors on the operational spacecraft that currently have no onboard calibration.

Pathfinder Data. NOAA and NASA have initiated a joint program to generate and make available to the global-change research community quality data sets concerning "research/climate". They have identified three NOAA operational satellite data sets as Pathfinder data sets under this activity: the five-channel Advanced Very High Resolution Radiometer data, since 1981; the TIROS Operational Vertical Sounder data, since 1979; and the GOES data, since 1978.

Operational Measurements Project. To provide ongoing data and informational products from operational satellite and in situ observations for the U.S. Global Research Program, NOAA has initiated a project on Operational Measurements as part of its Climate and Global Change Program. The Operational Measurements project will improve NOAA's ability to observe the physical climate system. Because of its global observing capabilities, the emphasis of this project will be the operational satellite observing system. New and improved products will provide climatological products for studying the atmosphere, oceans, land surface, and cryosphere.

Earth Radiation Budget. Since 1974, NOAA has been providing nearly continuous coverage of the outgoing long-wave radiation (OLR) flux and the planetary albedo from sensors on the polar-orbiting satellites. While current OLR products have been derived from a single channel on the AVHRR in the thermal infrared portion of the spectrum, an OLR product derived from four channels on the High-Resolution Infrared Sounder instrument has been developed and is being implemented. Beginning in May 1988, the planetary albedo has been computed from a scene-independent linear combination of two channels on the AVHRR and corrected for reflected radiation.

The OLR and the albedo have been extremely useful in monitoring the climatic effects of the burning Kuwaiti oil in the Persian Gulf region. Large decreases in the cloudless albedo were observed over normally bright desert sand the day after the fires were set. These decreases remained at year's end, although many fires had been extinguished, causing the surface temperatures to dip many degrees below normal values. NOAA also monitored the Mt. Pinatubo volcano by noting the very low values in the OLR of the ash clouds.

Joint Global Ocean Flux Study. The National Ocean Service has been providing satellite image data, ship and buoy reports, and numerical forecasts to support this critical element of the Climate and Global Change Program. NOS has communicated these data in real time to the Joint Global Ocean Flux Study (JGOFS) Time Series Stations at Bermuda and Hawaii. JGOFS scientists used them to direct data collection activities of participating research vessels and to establish a surface climatology for the region around the monitoring station. The measurements collected by JGOFS will assist in the determination of differences between daily, seasonal, annual, and decadal changes in the net flux of planetary carbon, one of the important indicators of statistically significant changes in global climate.

Ozone. Analysis of the currently archived total ozone data derived from measurements by the Solar Backscatter Ultraviolet Spectrometer/2 instruments on the NOAA-9 and -11 satellites have been merged along with data from the SBUV on the NASA Nimbus-7 satellite. The combined data set, normalized to data from the global Dobson spectrophotometer network, permitted analysis for trends over the resultant 11-year data record. While the analysis was preliminary at the end of FY 1991, the trend showed a decrease in the amount of total global ozone by about 3 percent per decade. This was in general agreement with trends derived from other satellite data. (See coverage above of ozone measurement.)

Atmospheric Sciences Research. NIST has had several other projects related to the problem of ozone depletion of the upper atmosphere and the greenhouse effect. One project used Molecular spectroscopy to provide the data for monitoring molecular species present in trace amounts in the Earth's atmosphere. NIST and NOAA were continuing to collaborate on measurements of concentrations of hydroxyl, water, ozone, chlorine, oxygen, and some nitrogen-oxygen compounds. Data from these and other measurements were being compiled into data base tables that will enable atmospheric modelers to predict equilibrium conditions for the atmosphere and its chlorine pollutants.

Scientists investigated the spectra of carbon dioxide, chlorine dioxide, and cyanogen under high resolution. Subtle perturbations such as temperature and pressure-dependent mixing of spectral lines have a strong effect on the interpretation of the observed spectra in terms of appropriate theoretical models. NIST scientists were making laboratory determinations of the effect of pressure on the spectroscopic line widths of important upper atmospheric molecules. Other research organizations such as the Smithsonian Astrophysics Laboratory used these laboratory measurements to interpret NASA's satellite and balloon measurements of atmospheric constituents.

NIST scientists were continuing to perform laboratory mea-surements of the rates of the chemical reactions controlling the atmospheric lifetimes of replacement compounds for chlorofluoro-carbons. NIST was engaged in extensive calculations of electron precipitation events in the Earth's atmosphere (auroras, sub-storms, magnetic storms) important in magnetospheric processes and interactions with the upper and middle atmosphere. Because direct measurements of the precipitating electrons were difficult, much experimental evidence has had to be based on indirect measurement from which researchers deduced initial electron distribution and the ionization profiles in the atmosphere.

NIST developed a computer code for the rapid calculation of absorbed dosage from electrons, electromagnetic radiation, and protons, as a function of depth in the aluminum shielding material of spacecraft, given the electron and proton influences encountered in orbit. Since 1980, when the code was made available to the space radiation effects community, its use has become quite widespread, so much so that it has become a de facto standard for dose estimates by NASA and DOD agencies and their contractors in many project areas. A new code was being developed, under the auspices of NASA, that will incorporate new radiation transport cross sections and will extend coverage to wider energy ranges of incident radiations, to a larger number of detector materials, and to a larger variety of geometries.

Several hundred scientists in more than 50 institutions and countries receive geophysical data records on a regular basis. The NESDIS National Geophysical Data Center continued, along with the NESDIS National Oceanographic Data Center (NODC), to provide the community of users with these publicly available Geosat data and selected derived data.

Global Vegetation Index. NOAA's experimental Global Vege-tation Index (GVI) provided a one-per-week view of Earth's vegetation since May 1982. The GVI derived from daily data acquired by the AVHRR onboard the NOAA polar-orbiting series of satellites. Research efforts continued to improve the quality and use of the normalized-difference vegetation index data in global circulation models and as direct indicators of year-to-year and regional variations in climatic conditions.

Snow Cover Observations. As of November 1990, NOAA began its twenty-fifth year of producing the NOAA satellite based Northern Hemisphere Weekly Snow and Ice Cover Chart. This has been the longest satellite based climate record ever available. Work continued to upgrade this product by evaluating microwave data from the Defense Meteorological Satellite Program's SSM/I sensor and the daily United States Air Force global snow cover product. The National Weather Service was studying the use of snow cover data in improving its forecast models.

Generic Cloud Algorithms. Under development at the end of FY 1991 was a multichannel algorithm for cloud detection. Its objectives were to provide a method for detecting clear pixels for remote sensing of surface parameters and to provide a means of estimating cloud amount and other cloud properties useful for diagnosis and initialization of climate and weather prediction models.

Increasing concern in the scientific community regarding global cloud census has led to improved estimates from polar and geostationary satellites using radiances in the carbon dioxide bands in concert with atmospheric window measurements. A 2-year global climatology has been prepared as a pilot program. This research has also spawned an operational product that will be used by NWS to augment the Automated Surface Observing System of the Modernized Weather Service.

Sea Surface Temperature Measurements. Since 1981 the National Environmental Satellite, Data, and Information Service has provided sea surface temperature measurements in real time on a global basis. These SSTs are derived from 4 km resolution, multi-channel (visible, reflective, and thermal-infrared), and digital data from the AVHRR instrument. The nonlinear model, implemented in March 1990 to better correct for atmospheric attenuation by water vapor, has worked well, but a simpler and improved nonlinear version replaced it in April 1991. The eruption of Mt. Pinatubo in the Philippines in June 1991 has had a significant effect on AVHRR-based SSTs in the tropics. The impact was stronger but much like that experienced with the apparently weaker El Chichon eruption in 1982, a severe loss in daytime SST retrievals and a degradation in accuracy of the nighttime ones. Methods of correcting for these effects, which were developed from data during the El Chichon episode, were under investigation as FY 1991 ended.

Dump Site Monitoring. NOS was using NOAA satellite imagery to monitor sea surface temperature as part of the 106-Mile Deepwater Municipal Sludge Dump Site project, carried out jointly with the Environmental Protection Agency and U.S. Coast Guard. SST imagery was being used for the identification of surface water masses, as an aid in the interpretation of the tracks of drifters released at the site, and for monitoring significant physical features such as the Gulf Stream and warm core rings.

Mesoscale and Severe Storm Research. NESDIS researchers continued to develop satellite based products to improve forecasting of severe and tornadic thunderstorms. Work this year has focused on using interactive computer systems to quickly and accurately analyze rapid changes in the thunderstorm environment. Recent research was pointing to the interaction of the thunderstorm with its environmental flow fields in defining the crucial difference between a storm that has beneficial rains and one that is destructive. NESDIS has developed products to look at these flow fields in real time—allowing the forecaster to look at satellite imagery in a storm-relative reference frame.

Tropical Cyclone Research. NESDIS research used observational data from satellites and aircraft as well as conventional weather data to improve the understanding of tropical cyclones. Tropical cyclones occurring in the Atlantic, eastern Pacific, western Pacific, and Australian regions have been extensively analyzed using digital multi-spectral satellite images. The genesis, intensity, and motion of tropical cyclones were the primary topics being studied with these multi-spectral data sets. Objective techniques have been made available to operational tropical cyclone forecast centers at the National Hurricane Center, Miami, FL, the Joint Typhoon Warning center, Guam, and NESDIS, Washington, DC.

National Marine Fisheries Research. Remote sensing of the oceans by satellite continued to play an important role in National Marine Fisheries Service research. Satellite observations provide the synoptic information needed for studying the effects of the ocean environment on the abundance and distribution of fish populations.

The Alaska Fisheries Science Center (AFSC), in collaboration with the Pacific Marine Environmental Laboratory and various academic institutions, was continuing a Fisheries Oceanography Coordinated Investigation in the Gulf of Alaska and the Bering Sea. A major objective of the study was to determine the effects of the ocean environment on the walleye pollock. Satellite measurements of ocean environmental parameters have been used in conjunction with data collected by ships and aircraft to describe and eventually predict the distribution of the parameters that affect the survival of the pollock.

The AFSC and Service ARGOS completed testing during FY 1991 of an ARGOS Environmental Shipboard Observer Platform (AESOP). The AESOP, developed by Service ARGOS, is a portable data entry and transmission unit that allows an observer aboard a fishing vessel to transmit data and messages to the Alaska Center through the NOAA polar orbiting satellites. The AESOP was tested by an observer placed aboard a U.S. factory trawler fishing off the northwest coast. The vessel transmitted daily information on the catch of Pacific whiting and salmon to the AFSC. Use of the AESOP significantly improved the ability of the observer to provide the Center with fisheries data required for management of fishery quotas.

Fisheries scientists in Alaska developed and tested a prototype satellite tracking system to monitor the movement of several hundred radio-tagged salmon in remote Alaskan waterways. The data received through the satellite was being used by U.S. and Canadian fisheries scientists to determine the migration patterns and distribution of salmon stocks in several transboundary rivers. This information was required for management of the salmon stocks according to the provisions of the Pacific Salmon Treaty.

The National Marine Mammal Laboratory used a satellite tracking system to monitor the movement of marine mammals fitted with radio transmitters. The data acquired with the system permitted researchers to study diving behavior, to locate feeding grounds, and to obtain information on habitats. Five studies took place in 1990 and 1991 in collaboration with scientists from the Soviet Union, Japan, and the state of Alaska.

The Southwest Fisheries Science Center was using satellite infrared imagery to monitor ocean conditions influencing west coast fisheries. The satellite data were used to locate and define features of the California Current that may affect the survival of early life stages and subsequent recruitment of commercially important fish species. The Center also was a NOAA CoastWatch Regional Node responsible for providing satellite remote sensing data to decision makers and researchers who manage the nation's marine resources and ecosystems.

The Southeast Fisheries Science Center completed a multi-agency research project to develop remote sensing capabilities using an Airborne Ocean Color Imager. Ocean color data it collected directed fishing vessels to areas with a high probability of significant concentrations of fish. The project demonstrated to the commercial and sports fishing industries the advantages of using remote sensing data in their operations in the northern Gulf of Mexico.

High Performance Aerospace Materials. The National Institute of Standards and Technology was in the process of studying the physics and chemistry involved in the combustion of metallic materials in high-pressure/high-temperature oxygen environments. An understanding of the interaction between oxygen and metals was needed to improve the performance and safety of the Space Shuttle main engine. Researchers were looking at frictional generation of oxides to estimate actual temperatures experienced during Shuttle operations.

NIST was continuing the study of the performance characteristics of state-of-the-art heat exchangers for use in high-mach aircraft. Fuel used in these high performance aircraft is preheated before injection into the engines by absorbing through these exchangers the heat developed by aerodynamic friction; this absorption also helps cool the skin of the vehicle. Development of predictive models based on theory and observed behavior is an important component of this research.

NIST has developed a unique capability to study the thermal conductivity of insulating materials for application in advanced aircraft and rockets. The facility involved in this research includes systems needed to study classical thermal conductivity as well as heat flow with extremely large temperature differences imposed.

Advanced ceramics offer significant advantages over conventional materials for a variety of aerospace applications where dimensional stability, stiffness, corrosion resistance, and high-temperature strength are required. To provide reliable data on the properties and behavior of these materials, NIST has conducted a program to develop the test methodologies required and to provide the critical data. These data as well as the test methodology are crucial to the design and operation of many aerospace components.

NIST was also conducting research on the use of composite materials containing solid lubricants in mechanical system components for space satellites in a project sponsored by the Air Force. The aim of the project is to develop a fundamental understanding of self-lubricating composites and also to suggest materials for actual systems. Project researchers have made recommendations to the Air Force on candidate materials (both metal- and ceramic-matrix composites) and deposited solid lubricant films for new designs of bearings and other moving mechanical systems.

Long life and high efficiencies are critical requirements for alkaline fuel cells used in aerospace applications. Techniques involving molecular chemical synthesis have been developed to generate finely divided, conductive oxides. Evaluations of the new materials suggest that they will offer advantages in longevity and efficiency over the present system. Work was also under way at year's end to establish the feasibility of using high temperature ceramic superconductors as radiant heat instruments for measuring temperature on missions to distant planets.

During alloy solidification in the Earth's gravitational field, it is difficult to avoid convection that arises from the thermal and density gradients inherent in the solidification process. Convection causes solute segregation that may degrade the properties of the solidified material. Using Floquet theory, researchers were making numerical calculations of the processing conditions for the onset of convection as a function of the magnitude and frequency of the acceleration.

Space Sciences Research. Development of a comprehensive data base of evaluated atomic spectroscopy data, covering all atoms and ions of astrophysical interest, was continuing for general use of space research groups. The data base will be compatible with the NASA astrophysics data system and be incorporated into appropriate existing NASA data bases to facilitate easy dissemination to space science groups.

NIST continued several studies of astronomical phenomena. Along with NASA investigators, researchers were determining accurate atmospheric parameters and elemental abundances of hot stars by providing the results of sophisticated model calculations of stellar atmospheres. NIST astronomers were also pursuing a major program to measure surface magnetic fields of stars cooler than the Sun. They have developed a Doppler imaging technique to determine the location and sizes of bright and dark regions on the surfaces of rapidly rotating stars.

NIST engineers have also designed and constructed a compact pulse heating system for microgravity simulations with NASA's KC-135 aircraft. Experiments performed during a series of flights have yielded valuable information regarding the parameters affecting specimen stability above the melting point. As a natural extension of the work on specimen stability, engineers demonstrated a technique for measuring surface tension of liquid metals at high temperatures in a microgravity environment. NIST has performed analytical procedures on biological samples collected from separation experiments aboard the Space Shuttle and has prepared reviews of separation science under low gravity. NIST has also performed modeling studies in gravitational and space biology and has provided leadership in the physical analysis of low gravity and simulated low gravity.

NIST was participating in work under the NASA Crustal Dynamics Project to determine worldwide tectonic plate motions and the intricacies of the Earth's rotation. The model produced by project engineers calibrates the atmospheric transmission delay due to water vapor so that the accuracy of geophysical and astronomical studies based on microwave distance measurements through the atmosphere can be improved. A more accurate determination of the displacement rate across the San Andreas fault system in California has been made from satellite laser range data.

A spectral irradiance intercomparison and instrument evaluation was conducted with NASA, NOAA, the Naval Research Laboratory, and two members of the European Space Agency. The main purpose is to put future radiometric space measurements on a common base. All of the participating laboratories developed and used a portable radiometric measurement setup. This project was useful in solving major measurement problems before the instruments were launched; the measurement evaluation maximized the success of the mission.

NIST has developed a theoretical model capable of predicting the dynamic structure of both flames from and smoldering of a cellulosic material in a reduced-gravity environment. The model has been extended to include ignition and subsequent flame spread to examine fire safety in spacecraft. The relationship between sets of NASA and NIST test data with flammability in reduced gravity was being studied as well.

Geosat Altimeter Program. Since 1986 the National Ocean Service has prepared Geosat altimeter data sets for distribution to the international scientific community. Although the involved satellite failed in early 1990, the 5-year U.S. Navy Geosat mission has been the most successful oceanographic mission of its kind. It has collected approximately 500,000 observations of sea level, wind speed, and wave height each day over the global oceans. NOS has used these data to study sea level variations in the tropical oceans as they relate to global weather and climate. During the past year, NOS has prepared a new Geosat data set for distribution by the NODC to the oceanographic community. The geophysical data records (GDRs) have been upgraded by incorporating a more accurate satellite orbit and improved corrections for water vapor, tides, dry troposphere, and the geoid. These new GDRs will be distributed on 7 CD-ROMs (as opposed to 36 9-track tapes). NOS was also actively supporting the next satellite altimeter, the European Space Agency Remote Sensing Satellite (ERS-1), launched in July 1991. NOS will assist in areas of calibration and verification and will use the fast delivery altimeter data to perform monthly monitoring of tropical sea level, as was done during the Geosat mission.

The Geosat altimeter data was also being used to enhance models of the geoid and the gravity field of Earth's oceans. This information is fundamental to improving our understanding of numerous geophysical processes.

Very Long Baseline Interferometry. During FY 1991, NOS maintained the NOAA portion of the global Very Long Baseline Interferometry (VLBI) network. NOS continued monitoring continental motion parameters using a 3-station network in the United States (Westford, MA; Richmond, FL; and Mojave, CA), plus the Wettzel station in Germany. These measurements are critical to remove the motion parameters from the global sea level record, which is an important indicator of global warming. Also, NOS deployed a mobile VLBI system to a site near San Francisco to monitor ground motion in the aftermath of the Loma Prieta earthquake of 1989.

Solar Geophysical Data. In 1990, the number of solar flares and related magnetic storms affecting the Earth dropped below the peak achieved in 1989, the year of sunspot maximum. However, as predicted by the National Geophysical Data Center, in 1991 both flares and major magnetic storms have returned to higher levels with serious effects on spacecraft, electrical power plants, and other high technology systems on Earth and in space. According to the classification system developed at NGDC, the March 1991 storm was the largest magnetic storm since the great one of March 1989. During the recent active flare period, several satellites experienced serious problems. Failures in electrical power subsystems on the ground at nuclear power plants were being studied by the Electric Power Research Institute (EPRI). EPRI scientists and contractors were using data obtained from NGDC about solar activity and magnetic storms during recent activity and for historical times.

National Oceanographic Data Center CD-ROMs. As a follow-up to the release of its initial prototype CD-ROM holding, concerned with temperature-salinity data for the Pacific Ocean, the National Oceanographic Data Center issued a 2-volume set of CD-ROMs containing global ocean temperature and salinity profiles. Late in the year, NODC and NOS began a cooperative project to issue Geosat data sets on CD-ROM. The first data to be issued will be a set of reprocessed Geosat Geophysical Data Records from the Exact Repeat Mission, collected from November 1986 through December 1989. These Geosat data incorporate improved water vapor and dry troposphere corrections, as well as a more accurate geoid model and modifications to the ocean tide model.

Global Monitoring. The NESDIS National Geophysical Data Center began its Global Change Database Program, a cooperative effort with many other laboratories and individual scientists, to compile and integrate improved data for global environmental monitoring. The program integrated data derived from NOAA satellites with a wide variety of other data. Activity for 1991 has included distributing a CD-ROM to about 200 evaluators, who are providing reviews of the data and their presentation. In addition, NGDC is helping to stimulate laboratories to produce improved data sets, as well as analysis software. NGDC also helped to organize the First International Conference/Workshop on Integrating Geographic Information Systems and Environmental Modeling, held in Boulder, CO, in September 1991. It significantly advanced the exchange of information on these techniques.

Earth System Data Directory. In 1991, NOAA expanded its Earth System Data Directory, an on-line computer directory of NOAA data sets. The system was part of the national and international Global Change Master Directory network of data directories, which includes the directories at European, Japanese, and Canadian space agencies. The NOAA Directory contained 680 descriptions of environmental data including over 100 descriptions of satellite data held in NOAA data centers. It was the keystone for the NOAA Earth Observing System Data and Information System and NOAA Data Management efforts.

National Climatic Data Center Holdings. The National Climatic Data Center (NCDC) is responsible for the archiving and distribution of much of the nation's environmental satellite data. NCDC satellite data archives consist of data originating from NOAA operational polar and geostationary satellites, the Defense Meteorological Satellite Program, and certain NASA satellites. The NCDC facilities in Suitland, MD, and Asheville, NC, and also the University of Wisconsin's Space Sciences and Engineering Center performed data management, quality control, storage, retrieval, and distribution for this information. Data holdings at all locations were primarily in digital format; however, the NCDC Satellite Data Services Division at Camp Springs, MD, maintained a film library that primarily contained AVHRR imagery. This library served as a browse facility to support digital data selection.

International Activities

World Meteorological Organization. The Eleventh World Meteorological Congress, which met in May 1991, recognized the critical need to continue the operation of environmental satellite systems and appealed to operators to ensure the continuity, quality, and coverage of their satellite programs. The 43rd session of the World Meteorological Organization (WMO) Executive Council emphasized the important role of satellites in all WMO programs and took steps to ensure appropriate coordination of satellite activities among members.

World Meteorological Organization Panel of Experts on Satellites. In March 1991, NOAA participated in the Ninth Session of the WMO's Executive Council Panel of Experts on Satellites. The purpose of the Panel was to advise the WMO on technical and programmatic matters relating to meteorological systems and their contributions to WMO programs.

The Panel discussions focused on: (1) an appropriate WMO structure for its satellite activities; (2) WMO relationships with international satellite coordination groups; and (3) satellite data requirements. Panel recommendations included: (1) restructuring of satellite activities within the WMO Commission for Basic Systems; 2) defining and establishing closer relationships and interactions with international satellite operator coordination groups; and 3) recognizing the need to develop satellite data requirements in such a way that they will be useful when presented to satellite operator groups.

Coordination of Geostationary Meteorological Satellites. In December 1990, the Coordination of Geostationary Meteorological Satellites group, which served as an informal technical forum through which independent national meteorological satellite pro-grams can be harmonized in order to achieve common meteorological mission objectives, met in Tashkent, USSR. The group members, including the European Meteorological Satellite Program (EUMETSAT), India, Japan, the United States, the Soviet Union, the Peoples Republic of China, and WMO, adopted a charter on a provisional basis that renames the group as the Coordination Group for Meteorological Satellites (CGMS). Under the charter, the group will expand its focus from geostationary satellite systems to include technical and operational matters involving polar orbiting meteorological satellite systems. CGMS seeks to harmonize, to the extent possible, meteorological satellite mission parameters such as orbits, sensors, data formats, and downlink frequencies.

Committee on Earth Observations Satellites. The Committee on Earth Observations Satellites (CEOS), formed in 1984 as an outgrowth of the international Economic Summit of Industrialized Nations, serves as the coordinating forum for the overall Earth observations space community. At the November 1990 CEOS plenary meeting, NOAA and NASA secured adoption of an initiative to strengthen CEOS interaction with both international scientific programs (International Council of Scientific Unions/International Geosphere-Biosphere Programme, World Climate Research Programme) and intergovernmental user organizations (Intergovernmental Panel on Climate Change, Intergovernmental Oceanographic Commission, WMO, United Nations Environment Programme) in order to enhance and further focus space agency Earth observation mission planning on global change requirements. Scientific and intergovernmental agency representatives have been invited to participate in CEOS deliberations and technical coordination activities. Moreover, CEOS members agreed to provide to the international community non-discriminatory and full access to their Earth observation data.

The goal of the CEOS Working Group on Data (WGD), chaired by NESDIS, is to facilitate the use of data from Earth observation missions by coordinating and standardizing aspects of data management where possible. WGD has created focused technical subgroups that address specific issues in detail and has established pilot projects and prototype systems to demonstrate and evaluate internationally coordinated approaches to Earth observations data management. Among WGD achievements were: (1) developed and supported standard data formats for digital user products; (2) the CEOS WGD Library; (3) an International Directory Network system; (4) a group to explore requirements for networks for exchange of data after the data are received on the ground; and (5) tutorials on data formats and format standards for use in training data managers.

International Polar Orbiting Meteorological Satellite Group. The 1984 Economic Summit of Industrialized Nations endorsed the creation of the International Polar Orbiting Meteorological Satellite Group (IPOMS) to explore the mechanisms for increased international cooperation in support of polar orbiting meteorological satellites and to ensure their continuity.

Since the September 1990 IPOMS plenary in Venice, Italy, NOAA and NASA have continued to explore with European counterpart agencies (EUMETSAT and European Space Agency) arrangements to fly U.S. instruments as part of ESA's Polar Orbiting Environmental Mission payload, and to fly European instruments on future NOAA polar orbiters.

World Administrative Radio Conference. The National Telecommunications and Information Administration Institute for Telecommunication Sciences completed a series of field measurements of rain attenuation to assist the U.S. Study Group of the Consultative Committee International Radio, part of the International Telecommunication Union. These measurements were taken to assess the impact of rain on requirements for preventing interference between fixed microwave services and satellite broadcasting services. Results showed that an additional margin in signal strength was needed to protect against potential unacceptable interference.

International Maritime Organization/International Maritime Satellite Organization Meeting. NTIA participated in the preparations for the joint meeting of the International Maritime Organization and the International Maritime Satellite Organization. The purpose of the meeting was to consider appropriate charging principles and a method of funding maritime distress and safety related communications in preparation for implementation of the Global Maritime Distress and Safety System.

International Training. The National Environmental Satellite, Data, and Information Service continued its international training activity in collaboration with the World Meteorological Organization and the National Weather Service. In February and March 1991, they offered the second regional training course at Florida State University in Tallahassee. The object of this advanced satellite imagery interpretation training course was to train operational meteorologists in basic and advanced techniques for the purpose of forecasting convection, heavy rainfall, tropical cyclones, and synoptic weather features. Twenty-six operational meteorologists from 19 countries in the Central and South American/Caribbean area participated.

NESDIS conducted training in climate computing in many countries, including Venezuela, Trinidad, and Mozambique. This training assisted in the use of the climate computing system and in the applications of climate analyses. NESDIS was participating, along with the U.S. Geological Survey and NASA, in a United Nations International Space Year 4-week international training course on remote sensing applications for environmental assessment and monitoring at the Earth Resources Observation System Data Center in Sioux Falls, SD (September 8 through October 4, 1991).

NESDIS has conducted several training courses at the Taiwan Central Weather Bureau on using satellite imagery to analyze and forecast heavy precipitation. It offered the most recent 2-week course in May 1991. NESDIS has continued to develop training aids that are geared to the international community. The U.S. Permanent Representative to WMO has made available a script-slide training set entitled "An Introduction to Polar Orbiter Satellite Imagery Interpretation" to WMO Members and the WMO Library. In addition, the Representative has made available a stand-alone training tool for forecasters titled "Workbook on Tropical Clouds and Cloud Systems Observed in Satellite Imagery."

NESDIS also has periodically participated in United Nations and other training programs. For example, under the United Nations Development Program, scientists from Pakistan studied for 6 months at the National Climatic Data Center and completed detailed quality control and analyses of historical land and marine data collected in Pakistan. This data set will become an integral addition to NCDC's Global Historical Climatology Network. During June 1991, a WMO trainee from Malaysia learned basic remote sensing techniques at the NESDIS Climate Applications Branch.

NESDIS's NGDC participated in several training missions: (1) a workshop in Dakar, Senegal (September 1990) on global change analysis sponsored by the United Nations Institute for Training and Research; (2) another similar workshop in Buenos Aires, Argentina, (June 1991) sponsored by the Latin American Society of Remote Sensing Specialists, Fundacion TUTELA, and the International Geosphere-Biosphere Program; (3) a workshop on global environmental data held at the First International Conference/Workshop on Integrating Geographic Information Systems and Environmental Modeling in Boulder, CO (September, 1991); and (4) a U.N. International Space Year Course on Remote Sensing Applications for Environmental Assessment and Monitoring, in Sioux Falls, SD (September 1991), sponsored by the United Nations Development Programme. The last two workshops, though held in the United States, were international in scope. All of the workshops incorporated satellite based (as well as other) data.

Department of Energy

The U.S. Department of Energy (DOE) provides nuclear power sources for highly specialized applications for the National Aeronautics and Space Administration and the Department of Defense. Such power units have enabled spectacular events, such as the Voyager flyby of the planet Neptune and the Apollo scientific investigations on the lunar surface. These missions have provided us with detailed photographs and data on a variety of planetary bodies including Jupiter, Saturn, Uranus, Neptune, and their moons, plus the discovery of the first extraterrestrial volcanos on the Jovian moon Io.

The majority of the power sources used on these missions have been Radioisotope Thermoelectric Generators (RTGs), capable of producing between 2.0 and 300 watts of electrical power. RTGs convert the heat from a decaying radioisotope into electricity by the use of thermoelectric materials. However, since some planned missions will require even higher power levels, a more efficient dynamic energy conversion process has also been under development.

Space Nuclear Power Systems

Thus far, radioisotope power units have used thermoelectric energy converters to provide electrical power for spacecraft operations. (See previous report for details.) Nuclear reactors offer a higher electrical power capability for space operations than is available from radioisotope power sources. The principal space reactor program currently in development at the end of FY 1991 was the SP-100.

Radioisotope Thermoelectric Generators

The United States has successfully used 37 RTGs on over 20 spacecraft launches covering a variety of different space applications. An RTG is a static device (that is, without moving parts) that directly converts the heat from the decay of the radioisotope Plutonium-238 (Pu-238) to electricity. Research and development has increased the conversion efficiencies of radioisotope power systems from less than 5 percent to almost 7 percent, which increases the power output or reduces the weight of the power supply, both of which are critical design factors. 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 design power levels. For example, the multihundred-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 is the latest in a series of nuclear power sources developed for space applications by DOE. The GPHS-RTG qualification unit life test ended after 54,588 hours of successful operation. Planning and facilities restart activities have begun to support the use of the GPHS-RTG design for the Cassini spacecraft to Saturn, and Comet Rendezvous Asteroid Flyby (CRAF) spacecraft scheduled for launch in the mid- to late-1990s (see above).

Significant program activities in FY 1991 included issuance of the Ulysses Final Safety Analysis Reports (FSAR), the launch of a GPHS-RTG aboard Ulysses spacecraft, and the restart of the facilities at Savannah River necessary to maintain the capability to process Pu-238 in support of the CRAF and Cassini missions. An Environmental Assessment addressing the facilities at Savannah River and Los Alamos National Laboratory needed in support of CRAF and Cassini resulted in a finding of no significant impact.

In order to obtain the Office of the President's approval for the Ulysses launch, the Interagency Nuclear Safety Review Panel, made up of representatives from DOE, DOD, and NASA, conducted independent reviews and analyses of the FSAR and related safety tests. After the review, the Panel issued a Safety Evaluation Report, which the Office of Science and Technology Policy used in approving the launch of the nuclear powered spacecraft.

DOE initiated planning and restart activities for the production of both GPHS components and the GPHS-RTG thermoelectric converters, in order to be prepared to meet NASA GPHS-RTG power system requirements for the CRAF and Cassini missions. The Department successfully completed an operational readiness review for the production at Oak Ridge of heat-source-clad vent sets made of iridium alloy and carbon bonded, carbon fiber insulator sets, and processing of qualification hardware began. Similar start-up activities for fueled clad fabrication, the GPHS module, and RTG assembly recently began at Los Alamos National Laboratory and Mound Plant of EG&G Mound Applied Technologies, respectively. After the termination of the GPHS-RTG qualification unit life test, the qualification unit was defueled and the fuel stored at the Mound Plant pending shipment to Savannah River for recycling. In January 1991 DOE awarded a prime system integration contract. The contractor's primary efforts have been focused on the reestablishment of the thermoelectric unicouple and converter production capability.

In FY 1991 the modular radioisotope thermoelectric generator program (MOD-RTG) focused on the design, development, manufacture, and test of improved multicouples both in an electrically-heated, engineering, 8-multicouple test module configuration and in individual multicouple test stations. Engineers collected over 6,000 hours of module test data; however, they terminated the test when power degradation occurred due to contaminants associated with the test environment. Test of four new individual multicouples in a high purity environment has proceeded through 3,600 hours with no abnormal power degradation. Testing of a high purity eight multicouple module has recently begun. The MOD-RTG design with its capability to tailor power to meet specific mission requirements will provide a significant advance in RTG specific power (watts/ kilograms) and improved efficiency for use in NASA's lunar, martian, and solar system exploration and DOD missions during the next decade. Other activities in FY 1991 included the development of a preliminary design for a new RTG shipping package and the continuation of construction on a new radioisotope power system assembly and testing facility.

SP-100 Space Reactor Program

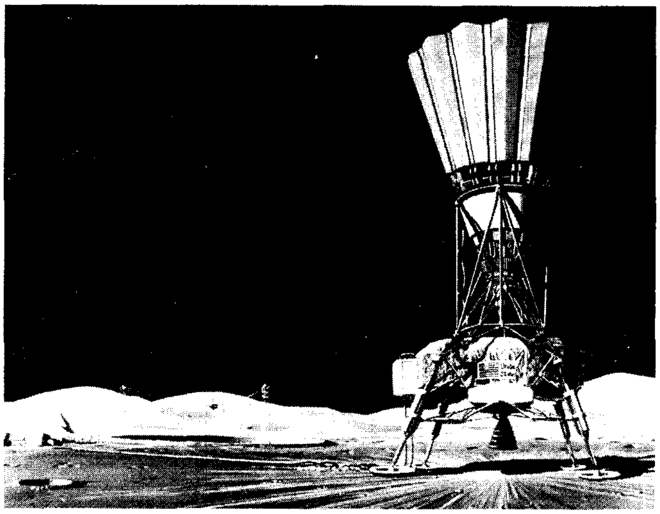
The purpose of the SP-100 program is to develop, demonstrate, and make available to NASA, DOD, and other potential users of space, nuclear reactor power system technology that can provide electric power in the range of tens to hundreds of kilowatts. This program began in 1983 and is sponsored by NASA, DOD, and DOE. This year, two exhibits have been added to the SP-100 Functional Requirements Document. They define NASA's projected space reactor power system requirements for surface power on Mars and the Moon and for nuclear electric propulsion for interplanetary exploration. The Air Force has joined DOE, the Strategic Defense Initiative Organization (SDIO), and NASA as a participant in the SP-100 Steering Committee and become a signatory to the memorandum of understanding. The Air Force has also provided an exhibit defining its requirements for space power but is not a funding agency. During FY 1991, the SP-100 program made progress in several major areas in its pursuit of a safe, reliable, long-lived, and versatile space power system. These advances were in the areas of thermoelectric cell development, fuel pin materials, and design of a viable radiation shield.

An SP-100 thermoelectric power conversion cell operated for 639 hours at temperatures up to 1,100 degrees centigrade. The cell produced 8.7 watts of electric power with a temperature gradient of 410 degrees. This represents a 17-fold increase in power output over the cells used in the Voyager/Galileo satellites. In addition, research conducted in 1991 demonstrated techniques that promise to improve the performance of future cell designs still further and should make it possible for the SP-100 program to realize its power output goal of 12.5 watts per cell.

Engineers were also making advances in the fuel pins for the SP-100 reactor. They successfully demonstrated manufacturing techniques to bond high-strength niobium zirconium (PWC-11) tubes to rhenium liners for fuel cladding. This cladding has greater creep strength and chemical stability in the reactor environment than cladding that uses standard niobium zirconium alloy tubing. This translates to greater design margins and improved reliability. All these attributes are important in designing and producing a space power system with a 10-year life.

Engineers tested the uranium nitride fuel under development for the SP-100 reactor to the full burnup (6 percent) required to support a 10-year mission. Upon examination after testing, it exhibited less outgassing and less swelling than predicted, which again contributes to a safer, more reliable design.

Radiation testing was completed on the lithium hydride (LiH) material to be used as the neutron radiation shield for the SP-100 reactor. Based upon the test data, a shield design incorporated LiH, beryllium, and boron carbide. It will provide the required shielding, while accommodating the high temperature experienced in close proximity to the reactor.



Artist's conception of SP-100 Space Reactor Power System being landed on the Moon.

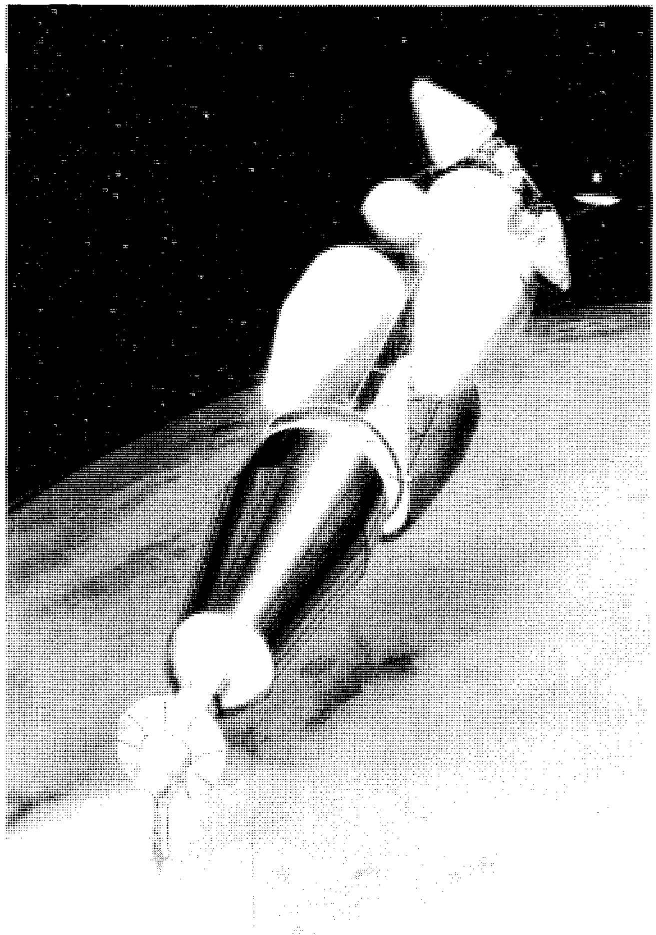
Thermionic Fuel Element (TFE) Verification Program

The TFE program is a component development effort established to resolve outstanding technical issues associated with the use of TFEs in space reactor power systems, so that thermionics could be a viable future technology choice. Thermionics, like thermo-electrics, is a means of converting heat directly to electricity without moving parts. It offers the potential of conversion efficiencies that are higher than thermoelectrics. The primary emphasis of this program is demonstration of a 7 to 10-year operational lifetime of TFE components sized for a 2-megawatt system through accelerated and real time testing in appropriate radiation environments.

DOE, the Air Force, and SDIO have signed an MOU on the development of Thermionic Space Nuclear Power Systems. Under this MOU, a program will be initiated to develop thermionic space nuclear power system technology to provide electric power for military applications in the range of 10 to 40 kilowatts for a lifetime to 2 to 10 years.

Space Exploration Initiative (SEI)

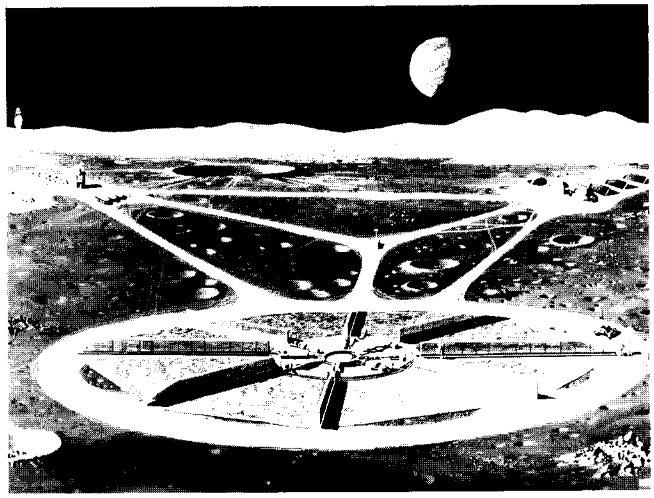
On July 20, 1989, President Bush announced the SEI and challenged us to land people on Mars before 2019, the 50th Anniversary of the Apollo lunar landing. In early 1990, the Secretary of Energy was added as a permanent member of the National Space Council, and Presidential policy for SEI established a major role for DOE, including technology development and concept definition. This policy statement also directed that investments be made in high leverage, innovative technologies, such as space nuclear propulsion and nuclear power, which could potentially make major impacts on SEI costs, schedule, and/or performance. Nuclear propulsion, for instance, offers several potential advantages over chemical propulsion. These advantages include the potential for shorter trip times, thereby reducing radiation exposure for the



Artist's conception of nuclear thermal propulsion.

astronauts, and smaller system mass resulting in lower launch costs. Surface electrical power will also play a critical and enabling role in lunar and Mars operations. Additionally, the DOE SEI effort will include a general subcategory of concepts and technologies to pursue the most promising SEI supporting technologies in which the Department has demonstrated expertise.

As part of the response to these directives, DOE, jointly with DOD and NASA, sponsored two nuclear propulsion workshops during the summer of 1990 to identify the technology status and issues involved in meeting the SEI propulsion requirements. After reviewing workshop results in early FY 1991, six DOE/DOD/NASA technical panels began to further assess specific nuclear propulsion technologies and issues, including mission analysis, nuclear electric propulsion, nuclear thermal propulsion, facilities, safety, fuels, materials, and related reactor technologies. Each technical panel received specific charters and direction, including preparing a written report by the fall of 1991.



Artist's conception of nuclear power on the surface of the Moon.

Nuclear Detonation Detection

Another important DOE responsibility in the space arena is providing the specialized sensors needed to satisfy national requirements for detection, identification, location, and characterization of nuclear detonations (NUDETs) anywhere within Earth's atmosphere or in neighboring interplanetary space. From the beginning, this program has been a joint effort of DOD and DOE. The program today has three primary objectives:

> Verification of compliance with the Limited Test Ban Treaty and the Nuclear Non-Proliferation Treaty, wherein nuclear testing was banned in the atmosphere, under water, and in space and the non-weapons states pledged not to manufacture or otherwise acquire nuclear weapons or explosive devices.
>
> Characterization of nuclear tests that occur outside the jurisdiction of the treaties or clandestinely in violation thereof.
>
> Detection and location of multiple atmospheric and near-earth nuclear bursts for strategic battle management in time of war.

The two departments have developed detector suites to address all three of these objectives simultaneously.

Sandia and Los Alamos National Laboratories maintain continuous development efforts for improving the underlying technologies. The goals of these efforts include better energy resolution, better timing, wider spectral coverage, greater reliability, and the development of advanced sensor concepts. In FY 1991 the labs placed emphasis on improved radiation hardening and miniaturization of the spaceborne electronic systems, on data compression logic to minimize communication channel demands, on the development of new detector concepts for the monitoring of x-rays, and on studying the effects of the space radiation environment on spacecraft systems. A highlight this year was the flight of the Uniformly Redundant Array Experiment aboard the Space Shuttle Discovery in April 1991 on STS-39. This was a coded aperture imaging system designed to investigate issues such as moving targets, thermal distortions, and background radiation rejection.

Communications Satellites

International Commercial Communications Satellites

As of October 1, 1990, the International Telecommunications Satellite Organization's (INTELSAT's) global communications system had deployed a total of fifteen satellites in geosynchronous orbit: seven over the Atlantic Ocean Region; four over the Indian Ocean Region; and four over the Pacific Ocean Region. The fourth INTELSAT VI series satellite, the INTELSAT VI (F-5) launched successfully on August 14, 1991, on an Ariane 44L commercial launch vehicle and was going to be ready for service in the Atlantic Ocean Region at the 335.5 degrees east longitude orbital location in October 1991. The last of the INTELSAT VI series, the INTELSAT VI (F-1) was scheduled for launch on an Ariane 44L launch vehicle in late October 1991 to replace the INTELSAT VI (F-4) at 332.5 degrees east longitude. The INTELSAT VI (F-4) will be moved to 63 degrees east longitude to serve the Indian Ocean region.

INTELSAT had plans to deploy the INTELSAT K satellite in March of 1992 to 338.5 degrees east longitude. Launch of the first two satellites in the VII series was scheduled for 1993. INTELSAT has also contracted with NASA for a shared STS mission in the April 1992 time frame in an effort to rescue the second INTELSAT VI series satellite, which failed to achieve geosynchronous orbit and was stranded in a low earth orbit some 300 miles high.

On June 28, 1991, the Commission granted the Orion Satellite Corporation's request for final authority to construct, launch and operate two Ku-band international satellites for which the United States and the United Kingdom had completed technical consultation with INTELSAT in August of 1989, pursuant to Article XIV(d) of the INTELSAT agreement.

In August 1991, the Commission granted conditional authority to Alpha Lyracom (doing business as Pan American Satellite) to construct, launch, and operate a hybrid satellite (PAS-4) with 24 C-band and 16 Ku-band transponders temporarily assigned to the orbital location at 192 degrees west longitude.

Domestic Commercial Communications Satellites

Satellites authorized in 1988 continued to be launched during FY 1991, with six domestic fixed satellites launched during the period. Five of these were expansion satellites launched into previously unoccupied orbital locations; one was a replacement satellite launched into the location of a satellite that was nearing the end of its fuel life. These satellites will provide domestic satellite capacity through the 1990s and will offer users a wide range of services including video, high speed data, private network, and audio services.

As of September 1991, 33 domestic fixed satellites were in orbit and located between 69 degrees west longitude and 141 degrees west longitude on the geostationary orbital arc. Thirty-five satellites were authorized for operation at that point in time.

Maritime Satellite Service

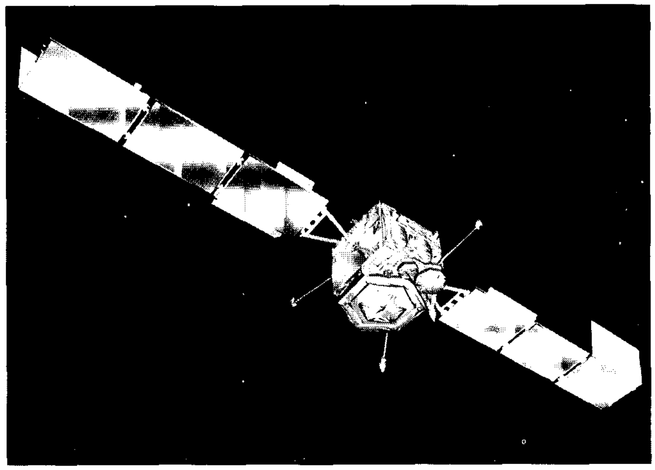
Efforts to establish a Global Maritime Distress and Safety System (GMDSS) were continuing. The GMDSS was expected to be phased in between 1992 and 1999. The International Maritime Organization (IMO) was developing the system, which initially will use the International Maritime Satellite Organization (INMARSAT) space segment and INMARSAT A, INMARSAT B, and INMARSAT C systems. On two other satellite systems, Emergency Position Indicating Radio Beacons (EPIRBs) were providing initial distress alerting information from ships to rescue coordination centers. The systems were the polar orbiting SARSAT, a NOAA Weather Service satellite for search and rescue satellite data tracking, and the Russian equivalent, called COSPAS. The INMARSAT Council, in mid-1990, approved L-band EPIRBs through the INMARSAT satellites at geostationary orbit.

INMARSAT served over 13,000 vessels through its 64 member-country organization. Twenty-four coast stations in 19 countries are in operation, with several more planned. At the end of the fiscal year, INMARSAT was leasing one in orbit satellite from the European Space Agency in the Atlantic Ocean Region-West; three in orbit INTELSAT Maritime Communications Subsystem (MCS) satellite packages in the Atlantic Ocean Region-East, the Pacific Ocean Region, and the Indian Ocean Region; and three satellites from Comsat General—two in the Pacific Ocean Region and one in the Indian Ocean Region.

The first INMARSAT second-generation satellite, the INMARSAT 2 (F-1), launched on October 30, 1990, and entered into service in the Indian Ocean Region in November 1990. It was followed by the INMARSAT 2 (F-

2), which launched on March 8, 1991, in the Atlantic Ocean Region-East and entered into service in April 1991. Launches were planned for the INMARSAT 2 (F-3) in the Pacific Ocean Region in December 1991 and for the INMARSAT 2 (F-4) in the Atlantic Ocean Region-West in the first half of 1992. The second generation satellites' capacity will roughly triple that of the leased first generation satellites.

In 1989, INMARSAT had issued a request for proposals for a third generation satellite system, including specifications for spot beams and the capability to operate within the full maritime spectrum. In early 1991, INMARSAT awarded a contract to General Electric Technical Services Co Inc. (GETSCO) for an initial order of four INMARSAT 3 satellites. In mid-1991, INMARSAT released a request for proposals for the procurement of launch services for these satellites, with a view toward awarding the contract(s) in the first half of 1992.



INMARSAT's first second-generation satellite, launched October 30, 1990.

Aeronautical Satellite Service

The process of adopting amendments to the INMARSAT Convention and Operating Agreement, which allow it to offer aeronautical services on a competitive basis, was completed in 1989 and the amendments were in effect during the period of this report. INMARSAT's four second generation spacecraft had three megahertz (MHz) of bi-directional bandwidth in the Aeronautical Mobile-Satellite Service (R) band. Two of these satellites were operational in the Indian Ocean Region and the Atlantic Ocean Region-East, with two more to be launched by mid-1992. The third generation satellites were expected to be capable of operating over the entire Aeronautical Mobile-Satellite Service (R) allocation of 10 MHz of bi-directional bandwidth.

The International Civil Aviation Organization through its subcommittee on Future Air Navigation Systems and the Aeronautical Mobile Satellite Service Panel (now called the Aeronautical Mobile Communications Panel) have been discussing standards for aeronautical satellite services and other issues involving the use of satellites in a coordinated program for civil aviation. The aviation community has developed, through the Airlines Electronic Engineering Committee, aircraft equipment standards for satellite voice and data services. The aviation industry, in cooperation with INMARSAT, was developing aircraft antennas and avionics needed for this service. Aeronautical Radio, Inc. (Arinc), was providing international data messaging via the Arinc Communications Addressing and Reporting System (ACARS) format by interconnecting its terrestrial very high frequency network with ground earth stations in the INMARSAT system for oceanic coverage. Arinc will also be providing voice messaging via the INMARSAT system. In addition, the American Mobile Satellite Corporation planned to provide exclusive U.S. domestic aeronautical mobile satellite service on its system.

Mobile Satellite Services

The U.S. mobile satellite service (MSS) satellite network will provide a variety of domestic land, aeronautical, and maritime mobile satellite services. The mobile telephone, radio, and data services proposed for the system will be used for long range vehicle dispatch and location services, emergency communications, rural telephone service, and paging service. Aeronautical voice and data communications were planned for both safety and commercial purposes, such as air traffic control and airline passenger communications.

The American Mobile Satellite Corporation (AMSC), the U.S. entity authorized to implement dedicated MSS space stations in 27 MHz of L-band spectrum, continued to build its system. The Commission granted AMSC temporary authority to continue to construct its system pending final action on a 1991 D.C. Circuit Court decision remanding two aspects of the Commission's 1989 decision to award the satellite system license to AMSC.

The Qualcomm Corporation continued to expand its mobile data communications network. Qualcomm was authorized in 1989 to construct and operate a two-way mobile satellite network that uses capacity on domestic fixed satellites. Qualcomm's network was designed to provide a variety of data services between a customer's operation center and its mobile users. In 1991, it was authorized to construct and operate an additional 20,000 mobile user units, bringing its total number of authorized units to over 40,000. Also, Canada and the United States agreed to permit cross-border roaming of certain mobiles without regard to normal U.S.-Canada border obligations.

Finally, in FY 1991 the Commission issued a Notice of Proposed Rulemaking to reallocate frequencies in the 137-138 MHz, 148-150.5 MHz, and 399.9-401 MHz frequency bands for a low Earth orbit satellite service. Low Earth orbit satellites orbit the Earth in a variety of orbital planes and would be able to provide a variety of low cost mobile data services to users.

Direct Broadcast Satellite Service

The Commission authorized the Direct Broadcast Satellite (DBS) service in July 1982, in order to provide satellite delivery of video programming directly to homes via small (2-3 foot diameter), relatively inexpensive ($300-$500) receiving stations. The Commission granted the first several conditional construction permits later that year.

The Commission has awarded DBS orbital positions and channels to three applicants. These parties are: United States Satellite Broadcasting Company, Inc.; Hughes Communications Galaxy, Inc.; and Advanced Communications Corporation. Each of the three permittees proposed to operate initially from a single orbital position cover-ing all of the continental United States, but they had plans to switch subsequently to paired east-west satellites, each covering half of the country. Six additional parties have received conditional DBS permits, and their requests for orbital positions and channels were being processed in order. Orbital positions and channels were awarded on a first-come, first-served basis. All permittees hoped to become operational in the mid-1990s.

International Conference Activities

In November 1990, INTELSAT's Assembly of Parties agreed that use of a separate satellite system for 100 sixty-four kilobit per second equivalent circuits interconnected with the public switched network would not result in significant economic harm to INTELSAT and could be consulted on an expedited basis by the Board of Governors. This policy was endorsed by the Executive Branch as consistent with U.S. plans. In March of 1991, the U.S., Bahamas, Costa Rica, the Dominican Republic, and Eastern Europe countries not members of INTELSAT, agreed at the Board of Governors meeting to use a Pan American Satellite (PAS-1) satellite for international public switched services comprised of not more than 100 sixty-four kilobit per second equivalent circuits.

In September 1991, the U.S. and the United Kingdom received INTELSAT approval of Article XIV(d) consultation for two 12-transponder C-band satellites operated by Columbia Communications under lease from NASA on board the Tracking and Data Relay Satellite deployed at 174 degrees and 41 degrees west longitude.

Department of the Interior

As the nation's principal conservation agency, the Department of the Interior is responsible for the management, conservation, and development of land and water resources on much of the nationally owned public lands. The Department uses data acquired by satellite and aircraft sensors to inventory natural resources and monitor changes on land under its management, and it conducts an active program of research and technique development in remote sensing and spatial data handling. The following bureaus were involved in remote sensing activities during 1991: Bureau of Indian Affairs, Bureau of Land Management, Bureau of Reclamation, Minerals Management Service, National Park Service, Office of Surface Mining Reclamation and Enforcement, U.S. Fish and Wildlife Service, and U.S. Geological Survey.

Remotely Sensed Data Acquisition, Processing, and Production

Satellite Data

Landsat. The U.S.Geological Survey maintained the U.S. Landsat archive at its Earth Resources Observation Systems (EROS) Data Center as part of the National Satellite Land Remote Sensing Data Archive. The archive contained approximately 960,000 scenes of data and references to more than two million Landsat scenes held by foreign Landsat receiving stations. The U.S. Geological Survey has begun to convert the U.S. Landsat archive to high-density magnetic tape cassettes, a next-generation durable storage medium. Landsat Thematic Mapper (TM) data will be converted first because these data have the highest current demand, followed by Landsat Multispectral Scanner data acquired since 1979. Even though MSS data acquired before 1979 are the oldest and face the highest probability of data loss, these data will be converted last because a new system to process the old wide-band video tapes is required.

Advanced Very High Resolution Radiometer. Since 1987 the U.S. Geological Survey EROS Data Center has been receiving and archiving NOAA Advanced Very High Resolution Radiometer data for the conterminous United States and portions of Canada and Mexico. Tape recorded AVHRR data of foreign areas have been received and archived via a Domestic Communications Satellite System since 1990; the archive now totals more than 22,000 AVHRR scenes. Uses of the data include Department of the Interior land science applications, global change research, and other Federal agency research projects. Discussions are under way with NASA, NOAA, and the European Space Agency to acquire a 1-kilometer resolution global AVHRR data set on a repetitive basis.

Aircraft Data

National Aerial Photography Program. The goal of the National Aerial Photography Program is to acquire complete aerial photographic coverage of the United States (except Alaska) at 1:40,000 scale every five years for applications in agriculture, forestry, soils, land and resource management, mapping, and Earth science studies. Approximately 75 percent of the United States (excluding Alaska) was covered during the first 5-year cycle using funds from Federal and state contributors. Federal agency participants include the U.S. Geological Survey (which manages the program), Bureau of Land Management, Agricultural Stabilization and Conservation Service, Soil Conservation Service, National Agricultural Statistics Service, U.S. Forest Service, and Tennessee Valley Authority. Contracts awarded in FY 1991 covered all or part of Kansas, Maine, Minnesota, Mississippi, eastern and central Montana, northern New Mexico, western and central North Dakota, South Dakota, eastern Washington, and western Texas. Because black and white panchromatic film is less expensive (and has higher resolution and wider exposure latitude) than color-infrared film, black and white film is a possible option to cover larger areas with limited funds. A commercial manufacturer also developed a new color-infrared film in 1991 to better meet the program's technical requirements.

Side-Looking Airborne Radar Data. The U.S. Geological Survey acquires side-looking airborne radar (SLAR) data to support re-search applications for energy and mineral exploration, hydrologic studies, earth-hazards investigations, and glacier and ice-sheet mapping. Since 1980 the Survey has acquired these data for approximately 40 percent of the nation. During 1991 it acquired SLAR data for approximately 287,000 square kilometers of Alabama, Arizona, California, Colorado, Illinois, Kansas, Louisiana, Mississippi, Missouri, New Mexico, Texas, Utah, and Wisconsin. Digital data for these study areas will be available on compact disc, read only memory for convenient storage and ease of use.

Remote Sensing Research and Applications

Renewable Resources

Resource Inventory and Assessment. The National Park Service continues to use an integrated remote sensing and geographic information system approach to resource management and analysis on a bureau-wide basis. During 1991 it used two new techniques for park planning applications. In the first project, it used the Environmental Protection Agency's aircraft-based thermal-infrared scanner to collect data with high spatial resolution (approximately 3.5 meters) for the developed areas and the entire road system of Yellowstone National Park. Geographic coordinates obtained by linking the scanner to the aircraft's Global Positioning System allowed the Service to perform preliminary rectification of the thermal-infrared data. The data are being used to detect previ-ously unknown thermal areas that may affect decisions concerning alternative road realignments and the development of other park facilities.

In the second application, the National Park Service coop-erated with the University of Minnesota to merge Landsat TM and terrain-corrected panchromatic data from the French Satellite Pour l'Observation de la Terre (SPOT) system to produce multichannel data sets. These data sets, which have the spectral information of the Landsat TM data while retaining the high spatial resolution and registration accuracy of the SPOT data, are being used for land cover classifications and view-shed analyses to support planning activities on the recently designated Mississippi National River and Recreation Area in Minnesota.

The Bureau of Reclamation used remote sensing and geographic information system techniques to monitor irrigated lands in the Newlands Irrigation Project in Nevada and along the lower Colorado River in Arizona and California. Crop maps generated from Landsat TM data were being combined with other data to assist scientists and managers in studying consumptive water use and irrigation efficiency.

The Bureau of Reclamation was also building a large digital geographic data base of selected sites encompassing 40 kilometers of the Colorado River within the Grand Canyon. This data base will aid in assessing environmental changes caused by the Glen Canyon Dam and in developing future operating criteria for the dam. This data base contains 0.6-meter topographic contours derived using photogrammetric techniques, river channel morphology, land cover data derived from current and historic aerial photographs, and other field-collected information.

The Bureau of Reclamation also used current and historic aerial photographs and ancillary data to develop geographic data bases in support of reservoir-management-plan development at Elephant Butte Reservoir, New Mexico; Owhyee Reservoir, Oregon; American Falls Reservoir, Idaho; and Bureau of Reclamation lands in the Columbia River Basin.

The Bureau of Land Management obtained both aerial photographs and satellite data to aid in public land management. In addition to participating in the National Aerial Photography Program, the Bureau acquired aerial photographs for approximately 36,000 square kilometers of portions of New Mexico, Idaho, and Oregon for recreation site development, mineral development operations, wilderness study analysis, and forest and rangeland monitoring. It concluded a study in the use of large-scale aerial photographs for the inventory and monitoring of surface resources and published a technical reference on this subject. In addition, it obtained large-scale aerial photographs for approximately 1,280 linear kilometers for riparian stream studies being carried out in New Mexico, Nevada, Oregon, and Colorado.

The Bureau of Land Management used Landsat TM data to map and monitor vegetative land cover on 28,000 square kilometers of land in southwestern New Mexico and southwestern and north-central Wyoming. It used two dates of Landsat TM data to assess biophysical change in a designated wilderness area in New Mexico and other Landsat TM data to generate soil maps for a 900-square-kilometer area in Utah.

The Bureau of Indian Affairs conducted several resource inventory and assessment projects that support its Indian Integrated Resource Information Program. It employed Landsat TM data to classify land cover digitally, with emphasis on modeling fire fuels on the Northern Pueblos of New Mexico. Land use and land cover data were digitally extracted from Landsat TM data for forest management on the Colville (Washington) Indian Reservation. SPOT panchromatic images were visually interpreted to update existing road networks on the Northern Pueblos (New Mexico) and Jicarilla (New Mexico) Indian Reservations. Results of these projects were permanently archived as part of the Bureau of Indian Affairs National Data Base.

The U.S. Geological Survey used aerial photographs from the National Aerial Photography Program to test new equipment and procedures for land use and land cover mapping for an area near Champaign, Illinois. The primary reasons for using these photographs were their suitability for interpreting the necessary land use and land cover categories and their good image quality. Because these photographs provide systematic coverage of the conterminous United States, they would be available for mapping land use in other parts of the country. These photographs were also being used to generate digital orthophotoquads, which can serve as a possible source for collecting land use and land cover data. (To make digital orthophotoquads, the Survey scans film diapositives to generate digital images and then uses control point coordinates and digital elevation model values to rectify the images and ensure their geometric accuracy.)

Resource Mapping in Alaska. During the past 11 years, the U.S. Geological Survey has worked cooperatively with Federal and state resource management agencies in Alaska to produce land cover and terrain maps and corresponding digital data bases for more than 1.13 million square kilometers. In 1991 the U.S. Geological Survey and the U.S. Fish and Wildlife Service began collecting and studying baseline satellite and thematic data to monitor large-mammal habitat and migration on the coastal plain of the Alaska National Wildlife Refuge. The two agencies were also using SPOT data and multitemporal aerial photographs to determine the extent and abundance of eel grass beds along the Pacific flyway from Mexico in the south to Alaska and the Soviet Union in the north. (Eel grass is the sole food source for the Pacific Black Brant goose during its biannual migration.) The Bureau of Land Management, relatedly, cooperated with Ducks Unlimited to identify and map waterfowl habitat using Landsat TM data for 14,000 square kilometers in east-central Alaska.

Wetlands Mapping and Inventory. The U.S. Fish and Wildlife Service continued to map the Nation's wetlands, as mandated by the Emergency Wetlands Resources Act of 1986 and in keeping with the President's challenge to conserve the Nation's wetland resources. It used aerial photographs, acquired through both the National Aerial Photography Program and the National High Altitude Photography Program, to conduct the National Wetlands Inventory. Wetland maps derived from these data sources were available at the end of FY 1991 for 70 percent of the conterminous United States (scale of 1:24,000) and 22 percent of Alaska (scale of 1:63,360). The annual rate of map production is 3,200 detailed wetlands maps for the conterminous United States and 60 maps for Alaska. The number of users has grown steadily since the maps were first released. Requests are common from individuals, all levels of Federal, state, county, municipal, and town governments, and educational and research groups including colleges and universities. More than 150,000 copies of wetlands maps are disseminated annually. Total wetland map dissemination is approaching 1.4 million copies. Maps are sold through 28 state distribution centers and a toll-free telephone service.

The National Wetlands Inventory has also used aerial photographs to monitor changes in national wetland acreage. The national status and trends study updates vital information on wetland trends via a periodic report to Congress. As this monitoring evolves into a continuous process, the National Wetlands Inventory will take advantage of other remote sensing tools, such as AVHRR data, to further stratify wetland regions in the nation. Developments in automated airborne video imaging may also be useful for updating wetland acreage statistics in the future.

The Bureau of Reclamation used historic and current large-scale aerial photographs to aid in studies of wetland dynamics in the James River Basin, North Dakota; the Klamath Lake area, Oregon; and the Black Sands area, Washington. Digitized maps stored in a geographic information system are easily compared to show trends in wetland vegetation over time so as to validate and calibrate ecological models.

As part of the Colorado River endangered fish recovery program, the Bureau of Reclamation has used airborne video images to monitor endangered fish habitat in the Colorado River Basin. Maps of side channels and backwaters on more than 300 kilometers of river channel each year document both the existence of critical habitat and river channel changes over time. The Bureau of Reclamation also uses large-scale airborne video sensing tech-niques to monitor aquatic weeds and other aquatic pests along the Hayden-Rhodes Aqueduct in Arizona. It targets areas with signif-icant problems for treatment, and it obtains video imagery again after treatment to determine its effectiveness.

Wildfire Mapping and Monitoring. The Boise Interagency Fire Center maintains a fire fuels and terrain data base that consists of fire fuel classes and the terrain parameters (slope, elevation, and aspect) for western lands administered by the Bureau of Land Management. The Bureau of Land Management developed the fire fuels data base using AVHRR data. In addition, a Remote Automatic Weather Station (RAWS) network developed by the Bureau of Land Management provided near real time remotely sensed weather information on a continuing basis for Bureau of Land Management lands in the conterminous United States and Alaska. The self-contained RAWS meteorological collection platforms collect and summarize weather data and then transmit it through the NOAA Geostationary Operational Environmental Satellite system to central site operations at the Boise Interagency Fire Center. Fire Managers use the fire fuels and terrain and RAWS data in planning for firefighting and in predicting fire behavior.

The Bureau of Land Management, U.S. Geological Survey, and U.S. Forest Service participated in a project to monitor seasonal changes in vegetation greenness using an AVHRR-derived vegetation greenness index. The purpose of this study was to determine the use of this index as a surrogate for assessing live fuel vegetative moisture for fire danger and behavior modeling. In another cooperative project with NOAA and the National Park Service, the Bureau of Land Management pursued a study testing the potential of using AVHRR data for the automated detection of wildland fires.

Hydrology

The Bureau of Reclamation used digital terrain data derived from stereoscopic aerial photographs or from topographic maps to quantify topographic characteristics of drainage basins for use in flood studies. It derived drainage basin parameters (such as basin perimeter, basin area, length of stream network, and slope of stream network) from the terrain data and used them to develop improved prediction equations for rain flood volume and lag time. These equations allowed the Bureau to assess the adequacy of existing flood control dams and set specifications for new dams.

The Bureau of Reclamation continued to generate maps of water transparency, chlorophyll-a concentration, and surface water tem-perature from Landsat TM data. Landsat data provide a valuable indicator of the trophic condition of a lake that cannot be obtained from surface sampling methods.

The Bureau of Reclamation continued to cooperate with the National Weather Service to develop new methods for snow-cover mapping using AVHRR data. Accurate estimates of snow-covered areas are critical for making accurate snowmelt runoff estimates. Emphasis in 1991 was on obtaining more accurate snow-covered area information from oblique aerial photographs to calibrate estimates derived from AVHRR data.

As part of the joint U.S. Geological Survey, NASA, and U.S. Department of Agriculture's satellite passive microwave study of the snowpack in the Upper Colorado River Basin, an 8-year climatology of this vital snowpack was developed using AVHRR observations acquired from 1979 to 1986. This study found a strong correlation between the Upper Colorado River discharge and the spatially averaged satellite observations. The cooperators have continued to collect snowpack property data at key sites across the basin. This unique 8-year data set contains the only synoptic information on the snowpack grain size, which is one of the two fundamental parameters that determine the passive microwave characteristics of a snowpack. The other parameter, the water equivalent, is obtained from the Soil Conservation Service. These data are being analyzed along with the satellite observations to develop algorithms for the determination of snowpack properties.

Oceanography

The Minerals Management Service sponsored research at Oregon State University to develop tags equipped with Argos satellite radio transmitters to monitor the migration of individual right whales along the Atlantic coast and bowhead whales in the Arctic Ocean. Two right whales were tagged and tracked along the northeast Atlantic coast for 6-week intervals. There was additional field work with right whales off Nova Scotia and with bowhead whales in the Arctic. The information collected on marine mammal migrations is used in planning offshore oil and gas activities to minimize the impacts on marine mammals.

Satellite-tracked drifting buoys, deployed in conjunction with a series of intentional oil spills off the coast of Norway, evaluated how well the buoys could follow surface slicks. Satellite-tracked drifter buoys, deployed in the Florida Straits, provided information on ocean currents for future modeling efforts.

Geology

Multispectral Data Analysis. U.S. Geological Survey scientists continued research using NASA Airborne Visible and Infrared Imaging Spectrometer data for lithologic mapping and mineralogic determinations in semiarid terrains. The U.S. Geological Survey also has entered into collaborative research with the Center for the Study of Earth from Space at the University of Colorado, Boulder, to develop techniques to analyze data to be collected by the High Resolution Imaging Spectrometer (HIRIS) scheduled for deployment on the Earth Observing System. The Airborne Visible and Infrared Imaging Spectrometer is already used to test numerous data-visualization techniques for atmospheric correction and information extraction as a precursor to HIRIS.

Underground and Surface Mining Applications. The Office of Surface Mining continues to use aerial photographs as part of its program with coal mining companies and state regulatory agencies to design, monitor, and reclaim surface coal mines. Aerial photographs served as the base for topographic maps to help plan mines and calculate earthwork volumes. Other design uses included evaluating the soil resources of areas to be mined and identifying the location of pre-mining drill-hole sites used to determine the geologic structure of mining sites.

The Office of Surface Mining used aerial photographs to determine regulatory compliance by identifying and monitoring areas under construction, areas to be reclaimed, wildcat mining sites, spoil ridges, and acid mine drainage. In other cases, 35 mm and 70 mm aerial photographs and videotape of inaccessible areas detected large surface cracks created by underground mining and helped to assess the danger posed by abandoned surface mines. The Office of Surface Mining also used aerial photographs for surveying and mapping hot spots in burning coal refuse to aid in planning to extinguish the fires by moving the coal refuse.

The Bureau of Land Management used SPOT panchromatic data to define areas of surface disturbance associated with gold mining activity near Ely, NV. Disturbances from mining were detected for a 12-square-kilometer area.

Radar Applications. Synthetic aperture radar systems are well-suited for measuring geophysical parameters for use in geological studies. However, topographic variation of the land surface distorts radar geometry and strongly alters radar backscatter, obscuring information such as surface roughness and surface dielectric properties. The U.S. Geological Survey was investigating data processing approaches that use available digital elevation models to characterize these terrain-induced effects and to correct radar imagery to a map base. Current research has focused on the PROgramme SPot Et Radar (PROSPER) initiative, a French program linking the use of SPOT data with radar data. The correction investigated in PROSPER was based on the geometric characteristics of the Seasat satellite sensor, the digital elevation models derived from SPOT data, and traditional photogram-metric techniques. Although local elevation differences in the digital elevation data sets introduced some discrepancies into the data, the results showed that the use of SPOT-derived elevation models for radar terrain correction and incidence angle modeling performed nearly as well as the 7.5-minute U.S. Geological Survey digital elevation model.

The U.S. Geological Survey evaluated radar geocoding and terrain correction software packages from the Jet Propulsion Laboratory, Defense Mapping Agency, and German Aerospace Research Establishment. Based on these evaluations, the U.S. Geological Survey developed radar geocoding and terrain correction routines (using digital elevation models of any resolution) and implemented them using the Land Analysis System image processing software. This system is able to correct radar imagery to any of 23 map projections.

Planetary Studies

Galileo Encounter of the Earth and Moon. The Galileo spacecraft flew past the Earth and Moon in December 1990 for a "gravity assist" on its way to Jupiter.

Basins and ridges on Venus appear in this computer-generated perspective view produced using radar data from the Magellan mission. The spider-like fracture patterns ("arachnoids") are believed to be related to volcanic upwelling followed by subsidence that formed the basins; note the bright lava in the foreground. Topography has been exaggerated 20 times.

The U.S. Geological Survey is cooperating with the Jet Propulsion Laboratory to write computer programs that generate images from the multispectral data Galileo collected to produce various planetary maps of the Earth and Moon. One of these maps depicts the discovery of enhanced iron content within the giant lunar basin of South Poie-Aitken.

Public Distribution of Magellan Data. The Magellan mission has provided the world of planetary science with a diversity of systematic, high resolution data of Venus. As part of the ongoing effort to distribute information about Venus to the public, the U.S. Geological Survey is cooperating with the Jet Propulsion Laboratory to redefine the approach for Magellan science support. The plan includes the traditional compilation of global mosaics, airbrushed shaded relief maps, and high resolution maps of areas of particular scientific interest. In addition, several new products were generated to visualize scientific information using computer techniques to combine elevation and surface property information with radar measurements. Two new products—a series of computer-animated movies and a planet-wide set of stereoimage pairs—have been received enthusiastically as innovative ways to visualize scientific information.

Cartography

Shaded Relief Mapping. The U.S. Geological Survey uses digital image processing technology to extract new information from older data gathered by aerial photography. It made one such product, a computer-shaded graphic of topographic land forms of the United States, by digitizing contour elevations from published topographic maps. The images portray surface features accurately and without distortion or interference from vegetation and clouds. They have uses in navigation, resource evaluation, mitigation of natural hazards, hydrologic studies, and analysis of regional and structural geology. Shaded relief mapping is complete for the entire conterminous United States. A recent image, computed from 12,000,000 elevation values at a relatively high spatial resolution (800 meters per grid cell), reveals more terrain detail than continent-wide maps compiled by manual (artistic) techniques.

Satellite Image Mapping. The U.S. Geological Survey produces satellite image maps from data acquired by a variety of satellite sensors, including AVHRR, Landsat MSS and TM, and SPOT. It modi-fies image map formats to suit specific requirements by using appropriate sensor band combinations, by imbedding projection grids and map collar annotation, or by combining other derived data with the base image data. The Survey completed projects in FY 1991 for a variety of Federal agencies, including the Department of Defense in support of

Operation Desert Shield and Desert Storm, the Defense Mapping Agency, the Central Intelligence Agency, the Department of the Army's Deputy Chief of Staff for Intelligence, the Agency for International Development, and the Bureau of Indian Affairs.

The Bureau of Indian Affairs continued to produce satellite image base maps by incorporating township grid and geographic coordinate information with Landsat TM data. It prepared such maps for the Ft. Peck (MA), Colville (WA), Yankton (SD), and Rosebud (SD) Indian Reservations. It produced a special image map with Landsat TM data for the region around the Franklin D. Roosevelt Reservoir (Washington) that is being used to address inter-jurisdictional issues along the lake corridor.

The U.S. Geological Survey cooperated with NOAA and the National Remote Sensing Center in the United Kingdom to produce a satellite image map at 1:5,000,000 scale for the continent of Antarctica from AVHRR data acquired between 1980 and 1987. The National Remote Sensing Center performed radiometric and geometric correction and compilation in preparation for the final image map. The U.S. Geological Survey conducted the geometric accuracy evaluation, edited the digital data, and rescaled and processed the materials for image map preparation.

Global Positioning System. The Bureau of Land Management uses the Global Positioning System (GPS) as a surveying and mapping tool to support natural resource management activities. Field-portable GPS receivers allow the digitizing of resource data in real time at more than five times the previous accuracy levels. Programs as diverse as archeology, wildfire management, cadastral survey, and photogrammetric mapping can greatly benefit from this spatial capability. The Bureau of Land Management also used GPS in an experimental cadastral survey project in the Anchorage, AK, area that demonstrated the capability of positioning ground control points to within 1.5 meters of their true positions.

The U.S. Geological Survey continued in FY 1991 to inves-tigate new applications for GPS technology. GPS systems are being used to develop cost effective techniques for establishing control for topographic mapping and the revision of 1:24,000-scale maps, to locate ground water test wells, to provide control data for subsidence projects, and to measure crustal motion in California and ground deformation in volcanic areas such as Hawaii. The U.S. Geological Survey is acquiring new hardware and data reduction software so that it can take maximum advantage of the space-borne GPS system when it becomes fully operational in 1993.

The U.S. Geological Survey was also evaluating the potential of using satellite data and GPS technology for first-time mapping in the Amazon that meets conventional horizontal accuracy standards and acceptable image resolution at 1:50,000 scale. The project is being conducted under the auspices of the Pan American Institute of Geography and History in cooperation with the Servicio Autonomo de Geografia y Cartografia Nacional de Venezuela, Instituto Geograficao Nacional de España, and Instituto Cartogrâfico de Catalunya. An unmapped area of approximately 12 by 20 kilometers in the Amazon territory of Venezuela serves as the test site. Preliminary findings show that the use of satellite image processing and geodetic positioning technology are a practical means of achieving accurate mapping in isolated, poorly mapped forest regions of the Venezuelan Amazon territory.

The Bureau of Land Management uses satellite communications technology linked to LORAN (Long Range) navigation systems to determine the location of airplanes that have crashed or made emergency landings. This developing technology allows the identification of an aircraft's last position to a few hundred meters for rapid emergency response. The aircraft's location is derived from LORAN and is uplinked to the Geostar satellite. This "flight following" system will assist in quick rescue operations to the last recorded aircraft position, thus reducing loss of life.

Global Change Research

Ice and Climate Project. The U.S. Geological Survey Ice and Climate Project actively participates with international cooperators in research to understand the variations of the cryosphere—sea ice, snow, ice sheets, and glaciers—in the global hydrologic cycle. These variations strongly affect the world's water resources through the complex interactions among the cryosphere, the atmosphere, and the ocean at time scales that range from days to decades and longer. Project investigators performed prelaunch experiments, developed data processing algorithms, and organized postlaunch experiments for the first European Space Agency European

Research Satellite, ERS-1, that was launched successfully in July 1991 and for the Franco-American Topex-Poseidon Satellite (TOPEX). The postlaunch Seasonal Ice Zone Experiment expedition will take place in 1992 and will involve remote sensing aircraft, ice-breakers, and oceanographic ships manned by scientists from eight countries. A TOPEX postlaunch experiment will take place in the Norwegian Sea in late 1992.

Monitoring Desertification. Global warming causes an increase in desertification of continental interiors. It also increases the occurrence of dust storms, which are indicators of extreme aridity. The U.S. Geological Survey uses computer processing of satellite data to track dust storms in the continental United States as part of the environmental assessment of desert regions. Windblown sand and dust are a significant hazard to human activity; increased development of desert regions has long term implications to human survival. Hence, the need for this program.

Earth Observing System. The U.S. Geological Survey EROS Data Center has been designated by NASA as the Distributed Active Archive Center for Land Processes data to be acquired by the NASA Earth Observing System (EOS). As part of the NASA EOS Data and Information System, U.S. Geological Survey prototype system- development activities have concentrated on a distributed information management system to link the various archive centers into a "one-stop shop" for earth science data. Additional tasks included early planning and design work to collect and process several types of global data, including digital topographic data, aircraft instrument data, and Landsat and AVHRR data. These "precursor" data sets are being used to develop algorithms and science scenarios in preparation for eventual data acquisition from the EOS instruments. (See related coverage above.)

Global Land Information System. As one of its contributions to the U.S.Global Change Research Program, the U.S. Geological Survey began testing a prototype of the Global Land Information System in 1991. It developed this interactive information system to assist scientists seeking information about, and access to, data on the Earth's land areas for use in continental and global scale earth science and global change studies. The U.S. Geological Survey EROS Data Center archives of AVHRR and Landsat data are the major satellite remotely sensed data sets currently indexed by the system, but the data inventory will be continually expanded. The system contains references to a variety of regional, continental, and global land data sets, provides query features to assist in determining the availability of data sets, and supports online requests for data products. The system can be accessed through a personal computer-based user interface and will be fully opera-tional in 1992.

Prototype Land Data Sets for Global Change Research. The U.S. Geological Survey continued to organize, produce, and distribute land-related data sets to support the global change research community. Scientists will use these data to quantify land surface parameters for land processes models, to detect and monitor land surface change, and to map land-use and land-cover conditions. Data set development efforts include the production of composited Normalized Difference Vegetation Index (NDVI) data sets using calibrated and registered 1-kilometer resolution AVHRR data including: (1) the 1990 and 1991 data for the coterminous United States (which are being distributed on CD-ROM media), (2) 15-day composites of Alaska for 1990 and 1991, and (3) 10-day composites for Eastern Europe and Western Asia during the growing season from 1986 to the present. A prototype 10-day NDVI composite data set of North America was produced from 1990 data in cooperation with the Canada Centre for Remote Sensing, and periodic composites will be produced for North America during the 1992 vegetation growing season.

The U.S. Geological Survey is also developing several Earth science data sets that can be integrated and analyzed with satellite-acquired data sets. Current activities include develop-ment of a 0.5-kilometer resolution digital elevation model data set for North America and a data base of global soils attributes using the United Nation Food and Agriculture Organization global soils map.

Baseline Studies for Monitoring Global Climate Change. For the past 2 years the U.S. Geological Survey has monitored Arctic ecosystems in Alaska affected by global climate change. At year's end it was in the process of establishing computerized, spatially-referenced data bases with historic and current remotely-sensed and thematic Earth science data at multiple scales for 10 study sites, each of which is about 100 square kilometers in area. The range of scales permits the extrapolation of local processes to global scales, and vice versa. Several data sets are also being organized into a statewide data base for Alaska: NDVI products from AVHRR data, mean annual precipitation from stream gage information, the 1965 permafrost map, a published map of the physiographic provinces, a statewide digital elevation-model mosaic from 1:250,000-scale sources, and 1:2,000,000-scale boundary data.

Sites have been identified for microscale monitoring at the Colville River Delta on the Arctic coastal plain, at the Bonanza Creek Long-Term Ecological Research site in interior Alaska, and on the coastal plain of the Alaska National Wildlife Refuge. Large data bases have been created for the first two sites with, in part, shared data from collaborators—the U.S.Fish and Wildlife Service, the University of Alaska at Fairbanks, and the National Science Foundation. Data types include Landsat MSS and TM, SPOT, and AVHRR data, 1:63,360-scaledigital elevation-model data, National Wetlands Inventory data, boundary data, and land cover and wildlife habitat data. The third site resulted from a cooperative agreement with the U.S. Fish and Wildlife Service to establish a cooperative monitoring program in the Alaska National Wildlife Refuge. High resolution airborne MSS data is being acquired over the entire coastal plain and foothills regions of the Alaska National Wildlife Refuge.

The Bureau of Land Management established the Environmental Science and Technology Center, a cooperative research unit with Colorado State University. Part of the work of this unit has been developing techniques for choosing ground based sites for global change monitoring using geographic information system technology to integrate Landsat TM and SPOT satellite images with other biophysical land attributes.

Land Cover Characterization. U.S. Geological Survey scientists developed a Coterminous United States Land Cover Characterization Data Base to evaluate the potential of using 1-kilometer resolution AVHRR data and ancillary regionally-descriptive attributes in characterizing global land cover. The data base consists of: (1) a set of homogeneous, seasonally distinct land cover regions that are derived from classification of multitemporal 1990 AVHRR vegetation index data and (2) corresponding regional descriptions consisting of vegetation and land cover composition, terrain elevation, climate, soil characteristics, growing-season parameters, and surface albedo or brightness. The attributes serve as a source of variables that can be aggregated to match specific classification systems.

International Activities

Africa

The U.S. Geological Survey continued to support the U.S. Agency for International Development through technical assistance projects based on remote sensing and geographic information sys-tems on the African continent. In early 1989, the U.S. Geological Survey became involved in the U.S. Agency for International Development project called AGRHYMET (AGRiculture HYdrology and METeorology). Since its inception in the 1970s, this project has sought to improve hydrological and meteorological data management for agricultural decisionmakers in nine west African countries and the World Meteorological Organization. A U.S. Geological Survey project team assists the AGRHYMET Regional Center in Niamey, Niger, to provide support for the National AGRHYMET Centers in each of the member countries (Mauritania, Mali, Burkina Faso, Niger, Chad, Senegal, The Gambia, Guinea Bissau, and Cape Verde). Successful technology transfer included computer hardware upgrades and the installation of image processing and geographic information systems software. The Center's full capability to receive, process, and distribute AVHRR data has been successfully used to provide vegetative condition mapping for the nine member nations during 1991.

The U.S. Geological Survey also continued to provide technical assistance to the U.S.Agency for International Development's Famine Early Warning System project. The Famine Early Warning System was established five years ago to assess and identify populations at risk for food shortages and famine in seven nations of the African Sahel. The U.S. Geological Survey provides technical expertise in: (1) the archive and management of a Famine Early Warning System data base, including AVHRR data, cartographic reference maps, and various socioeconomic data; (2) the development of data-handling and analysis procedures on personal computer systems used in Africa; and (3) training in technology awareness, as well as specific computer techniques and data bases that are part of the famine analysis process. U.S. Geological Survey expertise in data analysis is most relevant to the use of AVHRR greenness index data to evaluate the vegetation condition in a growing season.

Middle East

The U.S. Geological Survey continued its support of remote sensing activities in the Middle East. It supported the Saudi Arabia Directorate General for Mineral Resources' Remote Sensing facility with mineral-resource and general geologic mapping studies. Landsat image maps were produced at several scales for the Abu Dhabi Emirate, United Arab Emirates, to support ground water studies and general geologic mapping. At the request of the Yemen Government and U.S. Agency for International Development, the U.S. Geological Survey provides assistance in the application of airborne and satellite remotely sensed data to mineral resource assessments in North Yemen.

The U.S. Geological Survey supplied digital data, satellite images, and more than 350 image maps of various areas of the Arabian Peninsula to the Department of Defense and intelligence communities in support of the Persian Gulf War. Enhanced Landsat TM images were produced at scales ranging from 1:50,000 to 1:250,000 for change detection, map updates, and terrain analysis of Kuwait and portions of Saudi Arabia and Iraq, including the city of Baghdad. AVHRR data provided the basis for a photoimage mosaic of the Middle East for Department of Defense agencies. In the final phases of Operation Desert Storm Landsat TM data helped to evaluate the extent of the Kuwait oil field fires and the oil slick in the Persian Gulf. These data also aided military operations and assisted in environmental monitoring. During Operation Desert Shield and Desert Storm, the U.S. Geological Survey maintained a digital data archive and catalog system at the EROS Data Center of all civil satellite data purchased and all products produced for Department of Defense agencies.

The Survey provided a set of AVHRR data products of the Kuwait and Persian Gulf area covering the entire war period to United Nations Environment Programme offices in Geneva, Switzerland, and Nairobi, Kenya. The United Nations Environment Programme also provided a copy of the digital data to the Government of Japan to assist it in developing funding alternatives to aid in the reconstruction of Kuwait.

Latin America

U.S. Geological Survey scientists conducted a training program on the use of Landsat TM data for mineral exploration in the central Andes of South America. The training covered techniques for digital image processing and interpretation and was coupled with field and laboratory studies of some important mineral deposits in the region. Geologists from Bolivia, Chile, and Peru participated in the training program, which the Inter-American Development Bank sponsored.

In a cooperative mineral-resource assessment with the Geological Survey of Bolivia and the U.S. Trade Development Program, the U.S. Geological Survey used digitally processed Landsat TM data to prepare a map showing areas of potential hydrothermally-altered rocks in the Bolivian Altiplano. Landsat data also helped to identify volcanic features and geologic structures, to discriminate between lithologic units, and (as index and field maps) to locate potentially mineralized sites for field evaluation. Future investigations will center on identified anomalies that are related to areas of known mineralization and past mining and on other anomalies associated with geologic structures that are not known to be mineralized.

The U.S. Geological Survey cooperated with the Direccion General de Geografia of Mexico and the Inter-American Geodetic Survey of the Defense Mapping Agency to test the application of SPOT panchromatic and multispectral data, Landsat data, and personal computer-based technology for change detection and map revision at 1:50,000 scale. Approximately 70 percent of the changes in planimetric and thematic detail on the Aguascalientes, Mexico, map could be revised using the merged Landsat TM and SPOT panchromatic data set. Approximately 65 percent of the detail could be revised with SPOT panchromatic data alone. The use of personal computer-assisted techniques and satellite data produced a revised map at 1:50,000 scale that meets acceptable positional accuracy.

Antarctica

The U.S. Geological Survey has prepared new hybrid maps of North Victoria Land that combine aeromagnetic, geologic, and Landsat image maps from the GANOVEX IV expedition area of Antarctica. These maps aid in geologic interpretations by correlating geologic and aeromagnetic information. They show that old basement rocks have low magnetic relief and that younger volcanic rocks correlate with positive magnetic anomalies. This information helps identify ore deposits.

Department of Agriculture

Agencies in the U.S. Department of Agriculture (USDA) continued to develop remote sensing techniques and methodologies to monitor major sensitive aspects of land cover and the environment—water quality, vegetation health, disease and insect infestations, and the effects of natural disasters such as fires, droughts, and floods. Aerial photography has been and will continue to be an important source of remotely sensed data in USDA. However, electronic sensors that provide digital data rather than film were becoming vital components of land cover and environmental analysis. The advantages are numerous. Analysis can be performed quickly and easily on computers, computer files can be more easily stored than hard copy products, and digital data from remote sensors can be combined with digital data from other sources for detailed analysis previously not possible or too expensive.

Space Data Used to Monitor Crops Worldwide

For more than ten years, the Foreign Agricultural Service (FAS) has used satellite imagery to routinely assess current crop conditions in various countries. Based on extensive research in the mid-1970s, FAS continued the development of techniques and procedures to use data from the Landsat satellite system and polar-orbiting weather satellites to obtain early indications of weather-impacted harvests, both bumper grain crops and those reduced by drought. The FAS has been particularly interested in obtaining up-to-date information from areas that have not been readily accessible to its attaches or other observers or that do not have adequate crop reporting systems.

In FY 1991, FAS continued to use data from Landsat satellites and NOAA polar-orbiting environmental satellites to monitor and assess the conditions of agricultural crops around the world. The remotely sensed data provided critical information so that USDA personnel could make timely and realistic production assessments for key commodities in world markets.

Remote sensing specialists assigned to FAS also assisted in the Department's U.S. drought assessment effort with analysis of crop conditions in the Mississippi Valley, corn belt, and winter wheat areas of the United States. The analysis of satellite data, weather information, and ground observations together gave Department officials reports that helped delineate and more clearly define drought impact at the local level.

Anticipating the launch of Landsat 6 in 1992, the FAS began preparing for the receipt and use of data from the satellite. During 1991, the FAS upgraded and augmented its remote sensing analytical capability with an advanced graphic information system.

Paralleling the efforts of the FAS in assessing foreign agricultural areas, the National Agricultural Statistics Service (NASS) was responsible for similar activities covering the United States. Space related activities of NASS have focused on the use of satellite remote sensing data as one of the sources of information for direct estimation of crop area, assessment of crop condition, and land-use stratification for area frame sampling (see below). An extensive on-going NASS remote sensing applications research program has benefitted from lessons learned from earlier research.

One application was in the construction of general purpose area sampling frames (ASF). As an aid to crop and acreage estimation within the 48 contiguous states, NASS has selected a number of small sample areas from which it has collected detailed information on crops, livestock, and other agricultural topics. Stratification based on land use allowed concentration of samples in appropriate areas. The areas have been relatively small (averaging about one square mile) and were originally sampled and delineated using low-level aerial photography.

A major research effort over the last three years that became operational in 1991 was the Computer Aided Stratification and Sampling (CASS) project. This was a joint and cofunded project between the Agency and the National Aeronautics and Space Administration. CASS involved developing and sampling area frames using digital satellite data and U.S. Geological Survey digital map boundary data. The data, displayed on a color graphics work station, permit a cartographer to draw primary sampling units on screen rather than using paper-based inputs such as Landsat prints, high altitude photography, and county maps. This efficient new procedure will save substantial time, do a better job than the old (essentially manual) system, and facilitate revision of state ASF's as required.

Research in the mid-1970s on digital satellite information led to the creation of an operational procedure for large-area crop estimation. Researchers developed a statistical relationship, called a regression estimator, between the ground-gathered area frame data and computer-aided analysis of information contained in Landsat MSS images. The regression approach using satellite data markedly improved estimates of crops at regional, state, and county levels. By 1987, this project covered an eight-state region and benefitted acreage estimates for corn, winter wheat, and soybeans.

Estimation based on data from the Landsat Multispectral Scanner Sensors (MSS) ceased in 1988 in order to implement the increased capabilities of higher resolution sensors in a similar approach. Results from sensor comparison experiments and the operational eight-state program showed that the regression approach was most effective for rice and cotton estimation. The regression estimation approach became operational again in 1991 with the Delta Remote Sensing Project. It produced state and county estimates of rice, cotton, and soybean areas for two states in the Mississippi River Delta region. These estimates were based on computer analyzed Landsat thematic mapper data.

Other techniques that derived originally from remote sensing research directly affected 1991 operational surveys. Aerial photographs still served as a quality-control measure for field enumeration of area segments. Digitization procedures developed in satellite research studies have replaced manual measuring for size determination of land areas for sampling purposes. NASS analysts used data wholly or partially derived from remote sensing sources for interpretation of survey crop estimates and forecasts. These data sources included snow cover maps, soil moisture and temperature maps, and drought indices. Research on crop-condition assessment measures using the National Oceanographic and Atmospheric Administration's Advanced Very High Resolution Radiometer data began in fiscal year 1991 as a cooperative project between NASS and the Agricultural Research Service (ARS).

Management of Forest Resources Using Remote Sensing

Remote sensing has long been a significant source of information for the Forest Service. This USDA agency is charged with the administration and management of over 191 million acres of national forests and grasslands. The Forest Service is also responsible for assisting state and private forest owners.

Airborne Laser Profilers used by the Forest Service and Agricultural Research Service to study changes in landscape patterns due to erosion and other activities of man.

Aerial photography—from hand-held 35 millimeter (mm) cameras in low-flying aircraft to high altitude photography taken by U-2 planes—has been the primary form of remote sensing used to map and conduct inventories of the timber, forage, wildlife habitat, soil, water, recreation, and mineral resources on the National Forests. All types of aerial photography were used, including black and white, color, and color infrared films. Some of the newer forms of remote sensing have involved video cameras, laser profilers, thermal sensors, and earth observing satellites.

The Forest Service has the responsibility to conduct surveys of insect and disease infestations across *all* forested lands in the United States, and many of the remote sensing activities with state and private landowners have been concerned with forest pest management. The most recent technology to be incorporated in insect and disease surveys has been the use of a video camera in a fixed-wing aircraft.

Data from satellites were beginning to provide new ways to inventory and monitor U.S. forest resources. Imagery from weather satellites was being used in this period to monitor changes in vegetation, and in the Western United States, to map forest fuels and to assess forest fire suppression activities. Imagery from the Landsat satellites permitted rapid mapping of vegetation resources on National Forests in California, Oregon, and Washington. Landsat data, combined with imagery from other satellites, allowed the updating of maps showing new roads and clearcut areas in California. Vegetation maps of Forest Service land in the Pacific Northwest Region (Oregon, Washington) were being prepared through the use of remote sensing techniques, photograph interpretation, and filed data collection. In one segment of the project, Landsat data assisted in the assessment of old-growth timber.

The layers of digitized data, including data from satel-lites, aircraft, and other sources were already being used for a variety of analytical needs, including the analysis of the habitats of significant animal species, ecologically significant forest areas, and the development of a predictive model for the abundance of certain tree species, an example being the Pacific yew.

Video Remote Sensing

Recognizing the utility of airborne video imaging systems for rapid observation of conditions on the ground, scientists in the ARS have taken advantage of recent improvements and advances in video- and computer-image processing technology. Black and white, color, and color-infrared systems with sensitivity in the visible to infrared (just beyond the visible light energy spectrum) have been developed and used successfully to characterize a variety of natural-resource factors.

Video from aircraft has many advantages, but the most sig-nificant is the near real time availability of imagery. Video action can be viewed during acquisition on a monitor in the airplane or assessed within minutes after landing. This is particularly important in highly time-sensitive applications in monitoring catastrophic events such as hail or flood damage to crops. Airborne video has also been used for a variety of agricultural and rangeland applications. Important agricultural applications studied in fiscal year 1991 included detection or assessment of soil drainage and salinity, soil erosion, crop vigor and production, plant diseases and nutrient deficiencies, and insect and weed infestations. Due to the generally great expanse of range-lands and their low productivity per unit area, low-cost video systems were becoming attractive tools for assessing these areas. Rangeland applications include detection or discrimination of plant communities and species, brush and weed infestations, grazing intensity, plant production, drought stress, and rodent and insect infestations.

Microwave Sensor Systems and Soil Moisture

Information on the amount of moisture in the soil is in-valuable in many farm management decisions; an obvious example is determining when to irrigate crops. But soil moisture information has been difficult and expensive to obtain. Research in fiscal year 1991 included development and testing of sensor systems that will provide soil water measurements from airplanes and satellites. These sensors measure the amount of microwave energy coming from the soil. Recent research has shown that the amount of this energy depends primarily on the amount of water in the soil. Current research by ARS and NASA focuses on systematic testing of prototype instruments on airplanes and comparing their measurements with those made on the ground.

Microwave remote sensing offers three unique advantages over other types of remote sensing. First, clouds and rain have no effect, making microwave remotely sensed data available in all weather conditions. Second, microwave remote sensing does not require sunlight for illumination, which means that measurements can be made at any time of day or night. Finally, the effects due to most vegetation on the ability to sense moisture in the soil below are correctable. To be of value, soil moisture information must be available on a frequent and repetitive basis, so as to be in the hands of users almost immediately before changes in crop conditions, weather, or soil water content make the information worthless. As an added bonus, new research using microwaves shows great promise for determining the depth or water equivalent of the snowpack.

Water Forecasting Assisted by Snow Monitoring

The snow covering the high mountain ranges in the Western U.S. is the source of 50 to 80 percent of that region's annual water supply. Accurate and timely information on the extent and content of the snowpack is essential for efficient management of the growing and often competing water needs of households, agriculture, and industry. Remotely sensed data from weather satellites and ground-based untended sensors have been used in forecasting water supply available from snowfall.

Satellite measurements of the snow-covered area in specific river basins have recently been made by NOAA and transmitted to other Federal agencies. Snow cover maps can be sent over telephone lines and used for snowmelt analysis by computers. The data on snow cover derived from the satellite images, combined in a computer model with temperature data, yield the daily amount of snowmelt runoff and forecasts of future runoff. Using this technique, forecasters can predict water supplies for irrigated agriculture, hydropower, domestic supplies, and recreation.

Unattended sensors on the ground relay data on local snow conditions to centrally located receiving stations for weather analysis and for water supply forecasts. The Department's Soil Conservation Service (SCS) operated the SNOwpack TELemetry (SNOTEL) network, which measures snowfall in remote areas of the Western United States where manual surveys are difficult to carry out.

The automated SNOTEL remote sites include various sensors and measuring devices, such as "snow pillows" (which measure the weight of the snow), precipitation gauges, and temperature sensors. Other sensors may be present to measure wind speed and direction, snow depth, soil temperature, and other weather variables. A shelter at the site has protected the radio telemetry equipment and the communications antenna. The weight of the accumulated snow as it pressed on flexible pillows of stainless steel or synthetic rubber was converted into an electrical reading of the snow's water equivalent—that is, the actual amount of water in a given volume of snow.

During FY 1991, Over 500 remote SNOTEL sites transmitted data daily with radio signals from the sites reflected off the ionized layer of the Earth's atmosphere—the "meteor burst" zone—to master receiving stations at Boise, ID, and Ogden, UT. The network of stations has covered ten states in the Western U.S.—about one million square miles. Data from the receiving stations went to a centralized forecasting system computer in Portland, OR, where they could easily be accessed by forecasters, SCS agency personnel, and the public. Data provided by the SNOTEL network, ground snow surveys, and information derived from weather satellites provided up-to-date information on streamflow potential—information that was especially valuable during periods of flood or drought. SCS offices issued water-supply forecasts monthly from January to June in cooperation with the National Weather Service. Major sectors of the western economy—agriculture, industry, and recreation—then used them for planning.

Department of Transportation

The Department of Transportation (DOT) has two components engaged in aeronautics and space endeavors—the Federal Aviation Administration and the Office of Commercial Space Transportation.

Federal Aviation Administration

The Federal Aviation Administration (FAA) has the dual responsibility of regulating air safety and fostering the progress of civil aviation. The Agency conducts a broad range of research and development to reduce the hazards of flight, increase civil aviation security, and improve the efficiency of the national airspace system.

Aviation Safety

Traffic Alert and Collision Avoidance System (TCAS)

This new system will use air-to-air interrogations of transponder-equipped aircraft to provide pilots with traffic advisories that indicate the range, bearing, and altitude of aircraft posing a potential threat. Some of the three TCAS versions will also provide a resolution advisory when potential conflicts occur involving aircraft equipped with altitude-reporting transponders.

TCAS I, a low-power system that will provide alerting without recommended escape maneuvers, will be required in turbine-powered airplanes with 10 to 30 passenger seats in the mid-ninetys. The FAA had brought six TCAS I units to an advanced stage of fabrication by September 1991. The TCAS II version, which not only will alert the pilot to traffic but also advise whether to climb or descend, will be mandatory in all aircraft of more than 30 seats by December 31, 1993. The FAA implemented a transitional program to monitor the performance of the TCAS II systems, approximately 1,400 of which were in operation by the end of fiscal 1991. The Agency continued to develop minimum operating standards for TCAS III, which will provide traffic alerts and resolution advisories that include right or left turns as well as altitude changes.

Aircraft Crashworthiness

The Agency completed testing and analysis of the overhead storage bins in transport aircraft. The results demonstrated the need to improve the bins' resistance to crash impact forces. Upgrading proceeded to enable the program KRASH computer model to simulate the impact of water and soil upon an aircraft. Two full-scale vertical drop tests of a Cessna 421B low-wing commuter aircraft yielded data on occupant survivability as well as on metal aircraft structures, data that will be used for comparison with future tests on composite structures. To collect further data on low-wing commuter aircraft, the Agency was preparing a Metro III fuselage for a vertical drop test. The FAA was also engaged in developing a method of estimating the effects of repairs on damaged composite structures, and it concluded new agreements with elements of NASA and the DOD for joint research on advanced aircraft structures made of both composite and metallic materials.

Aviation Weather

Aviation Weather Services. During FY 1991, the FAA initi-ated three new efforts to improve aviation weather services. The first was the Aviation Gridded Forecast System (AGFS), which NOAA will develop and implement in stages under FAA sponsorship. AGFS will provide a high-resolution aviation weather analysis and forecast over the continental United States. Secondly, the two agencies will develop the Aviation Weather Product Generator to receive the improved AGFS forecasts from the National Weather Service and create a new class of alerting and forecasting products for aviation. Thirdly, the Integrated Terminal Weather System will provide very-short-range forecasts and warnings for pilots and controllers at larger airports, using input from AGFS, Automated Weather Observing Systems, and radar systems. The FAA worked cooperatively with NASA on ways to present and display these new weather-data products effectively to the pilot in flight.

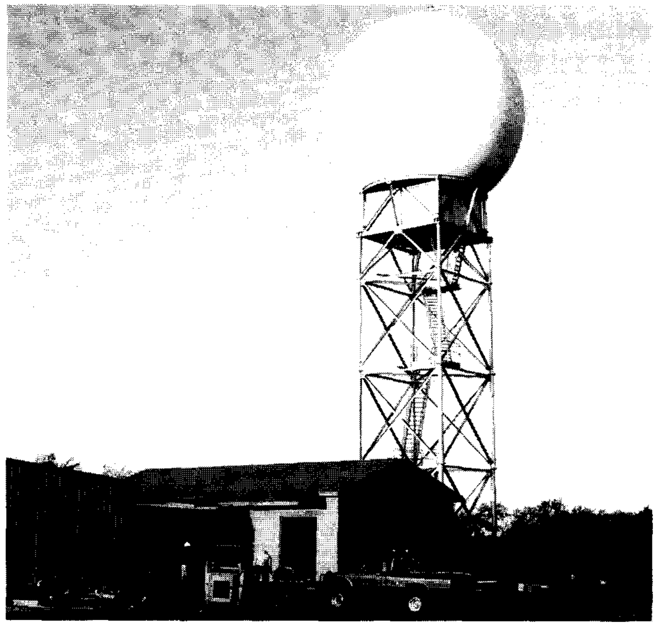
Meteorologist Weather Processor. The FAA started during FY 1991 to deploy a computer-based interactive meteorological data processing service for use by meteorologists at weather units located at Air Route Traffic Control Centers (ARTCCs). The system will be deployed at all ARTCCs and at the Air Traffic Control System Command Center.

Low Level Windshear Alert System. The Low Level Windshear Alert System (LLWAS) measured wind speed and direction from sensors located around the periphery of airports and analyzed this data to detect the presence of hazardous windshear. Phase-2 systems upgrade the basic LLWAS with a microburst detection algorithm developed by the National Center for Atmospheric Research. During 1991, all 110 LLWAS sites completed the implementation of phase 2. The FAA continued to improve LLWAS by expanding to a phase-3 configuration. Two prototype phase-3 systems, in operation since 1988, have a record of effectiveness that includes a documented aircraft save. The FAA awarded a contract during FY 1991 to upgrade seven additional major airports to phase-3 as an interim measure and completed a study recommending phase-3 for a total of 82 airports.

Terminal Doppler Weather Radar. During 1991, the FAA completed an operational evaluation of two Terminal Doppler Weather Radar (TDWR) test systems. The evaluation yielded positive results for establishment of procedures for use of TDWR data and assessment of air traffic displays. Site construction for a complete TDWR, meeting all Agency specifications, neared completion at Oklahoma City. The equipment will be used for operational testing, evaluation, and system integration while preparations continue for implementing TDWR at the first operational sites.

Airborne Windshear Program. The FAA and NASA continued joint development of airborne equipment for windshear detection and avoidance. Airborne tests of sensors using microwave radar and infrared technology and preparations for flight testing of laser radar sensors both occurred during the fiscal year. Initial analysis of data on predictive technologies produced very promising results, and transmission/processing of ground based data also proved a useful tool. The FAA began work on systems requirements documents as an initial step toward certification of airborne windshear equipment.

Icing. The FAA and the National Center for Atmospheric Research continued their 6-year program, begun in 1989, to address basic research issues relating to the icing hazard and to improve forecasting. Tests conducted in the winter of 1990/91 showed the feasibility of using multiple sensors to detect icing aloft.



The Terminal Doppler Weather Radar Facility nearing completion at Oklahoma City.

Weather Observing Systems. In addition to awarding grants for partial funding of Automated Weather Observing Systems (AWOS), the FAA continued to acquire advanced AWOS III units for installation at airports without towers. Forty more were ordered during fiscal 1991, primarily for use in Alaska, and the Agency had placed approximately 120 AWOS III units in operation nationwide by the end of September. In cooperation with the National Weather Service, the FAA also continued its program to acquire Automated Surface Observing Systems, which offer additional precipitation sensing capabilities. A production contract was awarded in February, and installation of the FAA's initial lot of 37 units began in August 1991.

Electromagnetic Environment Program. The FAA completed tests during 1991 using a Sikorsky S76 helicopter to measure disruption caused by both low- and high-level emitters of electric and magnetic fields. It also completed bench-level testing to determine the Electronic Flight Instrumentation System's vulnerability to electromagnetic interference. The FAA Research Electromagnetic Database (FRED) for lightning strike measurement became operational during the year. The Agency also participated in sponsoring an annual international conference on lightning and static electricity, and it drafted new publications on protecting aircraft against lightning and high intensity radiated fields.

Airport Pavement Research

The FAA sponsored research on factors affecting the durability of airport pavements, including load transfer efficiency and sealing joints between slabs in rigid pavements. The Agency investigated the use of chemical and fibrous additives to extend the life of flexible pavements and improve marginal materials. Research continued on updated criteria for sealing and protecting pavements, on using grids and membranes to increase the load-bearing capacity of weak subgrades, and on formulating the load-response characteristics of pavements under all service conditions. The FAA also reported on methods to assure smooth runway surfaces during overlay construction and on materials (such as soft grade asphalt, geotextiles, and foam) that mitigate cold weather damage.

Human Factors Research

In November 1990, the FAA released a draft National Plan for Aviation Human Factors developed by leading scientists from within the Agency, NASA, DOD, and other organizations. A 3-day conference in January centered on the Plan. A working group was formed to report on industry comments, and a FAA-NASA technical advisory group was established to coordinate activities under the Plan.

After evaluating 66 proposals received under a broad Agency announcement, the FAA awarded 15 research contracts dealing with a variety of human factors in flight operations and air traffic control. The FAA evaluated inexpensive air traffic control training simulators at two terminal radar approach control facilities (TRACONs). On the basis of preliminary results, it initiated further development of a personal computer based system to support training for the future combined Southern California TRACON. The Agency also developed an experimental computerized test battery as part of an effort to improve the controller screening process.

The Agency also completed an analysis of commuter and air taxi accidents caused by human error, and it sponsored flight simulator experiments to validate a model of pilot error in using flight management computers. Pilot response-time parameters for certain types of air traffic control instructions were determined for use in warning-system criteria. Two projects related to pilot-controller communications errors began: an analysis of pilot and controller reports on altitude deviations and a study of phraseology used in transmitting and acknowledging numerical data. The Agency also participated in developing a preliminary model for integrating evaluations of crew response management and flight technical skills under the Advanced Qualification Program for airline crew training.

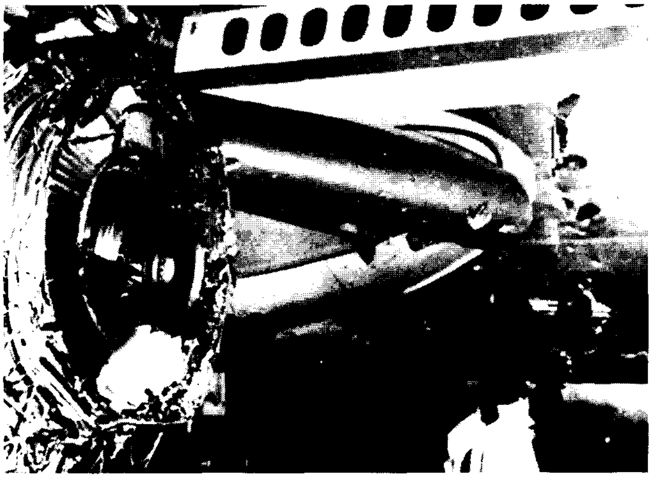
The FAA completed a study of the effects of course-deviator indicator sensitivity on instrument approaches using the LORAN (long range)-C navigation system, and it began the flight testing of pilot performance using positive guidance for missed course approaches. The Agency also completed experiments on format improvements for the charting of instrument approach procedures.

Aging Aircraft

In association with NASA and the Air Transport Association, the FAA prepared to sponsor an international conference on aging aircraft and structural airworthiness in November 1991. The Agency continued to study issues pertaining to fatigue and fracture, mechanics of corrosion fatigue, airframe repairs, corrosion control, and maintenance requirements for aging aircraft. The FAA completed 15 evaluation-team visits to commuter operators, and it circulated for coordination a long-range integrated plan for aging aircraft that will consolidate ongoing efforts and provide overall program direction.

Turbine-Engine Rotor-Failure Safety

The FAA initiated research to identify technology that will improve measures to protect against failures in turbine-engine rotors and resultant damage to the engines. The Agency completed an initial feasibility demonstration on an inspection method that would use a unique x-ray system to detect turbine disk cracks in an operating engine. Another research effort produced computer-based methodology and a prototype design for an integrated system to predict failure of rotating parts in



The results of turbofan overspeed failure, which caused multiple liberated-fan blade damage.

A Cessna 210 fuel fire being extinguished with dry powder chemical.

turbine engines. The Agency also continued to research and develop a variety of light-weight, advanced materials designed as barriers to absorb high energy fragments liberated by small failures in turbine engines. Testing in a rotor-spin facility established penetration-threshold thickness geometries, and baseline tests were completed on ceramic-based protective materials.

Aircraft Digital Systems

The FAA continued to assure the safety of aircraft digital systems through its validation research in cooperation with NASA. The Agency prepared new handbook materials on avionic data-bus integration, and it extended research to include such emerging fields as fiber-optics technology.

Aviation Fuels

FAA activity in the field of fuels for light aircraft related primarily to the impact on general aviation of 1990 legislation on removal of lead from fuels. The Agency supported workshops on this issue sponsored by industry and user groups, and it planned follow-on research on unleaded fuel usage. The FAA also began cooperative efforts with industry regarding use of ethanol in aircraft.

Aircraft Rescue and Firefighting

The Agency completed a first series of full-scale fire tests on damage tolerance and firefighting agent requirements for small aircraft and rotorcraft. These tests will assist in determining an optimal balance between response quickness and firefighting-agent capacity for fire trucks at small airports. The FAA also initiated work to improve skin-penetration nozzle systems that could expedite suppression of cabin fires in large aircraft.

Fire Safety

The Agency completed two years of testing an onboard cabin water spray system for suppressing post-crash fires. The system proved highly effective, providing as much as two to three addi-tional minutes for passengers to escape, and the FAA initiated research on such issues as weight optimization and the effects of an accidental discharge. The Agency published a handbook providing detailed documentation of all FAA-required aircraft-material fire-test procedures. The FAA also completed a study on recycling Halon 1301, an extinguishing agent used in aviation that will be banned from production no later than the year 2000 due to the stratospheric ozone depletion it helps to cause. The study demonstrated that appropriate recycling can meet needs through the year 2020. The FAA also initiated full-scale tests to define design modifications and firefighting procedures to safeguard against cargo fires in combined passenger/cargo aircraft.

Low Impact Resistance Structures

The FAA continued development of a computer-based analytical model for predicting the response to aircraft impact of low impact resistance structures (those designed to offer little resistance when struck by an aircraft). It likewise continued to develop computer software for evaluating break-away mechanism test results. The FAA performed preliminary calculations of break-away mechanism impact using state-of-the-art fracture analysis methods and National Institute of Standards and Technology testing equipment. Preparation of a 20-foot tower as a specimen for full-scale dynamic testing at the Naval Air Engineering Center was about 80 percent completed.

Jet Engine Bird Hazard Program

The Agency continued to collect and analyze worldwide service data on bird ingestion into jet engines. The information provided threat definition and damage characterization for use in updating engine certification standards and airport bird hazard studies. The FAA published the final report on a 2-year study of commuter and executive aircraft powered by small jet engines. It completed the final draft report on a 3-year study of the Boeing 737 transport fleet powered by jet engines of both older, low-bypass and modern, high-bypass design. The FAA also finished 2-year data collection on a group of seven large, modern, high-bypass jet engine models installed on eight types of contemporary transports.

Aviation Medicine

Activities in aviation-medicine research included active monitoring of the involvement of both therapeutic and illicit drugs in fatal aircraft accidents. Systematic assessment of all accidents in which sudden or subtle incapacitation was strongly suspected became a new part of the research program. Researchers validated a prototype automated cognitive function test to improve early detection of subtle cognitive loss from injury or disease. The FAA also developed and validated practical, job-related tests for the detection of color vision performance deficiency in air traffic controller applicants.

Aviation Security

In response to the Report of the President's Commission on Aviation Security and Terrorism and the Aviation Security Improve-ment Act of 1990, the FAA quickened the pace and broadened the scope of its aviation security research. The Agency continued research to identify technologies for the next generation of explosives detection systems, while beginning development of prototype devices to screen both people and baggage. Developmental efforts included nuclear, x-ray, and vapor detection technologies. As a short term strategy, the Agency evaluated a broad range of commercially available explosives and bomb detection devices that might be rapidly deployed in high risk circumstances.

The FAA began construction of an explosives detection research laboratory at its Technical Center. The first of its kind in the world, the laboratory will permit research, testing, and evaluation on the full range of nuclear and analytical technologies applicable to security.

Thermal-neutron-analysis (TNA) explosives-detection systems were in operation at New York Kennedy, Miami International, London Gatwick, and Washington Dulles airports as part of the FAA's program to demonstrate the system's capabilities in an operating environment. A high-technology system for screening passenger-checked baggage, TNA was capable of detecting given amounts of commercial explosives, including plastic explosives. The Agency planned for additional demonstrations at San Francisco International Airport.

The FAA filled program manager positions and began research into such new areas as threat/risk analysis and systems integration. Particularly noteworthy was the aircraft hardening effort, which aimed at quantifying the risk posed by an inflight explosion. The program will concentrate on increasing aircraft survival probability by such measures as strengthening baggage containers and cargo holds. Another new initiative involved the development of methods (and related systems architecture) for deploying and linking sensors together at airports.

The Agency defined and initiated a program for human factors involved in aviation security, including research, advice for the Agency on security operations, and cooperation with industry, academia, and other agencies. This growing program encompassed all significant human roles within the aviation security system. These roles included performance of passenger/baggage screeners and security system maintenance personnel, threat counteraction by security personnel and air crews, reactions of the flying public and airport customers, and security features of airport design. The Agency developed detailed plans and began research to improve screener performance.

Advanced Automation System equipment under evaluation at the FAA's new Development Demonstration facility.

Air Navagation and Air Traffic Control

Capital Investment Plan

During FY 1991, the FAA placed in effect its first annual Capital Investment Plan (CIP), a blueprint for major improvements in the air traffic control system to meet changing user needs. The plan replaced the National Airspace System Plan and encompassed its remaining projects. The CIP supported the Agency's Strategic Plan and was consistent with the Secretary of Transportation's National Transportation Policy.

Advanced Automation System

The Advanced Automation System (AAS) will be a wholly new replacement for automated equipment now used in controlling en route and terminal air traffic. The system will increase controller productivity, upgrade the capacity and reliability of the airspace system, and provide the flexibility needed for future enhancements. AAS will include new computer software, processors, tower position consoles, and controller workstations called sector suites.

The system's first element, the Peripheral Adapter Module Replacement Item (PAMRI), arrived at four facilities during FY 1991, and one of these sites, Seattle, achieved initial operating capability. Development of nearly one million lines of computer code for the initial sector suite system was approximately 80 percent completed at year's end, and a critical design review conference on the terminal AAS took place. The FAA oversaw construction of the Development Demonstration Facility for early evaluation and risk mitigation of AAS segments, and the first suitability evaluations in the facility began. Ground-breaking also occurred for construction of a new laboratory to house added AAS equipment and personnel at the FAA Technical Center.

Automated En Route Air Traffic Control System (AERA)

This program will provide higher levels of interactive and automated software as evolutionary enhancements for use with the Advanced Automation System. AERA's goals are to improve airspace system capacity and efficiency, increase flexibility for individual users, and reduce operational errors. The FAA continued progress during 1991 toward an introductory set of AERA services, formerly known as AERA-2. Laboratory evaluations of prototypes resulted in refinement and clarification of problem resolution and computer-human interface requirements. The Advanced AERA Concepts program, formerly known as AERA-3, defines the next evolutionary step toward a higher level of automation. Activities under this portion of the program included concept development and evaluation aimed at the complete automation of aircraft separation and of many planning functions, which will allow human attention to concentrate on managing the overall safe flow of traffic. Work continued on the integration of key functional elements into a "Protocenter" for demonstration and evaluation. These functional elements will ensure that aircraft pairs do not violate separation standards, that sufficient airspace is reserved for aircraft in clusters to maneuver safely, and that aircraft meet metering and central flow-control requirements.

Advanced Traffic Management System

The aim of the Advanced Traffic Management System (ATMS) is to develop enhanced automation capabilities for air traffic flow management. ATMS products that had been transitioned to the operational system by the end of FY 1991 included the Aircraft Situation Display (ASD), which collected and displayed the near real time position of every controlled aircraft operating in the National Airspace System within the continental U.S., and the Monitor Alert function that provided automated alerts of projected congestion and delay. Initial algorithms for automated generation of alternative flow management strategies were installed on the testbed system at the Command Center for evaluation and refinement during fiscal 1991.

Voice Switching and Control System

This system will provide air traffic control centers with efficient and economical computer-controlled voice switching for intercom, interphone, and air-ground communications. As FY 1991 ended, the FAA had brought testing of two prototype systems to an advanced stage in anticipation of contract award in December 1991.

New York TRACON

During 1991 the FAA completed Stage II of a complex program to upgrade the New York Terminal Radar Approach Control Facility, which serviced three major and 40 satellite airports. The tracking capability of the facility's ARTS IIIE radar control system thereby increased to 2,800 aircraft, with potential expansion to 3,400. Final improvements included local area networking and distributed processing with separate systems for three types of processing: common, tracking, and display. The upgrade also provided enhanced intruder conflict alert for aircraft with Mode C transponders. Five radar antennas were operating as sensors, with potential expansion to six sensors.

Aeronautical Data Link

The FAA completed implementation of Pre-Departure Clearance service at 29 major airports during FY 1991. This new data link application enabled pilots from four major airlines to receive their departure clearances in text form in the cockpit or at the gate through data communications, in lieu of standard voice transmissions. The system benefitted both pilots and controllers by reducing workload and frequency congestion and by improving reliability of communications. The program was being rapidly expanded to include other major air carriers, regional carriers, and general aviation service providers as the year ended.

The Agency completed testing of the Data Link Processor and installed this computer system at the first site. The system will manage all future data link communications in the national airspace system once it is installed at each en route center. Development of future data link applications for air traffic control, flight service, and weather service continued in cooperation with the international aviation industry.

Airport Visual Aids and Lights

The Agency completed an in-service evaluation of an FAA-developed "hold-short" lighting system at Boston Logan airport, and it intended to adopt this system as a national standard. In-service evaluation of a runway stop bar lighting system began at New York Kennedy airport in March.

Airport Capacity

Airport Capacity Design Teams. Airport capacity design teams are local groups operating with FAA sponsorship and participation to produce coordinated plans for improving capacity. They identify the causes of delay, study current and anticipated demand, evaluate new applications of technology, and quantify the benefits of options for enhancement. By the end of September

1991, teams had submitted their final reports at 23 airports, and approximately 700 task-force projects had been designed.

Simulation Models. The FAA's SIMMOD computer model addressed capacity and delay problems through detailed simulation of airports, terminal airspace, and en route airspace. Improvements to SIMMOD, which nearly 150 users had acquired since its public release in 1989, included a new version for use with workstation type computers. The FAA also upgraded the National Airspace System Performance Capability, which simulates the entire en route air traffic control system and the nation's busiest airports, to provide such additional practical information as the monetary impact of delays. The Agency developed a prototype sector design analysis tool that computes metrics, such as potential conflicts, to assist planners in designing en route sectors. The FAA established the Integration and Interaction Laboratory as a proof of concept for the National Simulation Laboratory, which will develop techniques for simulation studies of advanced air traffic management concepts.

Precision Runway Monitor. The goal of this program is to increase airport capacity through safe reduction of constraints on the use of parallel or converging runways during instrument meteorological conditions (when visibility is minimal). The FAA has developed two monopulse radar prototypes that are much faster and more accurate than current equipment. In one, an electronically scanned (E-scan) antenna updates the aircraft position as fast as every half second. The other prototype adds a second antenna to a Mode S-type ground interrogator to achieve a 2.4 second update rate. Both systems include improved radar display, automated predictor, and visual/aural alerting. They are expected to reduce by perhaps 40 percent the spacing required between parallel runways used for simultaneous, independent parallel approaches.

In February, the FAA published a report on operational demonstrations of both prototypes held during the previous fiscal year. The report provided recommendations on radar accuracy, update rate, controller display characteristics, and procedures for monitoring approaches to parallel runways spaced less far apart than the current 4,300 foot standard. It specifically recommended a 2.4 second update rate as satisfactory for spacings 3,400 feet or greater. Analysis and simulations continued as the year ended in order to develop a recommendation for less than 3,400 feet.

Airport Surface Traffic Automation. This program's purpose is to develop techniques to prevent runway incursions and more fully automate aircraft ground movement, thereby speeding traffic flow and increasing all-weather airport surface capacity. The FAA accelerated work with the aim of deploying a system by 1996, and it released a broad Agency announcement soliciting demonstrations of alternative technologies.

Terminal Air Traffic Control Automation. This program developed automation aids to increase safety, fuel efficiency, and capacity in terminal airspace. Work was under way on two projects, including a Converging Runway Display Aid (CRDA) to allow continued use of a pair of converging runways during instrument meteorological conditions. CRDA underwent an operational field evaluation at St. Louis Lambert airport in preparation for eventual national deployment. The second project was to develop, in cooperation with NASA, the Center-TRACON Automation System (CTAS) to reduce delays and facilitate fuel efficient descent paths. Air traffic controllers participated in rapid prototyping activities in a laboratory environment in preparation for CTAS operational evaluations. FAA controllers also participated in completion of the Final Approach Spacing Aid (FASA) study in the real time terminal area simulation facility at NASA Langley Research Center. The automation assistance afforded by the FASA displays resulted in a significant decrease in controller workload, increased precision in spacing aircraft, and greater "throughput" to the runway.

Terminal Area Surveillance System. The new Terminal Area Surveillance System (TASS) program was investigating sensor technologies to meet increased requirements for future airport capacity and air traffic safety. Research areas included func-tional capabilities for aircraft surveillance and tracking, detection and monitoring of hazardous weather, detection of aircraft wake vortex, and airport surface surveillance. TASS is envisioned as a multi-purpose system that will relay timely information about the total airport environment. The program explored modular design concepts to allow site-to-site custom configurations and reduce system costs. It proceeded toward establishing a set of operational requirements in cooperation with the aviation community, academia, and national laboratories.

Satellite Applications for Civil Aviation

When it becomes available to assist civil aviation, the U.S. Global Positioning System will provide an additional navigation aid and improve approach/landing capability at airports not served by any instrument approach aid. The FAA cooperated with the International Civil Aviation Organization (ICAO) in developing worldwide satellite system standards as part of the Agency's effort to promote the international acceptance of satellite navigation, which will be essential if U.S. civil aviation is to receive the full benefit of GPS. The FAA and the Soviet Union examined the combined use of GPS and the Soviet Global Navigation Satellite System (GLONASS) for sole-means civil aviation navigation. The two countries exchanged GPS and GLONASS receivers and conducted tests. Another rapidly emerging technology was the use of satellite communications for air traffic control clearances and for Automatic Dependent Surveillance (ADS) periodic position reporting, capabilities that will improve the safety and efficiency of oceanic flight. The FAA awarded a contract to add the ADS function to the Oceanic Display and Planning System, an automated aid to controlling oceanic flights that was operational in California and near operational status in New York at year's end. In September 1991, ICAO's Air Navigation Commission fully endorsed both GPS navigation and ADS, and the FAA announced that the U.S. was offering use of GPS to world civil aviation for a minimum of ten years, starting in 1993.

Synthetic Vision

The FAA and the Air Force continued their joint management of the Synthetic Vision Technology Demonstration, a government/in-dustry project to develop a visual-imaging system for landing under conditions of very low visibility. Relying principally on millimeter-wave technology, the system will give pilots a processed image of the runway area. Sensor development neared completion and testing began on a tower overlooking an unused airfield. A study team organized and documented over 100 issues involved in certificating this technology. Work began during FY 1991 under a contract to integrate all components into a working flight system aboard a Gulfstream II for evaluation and demonstration of the concept.

Rotorcraft/Powered Lift-Vehicles Program

Vertical Flight Planning. In November 1990, the FAA published a Rotorcraft Master Plan (RMP) that describes the relationships between FAA and industry research and development programs and highlights actions necessary for the rotorcraft industry to realize its full potential. The Agency began to develop a detailed Vertical Flight Program Plan for accomplishing RMP projects, and it continued research and development on infrastructural issues to improve vertical flight operations.

Vertical Flight Operations. The Agency began a multi-year project to identify requirements and improve procedures for instrument flight rule (IFR) operations at heliports and verti-ports, addressing steep angle approaches and noise abatement control. The FAA began two studies on minimum airspace requirements for IFR heliports, which should result in a revision of the design advisory circular used by heliport planners and in changes to criteria for helicopter approach instrument procedures. In cooperation with NASA, the Agency also began research addressing operational and certification issues relating to tiltrotor aircraft noise. The initial focus was on collecting data to use in optimizing technology and flight procedures for noise abatement. The FAA continued flight tests and analyses of obstacle avoidance systems, concentrating during the year on use of night vision goggles for emergency medical service operations.

Heliports and Vertiports. The FAA developed two video programs on recently published guidelines for incorporating helicopters into disaster relief planning. Other key publications included analyses of operations at Downtown Manhattan Heliport, helicopter accidents at various landing sites, and air ambulance helicopter operations, as well as a five volume set of reports on minimum heliport airspace requirements for instrument flight rule operations.

Civil Tiltrotor. The FAA and NASA jointly published a study of civil tiltrotor applications that included assessment of the commercial passenger market and appraisal of research necessary for developing a tiltrotor aircraft suitable for commercial application. FAA grants enabled state and local governments to complete several civil tiltrotor feasibility studies. Work was begun to quantify potential reductions in delays at major airports if passenger-carrying tiltrotors were used for certain short-haul missions.

Vertical Flight Performance Analysis. The Agency completed an advisory circular detailing the advantages of aeronautical decision making training, and it prepared various slides and videotape presentations for use by training schools and FAA accident prevention specialists.

Commercial Space Transportation

To date, a total of 19 successful U.S. commercial launches have taken place. These launches reflect a growing and diverse industry, including international business and foreign government customers, communications satellite and suborbital research payloads. According to the latest DOT Commercial Launch Manifest, issued in October 1991, more than 30 commercial launches are expected to take place in the next few years.

Licensing Division Activities

In FY 1991, the Department of Transportation's Office of Commercial Space Transportation (OCST) issued at least 6 licenses that authorized at least 18 launches. In addition, several applications are expected for new on orbit, space applications, and reentry events. As of 1992, OCST will have supervised launches from Vandenberg Air Force Base, Cape Canaveral, White Sands, Barking Sands, Kwajalein, and Wallops Island. OCST has also studied proposed reentry vehicle landing sites at White Sands, NM, and in other states.

OCST developed and issued launch operators licenses to General Dynamics, Orbital Sciences Corporation, and McDonnell Douglas Corporation. OCST continued to develop a computer system that tracks the progress of license processing, investigations, and enforcement actions.

Regulatory Activities

OCST planned to issue regulations, vehicle design and approval procedures, and/or standards for commercial launch ranges and certain on orbit activities. In support of the licensing of commercial launch and recovery activities, OCST was developing criteria for determining the adequacy of tracking, telemetry, and other vehicle/site requirements related to public safety.

To aid establishment of commercial range personnel certi-fication standards, OCST was conducting research to document and evaluate range-safety personnel requirements and training at the various national ranges. OCST was also carrying out studies using safety experts to ensure that commercial safety-personnel certification was effective, efficient, and consistent with the changing hardware and concepts employed by the commercial industry. OCST and the State of Hawaii were working at the end of FY 1991 on a joint environmental impact statement for a proposed Hawaiian commercial launch facility.

OCST has developed a comprehensive research plan. This plan was designed to respond to anticipated developments in commercial space transportation activity. It defined a systematic program that included risk analyses and assessments; the development of risk management strategies and options; regulatory impact analyses; and the development of licensing procedures and standards for new space vehicles and activities, including those associated with on orbit operations and reentry transportation vehicles and their operating procedures. OCST was also studying options jointly with NASA and DOD for reducing orbital debris.

Industry and Policy Planning Division Activities

At the National Space Council, OCST has participated in developing Federal policies affecting the commercial space launch industry, including the Commercial Space Launch Policy, Commercial Space Policy Guidelines, National Space Launch Strategy, and the National Nuclear Space Strategy. OCST has conducted rigorous economic impact evaluations of regulations and rules affecting the commercial space transportation industry, such as evaluations for regulations dealing with user fees, financial responsibility, and the licensing process.

OCST has analyzed the potential economic impacts of converting excess government space launch equipment, including former ballistic missiles, to non-governmental uses in order to minimize harm to the commercial launch industry from contemplated disposal options. OCST has developed a methodology to assess fair market value of excess government space assets, including ballistic missiles and space launch components, made available to the private sector.

OCST continued to participate in interagency talks to establish free and fair trade principles with the European Space Agency. OCST has also drafted and disseminated a major issue paper regarding participation of the People's Republic of China (PRC) in the international launch market as required by the US-PRC memorandum of agreement on International Trade in Commercial Launch Services. In addition, OCST continued to monitor the actions of the PRC in the international launch market to ensure compliance with the provisions of the agreement and to obtain current information on the status of the PRC in the international launch market.

Program Affairs Division Activities

OCST was continuing to expand its program of support and representation for the U.S. commercial space transportation industry to include a full schedule of domestic and international conferences, exhibits, and symposia. In keeping with the Department's National Transportation Policy, OCST has continued to participate in conferences and programs fostering the exchange of knowledge and innovative ideas with both professionals and students.

Through public outreach, the news media, industry activi-ties, and printed and audiovisual materials, OCST has continued to create better public and Congressional understanding and support for commercial space transportation and the role it can play in the economic, scientific, and national security interests of the country.

Environmental Protection Agency

The U.S. Environmental Protection Agency (EPA), primarily through its Environmental Monitoring Systems Laboratory in Las Vegas, NV, with assistance from its Atmospheric Research and Exposure Assessment Laboratory in Research Triangle Park, NC, routinely conducted research and provided technical support using remote sensing as part of an overall environmental monitoring program. It collected and interpreted large-scale aerial photo-graphy to support the provisions of the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). It used medium-scale photography to support studies of nonpoint pollution, wetlands and coastal-zone protection, and forest-ecosystem decline caused by acid deposition. High-altitude photography enabled broad area studies in the coastal zone and contributed land use and land cover information in risk assessment studies. Finally, the Agency collected and interpreted airborne and satellite multispectral data to support investigations of water quality, nonpoint-source pollution, hazardous waste, and critical-habitat areas. It was in the process of developing and applying airborne laser systems to air and water monitoring. And it was using a geographic information system (GIS) to integrate multiple data sets in support of many EPA programs.

Hazardous Waste

The Agency used aerial photography to develop site charac-terization data during remedial investigation and feasibility studies under CERCLA, among a host of other uses (see previous year's report). For example, it could also support site selection and monitoring at hazardous waste facilities operating under the RCRA. In this connection, airborne multispectral scanner data and satellite imagery also played a part in helping engineers develop detailed site characterizations.

Water Quality

The EPA developed and used remote sensing systems such as a second-generation Laser Fluorosensor to support the provisions of the Clean Water Act. Aerial photography and satellite data also supported studies of nonpoint-source pollution. For example, the Agency documented the system contamination from activities like leaking barrels and tanks, industrial effluent, and municipal sewage using satellite and aircraft passive remote sensing in Commencement Bay near Tacoma, WA. Output from drainage models combined with contaminant distribution information permitted prediction of potential pollution in the bay.

Air Quality

The EPA was continuing to use an airborne, aerosol Light Detection and Ranging laser radar to monitor particulates asso-ciated with major urban plumes and emission sources. It also continued (with NASA support) developing an airborne Ultraviolet Differential Absorption Light Detection and Ranging laser radar to measure ozone, sulfur dioxide, and particulates simultaneously.

In conjunction with NOAA, the EPA was also involved in a project to characterize dry deposition of sulfur and nitrogen on a regional scale. Surface vegetation, land-use type, and terrain were important input parameters for the deposition model. Landsat satellite systems (see above) were to be used to provide multispectral data of the Earth's surface in digital form. New satellite data has permitted the generation of databases on vegetation class, vegetation index, slope, aspect, and elevation. The two agencies will use this data to compute modeled sulfur dioxide deposition velocities and then compare that to deposition velocities calculated from data at ground monitoring sites.

Ecological Risk Assessment

The EPA has continued to champion an interagency program known as the Environmental Monitoring and Assessment Program (EMAP) to determine the status and long-term trends affecting the nation's ecological resources (see coverage in previous year's report). An example of the program's employment was its Forest component, in which high-resolution aerial photography supplemented the field monitoring activities at study locations. The photography characterized the landscape around these sites. This high-resolution characterization provided the material for linking the field measurements to the lower-resolution characterization derived from Landsat Thematic Mapper data. Both the Forest and the Integration and Assessment components of EMAP used satellite-derived landscape characterization and indicators to assess functions of the program. The EPA integrated the data within a GIS with other environmental information for purposes of assessment.

Interagency Cooperation

The EPA continued to work with other Federal agencies, state and local governments to coordinate environmental monitoring. For example, experts from the EPA have become members of the science teams for proposed NASA satellite sensor systems, including the Laser Atmospheric Wind Sounder and the Moderate Resolution Imaging Spectrometer. These experts have been helping define the sensor and data parameters for such systems based upon the EPA's need for this technology for environmental programs. Also, the use of other EPA systems, such as the previously mentioned Ultraviolet Differential Absorption Light Detection and Ranging laser radar were planned for use in NASA programs such as Global Change and Tropospheric Chemistry.

National Science Foundation

The National Science Foundation (NSF) continued to be the principal supporter of academic research in atmospheric sciences and ground-based astronomy. NSF provided this support partly through grants to individual investigators and partly through contracts and cooperative agreements with universities and con-sortia operating observatories and other large facilities.

Astronomical Sciences

To test whether at sufficiently large scales the universe is homogeneous, astronomers have to determine the distribution of galaxies over the largest possible sky areas and the distances to these galaxies must be determined. Recent surveys have shown extensive sheet-like concentrations of galaxies and extensive voids with few galaxies. Thus, the surveys have found no evidence of homogeneity at these distance scales.

Quasi-stellar objects, so-named because their optical images appear unresolved and stellar, are the most distant objects in the universe and produce the most energetic and explosive events ever seen. These two properties make an understanding of their nature essential to cosmology, general relativity, and high energy physics. Until recently, the only spatially resolved features associated with these objects were regions of extended radio emission. These features were similar in nature to radio emissions arising from some elliptical galaxies, providing a possible link between galaxies and quasi-stellar objects. Increased sensitivity of new detectors at Kitt Peak National Observatory in Tucson, AZ, have made it possible to obtain spatially resolved images of 15 quasi-stellar objects, typically 300,000 light years in size. They appear asymmetric or elongated, and these features appear to be aligned with the radio emission. Observations have suggested the underlying object is a system of stars.

Astronomers have hypothesized that disks surround many astro-nomical objects, from young stars to galactic nuclei to quasars. Although they have never been directly observed, indirect evidence for such disks may have been attained recently. Observations at Kitt Peak National Observatory of the star R Aquarii showed that it is a binary system. Images obtained strongly suggest that there is an accretion disk surrounding the hot object in orbit around R Aquarii. If this is so, these are the first ground-based observations of an accretion disk.

At the National Astronomy and Ionosphere Center, headquartered at Cornell University, astronomers have identified the first near-Earth metal asteroid. The asteroid's orbit around the Sun extends from just beyond Earth to just inside Jupiter's orbit. The asteroid's diameter is 1.6 miles and its radar reflection is brighter than that of other asteroids. The asteroid is probably composed of iron, nickel, or other metals, and it is likely that it originated in the asteroid belt between Mars and Jupiter.

New measurements at Kitt Peak National Observatory have indicated that the universe may be about 12.5 billion years old or less. This age, much younger than many astronomers are prepared to accept, was determined by measuring the rate of expansion of the universe, known as the Hubble constant. The age of the universe is believed to be inversely proportional to its rate of expansion. A determination of the constant affects how long one believes the universe has been expanding since its origin. To obtain the new estimate, one team measured the distance to the Virgo Cluster of galaxies (about 50 million light years away) and to a number of other galaxies. Another team determined the average apparent brightness of stars in galaxies to determine distances. Both teams calculated the value of the Hubble constant and obtained an es-timate for the age of the universe of about 12.5 billion years. However, calculations of the age of older stars indicate that they are about 15 billion years old. The discrepancy between estimates of the ages of the oldest stars and the universe itself remained unresolved at the end of FY 1991.

Atmospheric Sciences

In FY 1991, significant intellectual advances in under-standing the upper atmosphere emerged from the Coupling, Energetics, and Dynamics of Atmospheric Regions (CEDAR) and Geospace Environment Modeling (GEM) programs, components of the U.S. Global Change Research Program. CEDAR addressed development of ground-based remote sensing techniques for studying the upper atmosphere, including the mesosphere/lower thermosphere region, often called the "ignorosphere" because it is too low to study by satellites and too high to reach by aircraft or balloons. Nevertheless, important structures found there include the ozone layer, noctilucent clouds, airglow layers, meteoric layers, and sporadic sodium and iron layers.

The Airborne Lidar and Observations of Hawaiian Airglow (ALOHA) campaign addressed the dynamics of the "ignorosphere." Using instruments distributed around the low latitude Pacific region, nine groups from four countries collaborated on observations designed to explore equatorial gravity wave activity. The centerpiece instrument was an airborne lidar system for studying the horizontal density variations and temperature structure of the upper stratosphere and upper mesosphere/lower thermosphere regions. Scientists validated the airborne lidar and spectrometer measurements against ground based airglow and radar instruments. Strong wave activity was apparent throughout the region. A surprising conclusion was that airglow intensities and sodium densities in this region may be more related to dynamics than to chemistry.

The Arecibo Initiative on Dynamics of the Atmosphere (AIDA), a CEDAR campaign at Arecibo, PR, brought partial reflection radars, meteor wind radars, lidars, and interference spectrometers to the site of the Arecibo incoherent scatter radar for characterizing spatial- and time-varying atmospheric structures. Intercomparisons of measurements demonstrated that the partial reflection radar technique employed for two decades failed to give accurate wind measurements above 80 km because of distortions of inferred velocities produced by atmospheric gravity waves.

GEM, which concentrates on the outer plasma region of the atmosphere (magnetosphere) linked globally by electric and magnetic fields and shaped by interactions with solar wind, has addressed quantitative geospace models that will lead to the development of a "climatology of geospace" extending from the interface with CEDAR interests to the interplanetary medium. Recently scientists produced idealized, but realistic, three-dimensional numerical simu-lations of global, drum-like, oscillations resulting from solar wind perturbations of the magnetosphere. These developing models have already found wide application.

Smithsonian Institution

The Smithsonian Institution contributes to national space programs through basic research conducted at the Smithsonian Astrophysical Observatory (SAO) in Cambridge, MA, and at the Center for Earth and Planetary Studies (CEPS) and the Laboratory for Astrophysics (LfA) at the National Air and Space Museum (NASM) in Washington, D.C. NASM's exhibits, lectures, and education programs contribute to public understanding of space research and exploration. SAO also conducts programs designed to improve pre-college science instruction, and serves as the North American gateway for SIMBAD, an international astronomical computer database.

Space Science

High-Energy Astrophysics

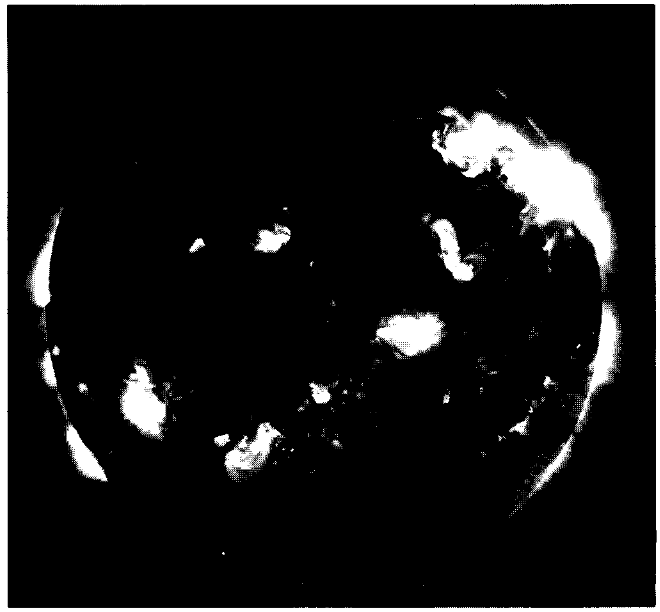
In 1991, NASA selected SAO to plan, develop, and operate the international science center that will receive, analyze, and archive data from the Advanced X-ray Astrophysics Facility, now scheduled for launch in 1999 (see above).

A high-resolution imaging instrument built by SAO and carried aboard the ROSAT satellite (see above) made detailed observations of x-ray objects selected from the spacecraft's initial 6-month, all-sky survey. Striking images of the Andromeda Galaxy suggest that x-ray sources may be highly variable, since many seen a decade earlier by the Einstein (HEAO-2) Observatory had disappeared and other new sources now glowed brightly. SAO also operated the U.S. ROSAT Data Center in cooperation with the Goddard Space Flight Center.

Each year, scientists from around the world have come to SAO to use archived data from the Einstein Observatory. In addition, SAO has converted the Einstein data to CD-ROM format and made it available free to all qualified scholars. Among the many results coming from this valuable data resource, SAO astronomers discovered an unusual x-ray arc associated with a gravitationally lensed quasar.

Solar Physics

A rocket-borne x-ray telescope developed by SAO and IBM gathered solar data on the day of the total solar eclipse that could help produce a detailed three-dimensional model of the Sun's corona, linking density and temperature variations with structure seen in its extended atmosphere. The x-ray observations will be compared with those in other wavelengths made at the same time, including infrared observations by a second SAO team operating at NASA's Infrared Telescope Facility site on Mauna Kea, HI. The combined observations will help create an improved model of extended corona, the hot, tenuous region of the solar atmosphere that is still little understood.



X-ray image of the solar corona from a telescope built by the Smithsonian Astrophysical Observatory and the IBM Watson Research Center, which flew aboard a NASA sounding rocket over New Mexico during the total solar eclipse of July 11, 1991. At the time of the photo, the partial phases of the eclipse had not yet begun over New Mexico, and the dark silhouette of the approaching Moon appears faintly on the right-hand side of the photo.

In anticipation of flight aboard the Solar Heliospheric Observatory in 1995, SAO scientists have been designing an Ultraviolet Coronal Spectrometer (UVCS). The experiment is intended to address the question of what type of physical mechanism heats the Sun's outer atmosphere and then accelerates it into the solar wind that streams out through interplanetary space.

Stellar and Galactic Studies

The Hubble Space Telescope's observations of the ring structure around Supernova 1987A in the Large Magellanic Cloud permitted the most precise calculation of the distance to another galaxy yet made. LfA scientists, using infrared detector arrays and Fabry-Perot spectrometers, obtained spectral images of regions of star formation in molecular clouds and of shocked and ionized gas in colliding and active galaxies. Images in the emission lines of iron and hydrogen revealed regions of supernova shocks and stellar winds. Theoretical research centered on constructing models of intergalactic collisions and line shapes from ionized winds in young stellar outflows. Researchers used the database created by the Infrared Astronomy Satellite (IRAS) extensively in this program.

Space Technology

In an unusual exchange of east-west timekeeping technology, engineers compared Soviet-built atomic-hydrogen maser clocks for stability with similar devices built at SAO for applications in space tracking, radio astronomy, and global navigation.

The Marshall Space Flight Center successfully tested the two largest mirrors of the Advanced X-ray Astrophysics Facility, thus marking a major milestone in the development of this orbiting observatory. At nearly 48 inches in diameter, the mirrors were the largest ever made to collect x-rays in space, and they should be capable of achieving angular resolution some 10 times better than any previous x-ray telescope. The unusual mirrors were based on the design of an SAO astronomer, who also served as the AXAF Telescope Scientist.

Terrestrial Studies

During 1991, CEPS staff continued the use of remote-sensing data on arid and semi-arid regions to address issues of global change. For example, investigations of sediment transport in selected desert regions compared Landsat images with field analyses, while other multi-temporal Landsat data provided reflectance characteristics and surface details for stabilized dune environments.

Remote sensing of the Earth's atmosphere with a balloon-borne spectrometer has allowed SAO scientists to measure the concentration, altitude distribution, and daily variations of ozone. The SAO program is unique in its ability to make simultaneous measurements of complete "families" of atmospheric molecules related to ozone chemistry. In support of both NASA's UARS experiment and related European efforts, SAO scientists have developed a series of space-borne experiments to operate in the ultraviolet, visible, and infrared wavebands. These instruments will study ozone in the stratosphere, as well as determine the sources, sinks, and distribution of greenhouse gases and atmospheric pollutants.

Planetary Sciences

Planetary geology at CEPS included the analysis and compari-son of crustal deformation on the Earth, Mars, and Venus. As a possible aid to selecting potential landing sites, detailed 1:500,000 mapping of parts of Mars continued. The understanding of that planet's geologic history was advanced by studies of the migration of dust deposits as well as of the timing and mechanisms for erosional and depositional modification of surface areas in Mars's eastern hemisphere.

In support of various planetary flyby missions, the LfA used infrared heterodyne spectroscopy to measure absolute wind velocities in the atmosphere of Venus, Mars, and Jupiter, and to model the troposphere/mesospheres of these planets. It also initiated a new millimeter-wavelength study of the martian atmosphere. The database created by IRAS proved invaluable in these investigations.

Planetary research at SAO includes the petrology of recovered extraterrestrial materials, in particular meteorites and lunar samples. In 1991, an ion-microprobe analysis of Apollo 15 rock sections was aimed at understanding the formation and evolution of the lunar highlands crust. Finally, as a principal investigator of data from the Magellan mission (see above), one SAO scientist was studying anomalously bright and reflective landforms seen at high altitudes on Venus.

Department of State

The Department of State is responsible for evaluating and advancing U.S. foreign policy interests in space activities. It evaluates the foreign policy aspects of space programs, policies, and agreements; advises the President on matters involving international space; and participates in National Space Council deliberations. State also represents the U.S. Government in space-related international negotiations with other governments. During the past year the State Department advised and assisted NASA and other agencies on numerous space programs involving cooperation with other nations.

The State Department worked closely with NASA to support the Space Shuttle Program. The Department's support activities included activation of a Space Shuttle Task Force for each Shuttle launch to provide a direct link to U.S. embassies in countries where emergency landing facilities were located. State negotiated new agreements with the governments of The Gambia, Morocco, and Spain for emergency landing facilities and support.

State also lead an interagency review of export controls for space commodities. When completed, the review will bring U.S. controls closer to those of our allies and improve the competitive position of this important U.S. industrial sector. And the Department took part in policy deliberations within the National Space Council in such areas as the President's Space Exploration Initiative, the Commercial Space Launch Strategy, the Commercial Space Policy, and the National Space Launch Strategy.

The Department of State again represented the U.S. Government in international organizations involved in space issues. These included the United Nations and related organizations such as the International Telecommunications Union, the International Telecommunications Satellite Organization (INTELSAT), and the International Maritime Satellite Organization (INMARSAT).

U.N. Committee on the Peaceful Uses of Outer Space

The 53-member U.N. Committee on the Peaceful Uses of Outer Space (COPUOS), its Scientific and Technical Subcommittee, and its Legal Subcommittee all met during 1991. For several decades after its inception in 1958, the Committee worked successfully in the exchange of scientific information, and it negotiated four conventions that form the basis of international space law. However, during the 1970s and early 1980s, the scientific and legal work of the Committee became increasingly political. In the last five years, the United States has worked closely with other delegations to reinvigorate the scientific content of the Committee's work. U.S. proposals dealing with astronomy, planetary exploration, and the geosphere/biosphere became part of the agenda of the Scientific and Technical Subcommittee, and an item concerning spin-offs from space programs likewise became part of the COPUOS agenda.

At the February 1991 Scientific and Technical Subcommittee meeting, member states focused on the use of space technology for prospecting mineral and groundwater resources and for monitoring and managing biological resources. The Legal Subcommittee met in March 1991 and considered questions relating to the use of nuclear-power sources in space, use of geostationary orbit, and the delimitation of outer space. The Subcommittee continued its application of the principle that space exploration should be carried out for the benefit of all countries, taking particular account of the needs of developing nations.

In 1991, the United States, with the support of other Western countries, continued efforts to make the work of COPUOS and the Subcommittee more relevant to the present state of space exploration. To this end, member states continued to work on activities related to the commemoration of a U.S.-proposed International Space Year (ISY). The U.S. first proposed ISY at the 1988 session of COPUOS. On the basis of joint resolutions of Congress, which Presidents Reagan and Bush endorsed, international scientific organizations and national space agencies will celebrate 1992 as the International Space Year. COPUOS recommended, and the General Assembly has since agreed, that is could play a meaningful role in ISY without any impact on the regular budget of the United Nations through the training and educational capabilities of the U.N. Programme on Space Applications.

INTELSAT

INTELSAT successfully launched the remaining two of its five VI-series satellites in 1991, one on August 14 and the other on October 29 (see related coverage above).

Both launched on Ariane vehicles and one was on station and carrying public switched voice and data traffic at INTELSAT's Primary Path location in the Atlantic Ocean Region at the end of the year. The other was undergoing in orbit testing. These satellites joined two previously launched INTELSAT VI-series satellites already in orbit, which will be redeployed at the Primary and Major Path Locations in the Indian Ocean Region. INTELSAT operated 17 satellites in geostationary orbit as of the end of October.

A fifth INTELSAT VI-series satellite, in low-Earth orbit as the year ended, will be retrieved during the maiden flight of the Space Shuttle Endeavour, scheduled for launch on April 9, 1992. This satellite was stranded in low orbit shortly after launch in March 1990 when the launch vehicle's perigree stage failed to separate from the second stage booster assembly. As part of a joint INTELSAT-NASA reboost mission, Space Shuttle astronauts will refit the satellite with a new perigree kick motor, which will allow INTELSAT to raise it to geostationary orbit. INTELSAT also plans to launch the INTELSAT K satellite in the second half of 1992 using an Atlas IIA vehicle. Carrying a payload of 16 Ku-band transponders, the INTELSAT K will be the first of its kind in the INTELSAT system and is intended to provide high-power coverage for international television and other services both between North America and Europe and among countries in the Western Hemisphere. At its 90th meeting in September 1991, the INTELSAT board of Governors recommended the use of two NASA Tracking and Data Relay Satellites by Columbia Communications Corporation to offer international private-line and video services separate from the INTELSAT system. Columbia's is the third U.S. international separate satellite system (after PANAMSAT's and Orion Satellite Corporation's) to be successfully coordinated with the INTELSAT system. It was expected to begin operation in both the Atlantic and Pacific Ocean Regions in 1992. The INTELSAT Board of Governors made its recommendation under new streamlined intersystem coordination procedures adopted by the 16th INTELSAT Assembly of Parties in 1990. Use of these streamlined procedures, which the U.S. supported, has also enabled the INTELSAT Board of Governors to make favorable recommendations for the use of PANAMSAT and other satellite systems, including INTERSPUTNIK, for public switched traffic between the U.S. and points overseas.

INMARSAT

Seamless Global Coverage

In 1990 INMARSAT decided to provide seamless global coverage. In October 1990 it repositioned one of its satellites to provide increased capacity in its heaviest traffic routes over the Atlantic Ocean and seamless global coverage except in the extreme sections of the South and North Poles.

INMARSAT-C Service

INMARSAT began offering this reliable, two-way message service on a worldwide basis starting in January 1991. Optional features included position reporting when connected to a navigation system such as GPS and a programmable distress alerting feature that goes into motion with the touch of a couple of buttons on the INMARSAT-C terminal. Small, inexpensive, portable data terminals allow users access to these services.

Start of Commercial Aeronautics Service

In 1991 participating parties ratified the aeronautical services amendments to the INMARSAT convention, and they entered into force. Air carriers were already test-marketing aeronautical services for international passenger flights, and corporate jets used the system successfully. The emergence of three consortia providing international aeronautical communications services promised a swiftly evolving market and technology base.

Project 21

Project 21 aimed to identify market and customer needs for mobile satellite services in the 21st Century. Requirements for improved connectivity may be met with smaller terminals, which could include handheld portable telephones. Project 21 will look at various satellite technologies and identify specific orbit and spacecraft alternatives that can satisfy the evolving demand for mobile satellite services.

Global Satellite Paging System

Beginning as early as the mid-1990s, INMARSAT will have the capability to provide global paging services via satellite. INMARSAT signatories will be able to offer paging services through stand-alone receivers or through integrated portable, briefcase-sized INMARSAT-C and INMARSAT-M terminals.

Article 8 Notifications

The eighth Assembly of INMARSAT Parties met in September 1991. The parties decided to establish an Intersessional Working Group to review the Article 8 process in view of the changing telecommunications environment. In addition, the parties made a nonbinding recommendation to the U.S. that the proposed 2-year use by Qualcomm, Inc and Alpha Lyracom Corporation of separate space segment facilities would not cause significant economic harm to INMARSAT. Finally, the parties also reconfirmed the authorizations made to the Council during the Seventh Session concerning expedited Article 8 notification procedures.

Transborder Use of Land Mobile Earth Stations

INMARSAT hosted a Meeting of Experts on Transborder Use of Land Mobile Earth Stations in October 1991. Among the major conclusions of the meeting was that it would be highly desirable to establish a generic global regulatory framework of uniform measures to assist governments in facilitating the transborder use of such terminals, while allowing flexibility to provide for specific national interests.

INMARSAT-III Procurement

In February 1991 the Director General of INMARSAT awarded a contract to the General Electric Astro Space Division as prime contractor for four INMARSAT-3 satellites. Included among the significant design features were five spot beams in addition to a global beam in each satellite, as well as a navigation package. The satellites were scheduled for launch in 1994-1995. In the fall of 1991, INMARSAT received bids from five organizations for the launch of the third-generation satellites. Bidders included Arianespace, China Great Wall Industry Corporation, General Dynamics Commercial Launch Services, Rocket Systems Corporation, and VVO Licensintorg. The decision on launch services was scheduled for April 1992.

Arms Control and Disarmament Agency

The United States Arms Control and Disarmament Agency (ACDA) was established in 1961 to provide the President, the Secretary of State, other officials of the executive branch, and the Congress recommendations concerning U.S. arms control policy; in addition, the Agency is obligated to assess the effect of these recommen-dations upon our foreign policies, our national security policies, and our economy. Issues related to outer space are discussed in the Nuclear and Space Talks and during sessions of the Conference on Disarmament and the First Committee of the United Nations General Assembly.

Bilateral Negotiations

The primary forum for bilateral negotiations on nuclear and space issues has been the Nuclear and Space Talks (NST) with the Soviet Union in Geneva. The bilateral NST framework was estab-lished in 1985 to conduct negotiations on intermediate-range missiles, strategic offensive arms, and defense and space issues. The United States and the Soviet Union concluded the Intermediate-Range Nuclear Forces Treaty (INF) in December 1987 and the Strategic Arms Reduction Treaty (START) in July 1991. The two countries were continuing their negotiations on defense and space.

Responding to a Changing Environment

Events in the Persian Gulf as well as the dramatic changes within Eastern Europe and the Soviet Union have served to underscore the fact that the strategic environment the United States will confront in the 1990s will differ significantly from the one we faced in the early 1980s when the Strategic Defense Initiative (SDI) program began. Because of these changes, which include the proliferation of ballistic missiles on a global scale and increased concern about accidental or unauthorized use of ballistic missiles, there is the opportunity (relative to the Soviet Union) and the incentive (because of ballistic missile proliferation) to move toward effective defenses sooner and at lower cost than was earlier believed possible.

In light of this changing environment, President Bush, in his State of the Union Address in January 1991, ordered a redirection of the SDI program to provide options for protection from limited ballistic missile strikes, whatever their source; this new defense strategy has been named Global Protection Against Limited Strikes (GPALS). The objective of such a defense deployment is the protection of U.S. forces deployed overseas, U.S. power projection forces, U.S. friends and allies, and the United States itself from accidental, unauthorized, and/or limited ballistic missile strikes.

At half the size of the original SDI "Phase I" architecture, the GPALS concept shifted the focus of strategic ballistic missile defense away from deterrence of a massive strategic ballistic missile attack to protection against the emerging and limited ballistic missile threat. Because it is limited in scope and scale, GPALS would not threaten the Soviet strategic retaliatory capability, an oft-stated Soviet concern about SDI. Therefore, given improving U.S.-Soviet relations and growing concern for ballistic missile proliferation and accidental, unauthorized launch (including concern over nuclear command and control in the Soviet Union) GPALS represents an appropriate approach to defenses based on the evolving international environment.

A GPALS deployment would consist of surface- and space-based elements to ensure continuous global detection and tracking of missiles of all ranges plus the capability to intercept ballistic missiles and their associated warheads, including theater missile threats. The defensive elements that make up GPALS could be deployed sequentially and need not wait for the deployment of an entire system.

If at some point in the future the United States decides that it needs to achieve more ambitious mission objectives, or if changes in the international environment result in a requirement to expand U.S. strategic defense efforts, the SDI program will have developed the systems and technologies required to do so. Such a decision would ultimately require consideration of the status of Soviet military power, particularly Soviet strategic capabilities. It would also require the consideration of political developments in the Soviet Union, progress in concluding and implementing U.S.-Soviet arms reduction agreements, and changes in any ballistic missile threats from third world countries.

New Opportunities for the Negotiations on Defense and Space

Positive changes in U.S.-Soviet relations, the need to address a truly mutual concern posed by the proliferation of ballistic missile technology and concern over accidental or unauthorized launch, and a U.S. ballistic missile defense program that averts stated Soviet concerns may provide a renewed opportunity for success in the defense and space negotiations with the Soviet Union. Therefore, the United States and the Soviet Union should have a common concern to defend against an accidental, unauthorized, or third-country attack.

In the June 1990 Washington Summit Joint Statement on Future Negotiations on Nuclear and Space Arms, the United States and the Soviet Union agreed to continue negotiations on ABM and space within the existing NST framework. They further agreed that, in the future talks, they will discuss strategic stability issues, including the relationship between strategic offensive and defensive arms, taking into account stabilizing reductions in strategic offensive arms and development of new technologies. They agreed to seek agreements that implement an appropriate relation-ship between strategic offenses and defenses. Finally, the United States and the Soviet Union underlined the important goal of reaching an early outcome in the ABM and space negotiations.

The GPALS approach is consistent with U.S. objectives in the Defense and Space Talks (DST). While the SDI program is being conducted in compliance with the 1972 Anti-Ballistic Missile (ABM) Treaty, the deployment of any meaningful defense against strategic ballistic missiles will require relaxation of ABM Treaty con-straints. For example, even the U.S. ground-based defense segment envisioned under GPALS would be prohibited under the ABM Treaty, which permits only one ABM system deployment area; approximately six such areas would be needed to provide coverage of the United States, including Alaska and Hawaii. Space-based sensors and interceptors are also key to accomplishing the GPALS mission. Therefore, our goal in the defense and space talks is to negotiate a cooperative transition to allow increased reliance on strategic ballistic missile defenses.

The United States also seeks greater transparency and predictability for each side's ballistic missile defense activities. To encourage openness in this area, the United States has proposed a number of confidence-building measures designed to create a better understanding of each side's strategic ballistic-missile defense activities as early as the research stage—years before the appearance of advanced defenses in the field. The U.S. measures include annual exchanges of data, meetings of experts, briefings, visits to laboratories, observations of tests, and ABM test satel-lite notifications. Reciprocal openness in this area would be inherently stabilizing and consistent with the developing trends in U.S.-Soviet relations. The United States will continue to build upon the improving relations with the Soviet Union to achieve suc-cess in the defense and space talks and deal cooperatively with the evolving international environment.

Multilateral Discussions on Space Arms Control

ACDA continues to deal with multilateral space arms control issues in accordance with U.S. National Space Policy as stated by President Reagan in July 1982 and reaffirmed in his March 1984 Report to Congress on U.S. Policy and Anti-Satellite Arms Control. The latter included the statement, "The United States will con-sider verifiable and equitable arms control measures that would ban or otherwise limit testing and deployment of specific weapon systems, should those measures be compatible with U.S. national security."

In FY 1991, ACDA participated in multilateral discussions on outer space mainly in two forums: the United Nations and the Conference on Disarmament in Geneva. Though these discussions were informative in that they provided a venue for nonspace powers to participate, the fact remains that neither the United States nor any other party has been able to identify any outer-space arms-control issues appropriate for multilateral negotiations.

Conference on Disarmament

In 1990 and 1991, ACDA participated in discussions on outer space arms control issues in the Conference on Disarmament in Geneva. During both the 1990 and 1991 sessions, the United States again supported the formation of an appropriate non-negotiating ad hoc committee to consider issues relevant to space arms control. The committee adopted the following program of work for both its 1990 and 1991 sessions:

> Examination and identification of issues relevant to the prevention of an arms race in outer space;

Continuation of existing agreements relevant to the prevention of an arms race in outer space;

Maintenance of existing proposals and pursuance of future initiatives on the prevention of an arms race in outer space.

The United States and its allies continued to participate actively in the work of the ad hoc committee, especially in reviewing the arms control aspects and implications of the current outer-space legal regime and confidence-building measures in outer space. Several experts, including the U.S. Defense and Space Negotiator, made presentations at meetings of the Committee. While discussions enhanced understanding, issues appropriate for multilateral ne-gotiations again were not, in the U.S. view, identified.

United Nations

The First Committee of the United Nations General Assembly, the other major forum where the United States pursues its multilateral arms control objectives for outer space, met from October through December 1990. During that session, the First Committee considered two draft resolutions (Non-Aligned and Argentina) on outer space. The United States again voted against the neutral and non-aligned resolution for the following reasons:

It took no notice of the more positive international climate that has developed from improved relations between the United States and the Soviet Union.

It called for negotiations at the Conference on Disarmament on measures to "prevent an arms race in outer space."

It consisted of hostile rhetoric, with elements that were deliberately aimed at, and critical of, fundamental elements of U.S. policy.

The Argentine resolution requested the Secretary-General to carry out a study on confidence-building measures in outer space and report its results at the 47th session in 1992. While the United States abstained on the resolution because of the financial implications, it is participating in the study. The United States urged members of the First Committee to call for studies only when they are likely to be productive and constructive.

United States Information Agency

Voice of America

The Voice of America (VOA), in English and 44 other languages, traced the course of the successes of the U.S. space program throughout the year. It provided live coverage of the launch of the Ulysses robot spacecraft in October on its 4-year voyage to Jupiter and the polar regions of the Sun. The following spring the Space Life Sciences mission was the subject of a backgrounder. On at least six occasions, VOA provided live coverage of the Space Shuttle. It also provided continuous coverage of the Astro-1 Shuttle astronomy mission with a half-dozen correspondent feeds daily. In April, the Gamma Ray Observatory mission was the subject of live coverage for lift-off and several scientific reports. VOA returned to the air with live space coverage for the launch of STS-43, which deployed the Tracking and Data Relay System Satellite (TDRSS). (See above for detailed coverage of each of these missions and others discussed below.)

In addition to live coverage, the VOA covered space and scientific achievements in eleven 20-minute "New Horizons" reports broadcast worldwide. "Science Notebook," a shorter version of "New Horizons," frequently translated into other languages, also broadcast worldwide. Among the themes covered by these two programs were "The Year in Space," a year-end review of 1990 space activities; "Ulysses: Probing the Sun;" "Soviet Space: Dealing with Uncertainty;" "The Cosmos Through a Bleary Eye," about environmental effects on the study of space; and "Is Smaller Really Beautiful," on the Space Station Freedom. "New Horizons" also covered "People, Rats, and Jellyfish: the Spacelab Life Sciences Mission," the Upper Atmosphere Probe, and NASA's discovery that the Sahara Desert is capable of shrinking or expanding in size. In its coverage of space programs, VOA reporters talked with scientists, policy makers, analysts, and opinion makers, such as Library of Congress space analyst Marcia Smith, author James Oberg, NASA official Margaret Finarelli, former astronaut William Lenoir, chairman of the National Research Council Louis Lanzerotti, and space policy researcher John Logsdon at George Washington University. Other newsmakers, appearing on such weekend public affairs programs as "Press Conference USA," included Tom Logsdon on the commercial possibilities of space; SDI director, Ambassador Henry Cooper; president of the United States Space Foundation Richard MacLeod; and former astronaut Michael Collins talking about his book, *Mission to Mars*.

Press and Publications

The USIA Press Division provided news and feature stories on eight Space Shuttle missions, including deployment of the nuclear-powered European satellite Ulysses on a 5-year voyage over the poles of the sun, permitting scientists for the first time to view the Sun from all latitudes. Another Shuttle crew deployed the Gamma Ray Observatory, designed to detect gamma rays for clues to exploding stars, quasars, and black holes. Astronauts performed the first U.S. space walks in more than five years to free a jammed antenna aboard the Observatory before it could be successfully deployed from the Space Shuttle. All of these exciting events received wide coverage.

The USIA Wireless File provided continuing coverage of each new discovery made by the Magellan spacecraft orbiting Venus, including radar images indicating that powerful quakes occur on Venus and that the surface of the mysterious planet is shaped by the same kinds of forces that molded the surface of Earth. The Wireless File also carried several in-depth features, including a story about a new generation of telescopes that astronomers hope will permit them for the first time to view planets orbiting nearby stars. Another feature reported on new radio telescope images that provide convincing evidence for a massive black hole lurking deep within the heart of Earth's Milky Way galaxy.

The Publications Division distributed five articles about the space program to 70 USIA posts overseas and produced a special packet containing six photographs that included views of Venus from the Magellan spacecraft and of the solar system as viewed by Voyager I. *America Illustrated*, USIA's Russian-language monthly magazine that circulates widely in the Soviet Union, published four articles on the space program. *Topic*, a quarterly magazine circulated in English and French to Africa, carried two articles on U.S. space efforts, including "A Pale Blue Dot" by Carl Sagan. And *al-Majal*, the Arabic-language monthly, published four space articles.

Television

In close cooperation with NASA, the Television and Film Service used its WORLDNET satellite system to deliver extensive information on the space program in a variety of formats. Every mission was covered extensively, and NASA officials were generous with their time in explaining U.S. space policy to audiences around the globe via WORLDNET's live interactive video-press conferences. During the past year, WORLDNET produced nine interactive programs on space- and science-related topics for journalists and science writers in Europe, Asia, Latin America, Africa, and the Pacific Ocean nations. The chief of NASA's Land Processes Branch talked about the use of remote sensors in relation to the environment with African journalists. A top NASA scientist joined with a senior EPA official to discuss the implications of global climatic change with fellow scientists and writers in China, New Zealand, and Australia, while the head of the Climate and Radiation Branch at Goddard discussed a similar topic with government ministers in Zambia. The director of the solar system exploration division participated in two programs on the Magellan mission, one to Latin America and the other to nations in Asia. A U.S. Embassy officer from one of these countries reported this program "was a tremendous success, not only in demonstrating America's continuing technical achievements in space, but in showing the engaging 'human face' of our space program."

The Newsfile, which offers short 2- to 3-minute clips for placement on overseas television networks 5 times a week, produced over 70 individual segments (in English, Spanish, French, and Arabic, as well as a music and effects version) that were seen by viewers from Tallin (Estonia) to Timbaktu. The "Science World" series, popular and well-known around the world, drew heavily on NASA stories. Over a dozen features were devoted to the National Aero-Space Plane, Space Station Freedom, recycling in space, and NASA's innovative space classroom, among other subjects. In addition to the four languages above, "Science World" appeared in Portuguese and Chinese.

Teleconferences

NASA's scientific efforts in both the environmental and the astronomic areas were the key subjects of interest to foreign media, scientists, scholars, and university students Experts in Brazil, Mexico, Honduras, and Thailand participated in six separate teleconferences with five NASA officials and scientists on NASA's role in the subspace airplane project, Project Sea Rise, the structure of the universe, and the July 11 solar eclipse.

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
ACTS	Advanced Communications Technology Satellite
Ada	A programming language used by the DOD
ADEOS	(Japanese) Advanced Earth Observing Satellite
ADP	Advanced Ducted Propeller
AEM	Animal Enclosure Modules
AESOP	ARGOS Environmental Shipboard Observer Platform
AERA	Automated En Route Air Traffic Control System
AFB	Air Force Base
AFSC	Alaska Fisheries Science Center
AFSCN	Air Force Satellite Control Network
AFTI	Advanced Fighter Technology Integration
AGFS	Aviation Gridded Forecast System
AGRHYMET	AGRiculture, HYdrology, and METeorology
AIDA	Arecibo Initiative on Dynamics of the Atmosphere
AKM	Apogee Kick Motor
albedo	The ratio of the amount of electromagnetic radiation reflected by a body to the amount incident upon it
ALOHA	Airborne Lidar and Observations of Hawaiian Airglow
AMLS	Advanced Manned Launch 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 that of 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
Arinc	Aeronautical Radio, Inc
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
ASRM	Advanced Solid Rocket Motor
ASTP	Advanced Space Technology Program
Astro	Astronomy Observatory

ATLAS	Atmospheric Laboratory for Applications and Science
ATMS	Advanced Traffic Management System
AVHRR	Advanced Very High Resolution Radiometer
AWOS	Automated Weather Observing Systems
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
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
CASS	Computer Aided Stratification and Sampling
CAT	Clear Air Turbulence
Cassini	A Saturn Orbiter/Titan Probe
CCAFS	Cape Canaveral Air Force Station
C-CAP	CoastWatch-Change Analysis Program
CD-ROM	Compact Disk-Read Only Memory
CCDS	Centers for the Commercial Development of Space
CCSDS	Consultative Committee for Space Data Systems
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFD	Computational Fluid Dynamics
CGMS	Coordination Group for Meteorological Satellites
CEDAR	Coupling, Energetics, and Dynamics of Atmospheric Regions
CELLS	Controlled Ecological Life Support System
CEOS	Committee on Earth Observations Satellites
CEPS	Center for Earth and Planetary Studies
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
CIRRIS	Cryogenic Infrared Radiance Instrumentation for Shuttle
CITE	Cargo Interface Test Equipment
CLAES	Cryogenic Limb Array Etalon Spectrometer
CNES	Acronym for the French Space Agency
COBE	Cosmic Background Explorer
COMPTEL	Compton Telescope
COPUOS	(U.N.) Committee on the Peaceful Uses of Outer Space
COSMIC	Computer Software Management Information Center
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
CTAS	Center-TRACON Automation System
CTV	Cargo Transfer Vehicle
DARPA	Defense Advanced Research Project Agency
DBS	Direct Broadcast Satellite
DCS	Data Collection System
DE	Directed Energy
Dem/Val	Demonstration/Validation
Dexterous End Effector	A device being developed for the Orbiters that will employ a sensor on the Shuttle RMS to provide more precise control over payloads; scheduled for a flight date of May 1994 on STS-65
DMSP	Defense Meteorological Satellite Program
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DOI	Department of Interior
DOLILU	Day-of-Launch I-Load-Update
DSCS	Defense Satellite Communication System
DSN	Deep Space Network
DSP	Defense Support Program
DST	Defense and Space Talks
ECS	EOSDIS Core System
EDFE	EVA Development Flight Experiments
EDOMP	Extended Duration Orbiter Medical Program
EFM	Enhanced Fighter Maneuverability
EGRET	Energetic Gamma Ray Experiment Telescope
EHF	Extremely High Frequency
ELV	Expendable Launch Vehicle
EMAP	Environmental Monitoring and Assessment Program
envelope	The operational parameters within which an aircraft can fly
EO-ICWG	Earth Observations-International Coordination Working Group
EOS	Earth Observing System
EOSDIS	EOS Data and Information System
EOSAT	Earth Observation Satellite Company
EPIRB	Emergency Position-Indicating Radio Beacons
EPRI	Electric Power Research Institute
ERBE	Earth Radiation Budget Experiment
EROS	Earth Resources Observation System
ERTS	Earth Resources Technology Satellite
ERS	European Space Agency Remote Sensing Satellite
ESA	European Space Agency
EUMESAT	European Meteorological Satellite Program
EUVE	Extreme Ultraviolet Explorer
EVA	Extravehicular Activity
FAA	Federal Aviation Administration
FAS	Foreign Agricultural Service
FASA	Final Approach Spacing Aid

FAST	Fast Auroral Snapshot
FDF	Flight Dynamics Facility
Floquet theory	A method of solving a second-order differential equation
FRED	FAA Research Electromagnetic Database
FSAR	Final Safety Analysis Report
FTS	Flight Telerobotic Servicer
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
GAS	Get Away Special
GBI	Ground Based Interceptor
GDR	Geophysical Data Records
GEM	Geospace Environment Modeling
geoid	The figure of the Earth as defined by the geo-potential surface that most nearly coincides with mean sea level over the entire surface of the planet's contiguous bodies of water
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
GGS	Global Geospace Science
GGSF	Gas-Grain Simulation Facility
GIS	Geographic Information System
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
HALOE	Halogen Occultation Experiment
HAPS	Hydrazine Auxiliary Propulsion System
HARV	High Angle-of-Attack Research Vehicle
HAX	Haystack Auxiliary Radar
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
HIRIS	High Resolution Imaging Spectrometer
HLFC	Hybrid Laminar Flow Control
HPCC	High Performance Computing and Communications
HRDI	High Resolution Doppler Imager
HRS	High Resolution Spectrograph
HSCT	High Speed Civil Transport
HST	Hubble Space Telescope
HUT	Hopkins Ultraviolet Telescope
hypersonic	Faster than 4,000 miles per hour
IBSS	Infrared Background Signature Survey
ICAO	International Civil Aviation Organization
ICBM	Intercontinental Ballistic Missile
ICE	International Cometary Explorer
IFM	Internal Fluid Mechanics
IFR	Instrument Flight Rules
IMI	Inner Magnetosphere Imager
IML	International Microgravity Laboratory
IMO	International Maritime Organization
IMP	Interplanetary Monitoring Platform
INF	Intermediate-Range Nuclear Forces (Treaty)
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
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
ISO	International Organization for Standardization
ISTP	International Solar-Terrestrial Physics
ISY	International Space Year (1992)
ITA	Instrumentation Technology Associates
ITP	Integrated Technology Plan
IUS	Inertial Upper Stage
IV&V	Independent Validation and Verification
IWG	Investigator Working Group
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
KE	Kinetic Energy
KSC	Kennedy Space Center
Ku-band	Radio frequencies in the 11-12 gigaherz range
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
LDEF	Long Duration Exposure Facility
LEAP	Lightweight Exo-Atmospheric Projectile
LEO	Low Earth Orbit
LFC	Laminar Flow Control
LfA	Laboratory for Astrophysics
Lidar	Light radar
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
low by-pass engine	A turbo-engine having a by-pass ratio of of less than four to one—see high by-pass engine
LWIR	Long-Wavelength Infrared
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
man-rated	Certified to transport people into space
maser	Microwave Amplification by Simulated Emission of Radiation—a device introduced in 1953 with multiple applications in physics, chemistry, radio and television communication
MBR	Mars Balloon Relay
MCC	Mission Control Center
MCS	Maritime Communications Subsystem
MESUR	Mars Environmental Survey Mission
MIDEX	Middle-Class Explorer
MILSATCOM	Military Satellite Communications
MLS	Microwave Limb Sounder
MMD	Mean Mission Duration
MO	Mars Observer
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
MTD	Maneuver Technology Demonstrator
NASA	National Aeronautics and Space Administration
NASCAP	NASA Charging Analysis Program
NASCOM	NASA Communications System
NASDA	(Japanese) National Space Development Agency
NASM	National Air and Space Museum
NASP	National Aerospace Plane
NASS	National Agricultural Statistics Service
NCC	Network Control Center
NCDC	National Climatic Data Center
NDVI	Normalized Difference Vegetation Index
NESDIS	(NOAA) National Environmental Satellite, Data, and Information Service
NGDC	National Geophysical Data Center
NHC	National Hurricane Center
NIST	(DOC) National Institute of Standards and Technology
NLS	New Launch System
NMC	National Meteorological Center
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NODC	National Oceanographic Data Center
NOS	National Ocean Service
NOx	Any of several compounds of nitrogen and oxygen, including nitrogen oxide
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
NTIA	(DOC) National Telecommunications and Information Administration
NTTC	National Technology Transfer Center
NUDET	Nuclear Detonation
NWS	National Weather Service
OCP	(NASA) Office of Commercial Programs
OCTW	Optical Communications Through the Shuttle Window
OLR	Outgoing Longwave Radiation
OSC	(NASA) Office of Space Commerce
OSL	Orbiting Solar Laboratory
OSSE	Oriented Scintillation Spectrometer Experiment
out-of-ground effect	See "ground 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 sheet	An extensive area of low energy, ionized gases in the tail region of the magnetosphere that undergoes considerable change during magnetospheric storms
PLS	Personnel Launch System
PMS	Physiological Monitoring System
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	Plutonium
PVO	Pioneer Venus Orbiter
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
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
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

RTG	Radioisotope Thermoelectric Generator
RTTC	Regional Technology Transfer Center
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 Background Ultra-Violet
SCS	Soil Conservation Service
SDI	Strategic Defense Initiative
SDIO	Strategic Defense Initiative Organization
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 Deployer System
SEI	Space Exploration Initiative
SEM	Space Environment Monitor
SETI	Search for Extraterrestrial Intelligence
SHARE	Space Station Heat Pipe Advanced Radiator Element
SMEX	Small Explorer
SIRTF	Space Infrared Telescope Facility
SLAR	Side-Looking Airborne Radar
SLC	Space Launch Complex
SLS	Space Life Sciences Laboratory
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 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
SOLSTICE	Solar/Stellar Irradiance Comparison Experiment
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
SRAM	Static Random Access Memory
SRM&QA	Safety, Reliability, Maintainability, and Quality Assurance
SSAAC	Space Science and Applications Advisory Committee
SSBUV	Shuttle Solar Backscatter Ultraviolet
SSCE	Solid Surface Combustion Experiment
SSF	Space Station Freedom

SSME	Space Shuttle Main Engine
SSMI	Special Sensor Microwave/Imager
SSMT	Special Sensor Microwave/Temperature
SST	Sea Surface Temperature
START	Strategic Arms Reduction Treaty
STDN	Spaceflight Tracking and Data Network
STGT	Second TDRSS Ground Terminal
STME	Space Transport Main Engine
STOL	Short Takeoff and Landing
STOVL	Short Take-off and Vertical Landing (Aircraft)
STS	Space Transportation System
STV	Space Transfer Vehicle
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
SUSIM	Solar Ultraviolet Spectral Irradiance Monitor
SWAS	Submillimeter Wave Astronomy Satellite
TASS	Terminal Area Surveillance System
TDRS	Tracking and Data Relay Satellite
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
TOMS	Total Ozone Mapping Spectrometer
TOPEX	Ocean Topography Experiment
TOPS	Toward Other Planetary Systems
TOS	Transfer Orbital Stage
TOVS	Television-and-Infrared-Operational-Satellite (TIROS) Operational Veitical Sounder
TPCE	Tank Pressure Control Experiment
TR	Thrust-reversing
TRACON	Terminal Radar Approach Control
TRMM	Tropical Rainfall Measuring Mission
TSS	Tethered Satellite System
TV	Thrust-vectoring
TVCS	Thrust Vector Control System
UARS	Upper Atmosphere Research Satellite
UHF	Ultra High Frequency
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
USMP	U.S. Microgravity Payload
UV	Ultraviolet
UVCS	Ultraviolet Coronal Spectrometer
VAS	Visible-and-Infrared-Spin-Scan-Radiometer Atmospheric Sounder
VCS	Voice Command System
VLBI	Very Long Baseline Interferometry
VLSI	Very Large Scale Integration
VoA	Voice of America
WARC	World Administrative Radio Conference
WEFAX	Weather Facsimile
WGD	(CEOS) Working Group on Data
WINDII	Wind Imaging Interferometer
WMO	World Meteorological Organization
WSGT	White Sands Ground Terminal
WSMC	Western Space and Missile Center
WUPPE	Wisconsin Ultraviolet Photopolarimeter Experiment
XTE	X-ray Timing Explorer

Appendixes

APPENDIX A-1

U.S. 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 (through Sep. 30)	25[c]	0	0	0
TOTAL	1,257	144	82	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 four commercial satellites launched on four commercial expendable launch vehicles.

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	U.S.S.R.	France	Italy	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[a]	1	1					
1971	30	83	1	2[a]	2	1		1			
1972	30	74		1	1						
1973	23	86									
1974	22	81		2[a]	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
TOTAL	922	2,256	10	8	41	28	1	1	35	3	2
1991 (through Sep. 30)	10[b]	45			2				6	1	
TOTAL	932	2,301	10	8	43	28	1	1	41	4	2

[a] Includes foreign launches of U.S. spacecraft.
[b] This excludes four commercial expendable launches.

Successful U.S. Launches October 1, 1990–September 30, 1991

Launch Date (GMT), Spacecraft Name, COSPAR Designation, Launch Vehicle	Mission Objectives, Spacecraft Data	Apogee and Perigee (km), Period (min), Inclination to Equator(°)	Remarks
Oct. 1 USA-64 88A Delta II	Objective: To place satellite into successful orbit from which Navy objectives can be met. Spacecraft: Not announced.	20,378.0 19,984.0 717.9 55.0	Ninth in a series of Block II operational Navstar Global Positioning Satellites (GPS) launched by U.S. Air Force expendable launch vehicle. Operational system to be composed of 24 satellites in six orbital planes. In orbit.
Oct. 6 Space Shuttle Discovery (STS-41) 90A	Objective: To successfully launch Ulysses spacecraft toward rendezvous with the Sun. Spacecraft Shuttle orbiter carrying spacecraft with Inertial Upper Stage (IUS) booster and Payload Assist Module (PAM-S) with additional experiments. Chromosome and Plant Cell Division (CHROMEX-2), Solid Surface Combustion Experiment (SSCE), Shuttle Solar Backscatter Ultraviolet (SSBUV) instrument, Intelsat Solar Array Coupon (ISAC) experiment, Physiological Systems Experiment (PSE), Investigations into Polymer Membrane Processing (IPMP), Voice Command System (VCS), and Radiation Monitoring Equipment-III. Weight of experiments: 1,671 lbs.	303.0 280.0 90.2 28.4	Thirty-sixth flight of Space Transportation System. Piloted by Richard N. Richards and Robert D. Cabana. Mission specialists Bruce E. Melnick, William M. Shepherd, and Thomas D. Akers. Discovery launched from KSC, Pad 39B, 7:47 a.m., EDT. Landed at Edwards AFB, CA, 9:57 a.m., EDT. Mission duration 4 days, 2 hours, 10 minutes, and 54 seconds, Oct. 10, 1990.
Oct. 6 Ulysses 90B	Objective: To investigate properties of the solar wind, the structure Sun/wind interface, the heliospheric magnetic field, solar radio bursts and plasma waves, solar X-rays, solar and galactic cosmic rays, and interstellar interplanetary neutral gas and dust. Spacecraft: Spin-stabilized: main bus, 10.5 by 10.8 by 6.9 feet. 5.4 foot diameter, parabolic high-gain antenna attached to main bus. After release from shuttle payload bay spacecraft will deploy 18 . 2 foot radial boom, a 238 foot dipole wire boom, and a 26. 2 foot agial boom. Booms serve as antennas for radio wave-plasma experiment. Power source is a radioisotope thermo-electric generator (RTG) attached to main bus. Weight, including IUS/PAM-S: 44,024 lbs.	Heliocentric orbit.	Successfully deployed by space shuttle Discovery. Ulysses will encounter Jupiter February 1992, where it will receive a gravity assist velocity increase enabling the spacecraft to dive down-ward and away from the ecliptic plane. Spacecraft will reach 70° south solar latitude in June 1994. Ulysses in a joint mission conducted by the European Space Agency and NASA. In orbit.
Nov. 13 USA-65 95A Titan IV	Objective: Development of spaceflight techniques and technology Spacecraft: Not announced.	Not announced.	In orbit.

Successful U.S. Launches
October 1, 1990–September 30, 1991

Launch Date (GMT), Spacecraft Name, COSPAR Designation, Launch Vehicle	Mission Objectives, Spacecraft Data	Apogee and Perigee (km), Period (min), Inclination to Equator(°)	Remarks
Nov. 15 Space Shuttle Atlantis (STS-38) 97A	Objective: To launch classified DoD payload. Spacecraft: Shuttle orbiter carrying classified Dod payload/ cargo. Weight: Not announced.	221.0 215.0 88.6 28.4	Thirty-seventh flight of Space Transportation System. Piloted by Richard 0. Covey and Frank L. Culbertson, Jr. Mission specialists Charles "Sam" Gemar, Robert C. Springer and Carl J. Meade. Launched from KSC, 6:48 p.m., EST. Landed Nov. 10, 4:43 p.m., EST, on Runway 33, KSC. First KSC shuttle landing since 1985. Mission duration: 4 days, 21 hrs., and 55 min.
Nov. 15 USA-67 97B	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	Not announced.	Successfully launched from shuttle Atlantis. In orbit.
Nov. 26 USA-66 103A Delta II	Objective: To successfully place Navy satellite in orbit from which objectives of mission can be met. Spacecraft: Not announced.	20,279.0 19,935.0 714.8 54.8	Tenth spacecraft in a series of operational Navstar Global Positioning Satellites (GPS). In orbit.
Dec. 1 USA-68 105A Atlas E	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	845.0 729.0 100.6 98.9	One in a series of Defense Meteorological Satellites. In orbit.
Dec. 2 Space Shuttle Columbia (STS-35) 106A	Objective: To carry ASTRO-1 astrophysical observatory into orbit and return to Earth. Spacecraft: Shuttle orbiter Columbia carrying ASTRO-1 to cargo bay. ASTRO-1 to provide around-the-clock observations and measurements of ultraviolet radiation from celestial objects. Instruments include the ultraviolet astronomy observatory (ASTRO) and the Broad Band X-Ray Telescope (BBXRT). Three additional instruments are Hopkins Ultraviolet Telescope (HUT), the Wisconsin Ultraviolet Photo-polarimeter Experiment (WUPPE) and the Ultraviolet Imaging Telescope (UIT). Weight: 27,454 lbs .	363.0 350.0 91.7 28.5	Thirty-eighth flight of the Space Transportation System. Piloted by Vance D. Brand, Guy S. Gardner. Mission specialists Jeffrey A. Hoffman, John M. "Mike" Lounge, and Robert A. R. Parker. Payload specialists Samuel T. Durrance and Ronald A. Parise. Launched from KSC at 1:49 a.m. EST. Landed at Edwards AFB, CA, Dec. 11 at 12:54 a.m., EST. Mission duration: 8 days, 23 hrs., 5 min.
Mar. 8 USA-69 17A Titan IV	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	Not announced.	First launch of Titan IV from the WSMC. In orbit.

Successful U.S. Launches October 1, 1990–September 30, 1991

Launch Date (GMT), Spacecraft Name, COSPAR Designation, Launch Vehicle	Mission Objectives, Spacecraft Data	Apogee and Perigee (km), Period (min), Inclination to Equator(°)	Remarks
Apr. 5 Space Shuttle Atlantis (STS-37) 27A	Objective: To successfully launch the Gamma Ray Observatory. Spacecraft: Shuttle orbiter carrying satellite. Additional experiments include EVA Development Flight Experiments (EDFE), Ascent Particle Monitor (APM), Bioserve ITA Materials Dispersion Apparatus (BIMDA), Protein Crystal Growth-III (PCG-III), Shuttle Radiation Monitoring Equipment-III (RME-III), Air Force Maui Optical System (AMOS), and Space Station Heat Pipe Advanced Radiator Element-II (SHARE-II).	465.0 449.0 93.8 28.5	Thirty-ninth flight of the Space Transportation System. Piloted by Steven R. Nagel and Kenneth D. Cameron. Mission specialists Linda Godwin, Jerry L. Ross, and Jay Apt. Launched from KSC, Pad 39B at 9:22:45 a.m., EST. Landed at Edwards AFB, CA., Apr. 11 at 9:55 a.m., EST. Mission duration: 6 days, 32 min.
Apr. 7 Gamma Ray Observatory (GRO) 27B	Objective: To successfully launch satellite for two year measurement of gamma rays covering most of the entire celestial sphere. Spacecraft: Rectangular shaped body with dual solar panels extending from the satellite. One high-gain and two low-gain antennas. Four scientific instruments include Burst and Transient Source Experiment (BATSE), Oriented Scintillation Spectrometer Experiment (OSSE), Imaging Compton Telescope (COMPTEL), and Energetic Gamma Ray Experiment Telescope (EGRET). Weight: 35,000 lbs.	444.0 432.0 93.3 28.5	Successfully launched from shuttle Atlantis after astronaut EVA to unfurl stuck solar panel. A NASA cooperative program with the Federal Republic of Germany, with co-investigator support from The Netherlands, the European Space Agency, the United Kingdom, and the United States. Satellite placed in space by Remote Manipulator System (RMS) arm. Returning data. In orbit.
Apr. 28 Space Shuttle Discovery (STS-39) 31A	Objective: To conduct Air Force and Strategic Defense Initiative (SDIO) experiments in orbit. Spacecraft: Shuttle orbiter carrying satellites and additional scientific experiments.	263.0 249.0 89.4 56.9	Fortieth flight of the Space Transportation System. Piloted by Michael L . Coats and Blaine Hammond, Jr. Mission specialists Gregory L. Harbaugh, Donald R. McMonagle, Guion S. Bluford, C. Lacy Veach, and Richard J. Hieb. Launched from KSC Shuttle Landing Facility, Runway 15, 2:55 p.m., EDT, May 6. Mission duration: 8 days, 7 hrs., 22 min.
Apr. 28 USA-70 31C	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	Not announced.	Successfully deployed from shuttle Discovery. In orbit.
May 1 Infrared Background Signature Survey (IBSS) 31B	Objective: To obtain scientific data for use in development of ballistic missile defense sensor systems for the Strategic Defense Initiative Organization (SDIO). Spacecraft: Shuttle Pallet Satellite II (SPAS II). Rectangular bus on which various experiments can be mounted. Weight: 4,197 lbs.	263.0 248.0 89.4 56.9	Successfully deployed from shuttle cargo bay by Remote Manipulator System (RMS) arm, 4:17 a.m., EDT. Discovery's manipulator arm grappled the payload at 6:25 p.m., EDT, May 2. Payload returned data on release of unsymmetric dimethyl hydrazine from Chemical Release Observation subsatellites. Returned to Earth in cargo bay of Discovery.

Successful U.S. Launches
October 1, 1990–September 30, 1991

Launch Date (GMT), Spacecraft Name, COSPAR Designation, Launch Vehicle	Mission Objectives, Spacecraft Data	Apogee and Perigee (km), Period (min), Inclination to Equator(°)	Remarks
May 2 Chemical Release Observation (CRO) subsatellite 31D	Objective: To provide short-lived clouds of vapor and frozen particles in orbit for observation by IBSS orbiting payload. Spacecraft: Cylindrical.	Not announced.	Successfully deployed from Discovery. Reentered May 14.
May 2 Chemical Release Observation (CRO) subsatellite 31E	Objective: To provide short-lived clouds of vapor and frozen particles in orbit for observation by IBSS orbiting payload. Spacecraft: Cylindrical.	Not announced.	Successfully deployed from shuttle Discovery. Reentered May 12.
May 3 Chemical Release Observation (CRO) subsatellite 31F	Objective: To provide short-lived clouds of vapor and frozen particles in orbit for observation by IBSS orbiting payload. Spacecraft: Cylindrical.	Not announced.	Successfully deployed from shuttle Discovery. Reentered May 13.
May 14 NOAA-12 32A Atlas E	Objective: To launch spacecraft into a sun-synchronous orbit of sufficient accuracy to enable spacecraft to accomplish its operational mission. To acquire daily global weather information for the short- and long-term forecasting needs of the National Weather Service. Spacecraft: In launch configuration is 371 cm high, 188 cm in diameter; three-axis-stabilized. Instruments include Advanced Very High Resolution Radiometer (AVHRR), TIROS Operational Vertical Sounder System (TOVS), Space Environment Monitor (SEM) and Argos Data Collection System (DCS) provided by France. Weight at launch: 1418 kg. Weight in orbit, with Apogee Kick Motor (AKM) expendables consumed: 735 kg.	841.0 821.0 101.3 98.7	Successfully launched by NASA from Vandenberg AFB, CA, Space Launch Complex 3 West (SLC-3W) at 11:52 a.m., EDT. Joins NOAA-10 and NOAA-ll in collecting meteorological and environmental data and will eventually replace NOAA-10, launched in Sept. 1986.
Jun. 5 Space Shuttle Columbia (STS-40) 40A	Objective: To carry Spacelab Life Sciences (SLS-1) dedicated life sciences research module in cargo bay. Spacecraft: Shuttle orbiter Columbia carrying SLS-l and Get Away Special (GAS) Bridge experiments in the cargo bay . Middeck payloads: Physiological Monitoring System (PMS), Urine Monitoring System (UMS), and Animal Enclosure Modules (AEM). SLS-1 includes 18 primary scientific scientific experiments.	302.0 276.0 90.1 39.0	Forty-first flight of the Space Transportation System. Piloted by Bryan D. O'Conner, and Sidney M. Gutierrez. Mission specialists James P. Bagian, Tamara E. Jernigan, and M. Rhea Seddon, Payload specialists Francis A. (Drew) Gaffney and Millie Hughes-Fulford. Launched from KSC, Pad 39B, 9:24 a.m., EDT. Landed at Edwards AFB, CA, 11:39 a.m., EDT, Jun. 14. Mission duration: 9 days, 2 hrs., 15 min.
Jun. 29 Radiation Experiment (REX) 45A Scout	Objective: To launch U.S. Air Force radiation experiment satellite. Spacecraft: Not announced. Weight: 188 lbs.	871.0 770.0 101.3 89.6	Successfully launched by NASA for Air Force from Vandenberg AFB, CA, Space Launch Complex (SLC) 5. 10:00 a.m., EDT. Test of sophisticated communications in a high-radiation environment. In orbit.

Successful U.S. Launches
October 1, 1990–September 30, 1991

Launch Date (GMT), Spacecraft Name, COSPAR Designation, Launch Vehicle	Mission Objectives, Spacecraft Data	Apogee and Perigee (km), Period (min), Inclination to Equator(°)	Remarks
Jul. 4 USA-71 47A Delta II	Objective: To place satellite into successful orbit from which Navy objectives can be met. Spacecraft: Not announced.	20,250.0 19,451.0 704.6 55.3	Eleventh in a series of operational Navstar Global Positioning Satellites (GPS) launched by Air Force expendable booster. Operational system to be composed of 24 satellites in 6 orbital planes. In orbit.
LOSAT-X 47B	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	416.0 402.0 92.8 40.0	Secondary payload launched by Delta II. Reentered Nov. 15, 1991.
Jul. 17 Microsat-l 51A Pegasus	Objective: To launch small satellite for communications experiment. Spacecraft: Seven and 1/2 inches high, 19 inches wide. Weight: 49 lbs.	454.0 356.0 92.7 82.0	Successfully launched by Pegasus vehicle carried to altitude by NASA B-52 off CA coast. Satellite sponsored by the Defense Advanced Research Projects Agency (DARPA). In orbit.
Microsat-2 51B	Objective: To launch small satellite for communications experiment. Spacecraft: Seven and 1/2 inches high, 19 inches wide. Weight: 49 lbs.	457.0 359.0 92.7 82.0	Second of seven satellites launched for DARPA. In orbit.
Microsat-3 51C	Objective: To launch small satellite for communications experiment. Spacecraft: Seven and 1/2 inches high, 19 inches wide. Weight: 49 lbs.	442.0 355.0 92.5 82.0	Third of seven satellites launched for DARPA. In orbit.
Microsat-4 51D	Objective: To launch small satellite for communications experiment. Spacecraft: Seven and 1/2 inches high, 19 inches wide. Weight: 49 lbs.	457.0 359.0 92.7 82.0	Fourth of seven satellites launched for DARPA. In orbit.
Microsat-5 51E	Objective: To launch small satellite for communications experiment. Spacecraft: Seven and 1/2 inches high, 19 inches wide. Weight: 49 lbs.	457.0 360.0 92.7 82.0	Fifth of seven satellites launched for DARPA. In orbit.
Microsat-6 51F	Objective: To launch small satellite for communications experiment. Spacecraft: Seven and 1/2 inches high, 19 inches wide. Weight: 49 lbs.	458.0 359.0 92.7 82.0	Sixth of seven satellites launched for DARPA. In orbit.
Microsat-7 51G	Objective: To launch small satellite for communications experiment. Spacecraft: Seven and 1/2 inches high, 19 inches wide. Weight: 49 lbs.	458.0 359.0 92.7 82.0	Seventh of seven satellites launched for DARPA. In orbit.

Successful U.S. Launches
October 1, 1990–September 30, 1991

Launch Date (GMT), Spacecraft Name, COSPAR Designation, Launch Vehicle	Mission Objectives, Spacecraft Data	Apogee and Perigee (km), Period (min), Inclination to Equator(°)	Remarks
Aug. 2 Space Shuttle Atlantis 54A	Objective: To successfully place in orbit NASA's fourth Tracking and Data Relay Satellite (TDRS-5). Spacecraft: Shuttle orbiter carrying satellite with Inertial Upper Stage (IUS). Cargo bay payloads: Station Heat Pipe Advanced Radiator Element-II (SHARE-II), Shuttle Solar Backscatter Ultraviolet Experiment (SSBUV), and Optical Communications Through the Shuttle Window (OCTW). Middeck payloads: Air Force Maui Optical System (AMOS), Auroral Photography Experiment-B (APE-B), Bioserve-Instrumentation Technology Associates Materials Dispersion Apparatus (BIMDA), Investigations into Polymer Membrane Processing (IPMP), Protein Crystal Growth-III (PCG-III), Space Acceleration Measurement System (SAMS), Solid Surface Combustion Experiment (SSCE), and Tank Pressure Control Experiment (TPCE). Weight of experiments: 2,699 lbs.	329.0 309.0 90.6 28.4	Forty-second flight of the Space Transportation System. Piloted by John E. Blaha and Michael A. Baker. Mission specialists Shannon W. Lucid, G. David Low, and James C. Adamson. Launched KSC, Pad 39A, 11:02 a.m., EDT. Landed at KSC's Shuttle Landing Facility, Aug. 11, 8:23 a.m., EDT. Mission duration 8 days, 21 hrs, 21 min.
Aug. 2 Tracking and Data Relay Satellite 5 (TDRS-5) 54B	Objective: To launch satellite to TDRS-3, into successful geosynchronous orbit with sufficient station keeping fuel on board to complete the on-orbit constellation and meet NASA requirements to provide full-capability user support services. Spacecraft: Three-axis stabilized, momentum-biased configuration with two sun-oriented solar panels attached. TDRS measures 57.17 ft tip to tip of deployed solar panels. Composed of 3 modules: (1) equipment module houses attitude control, electric power, propulsion, telemetry, tracking, and command subsystems; (2) payload module consists of processing and frequency-generation equipment; (3) antenna module supports dual deployable and fixed antennas, multiple-access array, and remainder of telecommunications hardware. Weight at launch, including IUS: 37,640 lbs. In orbit TDRS-5 will weigh 4,637 lbs, and measure 57.2 ft. from tip to tip of solar panels by 46.6 ft from outer edge to edge of its Single Access antennas.	39,011.0 38,855.0 1599.8 0.1	Successfully launched from Atlantis and successfully transferred to geosynchronous orbit by IUS. Placed at 175°W longitude. Oct. 7 officially replaced TDRS-3 as primary provider of customer suppoer in the western location. In orbit.

Successful U.S. Launches
October 1, 1990–September 30, 1991

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-48) 63A	Objective: To successfully launch Upper Atmosphere Research Satellite (UARS) and conduct other experiments. Spacecraft: Shuttle orbiter carrying satellite with additional experiments. Cargo Bay: Atmospheric Particle Monitor-3 (APM-3) Middeck payloads: Radiation Monitoring Equipment-III (RME-III-06), Protein Crystal Growth-7 (PGC-7), Middeck 0-G Gravity Dynamics Experiment-I (MODE-01), Investigations into Polymer Membrane Processing-4 (IPMP-04), Physiological and Anatomical Rodent Experiment-l (PARE-1), Shuttle Activation Monitor-l (SAM-03), Cosmic Radiation Effects and Activation Monitor-l (CREAM-Ol), Air Force Maui Optical System-12 (AMOS), and Electronic Still Photography Camera. Weight: 475 lbs.	553.0 538.0 95.4 56.9	Forty-third flight of the Space Transportation System. Piloted by John Creighton and Kenneth Reightler, Jr. Mission specialists Charles D. Gemar, James F. Buchli, and Mark N. Brown. Launched from Pad 39A, KSC, 7:11 p.m., EDT. Landed at Edwards AFB, CA, 3:38 a.m., EDT., Sept. 18. Weather conditions forced change of landing site from KSC. Mission duation: 5 days, 8 hrs., 28 min.
Sep. 15 Upper Atmosphere Remote Research Satellite (UARS) 63B	Objective: To launch satellite to study mankind's effect on planet's atmosphere and it's shielding ozone layer. Spacecraft: Containing nine complimentary experiments: Cryogenic Limb Array Etalon Spectrometer (CLAES), Improved Stratospheric and Mesospheric Sounder (ISAMS), Microwave Limb Sounder (MLS) Halogen Occultation Experiment (HALOE) to measure the chemistry of the atmosphere; High Resolution Doppler Imager (HRDI) and Wind Imaging Interferometer (WINDII) to measure the dynamics of the atmosphere; Solar Ultraviolet Spectral Irradiance Monitor (SUSIM), Solar/Stellar Irradiance Comparison Experiment (SOLSTICE), and Particle Environment Monitor (PEM) to determine energy inputs from the Sun and Earth's magnetosphere. A tenth instrument, Active Cavity Radiometer Irradiance Monitor II (ACRIM II) will extend long-term measurements of the solar constant. 3-axis stabilized spacecraft body. Weight: 14,419 lbs.	580.0 574.0 96.2 57.8	Satellite successfully launched from Discovery cargo bay by Remote Manipultor System (RMS) arm at 12:23 a.m., EDT. Will make measurements over the full range of local times at most geographic locations every 36 days. First major flight element of NASA's Mission to Planet Earth. Design life of 36 months. Returning data. In orbit.

U.S.-Launched Applications Satellites, 1985–1991

Date	Name	Launch Vehicle	Remarks
			COMMUNICATIONS
Mar. 22, 1985	Intelsat VA F-10	Atlas-Centaur	First in series of six improved satellites.
Apr. 12, 1985	Telesat-I	Space Shuttle	Launched for Telsat Canada.
Apr. 13, 1985	Syncom IV-3	Space Shuttle	Launched for US Navy.
June 17, 1985	MORELOS-A	Space Shuttle	Launched for Mexico.
June 18, 1985	Arabsat-1B	Space Shuttle	Launched for Arab Satellite Communication Organization (ASCO).
June 19, 1985	Telstar-3D	Space Shuttle	Launched for the American Telephone and Telegraph Company (AT&T).
June 30, 1985	Intelsat VA F-11	Atlas-Centaur	Second in series of improved satellites launched for INTELSAT.
Aug. 27, 1985	AUSSAT-1	Space Shuttle	Launched for Australia's National Satellite Company.
Aug. 27, 1985	ASC-1	Space Shuttle	Launched for American Satellite Company.
Aug. 29, 1985	Syncom IV-4	Space Shuttle	Launched for US Navy.
Sep. 29, 1985	Intelsat VA F-12	Atlas-Centaur	Launched for INTELSAT.
Nov. 27, 1985	MORELOS-B	Space Shuttle	Launched for Mexico.
Nov. 27, 1985	AUSSAT-2	Space Shuttle	Second satellite launched for Australia's National Satellite Company.
Nov. 28, 1985	RCA Satcom K-2	Space Shuttle	Launched for RCA American Communications, Inc.
Jan. 12, 1986	RCA Satcom K-1	Space Shuttle	Launched for RCA American Communications, Inc.
Dec. 5, 1986	Fltsatcom 7	Atlas-Centaur	Launched for DoD.
Mar. 20, 1987	Palapa B-2P	Delta 182	Indonesia domestic communications.
Sep. 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 Defence.
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.

U.S.-Launched Applications Satellites, 1985–1991

Date	Name	Launch Vehicle	Remarks
			WEATHER OBSERVATION[a]
Sep. 17, 1986	NOAA-10	Atlas E	Launched for NOAA.
Feb. 26, 1987	GOES 7	Delta 179	Launched for NOAA, operational as GOES-East.
June 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 replace NOAA-9.
Dec. 1, 1990	DMSP F-10	Atlas E	DoD meteorological satellite.
May 14, 1991	NOAA-12	Atlas E	Launched for NOAA.
			EARTH OBSERVATION
None launched since 1984.			
			GEODESY
Mar. 13, 1985	GEOSAT	Atlas E	Measure ocean surface height.
			NAVIGATION[a]
Aug. 3, 1985	Oscar 24	Scout	Part of Navy Transit System.
Aug. 3, 1985	Oscar 30	Scout	Part of Navy Transit System.
Oct. 9, 1985	Navstar-11	Atlas E	Global Positioning System Satellite.
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 IIR)	Delta II	Global Positioning System Satellite.
June 10, 1989	GPS-2 (Block IIR)	Delta II	Global Positioning System Satellite.
Aug. 18, 1989	GPS-3 (Block IIR)	Delta II	Global Positioning System Satellite.
Oct. 21, 1989	GPS-4 (Block IIR)	Delta II	Global Positioning System Satellite.
Dec. 11, 1989	GPS-5 (Block IIR)	Delta II	Global Positioning System Satellite.
Jan. 24, 1990	GPS-6 (Block IIR)	Delta II	Global Positioning System Satellite.
Mar. 26, 1990	GPS-7 (Block IIR)	Delta II	Global Positioning System Satellite.
Aug. 2, 1990	GPS-8 (Block IIR)	Delta II	Global Positioning System Satellite.
Oct. 1, 1990	GPS-9 (Block IIR)	Delta II	Global Positioning System Satellite.
Nov. 16,1990	GPS-10 (Block IIR)	Delta II	Global Positioning System Satellite.
Jul. 4, 1991	GPS-11 (Block IIR)	Delta II	Global Positioning System Satellite.

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

U.S.-Launched Scientific Satellites, 1985–1991

Date	Name	Launch Vehicle	Remarks
Apr. 29, 1985	NUSAT-1	Space Shuttle	Northern Utah Satellite (air traffic control radar system calibrator).
June 20, 1985	Spartan-1	Space Shuttle	Reusable free-flying platform.
July 29, 1985	Plasma Diagnostic Package (PDP)	Space Shuttle	Reusable experimental platform.
Oct. 30, 1985	GLOMR	Space Shuttle	Global Low Orbiting Message Relay satellite.
Nov. 14, 1986	Polar Bear	Scout	Experiments to study radio interference caused by Aurora Borealis, for DoD.
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.

Appendix B-3

U.S.-Launched Space Probes, 1975–1991

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 the 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 same 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.
Sep. 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.

U.S. and Soviet Manned Spaceflights, 1961–1991

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Vostok 1	Apr. 12, 1961	Yuriy A. Gagarin	0 : 1 : 48	First manned flight.
Mercury-Redstone 3	May 5, 1961	Alan B. Shepard, Jr.	0 : 0 : 15	First U.S. flight; suborbital.
Mercury-Redstone 4	July 21, 1961	Virgil I. Grissom	0 : 0 : 16	Suborbital; capsule sank after landing; astronaut safe.
Vostok 2	Aug. 6, 1961	German S. Titov	1 : 1 : 18	First flight exceeding 24 h.
Mercury-Atlas 6	Feb. 20, 1962	John H. Glenn, Jr.	0 : 4 : 55	First American to orbit.
Mercury-Atlas 7	May 24, 1962	M. Scott Carpenter	0 : 4 : 56	Landed 400 km beyond target.
Vostok 3	Aug. 11, 1962	Andriyan G. Nikolayev	3 : 22 : 25	First dual mission (with Vostok 4).
Vostok 4	Aug. 12, 1962	Pavel R. Popovich	2 : 22 : 59	Came within 6 km of Vostok 3.
Mercury-Atlas 8	Oct. 3, 1962	Walter M. Schirra, Jr.	0 : 9 : 13	Landed 8 km from target.
Mercury-Atlas 9	May 15, 1963	L. Gordon Cooper, Jr.	1 : 10 : 20	First U.S. flight exceeding 24 h.
Vostok 5	June 14, 1963	Valeriy F. Bykovskiy	4 : 23 : 6	Second dual mission (with Vostok 6).
Vostok 6	June 16, 1963	Valentina V. Tereshkova	2 : 22 : 50	First woman in space; within 5 km of Vostok 5.
Voskhod 1	Oct. 12, 1964	Vladimir M. Komarov Konstantin P. Feoktistov Boris G. Yegorov	1 : 0 : 17	First 3-man 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-man 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 manned flight to date.
Gemini 7	Dec. 4, 1965	Frank Borman James A. Lovell, Jr.	13 : 18 : 35	Longest-duration manned 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 37 min).
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-man mission.
Soyuz 3	Oct. 26, 1968	Georgiy T. Beregovoy	3 : 22 : 51	Maneuvered near unmanned Soyuz 2.
Apollo 8	Dec. 21, 1968	Frank Borman James A. Lovell, Jr. William A. Anders	6 : 3 : 1	First manned orbit(s) of moon; first manned departure from Earth's sphere of influence; highest speed attained in manned 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 descent to 14,300 m from the lunar surface.

U.S. and Soviet Manned Spaceflights, 1961–1991

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Apollo 11	July 16, 1969	Neil A. Armstrong Michael Collins Edwin E. Aldrin, Jr.	8 : 3 : 9	First manned landing on lunar surface and safe return to Earth. First return of rock and soil samples to Earth, and manned deployment of experiments on lunar surface.
Soyuz 6	Oct. 11, 1969	Georgiy Shonin Valeriy N. Kubasov	4 : 22 : 42	Soyuz 6, 7, and 8 operated as a group flight without actually docking. Each conducted certain experiments, including welding and Earth and celestial observation.
Soyuz 7	Oct. 12, 1969	Anatoliy 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 manned lunar landing. Explored surface of moon and retrieved parts of Surveyor 3 spacecraft, which landed in Ocean of Storms on Apr. 19, 1967.
Apollo 13	Apr. 11, 1970	James A. Lovell, Jr. Fred W. Haise, Jr. John L. Swigert, Jr.	5 : 22 : 55	Mission aborted; explosion in service module. Ship circled moon, with crew using LM as "lifeboat" until just before reentry.
Soyuz 9	June 1, 1970	Andriyan G. Nikolayev Vitaliy I. Sevastyanov	17 : 16 : 59	Longest manned spaceflight to date.
Apollo 14	Jan. 31, 1971	Alan B. Shepard, Jr. Stuart A. Roosa Edgar D. Mitchell	9 : 0 : 2	Third manned lunar landing. Mission demonstrated pinpoint landing capability and continued manned 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 19 Apr. 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 during 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 manned 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 manned 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 manned 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 unmanned 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 Yuriy P. Artyukhin	15 : 17 : 30	Docked with Salyut 3 and Soyuz 14 crew occupied space station.
Soyuz 15	Aug. 26, 1974	Gennadiy V. Sarafanov Lev. S. Demin	2 : 0 : 12	Rendezvoused but did not dock with Salyut 3.
Soyuz 16	Dec. 2, 1974	Anatoliy V. Filipchenko Nikolay N. Rukavishnikov	5 : 22 : 24	Test of ASTP configuration.

U.S. and Soviet Manned Spaceflights, 1961–1991

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Soyuz 17	Jan. 10, 1975	Aleksay A. Gubarev Georgiy M. Grechko	29 : 13 : 20	Docked with Salyut 4 and occupied station.
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 Valeriy N. Kubasov	5 : 22 : 31	Target for Apollo in docking and joint experiments of ASTP mission.
Apollo (ASTP)	July 15, 1975	Thomas P. Stafford Donald K. Slayton Vance D. Brand	9 : 1 : 28	Docked with Soyuz 19 in joint 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	Valeriy F. Bykovskiy Vladimir V. Aksenov	7 : 21 : 54	Earth resources study with multispectral camera system.
Soyuz 23	Oct. 14, 1976	Vyacheslav D. Zudov Valeriy I. Rozhdestvenskiy	2 : 0 : 6	Failed to dock with Salyut 5.
Soyuz 24	Feb. 7, 1977	Viktor V. Gorbatko Yuriy N. Glazkov	17 : 17 : 23	Docked with Salyut 5 and occupied station.
Soyuz 25	Oct. 9, 1977	Vladimir V. Kovalenok Valeriy V. Ryumin	2 : 0 : 46	Failed to achieve hard dock with Salyut 6 station.
Soyuz 26	Dec. 10, 1977	Yuriy 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	79 : 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	Valeriy 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 Valeriy 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)	73 : 18 : 17	Docked with Salyut 6, later served as ferry for Soyuz 32 crew while Soyuz 32 returned unmanned.
Soyuz 35	Apr. 9, 1980	Leonid I. Popov Valeriy 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	Valeriy 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	Yuriy V. Malyshev Vladimir V. Aksenov	3 : 22 : 21	Docked with Salyut 6. First manned 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	Yuriy 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 Gennadiy M. Strekalov	12 : 19 : 8	Docked wtih Salyut 6. First 3-man flight in Soviet program since 1971.

U.S. and Soviet Manned Spaceflights, 1961–1991

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Soyuz T-4	Mar. 12, 1981	Vladimir V. Kovalenok Viktor P. Savinykh	74 : 18 : 38	Docked with Salyut 6.
Soyuz 39	Mar. 22, 1981	Vladimir A. Dzhanibekov Jugderdemidiyn Gurragcha	7 : 20 : 43	Docked with Salyut 6. Gurragcha first Mongolian cosmonaut to orbit.
Space Shuttle Columbia (STS 1)	Apr. 12, 1981	John W. Young Robert L. Crippen	2 : 6 : 21	First flight of Space Shuttle, tested spacecraft in orbit. First landing of airplanelike craft from orbit for reuse.
Soyuz 40	May 14, 1981	Leonid I. Popov Dumitru Prunariu	7 : 20 : 41	Docked with Salyut 6. Prunariu first Romanian cosmonaut to orbit.
Space Shuttle Columbia (STS 2)	Nov. 12, 1981	Joe H. Engle Richard H. Truly	2 : 6 : 13	Second flight of Space Shuttle, first scientific payload (OSTA 1). Tested remote manipulator arm. Returned for reuse.
Space Shuttle Columbia (STS 3)	Mar. 22, 1982	Jack R. Lousma C. Gordon Fullerton	8 : 4 : 49	Third flight of Space Shuttle, second scientific payload (OSS 1). Second test of remote manipulator arm. Flight extended 1 day because of flooding at primary landing site; alternate landing site used. Returned for reuse.
Soyuz T-5	May 13, 1982	Anatoliy 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 Chretien	7 : 21 : 51	Docked with Salyut 7. Chretien 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 orbital flight 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 cancelled when spacesuits malfunctioned.
Space Shuttle Challenger (STS 6)	Apr. 4, 1983	Paul J. Weitz Karol J. Bobko Donald H. Peterson Story Musgrave	5 : 0 : 24	Sixth flight of Space Shuttle, launched TDRS 1.
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 crew members, including first woman U.S. astronaut.
Soyuz T-9	June 28, 1983	Vladimir Lyakhov Aleksandr Aleksandrov	149: 9 : 46	Docked with Salyut 7 station.
Space Shuttle Challenger (STS 8)	Aug. 30, 1983	Richard H. Truly Daniel C. Brandenstein Dale A. Gardner Guion S. Bluford, Jr. William E. Thornton	6 : 1 : 9	Eighth flight of Space Shuttle, launched one commercial satellite (Insat 1-B), first flight of U.S. black astronaut.
Space Shuttle Columbia (STS 9)	Nov. 28, 1983	John W. Young Brewster W. Shaw Owen K. Garriott Robert A. R. Parker Byron K. Lichtenberg Ulf Merbold	10 : 7 : 47	Ninth flight of Space Shuttle, first flight of Spacelab 1, first flight of 6 crew members, one of whom was West German, first non-U.S. astronaut to fly in U.S. space program.

U.S. and Soviet Manned Spaceflights, 1961–1991

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Space Shuttle Challenger (STS-41B)	Feb. 3, 1984	Vance D. Brand Robert L. Gibson Bruce McCandless Ronald E. McNair Robert L. Stewart	7 : 23 : 16	Tenth flight of Space Shuttle, two communication satellites failed to achieve orbit. First use of Manned Maneuvering Unit (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-11.
Soyuz T-11	Apr. 3, 1984	Yuriy Malyshev Gennadiy 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-1, for later retrieval, Solar Maximum Satellite retrieved, repaired, and redeployed.
Soyuz T-12	July 17, 1984	Vladimir Dzhanibekov Svetlana Savistskaya Igor Volk	11 : 19 : 14	Docked with Salyut 7 station. First woman 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)	Sept. 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 flight of 7 crewmembers, including first flight of two U.S. women and one Canadian.
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.
Space Shuttle Challenger (STS-51B)	Apr. 29, 1985	Robert F. Overmyer Frederick D. Gregory Don L. Lind Norman E. Thagard William E. Thornton Lodewijk Vandenberg 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.

U.S. and Soviet Manned Spaceflights, 1961–1991

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
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-1. First U.S. flight with French and Saudi Arabian crewmen.
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. Dedicted 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 Ernst Messerschmid Reinhard Furrer Wubbo J. Ockels	7 : 0 : 45	Twenty-second STS flight. Dedicated German Spacelab D-1 in shuttle cargo bay.
Space Shuttle Atlantis (STS-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.
Space Shuttle Columbia (STS-61C)	Jan. 12, 1986	Robert L. Gibson Charles F. Bolden, Jr. Franklin Chang-Diaz Steven 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.
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	Yuriy Romanenko Aleksandr Laveykin	174: 3 : 26	Docked with MIR space station. Romanenko established long distance stay in space record of 326 days.

U.S. and Soviet Manned Spaceflights, 1961–1991

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
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 Yuriy 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 Anatoliy Levchenko	180 : 5	Docked with MIR space station. Crew of Yuriy Romanenko, Aleksandr Aleksandrov, and Anatoliy Levchenko returned Dec. 29 in Soyuz TM-3.
Soyuz TM-5	Jun. 7, 1988	Viktor Savinykh Anatoly Solovyev Aleksandr Aleksandrov	9 : 20 : 13	Docked with MIR space station, Aleksandrov first Bulgarian in space. Crew returned Jun. 17 in Soyuz TM-4.
Soyuz TM-6	Aug. 29, 1988	Vladimir Lyakhov Valeriy Polyakov Abdul Mohmand	8 : 19 : 27	Docked with MIR space station, Mohmand first Afghanistan in space. Crew returned Sep. 7 in Soyuz TM-5
STS-26	Sep. 29, 1988	Frederick H. Hauck Richard O. Covey John M. Lounge David C. Hilmers George D. Nelson	4 : 1	Twenty-sixth STS flight. Launched TDRS 3.
Soyuz TM-7	Nov. 26, 1988	Aleksandr Volkov Sergey Krikalev Jean-Loup Chretien	151 : 11	Docked with MIR space station. Soyuz TM-6 returned with Chretien, Vladimir Titov, and Musa Manarov. Titov and Manarov completed 366-day mission Dec. 21. Crew of Krikalev, Volkov, and Valeriy 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 Norman 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	Sep. 5, 1989	Aleksandr Viktorenko Aleksandr Serebrov	166 : 6	Docked with MIR space station. Crew of Viktorenko and Serebrov returned in Soyuz TM-8, Feb. 9, 1990.

U.S. and Soviet Manned Spaceflights, 1961–1991

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
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	Anatoliy 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. Thout	4 : 10 : 19	Thirty-fourth STS flight. Dedicated DOD mission.
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	Gennadiy Manakov Gennadiy 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-II	Dec. 2, 1990	Viktor Afanasyev Musa Manarov	7: 21 :55	Docked with MIR space station. Toyohiro Akiyama returned Dec. 10, 1990, with previous MIR crew of Gennadiy Manakov and Gennadiy Strekalov.

U.S. and Soviet Manned Spaceflights, 1961–1991

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
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 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	7: 21 :14	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. Mission still in progress.
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).
STS-48	Sep. 12, 1991	John Creighton Kenneth Reightler, Jr. Charles D. Gemar James F. Buchli Mark N. Brown	5: 8 :28	Forty-third STS flight. Launched Upper Atmosphere Research Satellite (UARS).

U.S. Space Launch Vehicles

Vehicle	Stages/(engines)	Propellant[a]	Thrust (kilonewtons)	Max. Dia. x Height (m)	Max. Payload (kg)[b] 185-Km Orbit	Geosynch.-Transfer Orbit	Circular Sun-Synch. Orbit	First Launch[c]
Scout	1. Algol IIIA	Solid	431.1	1.14x22.9	255 205[d]	--	155[d]	1979(60)
	2. Castor IIA	Solid	285.2					
	3. Antares IIIA	Solid	83.1					
	4. Altair IIIA	Solid	25.6					
Delta 3900 Series (Thor-Delta)[e]	1. Thor plus	LOX/RP-1	912.0	2.44x35.4	3,045 2,180[d]	1,275	2,135[d]	1982(60)
	9 TX 526-2	Solid (each)	375.0					
	2. Delta	N_2O_4/Aerozine-50	44.2					
Delta II	1. Thor plus	LOX/RP-1	920.8	2.90x39.62	--	1,819	--	1989
	9 TX 526-2	Solid (each)	432.0					
	2. Delta	N_2O_4/Aerozine-50	43.0					
Atlas E	Atlas booster (MA-3) & sustainer	LOX/RP-1	1,722.0	3.05x28.1	2,090[d f]	--	1,500[d]	1972(59)
Atlas-Centaur	1. Atlas booster (MA-5) & sustainer	LOX/RP-1	1,913.0	3.05x45.0	6,100	2,360	--	1984(72)
	2. Centaur	LOX/LH_2	146.0					
Titan IV	1. Two 7-segment, 3.05 m dia	Solid	12,402.0	5.08x62.2	17,690	2,404		1989
	2. (LR-87)	N_2O_4/Aerozine	2,452.0					
	3. (LR-91)	N_2O_4/Aerozine	472.0					
	4. IUS 1st stage	Solid	185.0					
	5. IUS 2nd stage	Solid	76.0					
					185-Km Orbit	24-Hour Polar Orbit	Sun-synch. Transfer Orbit	
Titan II	1. (LR-87[2])	N_2O_4/Aerozine-50	2,108.4	3.05x28.5	2,200 1,905[d]	--	--	1988 (62)
	2. (LR-91)	N_2O_4/Aerozine-50	444.8					
Titan IIIB-Agena	1. (LR-87)	N_2O_4/Aerozine	2,341.0	3.05x48.4	3,600[d]		3,060[d]	1966
	2. (LR-91)	N_2O_4/Aerozine	455.1					
	3. Agena	IRFNA/UDMH	71.2					
Titan III(34)D/IUS	1. Two 5½-segment, 3.05 m dia	Solid	11,564.8	3.05x48.0	14,920	1,850[d]	--	1982
	2. LR-87	N_2O_4/Aerozine	2,366.3					
	3. LR-91	N_2O_4/Aerozine	449.3					
	4. IUS 1st stage	Solid	275.8					
	5. IUS 2nd stage	Solid	115.7					
Titan III(34)D/ Transtage	Same as Titan III(34)D plus:							
	4. Transtage	N_2O_4/Aerozine	69.8	3.05x46.9	14,920	1,855[d]	--	1984[h]
					280- to 420-Km Orbit			
Space Shuttle (reusable)	1. Orbiter; 3 main engines (SSMEs) fire in parallel with SRBs	LOX/LH_2	1,670 each	23.79x37.24 wing span long	24,900 in full performance configuration			1981
	2. Two solid-fueled rocket boosters (SRBs) fire in parallel with SSMEs	AL/NH_4CLO_4/PBAN	11,790 each	3.71x45.45				
	Mounted on external tank (ET)			8.40x46.88				

[a] Propellant abbreviations used are as follows: liquid oxygen and a modified kerosene = LOX/RP,RJ; solid propellant combining in a single mixture both fuel and oxidizer = Solid; inhibited red-fuming nitric acid and unsymmetrical dimethylhydrazine = IRFNA/UDMH; nitrogen tetroxide and UDMH/N_2H_4 = N_2O_4/aerozine; liquid oxygen and liquid hydrogen = LOX/LH_2; aluminum, ammonium perchlorate, and polybutadiene acrolonitrile terpolymer = AL/NH_4CLO_4/PBAN.

[b] Due east launch except as indicated.

[c] The date of first launch applies to this latest modification with a date in parentheses for the initial version.

[d] Polar launch.

[e] Maximum performance based on 3920, 3920/PAM configurations. PAM = payload assist module.

[f] With dual TE 364-4.

[g] With 96° flight azimuth.

[h] Initial operational capability in December 1982; launch to be scheduled as needed.

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

APPENDIX E-1

Space Activities of the U.S. Government

HISTORICAL BUDGET SUMMARY—BUDGET AUTHORITY

(in millions of dollars)

Fiscal Year	NASA		Defense	Other	Energy	Commerce	Interior	Agriculture	NSF	DOT	EPA	Total Space
	Total	Space[a]										
1959	331	261	490	...	34	...	...	...	...	...	...	785
1960	524	462	561	...	43	...	...	...	0.1	...	...	1,066
1961	964	926	814	...	68	...	...	...	0.6	...	...	1,808
1962	1,825	1,797	1,298	...	148	51	...	...	1.3	...	...	3,295
1963	3,673	3,626	1,550	...	214	43	...	...	1.5	...	...	5,435
1964	5,100	5,016	1,599	...	210	3	...	...	3.0	...	...	6,831
1965	5,250	5,138	1,574	...	229	12	...	...	3.2	...	...	6,956
1966	5,175	5,065	1,689	...	187	27	...	...	3.2	...	...	6,970
1967	4,966	4,830	1,664	...	184	29	...	...	2.8	...	...	6,710
1968	4,587	4,430	1,922	...	145	28	0.2	0.5	3.2	...	...	6,529
1969	3,991	3,822	2,013	...	118	20	0.2	0.7	1.9	...	...	5,976
1970	3,746	3,547	1,678	...	103	8	1.1	0.8	2.4	...	...	5,341
1971	3,311	3,101	1,512	127	95	27	1.9	0.8	2.4	...	...	4,741
1972	3,307	3,071	1,407	97	55	31	5.8	1.6	2.8	...	...	4,575
1973	3,406	3,093	1,623	109	54	40	10.3	1.9	2.6	...	...	4,825
1974	3,037	2,759	1,766	116	42	60	9.0	3.1	1.8	...	...	4,641
1975	3,229	2,915	1,892	107	30	64	8.3	2.3	2.0	...	...	4,914
1976	3,550	3,225	1,983	111	23	72	10.4	3.6	2.4	...	...	5,320
Transitional Quarter	932	849	460	31	5	22	2.6	0.9	0.6	...	...	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	28,443
1990	13,073	12,142	15,616	330	79	202	19	26	...	4	1	28,089
1991	14,004	13,036	14,181	375	108	211	24	27	...	4	1	27,592

[a]Excludes amounts for air transportation (subfunction 402).
[b]Includes $33.5 million 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.

SOURCE: Office of Management and Budget.

324,194

Appendix E-2

Space Activities Budget

(in millions of dollars by fiscal year)

Federal Agencies	Budget Authority			Budget Outlays		
	1989	1990	1991	1989	1990	1991
NASA[a]	10,098	12,142	13,036	10,195	12,292	13,351
Defense	17,906	15,616	14,181	14,504	12,962	14,432
Energy	97	79	108	97	79	108
Commerce	301	202	211	306	232	223
Interior	17	19	24	17	19	24
Agriculture	21	26	27	21	26	27
Transportation	3	4	4	2	3	4
EPA	1	1	1	1	1	1
TOTAL	28,443	28,089	27,592	25,143	25,614	28,170

[a]Excludes amounts for air transportation.

SOURCE: Office of Management and Budget.

Appendix E-3

Aeronautics Budget

(in millions of dollars by fiscal year)

Federal Agencies	Budget Authority			Budget Outlays		
	1989	1990	1991	1989	1990	1991
NASA[a]	872	932	968	855	889	1,017
Department of Defense[b]	8,240	7,867	6,148	6,420	7,649	6,792
Department of Transportation[c]	1,544	1,891	2,300	1,216	1,471	1,870
TOTAL	10,656	10,690	9,416	8,491	10,009	9,679

[a]Research and 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.

THE VICE PRESIDENT'S OFFICE

Office of the Press Secretary

For Immediate Release JULY 24, 1991

Vice President Announces National Space Launch Strategy

Today the Vice President announced a new National Space Launch Strategy which provides a long range plan to meet America's space launch needs. The strategy, which has been approved by the President, calls for maintaining current launch systems and facilities and extending their useful lifetimes well into the first decade of the new century. The new policy states that while the current fleet of Space Shuttles will continue to meet manned spaceflight needs, the purchase of additional Shuttle orbiters is not planned.

In the future, the nation's core launch needs will be met by a new family of vehicles — a new national launch system — to be developed jointly by the Department of Defense and the National Aeronautics and Space Administration. These new launchers will make space more accessible by reducing operating costs and improving reliability, responsiveness, and mission performance.

The strategy calls for a vigorous space launch technology program which can provide the basis for revolutionary improvements in launch capability in the future. The strategy also provides guidance which will ensure that actions taken to meet U.S. government launch needs also serve to strengthen the U.S. commercial space industry and enhance America's international competitiveness.

The National Space Launch Strategy was developed by the National Space Council, chaired by the Vice President.

NATIONAL SPACE LAUNCH STRATEGY

I. Introduction

a. National space policy provides a framework within which agencies plan and conduct U.S. government space activities. The National Space Launch Strategy provides guidance for implementation of that policy with respect to access to and from space.

b. Assured access to space is a key element of U.S. national space policy and a foundation upon which U.S. civil, national security, and commercial space activities depend.

c. United States space launch infrastructure, including launch vehicles and supporting facilities, should: (1) provide safe and reliable access to, transportation in, and return from space; (2) reduce the costs of space transportation and related services, thus encouraging expanded space activities; (3) exploit the unique attributes of manned and unmanned launch and recovery systems; and, (4) encourage, to the maximum extent feasible, the development and growth of U.S. private sector space transportation capabilities which can compete internationally.

II. Space Launch Strategy

a. The National Space Launch Strategy is composed of four elements.

(l) Ensuring that existing space launch capabilities, including support facilities, are sufficient to meet U.S. Government manned and unmanned space launch needs.

(2) Developing a new unmanned, but man-rateable, space launch system to greatly improve national launch capability with reductions in operating costs and improvements in launch system reliability, responsiveness, and mission performance.

(3) Sustaining a vigorous space launch technology program to provide cost effective improvements to current launch systems, and to support development of advanced launch capabilities, complementary to the new launch system.

(4) Actively considering commercial space launch needs and factoring them into decisions on improvements in launch activities and launch vehicles.

b. These strategy elements will be implemented within the overall resource and policy guidance provided by the President.

III. Strategy Guidelines

a. ***Existing Space Launch Capability***

(1) A mixed fleet comprised of the Space Shuttle and existing expendable launch vehicles will be the primary U.S. government means to transport people and cargo to and from space through the current decade and will be important components of the nation's launch capability well into the first decade of the 21st century.

(2) To meet U.S. government needs, agencies will conduct programs to systematically maintain and improve the Space Shuttle, current U.S. expendable launch vehicle fleets, and supporting launch site facilities and range capabilities. Such programs shall be cost effective relative to current and programmed mission needs and to investments in new launch capabilities.

(3) As the nation is moving toward development of a new space launch system, the production of additional Space Shuttle orbiters is not planned. The production of spare parts should continue in the near term to support the existing Shuttle fleet, and to preserve an option to acquire a replacement orbiter in the event of an orbiter loss or other demonstrable need. By continuing to operate the Shuttle conservatively, by taking steps to increase the reliability and lifetime of existing orbiters, and by developing a new launch system, the operational life of the existing orbiter fleet will be extended. The Space Shuttle will be used only for those important missions that require manned presence or other unique Shuttle capabilities, or for which use of the Shuttle is determined to be important for national security, foreign policy, or other compelling purposes.

(4) Consistent with U.S. national security and national space policy, the U. S . government may seek to recover residual value from ballistic missiles which are, or subsequently become, surplus to the needs of the Department of Defense. Prior to any release of such missiles, including components, beyond those already approved for use as space launch vehicles, the Department of Defense will conduct, and the National Space Council and the National Security Council will review, an assessment of alternative disposition options for such missiles.

Disposition options will be evaluated in terms of their consistency with U.S. national security and foreign policy interests, available agency resources, defense industrial base considerations, and with due regard to economic impact on the commercial space sector, promoting competition, and the long-term public interest.

b. ***New Space Launch System***

(l) The Department of Defense and the National Aeronautics and Space Administration will undertake the joint development of a new space launch system to meet civil and national security needs. The goal of this launch program is to greatly improve national launch capability with reductions in operating costs and improvements in launch system reliability, responsiveness and mission performance.

(2) The new launch system, including manufacturing processes and production and launch facilities, will be designed to support a range of medium to heavy-lift performance requirements and to facilitate evolutionary change as requirements evolve. The design may take advantage of existing components from both the Space Shuttle and existing expendable rockets in order to expedite initial capability and reduce development costs. While initially unmanned, the new launch system will be designed to be "man-rateable" in the future.

(3) The new launch system will be managed, funded, and developed jointly by the Department of Defense and the the National Aeronautics and Space Administration. The development program will be structured in the near term toward the goal of a first flight in 1999. However, the program should allow for several schedule options for the first flight and should identify key intermediate milestones. Since the new launch system will provide the opportunity for significant long-term benefits to the commercial space launch industry, the agencies should actively explore the potential for U.S. private sector participation. Final decisions on the program schedule, including the date of the first flight, will be made during fiscal year 1993, based on updated requirements and technical and budgetary considerations at that time. A joint program plan will be prepared by the Department of Defense and the National Aeronautics and Space Administration and reviewed by the National Space Council.

(4) The Department of Defense and the National Aeronautics and Space Administration will plan for the transition of selected space programs from current launch systems to the new launch system at appropriate program milestones to insure mission continuity and to minimize satellite and other transition costs.

c. ***Space Launch Technology***

(1) In addition to conducting the focused development program for a new launch system, appropriate U. S. government agencies will continue to conduct broadly based research and focused technology programs to support long-term improvements in national space launch capabilities. This technology effort shall address launch system components (e.g., engines, materials, structures, avionics); upper stages; improved launch processing concepts; advanced launch system concepts (e.g., single-stage-to-orbit concepts including the National AeroSpace Plane); and experimental flight vehicle program.

(2) The Department of Defense, the Department of Energy, and the National Aeronautics and Space Administration will coordinate space launch technology efforts and, by December 1, 1991, jointly prepare a 1O-year space launch technology plan.

d. ***Commercial Space Launch Considerations***

(1) In addition to addressing government needs, improvement of space launch capabilities can facilitate the ability of the U.S. commercial space launch industry to compete. Consistent with U.S. space policy, U.S. government agencies will actively consider commercial space launch needs and factor them into decisions on existing space launch capabilities, development of a new space launch system, and implementation of space launch technology programs in the following ways:

(a) U.S. government funded investments will be consistent with approved budgets and U.S. government requirements.

(b) U.S. government agencies, in acquiring space launch related capabilities, should:

(1) Allow contractors, to the fullest extent feasible, the flexibility to accommodate commercial needs when developing launch vehicles and infrastructure to meet government needs.

(2) Emphasize procurement strategies which are based on: "best value" rather than lowest cost, performance-based functional requirements, commercial production and quality assurance standards and techniques, and the use of commercially-offered space products and services.

(3) Encourage commercial, state, and local government investment and participation in the development ant improvement of U.S. launch systems and facilities.

(4) Provide for private sector retention of technical data rights, except those rights necessary to meet government needs or to comply with statutory responsibilities.

(c) U.S. government agencies should seek to remove, where appropriate, legal or administrative impediments to private sector arrangements such as industry teams, consortia, cost-sharing, and joint production agreements which may benefit U.S. government needs and economic competitiveness. Agencies should also seek legislative authority for stable long-term commitments to purchase space transportation services.

(d) Within applicable law U. S . government agencies are encouraged to use industry advisory groups to facilitate the identification of commercial space launch needs and the elimination of barriers that unnecessarily impede commercial space launch activities. U.S. agencies are also encouraged to consult with state and local governments.

(2) U.S. government agencies should develop explicit provisions to implement these guidelines for actively considering commercial space launch needs. As appropriate, agencies should solicit public views on these provisions.

IV. Reporting Requirements

U. S. Government agencies affected by these strategy guidelines are directed to report by December 1, 1991, to the National Space Council on their activities related to the implementation of these policies.

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