Aeronautics and Space Report of the President

Fiscal Year 1994 Activities

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1995

National Aeronautics and Space Administration

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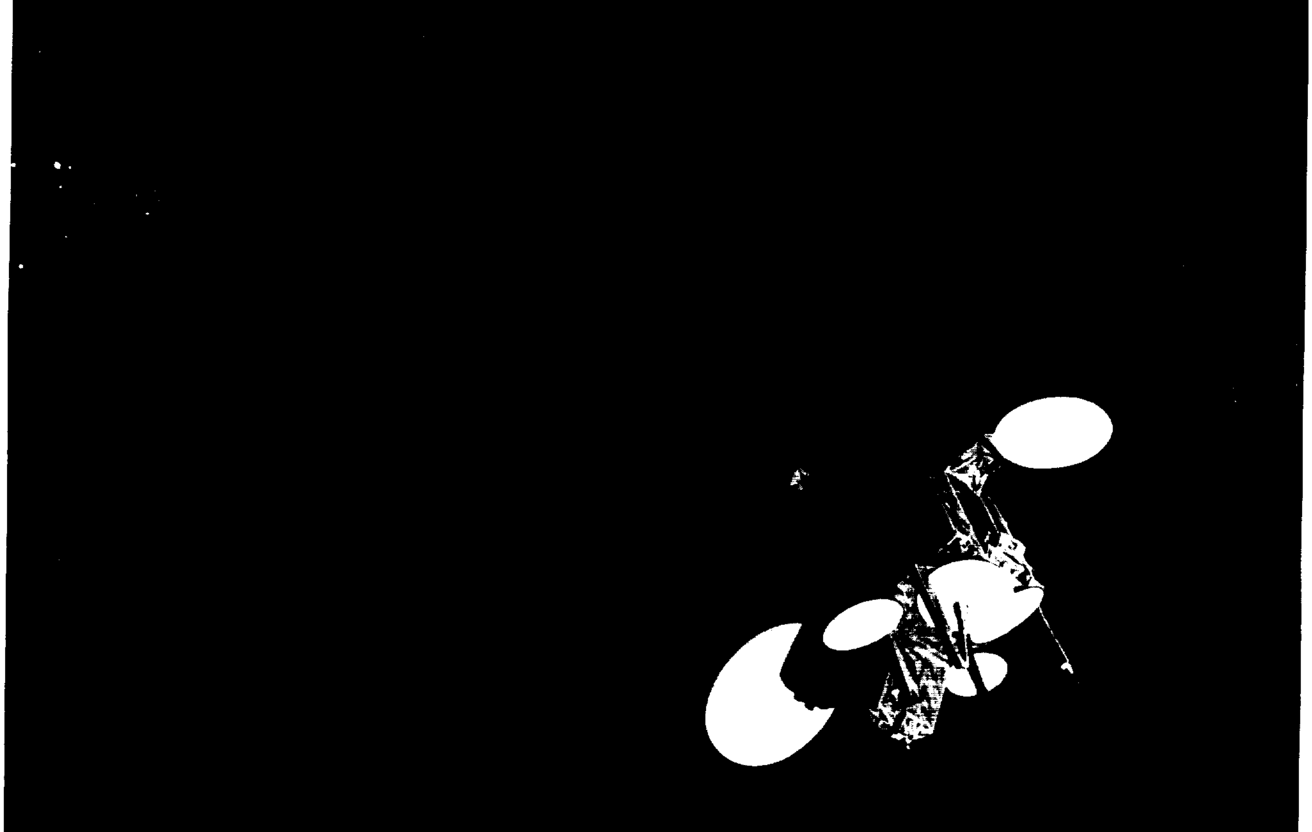
Contents



The first INTELSAT VII launched on October 22, 1993.

Executive Summary

Note: The National Aeronautics and Space Act of 1958 directed the annual Aeronautics and Space Report to include a "comprehensive description of the programmed activities and the accomplishments of all agencies of the United States in the field of aeronautics and space activities during the preceding calendar year." This year's report (like last year's) has been prepared on a fiscal year (FY) basis, consistent with the budgetary period now used in programs of the Federal Government. The Administration is continuing to work with Congress to amend the National Aeronautics and Space Act of 1958 accordingly.

There were numerous significant changes and developments in U.S. aeronautics and space efforts during FY 1994, which included seven Space Shuttle missions successfully completed before the year ended and an eighth that remained on orbit at the close of FY 1994. There were 15 Government launches of Expendable Launch Vehicles (ELV's) carrying payloads ranging from Global Positioning System (GPS) to Defense Support Program (DSP) satellites into orbit. Additionally, the Department of Defense (DoD) provided its facilities with minimal oversight to commercial contractors for the launch of five satellites, one of them a DoD payload, which the Office of Commercial Space Transportation (OCST) in the Department of Transportation (DoT) licensed and monitored. Highlights of the Shuttle missions included the servicing mission for the Hubble Space Telescope (HST), which replaced several faulty parts and installed a sophisticated package of corrective optics to compensate for the spherical aberration in HST's primary mirror. Also, the flight of the Space Radar Laboratory (SRL) began to provide information on environmental change, and a mission with a Russian astronaut, Sergei Krikalev, aboard signalled the beginning of a three-phased cooperative program in space between Russia and the United States, resulting from the completion of arrangements by the United States and its international partners to bring Russia into the partnership for the international Space Station. Among notable developments in the ELV area were the launch of the deep space probe, Clementine, initial use of the Titan IV Centaur upper stage, and the first launch of the Taurus launch vehicle. In aeronautics, activities included development of technologies to improve performance, increase safety, reduce engine noise and other environmental degradation, improve air traffic management, lower costs, and help American industry be more competitive in the world market. Additionally, on May 5, 1994, the White House announced that the National Oceanic and Atmospheric Administration (NOAA), the DoD, and the National Aeronautics and Space Administration (NASA) were establishing a joint program to effect the convergence of civil and military Polar-orbiting Operational Environmental Satellite systems into a single operational program. Other White House announcements during the year included a policy for licensing U.S. firms by the Secretary of Commerce to operate private remote sensing systems and sell their images to domestic and foreign entities and a national space transportation policy that will sustain and revitalize U.S. space transportation capabilities by providing a coherent strategy for supporting and strengthening U.S. space launch capabilities to meet the growing needs of the civilian and national security sectors. In these and other ways discussed below, the 15 Federal agencies involved in aeronautics and space activities have contributed significantly to furthering the Nation's scientific and technical knowledge, international cooperation, a healthier environment, and a more competitive economy.

National Aeronautics and Space Administration (NASA)

NASA advanced U.S. aeronautical and space goals in numerous ways during FY 1994 besides those just mentioned. In space science, astronomers using HST's revitalized optics discovered disks of protoplanetary dust orbiting stars in the Orion Nebula, suggesting that the formation of planets in the Milky Way and elsewhere may be relatively common. Also, HST's revelation of helium in distant constellations provides valuable information about the conditions in the universe during its initial evolution. Information from Ulysses increased our knowledge of the operation of the solar wind. Closer to home, the worldwide scientific community was able to predict and track the crash of Comet Shoemaker-Levy 9 into Jupiter with the resulting information greatly enhancing our ability to understand such impacts. Galileo discovered the first confirmed moon around an asteroid. And the Spacelab Life Sciences-2, U.S. Microgravity Payload-2, and International Microgravity Laboratory-2 greatly increased our understanding of the role of gravity on biological, physical, and chemical processes. In biology, we learned that gravity affects the function of the neural connections between brain cells, which can have profound implications for rebuilding damaged brain cells due to strokes and disease. In the physical and materials sciences, microgravity researchers made strides in understanding the structural characteristics of metals, important in their industrial processing, and of how to improve their physical and electronic properties. NASA also made great strides in applying technology used in the space program to medical care on Earth. In the Spacebridge to Moscow Telemedicine Project, medical personnel in the United States were able to remotely aid in diagnosing patients in Russian hospitals via two-way interactive video links. In Earth science, the Space Radar Laboratories-1 and -2 plus the Light Intersection Direction and Ranging (LIDAR) In-Space Technology Experiment payload used powerful radar and laser technology to penetrate cloud cover and map critical factors on a global scale.

In a year of tremendous accomplishments for the international Space Station, NASA developed an initial set of specifications for it that included Russian elements as part of the design. Russia's agreeing to join the 12 original participating nations as a partner resulted in the expansion of the existing Shuttle/Mir program into Phase I of the international Space Station program, which officially began with Sergei Krikalev's flight on the Shuttle. All of the partners held a successful systems design review in Texas in March, and in June, Russia and the United States signed an interim agreement on Space Station and a $400 million contract for Russian space hardware, services, and data. In August, the program completed a vehicle architecture review, and in September, the Space Station Control Board ratified the recommendations it included. The redesigned Space Station costs $5 billion less than Freedom and still offers increased research capability and user flexibility.

In aeronautics, NASA's Advanced Subsonic Technology program continued work on its goal to facilitate a safe, productive global air transportation system that includes a new generation of environmentally compatible, economic aircraft that will compete in international markets. Efforts in advanced subsonics focused on reducing aircraft and engine noise levels, on development of wind shear sensing devices, and on creating technologies that will improve general aviation aircraft and air traffic management. In the supersonic arena, NASA's SR-71 aircraft testbed program conducted baseline flights for aeronautical research to assist industry in making key decisions about developing a High-Speed Civil Transport (HSCT). More generally, NASA's High-Speed Research program continued during FY 1994 to focus on resolving critical environmental issues and laying the technological foundation for an economical, next generation HSCT. The United States reached agreement with Russia to use the Tu-144 supersonic transport as a testbed for HSCT development. In its high-alpha technology program, NASA sought to achieve a basic understanding of high angle-of-attack aerodynamics, including the effects of vectorable thrust nozzles as an advanced flight control concept. NASA also did important aeronautics research using its F-18 Systems Research Aircraft, its Vertical Short Take off and Landing (V/STOL) System Research Aircraft, and its F-15 testbed aircraft. A number of other NASA programs sought to reduce aircraft noise, to help U.S. industry remain competitive in an environment of increased worldwide competition, and to reduce the environmental impact of future commercial engines through decreased exhaust emissions. The joint National Aero-Space Plane (NASP) program of NASA and the DoD was reduced by congressional direction at the end of FY 1994 but continued throughout the year to develop exciting new technologies for potential commercial use in various industries.

Also during FY 1994, NASA made significant progress in measuring, modeling, and mitigating the orbital debris environment. NASA's Mission to Planet Earth program included the LIDAR In-Space Technology Experiment that flew on the Space Shuttle Discovery in September and observed clouds invisible to conventional weather satellites, dust clouds over Africa, and the structure of a super typhoon in the Pacific. In cooperation with Italy and Germany, the Space Radar Laboratory flew on the Space Shuttle Endeavour during April (SRL-1) and September-October 1994 (SRL-2), enabling a team of 52 scientists and ground teams around the world to observe the shifting boundaries between temperate and boreal (northern) forests, as well as other natural phenomena. FY 1994 was a year of transition for the Land Remote Sensing Satellite (Landsat) program, as NASA assumed the satellite-development responsibilities for Landsat-7 from the DoD in May, with NOAA and the U.S. Geological Survey (USGS) also having roles in this future Landsat mission. NASA's and NOAA's efforts to monitor ozone depletion continued to reflect the effects of the Mount Pinatubo eruption in June 1991. The Antarctic ozone levels for 1994 were nearly as small as the record lows from October 1993. The slight recovery in 1994 probably resulted from fewer sulfuric acid particles remaining from the eruption of Mount Pinatubo. TOPEX/Poseidon continued to provide valuable information during 1994. For example, data from the satellite have enabled scientists to track disturbances caused by the lingering effects of the El Niño event of 1991-93, the longest in the last 40 years.

Department of Defense (DoD)

The DoD also continued to pursue a wide variety of aeronautical and space activities. Air Force Delta II's placed two GPS satellites into orbit. An Atlas E launched a Defense Meteorological Satellite Program (DMSP) satellite. An Atlas II carried a Defense Satellite Communication System (DSCS) satellite into orbit. Two Titan II's launched Clementine and Landsat-6. Three launches got the Titan IV program back on track during FY 1994, placing a Milstar satellite, the 17th DSP satellite, and a classified spacecraft into orbit. The Taurus launch vehicle carried the Space Test Experiments Platform Mission 0 (STEP-0) and an Advanced Research Projects Agency (ARPA) satellite (DARPASAT) into orbit. STEP-2 was then launched successfully aboard a standard Pegasus vehicle. However, the inaugural attempt to launch a higher-performance, stretched Pegasus, known as Pegasus XL, ended in failure, resulting in the loss of the STEP-1 mission payload. A standard Pegasus then launched the Advanced Photovoltaic Experiment (APEX) mission. The 118th and final mission of the Scout rocket launched the second of the Miniature Sensor Technology Integration (MSTI-2) satellites into Sun-synchronous orbit. A DoD Atlas I launched the next in the series of Geostationary Operational Environmental Satellites (GOES-8) into orbit for the NOAA, and a commercial Atlas I carried an Ultra High Frequency (UHF) Follow-On satellite into orbit for the DoD.

The Ballistic Missile Defense Organization (BMDO) has been working with McDonnell Douglas to develop single-stage rocket technology, of which the Delta Clipper-Experimental (DC-X) has become the first working, one-third scale demonstration vehicle. Following mostly successful flight tests but one explosion during 1994, the DC-X is expected to be transferred to the Air Force's Phillips Laboratory from BMDO in January 1995 for completion of its flight series. NASA will then conduct further flight tests of a reconfigured DC-X as a means toward further development of reusable rocket technology. In a related area, the successful maiden flight of the Taurus standard small launch vehicle capitalized on ARPA's previous investment in the Pegasus air-launched vehicle to produce a fully transportable, ground-launched rocket capable of providing rapid, affordable access to space for moderate-sized satellites.

The 400-pound DARPASAT successfully performed its classified mission in support of worldwide deployed, joint military forces. With the launch of two Navstar GPS satellites into orbit on October 26, 1993, and March 9, 1994, the Air Force completed the 24-satellite GPS constellation of operational Block II/IIA satellites plus 1 Block I satellite. Launch of the 17th DSP satellite will provide the DoD with enhanced missile warning and surveillance capabilities. The highly successful launch of Clementine had as its primary mission the testing in space of 23 advanced technologies for high-tech, lightweight missile defense. The relatively inexpensive, rapidly built spacecraft constituted a major revolution in spacecraft management and design; it also contributed significantly to lunar studies. Also during FY 1994, BMDO's Space and Missile Tracking System (Brilliant Eyes) was slowed due to funding reductions, necessitating a restructuring of its contract, and because of a major DoD study that led to the combination of all nonimaging, space-based infrared systems into an integrated program. The DSCS program successfully launched a DSCS III satellite in November 1993; it was cut over to operational traffic in mid-1994 as a replacement for an older DSCS III. The Milstar program, the cornerstone of the DoD's military satellite communications network, launched its first satellite in February 1994. The second UHF Follow-On satellite, launched on September 3, 1993, began operational service over the Indian Ocean on December 3, 1993, thus achieving initial operational capability for the constellation. The third UHF Follow-On satellite launch, on June 24, 1994, was the first Atlas launch conducted by Martin Marietta following its purchase of the Atlas business from General Dynamics in March-April 1994; the satellite began operational service over the Atlantic Ocean in October 1994.

In aeronautics, among other programs, the joint X-31 Enhanced Fighter Maneuverability program, a cooperative effort involving the DoD, NASA, Germany's Ministry of Defense, Rockwell International, and Deutsche Aerospace, successfully completed its original program goals, compiling an impressive array of technically significant "firsts," including significant agility at extremely high angles of attack, significant combat value of its advanced technologies in close-in combat, and the effectiveness of thrust vectoring for stability and control at supersonic speed.

Department of Commerce (DoC)

The DoC's Office of Air and Space Commercialization (OASC) contributed to the new national space transportation policy, the new Presidential policy on commercial remote sensing, and a launch-services agreement between the United States and Russia as well as negotiations with China. The OASC was also involved in U.S. Air Force grants that fostered the growth of privately owned and operated spaceports across the Nation and in the renewal of the U.S.-China launch services agreement, as well as policy supporting commercial activity in GPS navigation satellite and ground system technology plus present- and future-generation high-power communications satellites. NOAA assumed leadership of the triagency convergence planning effort and invited the European Organisation for the Exploitation of Meteorological Satellites to cooperate in a future joint polar-orbiting satellite system taking into account the future converged U.S. system and assuming that key U.S. mission requirements can be met. A Titan II placed Landsat-6 into initial orbit on October 5, 1993, but the satellite's integral "kick motor" apparently failed to place it into final orbit. Then, on April 13, 1994, an Atlas I launched the next in the series of Geostationary Operational Environmental Satellites (GOES-I) into orbit for NOAA as GOES-8. NOAA managed a variety of data archives for information from satellites about global change and related matters. NOAA and the Russian Space Agency agreed to closer cooperation in the use of geostationary satellites for sea, air, and land search and rescue services. NOAA's National Environmental Satellite, Data, and Information Service has issued licenses to a number of aerospace companies planning to build remote sensing satellite systems under the new Presidential policy to which NOAA contributed. The National Institute of Standards and Technology (NIST) has applied its expertise in measurement science, developed through its mission to help industry with measurements, standards, and evaluated data, to assist NASA in 74 different project areas during the fiscal year. For example, NIST worked on projects to measure critical point viscosity, to assist in materials processing in space, to identify and quantify the presence of tropospheric methane and evaluate its effects on global warming, and to calibrate equipment for the NASA Sea-viewing Wide Field-of-view Sensor.

Department of Energy (DoE)

In 1994, the DoE continued to progress in space flight research and development of more than 30 years' duration in the fabrication of three General Purpose Heat Sources (GPHS's) and 157 Radioisotope Heater Units (RHU's) for the Cassini mission to Saturn scheduled for launch in October 1997. All of the Plutonium 238 (Pu-238) for the first of these Radioisotope Thermoelectric Generators (RTG's) has been processed, and the initial pellets have been pressed and encapsulated. The DoE took delivery in 1994 of 5 kg of Russian-produced Pu-238 to supplement the existing inventory. This Pu-238, purchased at an attractive price, will fuel the smaller and more efficient spacecraft used for future outer-planet exploration missions. In addition, the DoE received authority in 1994 to purchase an additional 4 kg of Russian Pu-238, which will be the first foreign-produced material capable of being pressed directly into pellets to fuel the RTG's. The SP-100 Space Reactor Power System program was terminated in FY 1994. DoE archived the data from the SP-100 program for future applications. In addition, DoE and the Jet Propulsion Laboratory have initiated an effort to transfer SP-100 technologies to industry. DoE continued its support of the Air Force space reactor systems development by cosponsoring the Air Force Bimodal Power and Propulsion Program to evaluate reactor bimodal system options, which would replace existing upper stages and provide propulsion to transfer spacecraft to their operational orbit, power the spacecraft once in orbit, and reposition the operating spacecraft. DoE continued working with the DoD on the Thermionic Space Nuclear Power System. Los Alamos National Laboratory's Blackbeard radio frequency experiment, piggybacked aboard the Array of Low Energy X-ray Imaging Sensors (ALEXIS) satellite launched last year, is continuing to monitor mysterious twin-pulsed radio bursts. The bursts mimic emissions from nuclear detonations. Los Alamos said these events are associated with thunderstorms but not caused by lightning.

Department of the Interior (DoI)

The DoI applied remote sensing from satellites and aircraft to a variety of research and operational programs during FY 1994. The USGS successfully completed the first full-resolution global radar mosaic of Venus and was processing data from Clementine as the year ended to produce global digital maps of the Moon. Substantial public and scientific attention focused on the collision of Periodic Comet Shoemaker-Levy 9 with Jupiter, emphasizing the need for an inventory of comets and asteroids that may collide someday with the Earth. DoI signed an agreement with the DoD to permit the DoI to use the Navstar GPS Precise Positioning Service, which will provide more accurate, real-time, on-the-ground information about geographic location than is currently available for programs in mapping, inventory, monitoring, and research. The Bureau of Reclamation used airborne video and thermal infrared scanner imagery to map river habitat in the Colorado River system to help develop reservoir water release schedules that maximize the survival of endangered fish. The Bureau of Indian Affairs continued to conduct inventories of natural resources, projects for image mapping, and GPS training services to support its Indian Integrated Resource Information Program. The Bureau of Land Management used satellite data, aerial photographs, and GPS technology to monitor the health of public lands and the effectiveness of ecosystem-based management practices. The National Biological Survey used Landsat data to map wildlife habitat in 36 states for the Gap Analysis Program, which is identifying land areas that are not being protected and managed to maintain biological diversity. The National Park Service continues with a comprehensive, multiyear program using aerial photographs to map vegetation in 235 units of the National Park System (excluding Alaska). The U.S. Fish and Wildlife Service used computerized mapping, aerial photographs, and Landsat and (French) Satellite Pour l'Observation de la Terre (SPOT—Satellite for Observation of the Earth) data for day-to-day operations, especially managing wildlife habitat from an ecosystem perspective. The U.S. Bureau of Mines conducted research to inventory and characterize noncoal mine wastes at abandoned mines using Landsat Thematic Mapper and Airborne Multispectral Scanner data. The USGS cooperated with the Environmental Protection Agency (EPA), NOAA, and the U.S. Fish and Wildlife Service to prepare a baseline of multiscale data on environmental characteristics for the United States and to develop mechanisms for identifying, monitoring, and assessing environmental change. Several DoI bureaus and other agencies formed the Scientific Assessment and Strategy Team that developed an environmental information system for the Upper Mississippi and Missouri River Basins to support recovery and river-basin management planning following the severe flooding in that area in 1993.

Department of Transportation (DoT)

Federal Aviation Administration (FAA)

The FAA continued a dynamic research and development program in support of its mission to ensure the safe and efficient use of the Nation's airspace, to foster civil aeronautics and air commerce in the United States and abroad, and to support the requirements of national defense. During the fiscal year, the GPS achieved initial operational status for civil aviation. The FAA certified various types of GPS receivers for use in all phases of flight, including nonprecision approaches, and it approved the first GPS nonprecision approach procedure for use by helicopters. The agency also approved the first public "stand-alone" GPS instrument approach for aircraft. In a move designed to focus on the adoption of satellite technology and to save money, the FAA decided to halt further development of the Category II and III microwave landing system.

Following a series of independent reviews of the Advanced Automation System (AAS) program, the FAA restructured the system to contain cost growth and minimize delays. The restructured program will provide the same functions and benefits as the original AAS but will follow a different implementation approach. The FAA also accepted delivery on the first two Voice Switching and Control Systems, which, when fully operational, will be responsible for the air-to-ground and ground-to-ground communications between controllers at air route traffic control centers. In addition, the FAA certified a forward look wind shear detection device that provides aircrews with advanced warning of hazardous wind shear, allowing them to avoid the hazard. The air carrier community has been required to have "reactive" warning devices onboard civil air transports since early 1994. Among its other safety-related programs, the FAA made significant strides in the study of icing, wind shear, and other atmospheric hazards.

The Agency completed and implemented a Wake Vortex Program Plan, a joint effort with NASA, which will permit increases in airport capacity and will stress avoidance of wake turbulence through improved knowledge of vortex behavior. Also during FY 1994, the FAA approved for limited use a new oceanic in-trail climb procedure. The maneuver allows a trailing aircraft to climb to a more fuel-efficient altitude with less horizontal separation from a leading aircraft than previously required. In addition, the FAA identified and documented Oceanic Data Link (ODL) and tested a prototype ODL for use by controllers as well as the related prototype Boeing data link avionics package, which will be installed in aircraft.

Progress continued on aircraft safety programs. As part of those efforts, the agency continued to develop and research technologies and methodologies to mitigate and prevent the threat of catastrophic failure to aircraft; initiated a test program to develop certification criteria for halon replacement agents; published the revised "National Aging Aircraft Research Program Plan"; began publication of a quarterly newsletter describing aging aircraft research activities; and continued working on the development of an unleaded aviation gasoline for use in the existing fleet of general aviation aircraft with piston engines. Under its civil aviation security mandate, the FAA continued its efforts to strengthen aviation security through its research and development program. The agency initiated several extensive tests at its Security Research Laboratory, including the demonstration and evaluation of a resonance device for explosives detection in baggage, evaluation of two commercially available trace explosives devices, and development of standards for explosives detection devices.

Office of Commercial Space Transportation (OCST)

Besides licensing and monitoring five commercial launches during FY 1994, the OCST has overall responsibility for regulating the U.S. launch business, including the regulation of any future commercial launch sites, such as those proposed by Alaska, Florida, Hawaii, New Mexico, California, and Virginia. The office had seven applications for commercial launch licenses that were in process during FY 1994. It issued four licenses, amendments, or transfers during the year and made the same number of maximum probable loss determinations. The office was instrumental in developing the national space transportation policy already discussed. The OCST also played a significant role in supporting the U.S. Trade Representative (USTR) by chairing the Interagency Working Group on Information, which is charged with gathering data that enable the USTR to conduct negotiations about commercial space launch agreements with both the Russians and Chinese. The OCST continued to support the development of voluntary standards for the commercial launch industry, especially those in the area of safety, reliability, and quality assurance. The OCST is also a member of the National Spacelift Requirement Process group, whose charter is to establish a common set of requirements for the U.S. spacelift system. The office has maintained communications with members of the commercial space industry to ensure that industry inputs have been considered.

The U.S. Department of Agriculture (USDA)

Within the USDA, the remote-sensing program of the Foreign Agricultural Service continued to be a critical element in the analysis of domestic and foreign agricultural production, supply, and demand—providing timely, accurate, and unbiased estimates of global area, yield, and production. The National Agricultural Statistics Service used remote-sensing data in constructing area frame samples (using data from small sample areas as an aid to estimating crops and acreages), crop-specific land cover mapping, direct estimation of planted crop area, and assessment of crop conditions. The Agricultural Research Service used data from remote sensing and other sources for a variety of purposes, including maps of soil salinity, biomass, crop management, and crop yields as well as to aid in understanding how conditions in river basins influence climate and climate change. During a record year for damage from wildfires, the Forest Service used remote sensing and associated technologies to fight fires throughout the Western United States as well as to detect high-risk fire zones, assess damage, monitor national and foreign ecosystems, and administer/manage more than 191 million acres of National Forest System lands and works. The Soil Conservation Service (redesignated the National Resources Conservation Service in October 1994) adopted digital orthophotography as the common framework for collecting and managing natural resource geospatial data bases and cooperated with other Federal and State agencies to acquire digital orthophotography.

Federal Communications Commission (FCC)

There were three new commercial domestic fixed satellites launched for the United States during FY 1994. Galaxy 1R(S), launched on February 19, 1994, will provide video services into the next decade. General Dynamics Commercial Launch Services successfully launched the Telstar 401 communications satellite from Cape Canaveral aboard an Atlas IIAS on December 15, 1993. Unfortunately, the

DBS-1, the first U.S. Direct Broadcast Satellite, was launched on December 17, 1993.

September 9, 1994, launch of Telstar 402 by an Ariane launch vehicle from Kourou, French Guiana, was not as successful; operators lost contact with the satellite as it passed over the Indian Ocean. Two other communications satellites that were not in the domestic fixed category but did provide domestic service were the first two Direct Broadcast Satellites (DBS's), launched by an Ariane booster from Kourou, French Guiana, on December 17, 1993, and from Cape Canaveral Air Force Station by a Martin Marietta Atlas IIA on August 3, 1994. Still another communications satellite, placed into orbit on July 8, 1994, was PanAmSat's PAS-2—designated PAS-4 by the FCC. The International Telecommunications Satellite (INTELSAT) Organization successfully launched its INTELSAT 701 satellite on October 22, 1993, aboard an Ariane 44LP rocket. On June 17, 1994, INTELSAT successfully launched the second of nine VII-VII-A satellites, INTELSAT 702, aboard an Ariane 44LP launch vehicle. The International Maritime Satellite Organization (INMARSAT) began providing the world's first satellite voice connection to a cellular-sized phone during trials for a future global handheld phone system.

The U.S. Environmental Protection Agency (EPA)

The EPA also routinely conducted research and provided technical support using remote sensing as part of its overall environmental monitoring program. The Agency used large-scale aerial photography to develop site characterization data during the remedial actions under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), as well as to support site selection and monitoring at hazardous waste facilities operated under the Resource Conservation and Recovery Act (RCRA). It developed and used remote sensing systems to support the provisions of the Clean Water Act. In FY 1994 the Agency completed approximately 150 aerial-photographic site-characterization projects under CERCLA and RCRA, and satellite imagery played a part in helping engineers develop detailed site characterizations. Aerial photography and satellite data also supported a broad variety of pollution, global change, pollution prevention, compliance, and other ecosystem monitoring studies in FY 1994, such as those of critical-habitat areas for wildlife. In support of activities associated with the identification of the impacts and hazards resulting from the severe flooding along the Mississippi River and its tributaries in FY 1993, the EPA's Environmental Photographic Interpretation Center identified and mapped changes that have occurred at known waste disposal sites affected by the flooding.

National Science Foundation (NSF)

Among other findings by NSF scientists, recent work by Mark Phillips of the Cerro-Tolodo Interamerican Observatory in Chile has shown that there is a significant spread in the intrinsic radiated energy in visible light of Type Ia supernovae. As a result of this and other discoveries, supernovae are now among the most accurate of the standard candles, suitable for use as distant probes measuring features of the early universe. Work by other NSF astronomers has modified scientists' theories about the existence of a "Great Attractor," a concentration of mass that causes a bulk flow of galaxies toward it. Their work opens fruitful new directions for understanding the scale of the largest structures in the universe. The application of seismology to the study of the solar interior in a new way by NASA and NSF scientists opens the way for seismic studies of local solar phenomena, such as inhomogeneities beneath the Sun's surface near sunspots. It should also help refine models of the gas velocities below the Sun's surface. Drs. Joseph Taylor and Russell Hulse of Princeton University won the 1993 Nobel Prize in Physics for their discovery using the Arecibo radio telescope in Puerto Rico of the binary pulsar PSR B1913+16 and their subsequent monitoring and analysis of this object. Their work demonstrated convincingly the appropriateness of general relativity as a theory of gravitation under extreme conditions and indirectly confirmed the existence of the gravitational radiation Albert Einstein had predicted. The NSF's Office of Polar Programs continued during the year to support researchers studying the cause and effects of the Antarctic ozone hole at each of three year-round stations. Finally, among other findings by the NSF, its Center for Astrophysical Research in Antarctica (CARA) made wintertime astrophysical observations from NSF's observatory at the South Pole for the first time during the austral winter of 1994. CARA's South Pole Infrared EXplorer (SPIREX) telescope was able, because of its unique location, to image more of the impacts of the Comet Shoemaker-Levy 9 with Jupiter than any other instrument. Also, site measurements by SPIREX confirmed that the sky at the South Pole is darker by a factor of at least three than any other site previously surveyed.

Smithsonian Institution

An astronomer from the Smithsonian Astrophysical Observatory (SAO) heading an international team used HST's Wide Field Planetary Camera 2 in May 1994 to obtain valuable new images of supernova 1994I. Shuttle Pointed Autonomous Research Tool for Astronomy (SPARTAN) 201-2, a small satellite deployed and then retrieved several days later by the Space Shuttle Discovery in September 1994, examined the Sun's hot outer atmosphere, or extended corona, and the solar wind, the flow of charged ions from the Sun. On its second of four planned missions aboard the Shuttle, SPARTAN contained two instruments—the NASA-designed White Light Coronograph to measure the density and distribution of the electrons in the coronal holes and polar plumes of the Sun and the Ultraviolet Coronal Spectrometer, designed by the SAO. In a separate effort, two SAO scientists discovered a huge, hot, gaseous halo surrounding a distant galaxy, perhaps providing evidence for the presence of both dark matter and so-called cooling flows. This, in turn, may shed new light on whether the universe is open or closed. The SAO-conceived and -designed Small Expendable Tether Deployable System-2 was a secondary payload on a Delta II rocket launched from Cape Canaveral AFS, Florida. The longest object ever placed in space, it was the third SAO-developed tether launched within the past year, each on time and with an increasingly ambitious goal.

Department of State (DoS)

With the existing partners agreeing to welcome Russia into the Space Station partnership in early FY 1994, the main focus of the DoS thereafter was on shaping an agreed approach to the negotiations. Once agreement was reached within the partnership and with Russia on these points, the DoS initiated the intergovernmental negotiating rounds, three of which have been held so far. In addition, the DoS facilitated an arrangement to keep fiscally constrained Canada in the partnership. The DoS worked closely with NASA throughout the year on several agreements with Japan on joint space activities. The DoS also worked closely with Government and private organizations to promote space cooperation at all levels with Latin America, and the DoS continued to coordinate U.S. Government involvement in international space science, satellite remote sensing, and related applications programs. During FY 1994, the DoS led efforts to advance U.S. interests in multilateral discussions concerning international space cooperation, including the renewal of the mandate of the Committee on the Peaceful Uses of Outer Space. The DoS also represented U.S. interests in INTELSAT and INMARSAT and continued to further the interests of privately owned international satellite companies. The executive branch and other member countries of the two organizations have been addressing policy changes to further stimulate competition and market opportunity.

The U.S. Trade Representative (USTR)

During the year, the United States and Russia held two special and one annual consultation under the U.S.-Russian Commercial Space Launch Agreement. Both sides exchanged information on specific geosynchronous Earth orbit and Low-Earth Orbit (LEO) competitions and LEO market prospects. Meanwhile, the United States and the People's Republic of China held negotiations to renew a follow-on commercial space launch agreement. The current agreement, signed in 1989, will expire on December 31, 1994. On September 21-23, 1994, a USTR-led negotiating team (made up of representatives from DoS, DoC, DoT, NASA, and OSTP) held its first round of consultations in Beijing with the Chinese National Space Administration on the possible renewal of the existing agreement regarding international trade in commercial launch services. As FY 1994 ended, the United States continued working from the existing agreement to refine quantitative and pricing disciplines to respond to new developments in the market and to improve the functioning of the agreement.

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

As we increase our cooperation with Russia, the United States must ensure that militarily useful technology is not transferred to Russian missile programs and that such programs are not supported indirectly–e.g., by funding Russian production facilities that conduct both commercial and missile-related work. The ACDA endeavors to ensure that cooperation with Russia in the areas of civil and commercial space is carried out in accordance with our treaty obligations and nonproliferation standards. The United States does not authorize transfers that could contribute to Russia's still formidable missile capability or that would assist Russia financially to continue the production of a missile by allowing it or modifications of it to be sold as commercial launch vehicles. The ACDA also worked to ensure that no use of ballistic missiles as space launch vehicles and no export of missiles and missile technology contributed in any way to the proliferation of weapons of mass destruction. The United States and its Missile Technology Control Regime partners exchange information and coordinate their control processes to prevent any such contribution.

The U.S. Information Agency (USIA)

The USIA joined the world in celebrating the 25th anniversary of the Apollo 11 Moon landing in July 1994. Numerous posts abroad held special events that included exhibits (some featuring Moon rocks), seminars, and video programs. Additionally, the USIA covered the collision of Comet Shoemaker-Levy 9 with the planet Jupiter and provided information on Shuttle launches and space probes to interested foreign audiences.

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Space Launch Activities

Space Shuttle Missions

During FY 1994, NASA successfully completed seven Space Shuttle missions and launched an eighth that remained on orbit at the close of FY 1994. In order of flight, the missions were STS-58 (STS standing for Space Transportation System), STS-61, STS-60, STS-62, STS-59, STS-65, STS-64, and STS-68. All launches occurred at Kennedy Space Center (KSC), Florida.

The launch of **STS-58** (in the orbiter Columbia) occurred on October 18, 1993. This marked the second Spacelab flight dedicated to life sciences research. *Columbia*'s seven crewmembers performed a series of experiments to gain more knowledge of how the human body adapts to the weightless environment of space. Fourteen experiments, conducted as part of this Spacelab Life Sciences-2 mission, focused on the cardiovascular, regulatory, and musculoskeletal systems of the body, as well as on the vestibular apparatus. Also included were experiments to gather data and tissue samples from rodents. These experiments were essential in developing NASA's capability to support Space Station missions in the future. Columbia landed safely at KSC on November 1, 1993.

The last flight of calendar year 1993 was **STS-61** (Endeavour), which began on December 2, 1993. This was the first of several planned servicing missions to the orbiting Hubble Space Telescope (HST) launched in 1990. The primary objectives of this mission were to restore the planned scientific capabilities and reliability of HST and to validate the on-orbit servicing concept. Employing five spacewalks, the astronauts met all of the objectives of the mission in a spectacular display of technical competence. They then returned the Endeavour safely to KSC on December 13, 1993.

The first flight of calendar year 1994, **STS-60** (Discovery), began with a February 3, 1994, launch. A mission highlight was the participation of a Russian astronaut serving as a crew member. This signalled the beginning of a three-phased cooperative program between the United States and Russia. Phase one will entail 7 to 10 Space Shuttle-Mir missions, including rendezvous, docking, and crew transfers, between 1995 and 1997. Phase two will be the joint development of the core international Space Station program. Phase three will involve the expansion of the Space

Station to include all of the international partners. The STS-60 mission included the first use of the Wake Shield Facility, a 12-foot-diameter, stainless steel disk that gathered data while attached to the Shuttle's mechanical arm. Spacehab-2, a privately funded module that increased the Shuttle's experimental space, furthered our knowledge of materials processing and biotechnology in space. STS-60 landed at KSC on February 11, 1994.

On March 4, 1994, **STS-62** (Columbia) began the second mission of the U.S. Microgravity Payload (USMP-2). Mission objectives focused on studies to produce better semiconductors. The 14-day, extended duration orbiter flight also provided additional information for ongoing medical studies assessing the effects of long-duration space flight. Columbia landed safely at KSC on March 18, 1994. **STS-59** (Endeavour) was then launched on April 9, 1994. The primary payload was the Space Radar Laboratory, undergoing its first flight to give scientists highly detailed information to help distinguish human-induced environmental changes from other natural forms of change. Another mission objective was the Measurement of Air Pollution from Satellite experiment, designed to measure the global distribution of carbon monoxide in the lower Earth atmosphere. Scientists will be able to compare the data collected from this flight with those from two previous Shuttle missions in November 1981 and October 1984. STS-59 landed safely at Edwards Air Force Base (EAFB), California, on April 20, 1994.

NASA successfully launched **STS-65** (Columbia) on July 8, 1994. The primary payload for this 17th flight of Columbia was the International Microgravity Laboratory-2 (IML-2), a payload that involved a worldwide research effort into the behavior of materials and life in the nearly weightless environment of low Earth orbit. It carried newts and fish living in a special Aquatic Experiment Unit. STS-65 landed at KSC on July 23, 1994, following a record duration flight of 14.75 days.

STS-64 (Discovery) launched successfully on September 9, 1994, for a mission that was unique in several respects. The LIDAR In-Space Technology Experiment payload carried a laboratory laser into space to beam narrow pulses of laser light through the atmosphere. The reflected light gives an indication of the particles suspended in the air and those arising from the Earth's surface. This marked the first time a laser system had flown in space for atmospheric study. The STS-64 crew deployed and retrieved the SPARTAN payload, designed to study the acceleration and velocity of the solar wind and measure aspects of the Sun's corona. Discovery's cargo bay also carried the Robot Operated Processing System, the first U.S. robotics system to be used in space; it transported a variety of semiconductors from storage racks to a halogen lamp furnace for processing. In addition, the STS-64 crew performed untethered spacewalks using a new small, self-contained propulsive backpack device to provide mobility for an astronaut in an emergency. Discovery landed safely at EAFB on September 20, 1994.

The first launch attempt of **STS-68** (Endeavour) had to be aborted on the pad. During the attempted launch on August 18, 1994, the discharge temperature in the high-pressure oxidizer turbopump of main engine three exceeded the 1,560-degree redline limit for launch. As of the end of the fiscal year, the contractor for the turbopump, Rocketdyne Division of Rockwell International, was still investigating the causes of the unexpected temperature increase. Meanwhile, following engine testing and replacement, the STS-68 mission was successfully launched on September 30, 1994, with a primary payload consisting of Space Radar Laboratory-2 (SRL-2). STS-68 landed on October 11, 1994, at EAFB and will be reported more fully in the FY 1995 report.

Expendable Launches

Both the DoD and the commercial transportation industry employed a number of Expendable Launch Vehicles (ELV's) in the course of FY 1994. The DoD either launched or supported launches for 15 of its own or other Government payloads. These included two Delta II, one Atlas E, one Atlas I, one Atlas II, two Titan II, three Titan IV, one Taurus, one Scout, two Pegasus, and one Pegasus XL launch vehicles. The Delta II's placed Global Positioning System (GPS) satellites into orbit on October 26, 1993, and March 9, 1994 (local, March 10, Greenwich Mean Time). The Atlas E launched a Defense Meteorological Satellite Program (DMSP) satellite on August 29, 1994. The Atlas II carried a Defense Satellite Communication System (DSCS) satellite into orbit on November 28, 1993. The mission of one of the Titan II's was to launch Clementine, an experimental deep space probe developed by the Ballistic Missile Defense Organization (BMDO) from recent, off-the-shelf hardware and carried into space on January 25, 1994.

The three Titan IV launches got that program back on track during FY 1994, after its seventh mission the previous year ended in failure when the launch vehicle exploded 100 seconds after launch from Vandenberg AFB. The Air Force completed its failure investigation in early FY 1994, concluding that the probable cause of the accident was a solid rocket motor segment repaired during manufacture. It apparently had allowed propellant to burn through the motor's case wall and activate the flight termination system. After replacing all repaired segments, as well as those affected by corrosion, the Air Force launched the three missions from Cape Canaveral AFS. The first launch carried a Milstar satellite into orbit on February 7, 1994, marking the initial use of the Titan IV Centaur upper stage. This doubled the U.S. capability for placing payloads in geosynchronous orbit from 5,000 to 10,000 lbs. A second successful Titan IV launch on May 3, 1994, carried a Defense Support Program (DSP) satellite into orbit using a Centaur upper stage. The final launch of a Titan IV with Centaur upper stage occurred on August 27, 1994; it carried a classified mission and marked the 10th Titan IV launch since FY 1989 when the program began.

The DoD's Space Test Program (STP) used the Taurus and Pegasus launch vehicles for three of its missions during FY 1994. On March 13, 1994, an Advanced Research Projects Agency (ARPA) Taurus launch vehicle, built by Orbital Sciences Corporation, carried the Space Test Experiments Platform Mission 0 (STEP-0) and an ARPA satellite into orbit. This was the first mission for both booster and STEP-0. STEP-2 launched successfully on May 19, 1994, using a standard Orbital Sciences Corporation Pegasus vehicle. However, the inaugural attempt to launch a higher-performance, stretched Pegasus, known as Pegasus XL, ended in failure on June 27, 1994, resulting in the loss of the STEP-1 mission payload. The program got back in the success column on August 3, 1994, with the launch of the Advanced Photovoltaic Experiment (APEX) mission, again using the standard Pegasus launch vehicle. The STP's next planned launch is the STEP-3 mission, again using a Pegasus XL.

Meanwhile, the 118th and final mission of the Scout rocket, developed by NASA, launched the second of the Miniature Sensor Technology Integration (MSTI-2) satellites into Sun-synchronous orbit on May 8, 1994. Additionally, the DoD launched two satellites for other Government agencies during FY 1994. A Titan II placed the last of the National Oceanic and Atmospheric Administration (NOAA)-operated Landsat satellites, Landsat-6, into initial orbit on October 5, 1993, but following successful separation from the Titan II, the satellite's integral "kick motor" apparently failed to place it into final orbit. Then, on April 13, 1994, an Atlas I launched the next in the series of Geostationary Operational Environmental Satellites, GOES-I, into orbit for NOAA.

In addition to these Government launches, the DoD provided its facilities with minimal oversight to commercial contractors for launch of five satellites, one of which was a DoD payload. The table below summarizes these missions, which the Office of Commercial Space Transportation (OCST) in the Department of Transportation (DoT) licensed and monitored.

Company	Launch Vehicle	Payload	Date
McDonnell Douglas	Delta II (7925)	Nato IVB	Dec. 7, 1993
General Dynamics	Atlas IIAS	Telstar 401	Dec. 15, 1993
McDonnell Douglas	Delta II (7925)	Galaxy 1R	Feb. 19, 1994
Martin Marietta	Atlas I	UHF Follow-On-3	Jun. 24, 1994
Martin Marietta	Atlas IIA	DBS-2	Aug. 3, 1994

The last of these launches brought to 40 the total number of commercial launches licensed to date. The first such launch occurred in March 1989 with a suborbital launch of a scientific payload on a Starfire rocket from White Sands Missile Range, New Mexico. Space Services, Inc. built the Starfire. The first orbital commercial launch occurred using a McDonnell Douglas Delta I. On August 27, 1989, it succeeded in placing a British Satellite Broadcasting communications satellite in orbit. Martin Marietta Corporation's commercial Titan and Atlas rockets and the Pegasus air-launched vehicle built by Orbital Sciences Corporation have also successfully launched commercial payloads.

Space Science

Astronomy and Space Physics

During FY 1994, space scientists continued to add to the fund of information about the universe gathered not only through instruments located on the Earth, but also from those on satellites above the distorting medium of the home planet's atmosphere. For example, scientists working on the **Hubble Space Telescope** (HST) team made a number of important discoveries during FY 1994, including images of an exploding star (Nova Cygni 1992). Many of these findings preceded the highly successful servicing mission in December 1993, when astronauts on STS-61 replaced several faulty parts and installed a sophisticated package of corrective optics to compensate for the spherical aberration in the HST's primary mirror. Coin-sized mirrors on the Wide Field and Planetary Camera 2 and Corrective Optics

Space Telescope Axial Replacements units have since served as "contact lenses" for the HST. While the telescope has always had a view of the sky unobstructed by haze from the Earth, scientists since have been able to accomplish all the astronomical goals initially planned for the most sophisticated observatory ever built. In the process, the HST's first servicing mission proved the capability of NASA's highly trained astronauts to work productively in space.

As one fruit of their efforts, an astronomer from the Smithsonian Astrophysical Observatory (SAO), heading an international team, used the HST's Wide Field Planetary Camera 2 in May 1994 to obtain valuable new images of **Supernova 1994I**, discovered by amateur astronomers in April 1994 in the inner regions of the "Whirlpool Galaxy," M51. The HST has the unique capability of imaging and measuring the spectra of distant supernovae in ultraviolet light. As the M51 supernova ages, Hubble will "see" more deeply into the interior of the exploding star. This will permit astronomers to probe the chemical composition of the debris and learn more about the type of star that exploded. The team of scientists thereby hope to learn which stars explode as supernovae, what chemical elements are ejected, and how to use these bright events as yardsticks for measuring the size of the universe.

In June 1994, two scientists using the HST discovered disks of **protoplanetary dust** around stars in the Orion Nebula region of the Milky Way galaxy. This revelation indicates that the formation of planets may be relatively common both in the Milky Way and in other parts of the universe. The newly found disks contain many of the same basic chemicals that compose the planets in ourSolar System. Because planets are the only heavenly bodies that can support life as we know it, the existence of planets around other stars would raise the likelihood of life in other parts of the universe.

Then in July 1994, an international team of astronomers using the HST's Faint Object Camera confirmed that **helium** is widespread throughout the early universe, a key hypothesis of the Big Bang theory. The discovery of helium in the constellation of Cetus, which is 13 billion light years away, gives scientists valuable information about conditions at the time of the universe's initial evolution. Additionally, this finding lends further weight to the scientists' conception of chemical evolution in the universe; scientists believe that hydrogen and helium evolved within three minutes after the Big Bang, while heavier elements such as oxygen and carbon came later.

In other developments, scientists analyzing data from the Compton Gamma Ray Observatory (CGRO), which was launched in April 1991, found new evidence that **gamma-ray bursts** extend into the far reaches of the universe and thus bear an imprint of the universe's expansion. These huge explosions come from all directions, suggesting a cosmological cause; until this discovery, it was believed that the bursts were limited to within the Milky Way galaxy. Because the bursts come from so far away, they demonstrate "time dilation," an effect created when time seems to be running more slowly at the bursts' source than at their destination, because the universe itself is thought to be expanding.

Relatedly, the CGRO's Energetic Gamma Ray Experiment Telescope (EGRET) provided the first detailed all-sky map of **highly energetic gamma ray objects**, pointing out several different types of gamma ray sources. Scientists believe, for example, that the interactions of cosmic ray particles with gas between the stars produce diffuse gamma ray emissions from our Milky Way galaxy. Within this band are gamma ray pulsars and other unidentified sources of gamma rays. Astronomers analyzing EGRET's data have also identified what they think are massive black holes in the middle of distant galaxies that are sending gamma rays in the Earth's direction.

Similarly, the Extreme Ultraviolet Explorer (EUVE), launched in June 1992, produced the first all-sky map in four **extreme ultraviolet wavelength bands**. This survey has identified large numbers of very hot stars such as white dwarfs and active corona stars. For purposes of comparison, scientists also surveyed a companion area along half the ecliptic plane on which the Earth travels around the Sun.

Space physicists using the Solar, Anomalous, and Magnetospheric Particle Explorer (SAMPEX), launched in June 1992, discovered a radiation belt of trapped anomalous cosmic rays in the **magnetosphere**. They have determined the chemical composition and electrical charge of these rays in the region beyond the Earth's upper atmosphere where the planet's magnetic field affects charged particles. In addition, these scientists have learned a lot about the effects of electrons in the upper atmosphere. SAMPEX's mission is to monitor energetic electrons and atomic ions from the Sun and from interplanetary, interstellar, and magnetospheric space.

Space physicists also achieved breakthroughs in **computer modeling**. In particular, complex numerical modeling has led to a detailed conception of the Earth's magnetosphere. As a result, scientists are now able to predict "space weather" caused by solar-terrestrial interactions. Investigators using computer simulations have also gained a refined understanding of the heliopause, the boundary of the Solar System where the solar wind's outward flow is balanced by the pressure of the interstellar medium. This model's parameters are expected to be confirmed or denied when the two Voyager spacecraft reach this area and transmit their data back to the Earth sometime within the next decade. (Voyager 1 was launched in September 1977 and Voyager 2 in August 1977.)

SPARTAN 201-2, a small satellite deployed and then retrieved several days later by the Space Shuttle Discovery in September 1994, examined the Sun's hot outer atmosphere, or extended corona, and the solar wind, the flow of charged ions from the Sun. On its second of four planned missions aboard the Shuttle, SPARTAN contained two instruments—the NASA-designed White Light Coronograph to measure the density and distribution of the electrons in the coronal holes and polar plumes of the Sun and the Ultraviolet Coronal Spectrometer, designed by the SAO. Together, the two instruments can determine the velocity of the solar wind as it accelerates out of the Sun so that scientists can grasp exactly how and when the Sun creates this wind as well as what the shape and spectroscopy of the solar corona may be. The measurements made by SPARTAN 201 will be used in conjunction with those from the Ulysses spacecraft, which was launched in October 1990 and which detected the solar wind from the south polar corona as SPARTAN observed the source region of that wind as well as other portions of the Sun's corona. Data from SPARTAN 201 will also calibrate measurements to be made by the European Space Agency (ESA)-NASA Solar and Heliospheric Observatory, scheduled for launch in 1995. Scientists hope to derive practical information from these missions about exactly how the solar wind produces magnetic storms near the Earth that can disrupt communication systems and trigger power outages, resulting in losses estimated at $100 million each year worldwide.

Ulysses, meanwhile, became the first spacecraft to fly over a polar region of the Sun when, in June 1994, it began its primary mission to observe the solar wind at high-solar latitudes. Built by ESA and equipped with both European and U.S. instruments, Ulysses will take direct measurements of many complex solar phenomena that cannot be observed remotely. Scientists are eager to learn more about the Sun's polar magnetic fields, which reverse polarity every 11 years in conjunction with the solar cycle; they play an important role in the Sun's corona and solar wind. The ionic composition of the solar wind, measured by Ulysses, indicates that its source in the coronal gas measures just over a million degrees Centigrade. This is not hot enough to make the wind go as fast as it does, indicating that some unknown electromagnetic process near the Sun is responsible for accelerating the solar wind.

In a separate development, researchers from the University of Alaska in Fairbanks recorded spectacular **upper atmospheric flashes** occurring above electrical thunderstorms. For many years, pilots have noticed these bright blue and red flashes that last only a few thousandths of a second. Using special low-light-level cameras mounted on two small aircraft, scientists recently captured these flashes on video for the first time. They extended upward as high as 60 miles, and some even reached through the Earth's ozone layer to the ionosphere. After coordinating their measurements with scientists at other institutions, the researchers came to suspect that the flashes are a form of electrical discharge. The scientists plan further study to understand the origin of the flashes and their potential impact on aircraft safety. More broadly, this phenomenon links the weather in the Earth's lower atmosphere to upper atmospheric layers that form our planet's border to space.

In other weather-related space science, NASA conducted a series of sounding rocket flights during FY 1994 to examine the Alaskan auroras. Space physicists are interested in these colorful phenomena known as "**Northern Lights**" because they are caused by variations in the solar wind's interaction with the Earth's magnetic field. Equipped with sophisticated payloads, sounding rockets flew directly through the auroras, allowing scientists to take direct measurements of the ions' energy levels. Researchers hope to gain a better understanding of how these particles are accelerated and energized. This campaign of eight rocket flights formed a significant part of the Space Physics Division's 41 rocket flights this fiscal year.

Because of their extreme luminosity at maximum light, **Type Ia supernovae** have proved themselves to be valuable in measuring both the local rate of expansion of the universe and the rate of change of that expansion. Recent work by Mark Phillips of the Cerro-Tolodo Interamerican Observatory in Chile has shown that there is a significant spread in the intrinsic radiated energy in visible light of this key subtype of supernova. That spread can introduce a bias in samples of distant supernovae, leading to erroneous estimates of universal deceleration. Phillips and his collaborators found a good correlation between the rate of decline with time of the luminous output of supernovae and their peak brightness. They also found that silicon absorption features easily detected in the spectra of supernovae are strongly correlated with both the rate of decline and peak brightness. The strength of the spectral features can be used to increase the accuracy of the estimate of each supernova's intrinsic brightness and, therefore, its distance. The use of this technique now places supernovae among the most accurate of the standard candles, suitable for use as distant probes measuring features of the early universe.

A series of systematic observations by astronomers has long suggested the existence of a "**Great Attractor**," a concentration of mass that causes a bulk flow of galaxies toward it. Scientists discovered this large-scale flow by comparing the motion of the local group with respect to clusters versus the motion with respect to the cosmic microwave background, which is assumed to be a "stationary" reference. The strength of such large-scale flows can distinguish among models that explain the formulation of galaxies and clusters in the early universe. More recently, astronomers have begun to examine large volumes of space to search for structure and flows on even larger scales. Work by Todd R. Lauer (National Optical Astronomy Observatories) and Marc Postman (Space Telescope Science Institute), using the Kitt Peak National Observatory's 4- and 2.1-meter telescopes in Arizona and the Cerro-Tolodo Interamerican Observatory's 1.5-meter telescope in Chile, suggests that bulk flows can be identified over scales as large as some 600 million light-years, almost three times larger than those found in previous investigations. They used the brightest galaxies to measure the distances and velocities of 119 clusters, creating the cluster reference frame. The motion of the local group of galaxies derived with respect to these galaxy clusters was significantly different from the one derived with respect to the cosmic microwave background. The most straightforward interpretation of this result is that all the galaxies in the volume of space defined by these clusters are streaming with a velocity of nearly 700 kilometers per second and that any "attractor" has to lie beyond the boundaries of the original search. A structure this large cannot be explained by any current theoretical model and opens fruitful new directions for understanding the scale of the largest structures in the universe.

The application of seismology to the study of the **solar interior** has advanced almost solely by the prediction and measurement of the Sun's frequencies of oscillation. Thomas L. Duvall (Goddard Space Flight Center), Stuart Jeffries (Bartol), Jack W. Harvey (National Solar Observatory, Tucson), and Martin A. Pomerantz (Bartol) have shown that it is also possible to obtain direct measurements of the travel times and distances of individual accoustic (sound-like) waves, which is the predominant approach in terrestrial seismology. The basic concept is simple: At the surface, a wave propagating upward from the interior is reflected back downwards by the steep change in the density of the gas at the Sun's surface. As the wave travels into the interior, its path is curved back toward the surface by refraction, caused by the strong increase of temperature with increasing depth. If the upward wave causes a brightening in the area of the Sun's surface, then there will be a correlated brightening where the wave resurfaces at a later time. By measuring this time difference as a function of the distance of separation of two surface locations, it is possible to develop a plot of the travel time versus the distance of separation, a plot familiar from terrestrial seismology. The initial work showed that acoustic waves with frequencies of oscillation greater than a critical value predicted from the physical conditions in the solar atmosphere are not significantly reflected by the atmosphere, with a less than 2-percent reflection coefficient. This approach opens the way for seismic studies of local solar phenomena, such as inhomogeneities beneath the Sun's surface near sunspots. It should also help refine models of the gas velocities below the Sun's surface.

Drs. Joseph Taylor and Russell Hulse of Princeton University won the 1993 Nobel Prize in Physics for their discovery using the Arecibo radio telescope in Puerto Rico of the **binary pulsar** PSR B1913+16 and their subsequent monitoring and analysis of this object. Their work demonstrated convincingly the appropriateness of general relativity as a theory of gravitation under extreme conditions and indirectly confirmed the existence of the gravitational radiation Albert Einstein had predicted. In more recent use of the Arecibo radio telescope, continued timing of the millisecond binary pulsar PSR B1257+12 by its discoverer, Alexander Wolszczan of Pennsylvania State University, has greatly strengthened the case for the previously announced pair of planets that orbit this object; the observations have begun to show the expected effects that the planets' mutual gravity has on their orbital motion. The observations have also revealed the presence of a third planetary body, with a mass only 1.5 percent that of the Earth, that orbits the central neutron stars at a distance of only 0.2 astronomical units.

Observations of gas clouds associated with the **high-redshift quasar** PC 1643+4631A, using the 140-foot and 12-meter radio telescopes at the National Radio Astronomy

Observatory (NRAO—Kitt Peak, Arizona), have revealed the presence of carbon monoxide emission. Clouds such as this have been identified previously with the progenitors of current galaxies. The red shift of the molecular spectral lines indicates that they were emitted when the universe was about one-fifth of its present age. The observations by David T. Frayer, NRAO associate director Robert L. Brown, and NRAO director Paul A. Venden Bout are striking in that they indicate a molecular mass of 4.5 trillion solar masses. This equals the stellar mass of a large galaxy, but here the material apparently lies in an extended, gaseous, prestellar state. Also noteworthy are the substantial quantities of carbon and oxygen that make up the carbon monoxide molecules; these elements must have themselves been produced in a burst of massive star formation preceding the observed protogalactic state.

The National Science Foundation's (NSF) **Center for Astrophysical Research in Antarctica** (CARA) made wintertime astrophysical observations from the NSF's observatory at the South Pole for the first time during the austral winter of 1994. CARA's South Pole Infrared EXplorer (SPIREX) telescope was able, because of its unique location, to image more of the impacts of the Comet Shoemaker-Levy 9 with Jupiter than any other instrument. Also, site measurements by SPIREX confirmed that the sky at the South Pole is darker by a factor of at least three than any other site previously surveyed. Another of CARA's experiments is on the Cosmic Background Radiation Anisotropy; at the end of the fiscal year, it consisted of a suite of two telescopes designated PYTHON and VIPER. PYTHON has made measurements at the South Pole during the past two austral summers and has now been operated for the first time during winter. It has made important confirmation of the Cosmic Microwave Background (CMB) anisotropy first measured by the Cosmic Background Explorer (COBE), launched in 1989, and it has begun to make a finer scale map of the CMB than is possible with the smaller antennas of COBE. The quiet atmospheric conditions at the South Pole have allowed PYTHON to make measurements of unprecedented sensitivity.

Using new data from the Advanced Satellite for Cosmology and Astrophysics (ASCA, launched by Japan in February 1993) about two **supernova remnants** (designated E0519-69.0 and N103B) in the Large Megallanic Cloud, a binational team of astronomers led by the SAO's John P. Hughes discovered significant amounts of iron, calcium, and other newly synthesized elements. ASCA gives astronomers a better tool for direct observation of the emissions from many atoms, including oxygen, silicon, calcium, and iron, in the ejected gas of supernovae, lasting for many hundreds of years after the explosion that created the supernova. Scientists believe that the explosions that created the remnants occurred somewhere between 500 and 1,500 years ago. The obvious presence of iron emissions coupled with the lack of strong oxygen emission suggest that these remnants belong to the select group of supernova explosions that produced the bulk of the iron in the universe, according to Hughes. Further study of the new data should help astronomers refine current models of supernova explosions and "because of the ubiquitous presence of iron throughout the universe," Hughes expected the results to have a large influence on astronomy in general.

Two other SAO scientists, Dong-Woo Kim and Giuseppina Fabbiano, discovered a huge, hot, gaseous halo surrounding a distant galaxy, perhaps providing evidence for the presence of both **dark matter** and so-called cooling flows. This, in turn, may shed new light on whether the universe is open or closed. The two astronomers used the joint German-U.S.-U.K. Roentgen Satellite (ROSAT), launched in June 1990, to observe an x-ray-bright elliptical galaxy, NGC 507, some 300 million light years from Earth. Measuring the temperatures of x-ray-emitting hot gas, they observed a steady decrease of heat toward the galaxy's center. They believe this fall in temperatures may result from cooling flows in the central region. Also, uncertainty in measurements of the mass of NGC 507 suggests that a large amount of dark matter may be present. Observations indicate that baryonic matter (mass seen as stars and gas in all wavelengths) makes up some 15 percent of the estimated total mass of the galaxy. Because current cosmological theory predicts that baryonic mass must be less than 5 percent to "close" the universe, this finding has implications for cosmology. However, similar measurements of many other systems will be necessary before scientists can determine whether the universe is open or closed.

Solar System Exploration

Closer to home, scientists were also making new discoveries about our own Solar System. For example, ground observations conducted under the Near Earth Object program detected the **Shoemaker-Levy 9 comet** in 1993 and predicted its impact on Jupiter in July 1994. This event marked one of the more spectacular results of a detailed, long-term telescopic survey of the night sky at Palomar Observatory, California, by U.S. Geological Survey (USGS) geologist Eugene M. Shoemaker and two volunteers, Carolyn S. Shoemaker and David H. Levy. It was the first totally disrupted (fragmented) comet ever to be observed, and the first to be seen orbiting and impacting a planet. For the first time, the worldwide scientific community was able to predict and track such a crash. Astronomers using most available ground-based observatories and a variety of operating spacecraft, from Galileo (launched in October 1989) to the HST and the Kuiper Airborne Observatory, obtained an array of interesting and revealing data about the composition of comets and Jupiter, including a wide range of effects on the planet's atmosphere and plasma environment from the impact. A total of 21 observable fragments collided with Jupiter over a week-long period. The impact, observed in regions of the electromagnetic spectrum ranging from the ultraviolet to long radio wavelengths, produced fireballs that left major visible marks on the planet; it revealed a clearcut need for an inventory of comets and asteroids that may someday collide with the Earth. During the last few months of the fiscal year, scientists under contract to the Defense Nuclear Agency (DNA) used their expertise in simulation and modeling of the nuclear effects in the Earth's atmosphere to explain the enhanced radio emission data resulting from measurements in various radio frequency bands from Jupiter's magnetosphere during the impact. Their findings, in line with a shock acceleration model, suggest a greater effect than had previously been assumed. As the fiscal year ended, previous calculations were being refined in collaboration with a variety of radio and optical observers and investigators. In anticipation of the collision of the comet with Jupiter, the Divisions of Astronomical Sciences and Atmospheric Sciences within the NSF and the Solar System Exploration Division of NASA sponsored a special program to support observational and theoretical investigations into the mechanism of energy deposition into different regions of Jupiter's atmosphere. Theoretical models account for the amount and velocity of material ejected during the collisions as well as the chemical reactions that occur as a result of the interaction of this material with the neutral and ionized components of Jupiter's atmosphere. The impact is expected to have generated dust that, on being charged through exposure to the plasma environment, will form new dust rings around the planet. Data obtained from a variety of instruments strategically deployed to observe the effects of the impacts will test the theoretical predictions.

NASA scientists also made exciting new strides in lunar studies while working on the DoD-sponsored **Clementine** mission. This effort, in which lunar research was only one of the goals, was conducted by the Naval Research Laboratory (NRL) under sponsorship of the BMDO with the support of NASA, Lawrence Livermore National Laboratory, and the Jet Propulsion Laboratory (JPL) in California. Launched on January 25, 1994, the Clementine spacecraft entered lunar orbit on February 19, 1994. For the next 2 1/2 months, four cameras took 1.8 million images of the surface of the Moon in 11 discreet wavebands with coarse altimetry over most of the lunar surface, resulting in the first comprehensive digital map of that surface. In addition, NASA scientists are excited to have multispectral surface data covering 11 colors in the visible and infrared spectra. Instruments such as a laser ranger, a charged particle telescope, advanced thermal imagers, and radio tracking gear also contributed significant new information about the Moon's topography, surface composition, and charged particle environment. For example, the lidar system compiled a complete map of lunar elevations, discovering a 12-kilometer-deep impact crater at the lunar south pole in the process. An in-flight contrived experiment to use the communications transmitter for active, bistatic measurements produced supportive but not conclusive evidence for the existence of ice in the permanent shadows of craters near the lunar poles. NASA planned to sponsor a series of multiyear grants to scientists to examine Clementine's lunar data in expectation of discovering new insights about the Moon's formation. The USGS has begun processing the Clementine data to produce global digital maps as well. A secondary mission of Clementine, a deep-space encounter with the asteroid 1620 Geographos, could not be completed because of a problem that occurred after completion of the lunar mapping mission.

Galileo, on the other hand, did complete its encounter with the **asteroid Ida** and in the process made the curious discovery of the first confirmed moon around an asteroid. This was the 1.5-kilometer-in-diameter satellite, Dactyl. Although scientists previously believed that natural satellites of asteroids probably existed, they now contend that such moons may be more widespread than previously considered. As the fiscal year ended, researchers were busy examining data about Ida's moon to learn how both bodies were formed. One possibility is that the moon was formed during the explosion of a larger asteroid of heterogeneous composition that also gave birth to Ida. Spectral analysis by Galileo's near-infrared mapping spectrometer revealed that Dactyl is composed of different amounts of specific compounds than Ida, indicating that it did not come directly from Ida. New data gathered by Galileo indicate that Ida's composition is more diverse than previously thought. By examining the moon's orbital parameters, scientists, including those from NASA and the USGS, can better determine Ida's mass. Combining this information with prior data on Ida's size will enable scientists to deduce the asteroid's density and composition. While on its way to Jupiter, Galileo also examined another asteroid, Gaspra, which, like Ida, travels in the main asteroid belt orbiting the Sun between Mars and Jupiter.

In other planetary exploration, the Magellan spacecraft, launched in May 1989, determined that **Venus** is still geologically active. After completing the mapping of the planet's surface, Magellan began collecting information about its density. By tracking the spacecraft's precise speed over specific areas of the planet, ground controllers back on the Earth calculated the strength of gravity in these locations and thus the subsurface density. The data indicate that Venusian areas of high gravity correspond to areas of high elevation, in contrast to the situation on the Earth, where mountain ranges correspond to gravitational lows. Relatedly, the USGS successfully completed the first full-resolution global radar mosaic of Venus (1:1,500,000 scale); a series of 170 CD-ROMs containing the same spacecraft data was in production as the fiscal year ended. Nearly half of the 1:1,500,000-scale geologic base map quadrangles have been completed to support NASA's Venus Geologic Mapping Program.

In addition, the USGS has been involved in planning for unpiloted missions that NASA proposes to send to Mars, including **Pathfinder** (a lander with a small rover projected for 1996-97), at least two orbiters named Mars Global Surveyor, and a series of Mars Surveyor landers. Geologists from the Survey served on the Pathfinder imaging team and helped plan for a wide range of Pathfinder experiments and geologic observations, including selection of a landing site at the mouth of a large Martian outflow channel. Survey personnel also helped plan for Surveyor orbiter and lander missions projected to take place between 1998 and 2005.

Other Space Science

NASA made significant strides in microgravity and life sciences research during FY 1994, beginning with the **Spacelab Life Sciences-2** (SLS-2) mission in October 1993. Its payload consisted of 14 experiments that examined physiological responses of humans and rodents to microgravity and their subsequent readaptation to the Earth's gravity. As an extension of the SLS-1 mission in June 1991, research on SLS-2 focused on identifying and further characterizing the changes in physiological systems during and after space flight and on increasing our knowledge about underlying mechanisms so we can minimize or counteract changes adverse to human health before the international Space Station begins its operations. Important findings from SLS-2 included independent demonstration by three different investigator teams that current models for understanding the effects of gravity on the heart, lungs, and circulation could not predict the observed physiological responses during space flight. These studies will yield important new understanding of blood pressure regulation, in health and disease, and of cardiopulmonary disorders. Researchers also learned that a surprising degree of neural plasticity results from exposure to microgravity. These results will improve our understanding of the nervous system's adaptation to change. Research into the role that physical loading (gravity) plays in maintaining muscle function—combining anatomy, biochemistry, and functional measures—will help the joint NASA-National Institutes of Health (NIH) program in muscle physiology.

The flight of a cosmonaut on STS-60 in February 1994 began Phase 1 of the **international Space Station**. In August, the first launch of U.S. research hardware aboard a Russian Progress rocket included an acceleration measurement system to support both U.S. and Russian research programs. Additional U.S. hardware is being tested and shipped to Russia for launch aboard Progress rockets next year. Ultimately, a planned International Space Research and Technology Institute will sponsor new interdisciplinary teams consisting of biologists, technologists, physicists, and material scientists to conduct research both on the Earth and in the Space Station, bringing fresh insight and methodology to bear on problems humans face.

Meanwhile, in March 1994, NASA flew the **USMP-2**—a facility exposed to the space environment in the Shuttle payload bay that provides power, cooling, and data collection for a variety of experiments. The Isothermal Dendritic Growth Experiment advanced our knowledge of materials science. Dendrite growth is the common form of crystal growth encountered when metals, alloys, and many other materials solidify in most industrial processes. Study of the formation of dendrites in orbit showed conclusively that to provide rigorous tests of fundamental theories of dendrite formation and development, long-duration, high-quality microgravity conditions are required. These theories are needed to predict and achieve in solidified materials the desired microstructures that control many of their physical and chemical properties, such as their mechanical strength and resistance to corrosion. The Crystal Growth of Solid Solution Semiconductors Experiment, using the Advanced Automated Directional Solidification Furnace on its first mission, successfully grew a crystal of mercury cadmium telluride alloy, a semiconductor, to study the physics of additive thermal- and composition-driven convection during crystal growth. The in-situ monitoring available in the MEPHISTO (Material pour l'Etude des Phenomenes Interessant la Solidification sur Terre et en Orbite) apparatus enabled the study of transport and kinetic phenomena during crystal growth of bismuth/tin alloys. The MEPHISTO furnace, developed by the French Space Agency and shared by U.S. and French investigators under a cooperative agreement, has the unique ability to study the formation of microstructures in solidifying materials to help understand how metals acquire their physical properties. The Critical Fluid Light Scattering Experiment studied phase transition phenomena near the critical point of the element, xenon. Studying an area known to physicists as dynamic critical phenomena, this experiment provided theorists with new guidance for modeling how systems with many degrees of freedom respond to fluctuations. Such models can help interpret such varied phenomena as atmospheric turbulence, human population dynamics, and superconductivity.

IML-2 in July 1994 continued IML-1's exploration of the effects of gravitational force on biological, physical, and chemical systems. Some 82 investigations sent into orbit by 75 principal investigators from 13 countries showed how crewed space laboratories can be used with high efficiency in international investigations such as those to be done on the Space Station. On IML-2, 11 major U.S. microgravity experiments used new flight apparatuses developed by NASA's international partners. Four U.S. investigator teams used the German electromagnetic containerless processing facility (TEMPUS) to conduct studies of nucleation in solidification while also measuring thermophysical properties. One U.S. investigator used ESA's Advanced Protein Crystallization Facility, flown on its first long-duration mission, to study crystallization of macromolecules using the "liquid-liquid diffusion technique." Another U.S. investigator successfully completed protocols to study the phenomenon of liquid-phase sintering—a process used to produce alloys of novel compositions from high-temperature materials—in the National Space Development Agency (NASDA) of Japan's Large Isothermal Furnace. Two U.S. investigator teams studied liquid-phase interactions using ESA's Bubble, Drop, and Particle Unit, and one U.S. investigator group studied phase changes, employing ESA's Critical Point Facility. Preliminary results from the mission include new insights into the transport of mass and energy in systems at vapor-liquid critical point—a unique condition of matter that promises to reveal an important new understanding of complex systems on scales ranging from the atom to global weather and of subtle changes such as the magnetization of an iron bar or the way substances transition from conductivity to superconductivity, as well as observations of surface-tension driven motions of drops and bubbles under conditions of strongly coupled heat and momentum transport. The IML-2 studies of radiation biology showed damage to living cells as an effect of the natural space environment. Nematode worms showed a significant number of mutations compared to control specimens but no unusual reproductive behavior. Investigations on animals and plants exhibited the effects of microgravity and radiation on growth patterns, genetic material, bone development, cell differentiation and reproduction, and the effectiveness of antibiotics. The first documented, successful vertebrate reproduction in space involved the mating and hatching of Medaka fish eggs. One fry resulting from in-space fertilization actually hatched and survived, as did prefertilized eggs. Two newt eggs, laid on orbit, survived, and a high percentage of pre-orbit selected eggs remained viable as embryos and larvae. In another first occurrence in space, researchers established a gravity threshold, the point where gravity's effects can be observed, for two organisms—Euglena and jellyfish. Fruit flies exposed to microgravity exhibited hyperactivity compared to control specimens on the Earth, indicating an accelerated aging process in space.

At the request of the governments of Ukraine and the Republic of Georgia, NASA life scientists associated with **Space Radar Laboratory-2** received data in October 1994 on Shuttle passes over the two countries. These data will support technological developments and environmental monitoring in response to concerns of those governments about pollution and disease control.

NASA continued in FY 1994 to make strides in the field of **telemedicine**, the practice of medicine across distances using a phone line, satellite, microwave, or other telecommunications medium. The Spacebridge to Moscow Telemedicine Demonstration Project, a flagship program in this arena begun in November 1993, uses two-way, interactive video between clinical consultants at the Moscow Hospital of the Ministry of Information and four clinical sites in the United States. Remote aid in diagnosing patients under this project constitutes a successful follow-on to the Spacebridge to Armenia in 1988.

Regenerative life support research has led to significant advances in the development of new **biofilm resistant coatings** using application techniques common in industry. NASA initiated this research to control or prevent the buildup of medically harmful microorganisms in the air, water, and trace-contaminant control systems of long duration on crewed spacecraft. Preliminary results (independently confirmed by the Center for Biofilm Engineering at Montana State University) show a 50 to 90+ percent reduction in the buildup of a common biofilm-forming organism when the coating is applied to plastics or metal. The coated surface is heat-stable, thus allowing sterilization and reuse. Of particular note, the coated surface is also extremely easy to clean. These coatings may have application to preventing biofilm buildup in a number of commercially important areas. Preliminary estimates by the Center for Biofilm Engineering and the EPA conservatively place the commercial potential of these technologies in the hundreds of millions of dollars.

NASA also continued its close **cooperation with other Government agencies in research**. A joint biotechnology program between NASA and the NIH emphasized establishing joint centers to accelerate the transfer of NASA technology and allow its application to biomedical research, developing advanced tissue-culturing technology for application to biomedical research and developmental biology; advanced protein crystallization technologies to advance structural biology and drug design to fight diseases; and technology for early detection of cataracts. At the end of the fiscal year, NASA had 18 cooperative agreements with 10 institutes of the NIH as well as the National Library of Medicine. Under an interagency agreement between NASA and the NIH, the two agencies established a Center for Three-Dimensional Tissue Culture at the National Institute of Child Health and Human Development. This agreement supports the transfer of NASA's bioreactor technology to the NIH, its further development with NASA support, more protein crystal growth flight experiments, and new investigations of microgravity cell culture. Additionally, NASA and the NIH have selected 22 investigators to fly life science experiments on the Space Shuttle in the period 1994-1996, the first such NASA/NIH space flight experiments, and 34 investigators for Neurolab, a Spacelab mission to fly on the Shuttle in 1998, dedicated to brain and behavioral sciences. NASA has also signed agreements with the National Cancer Institute, the National Library of Medicine, and the National Institute of Child Health and Human Development to conduct research in areas of common interest. In 1994 NASA received 141 proposals in biotechnology in response to a research announcement. Peer reviews in FY 1995 will determine which will be pursued further. NASA and the National Cancer Institute will apply the imaging technology used in HST and elsewhere to the diagnosis and treatment of breast cancer. Three projects in particular offer the promise of developing direct digital mammography systems with high resolution and a wide field of view. With the National Institute of Mental Health, NASA will help apply recent advances in computer and information sciences to the brain and related health sciences.

In related endeavors, NASA, the Air Force, and GTE Corporation recently completed a program studying the growth of gallium arsenide in the space environment. NASA also funds a protein crystal growth program at the Naval Research Laboratory, and under a NASA agreement with the DoD, Walter Reed Army Institute of Research has been conducting cell culture research in a flight system. A memorandum of understanding between NASA and the NSF has committed those two agencies to collaborative research in environmental signal transduction and cell differentiation in plants in response to environmental stimulation, especially gravity. Another agreement between NASA and the Multiple Sclerosis (MS) Association of America will use the technology developed for cooling systems in space suits to develop cool suit technology for victims of MS who have trouble regulating internal body temperature. A result from a joint project development effort between NASA's Ames Research Center and the NSF's Closed Ecological Life Support System Antarctic Analog Project will be NASA's largest-scale application to date in bioregenerative life support technology and will also feature a recycling system to support Antarctic researchers. Designed to increase the habitability of the Amundsen-Scott South Pole research station and help the United States meet its international obligations to maintain the Antarctic environment in a pristine condition, this project will allow NASA to meet the goal of obtaining long-duration experience in a similar environment to test regenerative life-support candidates for planetary habitats by deploying regenerative food, water, and waste-processing systems for use at the South Pole.

Space Flight and Space Technology

Space Shuttle

The Space Shuttle's primary purpose in FY 1994 continued to be transporting people and cargo safely into low-Earth orbit (100 to 350 nautical miles above the Earth). As of the end of the year, NASA had four active **orbiters** in its fleet: Columbia, Discovery, Atlantis, and Endeavour. During FY 1994, Atlantis completed its Orbiter Maintenance Down Period (OMDP) in the Orbiter Facility in Palmdale, California. During OMDP, Atlantis was outfitted with the modifications necessary to dock with the Russian Mir space station, with the first docking mission scheduled for the third quarter of FY 1995. As the year ended, the orbiter Columbia was being prepared for delivery to Palmdale for an OMDP.

During the year, NASA initiated a redesign of the **external tank** for structural weight reduction, which will improving the performance of the Shuttle system. The redesign involved substitution of aluminum lithium for the existing aluminum alloy, thus taking advantage of the greater strength per unit of weight characteristic of the new material. The first launch of the resultant super lightweight tank will be in late calendar year 1997.

The **Space Shuttle Main Engine** program aggressively pursued the development and implementation of safety and reliability improvements in FY 1994. In the current engine, five major components were in the process of being upgraded in two block changes. Block I incorporates the new phase II+ powerhead, the single-coil heat-exchanger, and the alternate high-pressure oxidizer turbopump. Block II contains the Block I improvements and adds the alternate high pressure fuel turbopump and the large throat main combustion chamber. Engineers conducted 101 ground tests in FY 1994 for a total of 47,775 seconds in support of the development and current flight programs. To date, the oxidizer turbopump has satisfied its requirements for total development seconds, and the first of two formal certification units has successfully completed its 20 test series. The first Block I certification engine, which contained the second oxidizer turbopump certification unit, began testing in October 1994. As of the end of the fiscal year, Block I was scheduled for its first flight in June 1995. Engineers involved in the oxidizer turbopump development successfully resolved all of the major technical problems encountered early in development. Due in large part to this success, Congress approved the resumption of development work on the fuel turbopump, which had been in caretaker status since 1991. Development testing of the fuel turbopump was under way at the end of the fiscal year, and the Block II configuration was scheduled to enter service in September 1997. The Space Shuttle Main Engine program has also been pursuing performance-enhancing changes in engine operation for Block II—part of the overall Shuttle performance enhancement program to support Space Station objectives.

The **Solid Rocket Booster** successfully supported the eight Shuttle flights begun during FY 1994. There was one static test firing of a heavily instrumented flight support motor. Efforts began to transition Redesigned Solid Rocket Motor nozzle production from Utah to the former Advanced Solid Rocket Motor site in northeast Mississippi. The elimination of ozone-depleting substances in booster manufacturing continued. Engineers have been developing two performance enhancements related to the booster as part of the overall Shuttle performance enhancement program to support Space Station objectives. A motor nozzle exit cone extension will increase the vacuum-specific impulse of the motor. The lightweight booster program will replace the current nylon parachutes with kevlar versions and will include minor structural weight reductions.

In the area of **Space Shuttle Systems Integration**, the Day-of-Launch I-Load-Update (DOLILU I) system was available for all FY 1994 missions. The system updates the flight trajectory to account for the actual winds on the day of launch. The DOLILU II system, which will incorporate the main engine control tables, solid rocket trim data, and aerodynamic control data on the day of launch, will further optimize the ascent trajectory of the Shuttle. NASA expected the first flight using this improvement to occur in May 1995. Integration efforts during FY 1994 also included analyses of structural loads; resolution of in-flight anomalies, waivers, and changes; and software development and testing for the control of each mission. To support the international Space Station mission requirements, NASA has initiated efforts to identify, develop, and baseline Shuttle performance enhancements. Engineers have developed systems integration plans to ensure their orderly implementation into the Space Shuttle program. Analyses were under way at the end of the year to ensure the compatibility of design modifications to the external tank, main engine, solid rocket boosters, and the orbiter itself. Engineers have specified design analyses and test requirements to provide definition of flight margins. All of the enhancements have been specified in support of the first international Space Station assembly flight scheduled for December 1997.

During 1994, the **Space Shuttle ground processing team** at KSC achieved several innovations and enhancements that increased efficiency, improved scheduling, and reduced costs. A reliability-centered maintenance program continually adjusted procedures based on actual performance data and operational experience. An integrated work control system, still under development, has already streamlined and automated work control functions related to more than 10,000 major tasks performed in preparing an orbiter's 22 major systems for flight. It has prestaged work packages, provided automated notification of needs for parts and material, and thereby reduced the number of tasks experiencing holds. Another improvement in ground processing involves selecting a team leader from a work unit, training him or her, and defining the responsibilities and authority for processing tasks from planning to completion. This enables problems to be resolved at the lowest operational level while providing structure and cohesiveness to the effort. The task team leader concept has enhanced Shuttle processing, facilitated teamwork, minimized delays, and improved quality. More than 4,400 NASA and contractor personnel have received training in this concept, which has been employed successfully in all areas of the operation.

Single Stage Rocket Technology (SSRT)

The BMDO remained the contracting agent for the SSRT program with the objective of demonstrating aircraft-like operations and supportability for future **Single-Stage-To-Orbit** (SSTO) launch vehicles, as well as relevant vehicle maneuvers scalable to a prototype vertical take off/vertical landing, SSTO vehicle. If successfully developed, such a vehicle could reduce the cost of launching payloads by an order of magnitude. McDonnell Douglas' Delta Clipper-Experimental (DC-X) has become the first working, one-third scale demonstration vehicle for this concept. Congress allocated $40 million in FY 1994 funds for reusable rocket technologies, of which $5.1 million were identified for completing the DC-X flight series (flights 4-8). The fourth flight occurred on June 20, 1994, at White Sands Missile Range. It demonstrated 100-percent engine thrust for the first time, use of the radar altimeter in the vertical control loop, and a relatively constant translation vehicle movement of 70 degrees relative to the ground. On the fifth flight test 7 days later, a hydrogen explosion outside the vehicle at liftoff ripped a hole in the aeroshell, causing an unplanned demonstration of the DC-X's auto-land mode. The vehicle successfully landed after 78 seconds of flight time and an achieved altitude of 2,600 feet. The explosion was due to vented hydrogen collecting near the vehicle. A modification to ground systems will prevent the recurrence of this problem. Funding to complete the flight tests was reallocated to repairing the vehicle. The DC-X was shipped back to the McDonnell Douglas facility in Huntington Beach, California, where the aeroshell and several other subsystems were being repaired as the fiscal year ended. The vehicle was expected to be repaired by the end of November 1994 and ready for reflight soon thereafter. Congress has directed that funding be allocated to cover the remaining flight test program. The DC-X is expected to be transferred to the Air Force's Phillips Laboratory from the BMDO in January 1995 for completion of the DC-X flight series. Ultimately, NASA will inherit the program and has indicated a keen interest in completing the flight test program to demonstrate low-and high-altitude rotation maneuvers necessary for reentry of a prototype vertical take off/vertical landing SSTO vehicle. This rotation maneuver data, as well as additional information gained on vehicle ground operations and supportability, will be used by NASA (with the DoD in a supporting role) in selecting a candidate concept for the advanced technology demonstration for reusable rocket technology.

In this connection, during FY's 1993 and 1994 NASA conducted a comprehensive in-house study of alternative approaches for ensuring **access to space** in the 2000 to 2030 timeframe. The goal was to reduce the cost of access to space and to increase the reliability and operability of the launch systems. More specifically, the study sought to identify the best vehicles and architectures to make major reductions in the cost of space transportation (at least 50 percent), while increasing safety for crews by at least an order of magnitude. The study concluded that the preferred option was to develop and deploy a fully reusable, SSTO pure rocket launch fleet incorporating advanced technologies. This class of vehicle had by far the lowest annual operating costs and lowest life-cycle costs of all options (including upgrading the Space Shuttle and ELV's). Relatively recent advances in technology make such a vehicle feasible and practical in the near term, assuming those technologies mature and are demonstrated before vehicle development begins. The study recommended a new vehicle as a NASA goal because it would result in an 80-percent reduction in annual and single-flight costs as well as provide a highly reliable, safe, and operationally efficient capability. Major changes in acquisitions and operations practices as well as Agency culture would be necessary for realizing these economies. The recommendations of this study contributed to the National Space Transportation Policy crafted by the Office of Science and Technology Policy (OSTP), signed by the President, and issued on August 5, 1994 (see appendix F-6 of this report). The policy assigns NASA lead responsibility to pursue the development of reusable launch vehicles, such as the SSTO concept, with a decision on whether to proceed with a large-scale flight test vehicle to be made by December 1996.

Other Launch Systems

ARPA's space launch activities expanded significantly in FY 1994 in response to congressional interest in alternative and innovative approaches to development and demonstration of directed technologies. ARPA funding, for example, went to the BMDO for the DC-X flight tests. Two ARPA programs were for Reusable Space Launch Technologies and Innovative Space Technologies Development. In both programs, ARPA planned to exploit the identification, development, and demonstration of technologies primarily available from industry through the use of Broad Area Announcement solicitations. These permitted ARPA to use the full array of its contractual options and provided a means to accommodate the personnel skills and unique facilities of Government laboratories, such as the Air Force's Phillips Laboratory (New Mexico), which used ARPA funding to support competitive advanced propulsion systems.

The **Inertial Upper Stage** (IUS) continued to be the most accurate upper stage in the Air Force inventory. The Air Force has used the IUS to deliver the DSP spacecraft from low-Earth orbit at about 150 nautical miles, after two different burns of the IUS solid stages, to geosynchronous orbit at more than 22,000 nautical miles. The Air Force plans for the IUS to continue to support the DSP into the next century. Additionally, NASA and Boeing entered into a separate production contract for one additional IUS in support of NASA's Advanced X-ray Astrophysics Facility (AXAF) to be launched around the end of the century.

The **Taurus** standard small launch vehicle, developed by Orbital Sciences Corporation and ARPA, was successful on its maiden mission from Vandenberg AFB on March 13, 1994. This first Taurus launch flawlessly placed two advanced technology satellites, the Air Force STEP-0, also referred to as STEP-TAOS (Technology for Autonomous Operational Survivability), and ARPA's own DARPASAT (referring to ARPA's former name as the Defense Advanced Research Project Agency), into a 290-nautical-mile, 105-degree-inclination orbit. The Taurus launch vehicle capitalized on ARPA's previous investment in the Pegasus air-launched vehicle to produce a fully transportable, ground-launched rocket capable of providing rapid, affordable access to space for moderate-sized satellites. Taurus is a four-stage, solid propellant, inertially guided rocket consisting of a Peacekeeper first stage motor and modified Pegasus motors for the upper three stages. With ARPA providing only a 38-foot square cement pad, the Taurus program demonstrated the ability to establish a launch site, integrate the launch vehicle and payloads, and conduct countdown operations in 200 work hours using a crew of about 30 people without any support from a permanent infrastructure.

Satellites

The 400-pound **DARPASAT**—developed by Ball Aerospace Corporation for ARPA and launched on March 13, 1994—underwent demonstration operations during the rest of the fiscal year, successfully performing its classified mission in support of worldwide deployed, joint military forces. The goals of the DARPASAT program during its 3-year mission are to demonstrate a low-cost, classified space capability, validate advanced technologies, and assess the operational utility of direct user tasking and collection of payload data. The successful launch of Taurus and demonstration of DARPASAT mark the culmination of ARPA's advanced space technology program. Over the past 4 years, ARPA had developed technologies aimed at achieving affordable production, launch, and operation of future DoD civil and commercial satellites and launch systems.

With the launch of two **Navstar Global Positioning System satellites** into orbit on October 26, 1993, and March 9, 1994, the Air Force completed the 24-satellite GPS constellation. Already in December 1993, the Secretary of Defense declared that initial operational capability had been achieved for civil use of the Air Force-managed GPS. The

October and March launch of Block IIA satellites provided the required assets available for declaration of full military operational capability. Initial operational testing and evaluation of the full constellation was wrapping up at the end of the fiscal year and an actual declaration of full military operational capability was on track for the second quarter of FY 1995. Meanwhile, the FAA certified various types of GPS receivers for use in all phases of flight, including nonprecision approaches. On June 30, 1994, the FAA approved the first GPS nonprecision approach procedure for use by helicopters. In another milestone, on July 16, 1994, FAA Administrator David Hinson and Aircraft Owners and Pilots Association President Phil Boyer landed at the Frederick, Maryland, airport using the first FAA-approved public "stand-alone" GPS instrument approach for aircraft. The agency also issued specifications for manufacturers that wish to build GPS receivers for Category I precision approaches, which involve a runway visual range of not less than 1,800 feet. The FAA continued to work with NASA to use GPS to satisfy Category II and III precision approach requirements, for use in conditions of more limited visibility than Category I. In addition, the FAA issued a Request For Proposals (RFP) for a wide area augmentation system, a network of ground stations and communications systems that will enhance the integrity and availability of GPS signals. The RFP is for a 6-year contract to develop an initial system of 24 ground reference stations and ground and satellite communications systems. Also during the fiscal year, the FAA worked with the International Civil Aviation Organization (ICAO) to promote the benefits of a worldwide Global Navigation Satellite System.

In related developments, the Department of the Interior (DoI) signed a memorandum of understanding with the DoD in 1994 that permits the DoI to use the **Navstar GPS Precise Positioning Service**. This agreement will provide more accurate, real-time, on-the-ground geographic location information (accurate to approximately 10 meters horizontally) than was previously available to DoI field personnel in support of mapping, inventory, monitoring, and research activities related to natural and cultural resources. The agreement permits DoI users to purchase and use precision, lightweight GPS receivers to access the encrypted DoD code for GPS data. The staff of the National Biological Survey is supporting this activity, working through the Interior Geographic Data Committee Remote Sensing Working Group, which coordinates remote sensing and GPS activities within the DoI.

The **Defense Support Program** (DSP) provided a highly available, survivable, space-based surveillance system to detect and report missile and space launches as well as nuclear detonations in near real time for the National Command Authorities and theater commanders. The most recent launch on May 3, 1994, of the 17th DSP satellite will provide the DoD with enhanced missile warning and surveillance capabilities. The DSP system consists of a constellation of satellites in geostationary orbits, fixed and mobile ground processing stations, one multipurpose facility, and a ground communications network. In this connection, the Army's Joint Tactical Ground Station (JTAGS) program supports the Theater Missile Defense architecture by providing timely reports on tactical ballistic missile launches. It does this by processing in-theater, infrared data downlinked directly from DSP sensors to the theater commander, resolving a major deficiency identified in Operation Desert Storm. The ability of JTAGS to process and disseminate data within theater minimizes the risk of single-point operation failures, provides improved reporting time lines, and minimizes the loading on high-priority communications links between the Continental United States and the theater user. The JTAGS system is scheduled for fielding during 1996-1997. (For the most recent follow-on program to DSP, see below under Brilliant Eyes and SBIRS [Space-Based Infrared Systems] in the glossary.)

The highly successful NRL and BMDO effort to launch the **Clementine Deep Space Probe** in January from Vandenberg AFB had as its primary mission the testing in space of 23 advanced technologies for high-tech, lightweight missile defense. The newly developed Clementine hardware—none of it dating back before 1990—included a common-pressure-vessel nickel hydrogen (NiH_2) battery; lightweight imaging sensors; a high-capacity, solid-state data recorder; lightweight inertial measurement units; solar cells; momentum wheels; a reduced-information-set computer for onboard processing; composite materials; new near-infrared, long-wavelength infrared, ultraviolet-visible, and high-resolution imaging sensors; two startrackers; a laser altimeter; and software language. The testing of these technologies for possible use in BMDO sensors and interceptors used the Moon as a "target." In addition, Clementine's interstage adaptor included several new CMOS (Complimentary Metal Oxide Semiconductor) electronic chips and advanced sensor materials for radiation testing. Clementine's secondary mission to perform an asteroid flyby of Geographos was canceled in May 1994 because of a software error on the satellite that resulted in the loss of the entire propellant store of the attitude control system. The new technologies onboard Clementine continued to function as designed, although communications were lost in July 1994 because of battery depletion as the satellite turned away from the Sun. Mission operators expect the link to be restored in January 1995 as the solar arrays again assume a position permitting recharge of the batteries. Meanwhile, Clementine remained in orbit around the Earth, constituting a major revolution in spacecraft management and design. Conceived, built, and launched in 22 months, it cost only $55 million for the spacecraft, $19 million for the launch vehicle (a Titan IIG), and $6 million more for launch operations—a total of roughly $80 million.

The **STEP-TAOS satellite** launched on March 13, 1994, from Vandenberg AFB, California, was demonstrating and validating state-of-the-art spacecraft technologies to ensure autonomy and survivability in an operational space environment as the fiscal year ended. Future spacecraft using this technology will experience decreased dependence on ground control and communication sites and autonomous spacecraft guidance, control, and navigation. The satellite continued to function successfully as the fiscal year ended.

The **STEP-2 satellite**, launched from Edwards AFB on May 19, 1994, identified and detected unique transmissions in a special environment, crowded with signals. The purpose of this effort was to evaluate unusual detection techniques so as to separate adjacent, overlapping cochannel communications transmitted at a low signal level. The need for this technology is especially great where deliberate cochannel programmer interference is present. Like STEP-TAOS, STEP-2 was operating successfully at the end of the fiscal year.

Another successful satellite program for the DoD was **Miniature Sensor Technology Integration** (MSTI), with the Air Force's Phillips Laboratory serving as the execution agent for the BMDO in implementing it. MSTI's goals include proving miniaturized sensor and seeker technologies to support low-Earth-orbit satellite and other platform applications for ballistic missile launch detection and dual use for environmental/ecological monitoring. The launch of the second MSTI satellite (MSTI-2)—by the last Scout rocket on May 8, 1994—into a 425-kilometer, Sun-synchronous orbit led to highly successful performance until September 5, 1994, when an apparent transmitter failure left the satellite unable to communicate. During the 4 months of its planned 6-month operational lifetime, the satellite's short- and mid-wave infrared sensors collected more than 3 million images that were still undergoing analysis at the end of the fiscal year. MSTI-2 also participated in ballistic missile defense tracking exercises and proved the concept of relaying on-orbit missile tracking directly and in real time to a U.S. Navy cruiser, the U.S.S. *R. K. Turner*. MSTI-2 imagery also contributed to dual-use efforts—in particular, studies of volcanic activity in Chile in conjunction with the Smithsonian Institution's Global Vulcanism Network. As the fiscal year ended, the imagery was being analyzed to determine the phenomenology of infrared-background clutter in support of future, space-based infrared sensors for viewing the Earth—especially those to detect ballistic missile launches. MSTI-1 and -2 have proven the concept of the common, highly capable spacecraft bus. MSTI-3, with its bus built by Spectrum Astro and its payload by Science Applications International Corporation, has been transferred to the Air Force Space and Missile Center, Los Angeles, California, and was scheduled for launch in late 1995 or early 1996.

The BMDO's **Midcourse Space Experiment** (MSX) program completed final assembly of the MSX satellite by Johns Hopkins University's Applied Physics Laboratory (JHU/APL) in June 1994. The principal purpose of the satellite will be to collect phenomenological data in support of ballistic missile defense objectives. The five instruments on the satellite—an infrared imaging radiometer and spectrometer built by the Space Dynamics Laboratory of Utah State University; four ultraviolet and visible and five spectrographic imagers built by JHU/APL; a space-based visible surveillance camera constructed by Lincoln Laboratory at the Massachusetts Institute of Technology (MIT); an onboard signal and data processor from Hughes Aircraft; and semiconductor devices for monitoring radiation effects from Hughes—will not only collect several terabytes of high-quality data on ballistic missile-type targets and other objects in space but will also serve as a potential collector of data on a variety of civilian scientific objectives in atmospheric remote sensing and astronomy, including measurements of the ozone layer and greenhouse gases. As a result, NASA scientists have been active participants in planning the MSX's experiments, a process nearing completion at the end of the fiscal year. Goddard Space Flight Center, in Greenbelt, Maryland, carried out the successful thermovacuum, acoustic, and pyroshock testing of the satellite, and it was shipped in September to Vandenberg AFB, California, for a projected launch by a McDonnell Douglas commercial Delta II in early 1995.

On June 17, 1994, an Ariane 44LP launched BMDO experiments onboard two microsatellites—**Space Technology Research Vehicle-1A and -1B**—developed by the Defense Research Agency of the United Kingdom. (STRV-1A and -1B were secondary payloads on a mission to launch INTELSAT 702.) The experiments performed well, with data from an adaptive-structures vibration-suppression experiment showing that this technology could reduce the motion of critical sensors by a factor of 100 in space, equalling ground laboratory test results. This positive result generated considerable interest from scientists and engineers who require highly stable platforms for space experiments and platforms. A radiation monitor experiment has been gathering data on levels of radiation encountered by the spacecraft as it traverses the Earth's trapped radiation belts. These data will be correlated with data obtained by other radiation sensors on both microsatellites. The performance of the neural network and silicon infrared sensor was being monitored as the radiation dose it received was increasing.

In an unrelated development, on May 5, 1994, the White House announced that, on the recommendation of the President's National Performance Review, NOAA was joining with NASA and the DoD to effect the **convergence** of civil and military Polar-orbiting Operational Environmental Satellite (POES) systems into a single operational program (see appendix F-3). Specifically, the systems converged were the DoD's follow-on DMSP Block-6 and NOAA's follow-on O/P/Q satellites, with the first converged spacecraft planned for launch in the 2006 timeframe. The program will employ an integrated management approach, whereby each agency will provide the expertise for a lead role in one or more of four functional areas, and technical personnel will form triagency teams performing each function. Under the directive, NOAA has lead agency responsibility to a triagency executive committee for the converged system, for supporting the Integrated Program Office (IPO) for satellite operations, and for relations with national and international civilian users of the system. The DoD has lead agency responsibility to support the IPO for the program's acquisitions and launch and systems integration. NASA has lead agency responsibility to support the IPO in facilitating the development and incorporation of new, cost-effective technologies that will enhance the capabilities of the converged system. The new system is expected to reduce duplication of efforts in meeting common requirements while satisfying the unique requirements of the civil and national security communities. The converged system will continue the open distribution of environmental data and accommodate international cooperation. Key European partners—the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT), with involvement as appropriate of ESA—have been invited to consider a joint polar system taking into account, on the U.S. side, the converged U.S. system. This complements longstanding plans by NOAA and EUMETSAT to exchange instrumentation for flight on meteorological operational satellites.

Meanwhile, following the loss of Landsat-6 in October 1993, NOAA continued to rely on Landsat-5, in operation since 1984. The **Landsat** series has provided regular observations of the surface of the Earth for two decades, monitoring renewable and nonrenewable resources. Landsat data applications support programs such as global change research, coastal zone monitoring, timber management, regional planning, and environmental monitoring. On May 10, 1994, the White House announced the Landsat Remote Sensing Strategy (see appendix F-4), which provides for continuity of existing Landsat and future Landsat-type data. The strategy assigned Landsat-7 program responsibilities jointly to NASA, NOAA, and the DoI (USGS). NASA assumed the satellite-development responsibilities for Landsat-7 from the DoD. NASA and NOAA will jointly develop the ground system, which NOAA will operate in cooperation with the USGS. The Earth Resources Observation System (EROS) Data Center of the USGS will continue to be responsible for maintaining Government archives of Landsat and other land-related remote-sensing data. Landsat-7, planned for launch in December 1998, will carry an improved Enhanced Thematic Mapper (ETM-Plus).

The successful April 13, 1994, launch of Geostationary Operational Environmental Satellite (GOES)-I, renamed **GOES-8** once it achieved orbit, resulted in more precise and timely weather observation and provision of data on the atmosphere. Its design, featuring three-axis stabilization, permits the satellite's sensors to observe the Earth continuously, compared to only 5 percent of the time for current spin-stabilized satellites. The first in a series of five advanced weather satellites to be launched over the next several years, GOES-8 was checked out and fine-tuned by NASA for 6 months after launch. Thus, NOAA did not obtain control over the satellite until after the end of the fiscal year. During checkout, the satellite was positioned at longitude 90° W., but plans called for it to be moved to longitude 75° W. once it became operational and for GOES-7, still operational seven years after launch, to move from longitude 112° W. to longitude 135° W. so the two satellites together could provide continuous coverage of the Western Hemisphere. NASA, which procures launches and check-outs for the GOES series of satellites and manages their design, development, and launch, planned to launch GOES-J in 1995 to replace GOES-7, which has already exceeded its expected lifetime. NOAA is responsible for the operations, including command and control, data receipt, and product generation and distribution for the satellites.

In a totally different area, NOAA announced at the beginning of the calendar year that two new ground stations had been added to the network of satellite search and rescue facilities throughout the United States. Located in Guam and Puerto Rico, they were the final of six new, fully automated installations designed to upgrade the satellite search and rescue system, which helps to bring emergency assistance to mariners, ground-based users, and pilots in distress. The stations and four others installed in the United States over the preceding year and a half are part of an international satellite search and rescue system known as **COSPAS-SARSAT** (from a Russian acronym meaning Space System for Search of Vessels in Distress and an English one for Search and Rescue Satellite-Aided Tracking System). The system enables distress signals from ships or airplanes to be received and processed more quickly than before. It uses a total of six NOAA environmental satellites and Russian navigational satellites, plus a network of ground stations to pick up radio and beacon signals from the distressed individuals and send them via mission control centers such as NOAA's in Suitland, Maryland, to rescue coordination centers. Since the inception of the system in 1982, a total of 4,310 lives had been saved as of September 30, 1994--960 of them during calendar year 1993.

The Small Expendable Tether Deployable System-2 (**SEDS-2**), conceived and designed by the SAO, was a secondary payload on a Delta II rocket launched at 10:40 p.m. EST on March 9, 1994, from Cape Canaveral AFS, Florida. At a length of nearly 20 kilometers, it was the longest object ever placed in space. At 11:45 p.m., the Delta's second stage ejected the 23-kilogram SEDS-2, using a spring-loaded device. The minisatellite reached a final deployed length of 19.8 kilometers in just 1 hour 48 minutes, achieving the primary purpose of the experiment, to suspend such a payload with a minimum of swing. Thereafter, SEDS-2 remained in space to determine the resistance of its braided polyethelene to micrometeoroids, space debris, and atomic oxygen. The tether apparently was severed by a micrometeoroid (or debris) on March 15. Thereafter, the end of the tether reentered the upper atmosphere and burned, while about 10 to 12 kilometers of its length remained attached to the rocket's second stage and continued orbiting until May 8, 1994. This marked the third SAO-developed tether launched within the past year, each on time and with an increasingly ambitious goal.

One of the Department of Energy's responsibilities is providing **spaceborne sensors** to scan for above-ground (and above-water) nuclear explosions. Such sensors, aboard GPS and DSP satellites, verify nations' compliance with nuclear test ban treaties, monitor nuclear proliferation, and meet military needs in the event of a nuclear attack. These specialized sensors satisfy national requirements for detection, identification, location, and characterization of nuclear detonations anywhere within the Earth's atmosphere or in near-Earth space. From its beginnings in the 1960's, this program has been a joint effort of the DoE and the DoD. Development, design, and production of the instrumentation for detecting nuclear explosions are the responsibility of the DoE, while the rest of the satellite hardware, launch, telemetry, and day-to-day operations are the responsibilities of the DoD, which also has the overall coordination and scheduling role. The DoD and the DoE have shared in special operations and in the use and interpretation of data.

Los Alamos National Laboratory's **Blackbeard radio frequency experiment**, piggybacked aboard the ALEXIS satellite launched last year, is continuing to monitor mysterious twin-pulsed radio bursts. The bursts mimic emissions from nuclear detonations. Los Alamos stated that these events are associated with thunderstorms but not caused by lightning. Los Alamos has set up two ground stations on its premises to attempt to record the events at the same time that the Blackbeard equipment does.

Space Station

Fiscal year 1994 was a time of tremendous accomplishment for the **international Space Station** program. In October 1993, the program formally developed an initial set of specifications, including Russian elements as part of the design. In December 1993, the original 12 participating nations in Space Station Freedom (the United States, Canada, Italy, Belgium, The Netherlands, Denmark, Norway, France, Spain, Germany, United Kingdom, and Japan) extended an official invitation to Russia to join the partnership, and

Russia accepted. The existing Shuttle/Mir program was then expanded and made Phase I of the international Space Station program. In February 1994, the Phase I activity officially began when Sergei Krikalev became the first Russian to fly on the Space Shuttle. NASA astronauts Bonnie Dunbar and Norm Thagard have been training to fly on the Mir space station since March 1994 at the Russian Cosmonaut Training Center in Star City. The first American was scheduled to be launched on a Russian spacecraft to Mir in March 1995. All of the international Space Station program partners took part in a successful systems design review at Johnson Space Center (JSC), Texas, in March 1994. On June 23, 1994, NASA Administrator Daniel S. Goldin and Russian Space Agency (RSA) Director General Yuri N. Koptev signed a NASA/RSA interim agreement on Space Station and a $400 million contract. The agreement permits Russian participation in joint program management bodies, and the contract covers Russian provision of hardware and data in the program's early phases (primarily for Shuttle-Mir activities). Additionally, on August 31, 1994, NASA and the Boeing Company signed a memorandum of agreement that defined the content and maximum cost of the prime contract, scheduled for signature by late 1994. Also during August, the program completed a vehicle architecture review. Finally, on September 28, 1994, the Space Station Control Board examined the vehicle architecture review and ratified its recommended modifications to the assembly sequence and element requirements for the Space Station.

The **redesign of the Space Station** that resulted from these activities preserved the best of the previous Space Station Freedom program's hardware and capability, while adding increased research capability and user flexibility. The new international Space Station costs $5 billion less than Freedom. It has adopted a streamlined management structure and significantly reduced the number of civil service personnel and contractors assigned to the program. It includes an integrated product team approach, using the skills of the civil service workforce to develop a number of Station elements more economically and efficiently, saving millions of dollars in the process. Furthermore, Russian cooperation has added greater capability to the international Space Station and further reduced U.S. costs, making the Station an important aspect in the new and evolving relationship between the two countries. To date, the program has produced 26,700 pounds of Space Station hardware—almost 2,000 pounds more than projected. There has been a number of successful technical interchange meetings with the Russians, and Russia has begun delivery of items called for in the contract signed in June. Before the end of the fiscal year, a NASA liaison team was in place in Moscow, and NASA was working with the Russians to get their liaison office established in Houston. At a technical interchange meeting in August 1994, NASA and RSA agreed on a number of important integration and operations issues, such as how command and control orders would be sent to the Space Station. Joint management team discussions in Moscow the following month continued and expanded these efforts, resulting in agreement on matters necessary for working together, such as the use of English as the common language.

Meanwhile, the new Canadian government recently reaffirmed support for the international Space Station. Canada has been restructuring government spending to reduce its debt. In the face of difficult budget decisions, the Canadian government has continued to recognize its responsibility for developing the Mobile Servicing System, which will provide external Space Station robotics. Canada also planned to develop the Special Purpose Dexterous Manipulator for more delicate robotic operations. ESA has continued to develop the Columbus Orbital Facility (COF—a pressurized laboratory) and laboratory support equipment for early scientific use. ESA has also been developing the Ariane V launch vehicle and associated transfer vehicles; as FY 1994 ended, it was involved in discussions with NASA on a possible role for these vehicles in Space Station logistics resupply. ESA conducted a design-to-cost exercise on the COF, coordinating the technical and management changes closely with NASA. The Europeans have expressed interest in examining the possibilities for providing a crew rescue vehicle and also an automated transfer vehicle, which would provide propellant resupply and reboost. Japan has been developing the Japanese Experiment Module (JEM), consisting of a multipurpose pressurized laboratory element, an unpressurized exposed facility, a remote manipulator system, and experiments logistics modules. Japan's Space Station program has been making steady progress, with 63 percent of its development funds contracted out.

Energy

To date, the United States has successfully employed **37 Radioisotope Thermoelectric Generators** (RTG's) on more than 20 spacecraft launches. An RTG is a device without moving parts that converts the heat from the decay of the radioisotope Plutonium-238 (Pu-238) into electricity. RTG's have shown the flexibility and ability to operate beyond specified mission lifetimes demanded by a variety of space missions. For instance, the multihundred-watt RTG on the Voyager 2 spacecraft, launched in 1977, has continued to operate as it has traveled beyond Neptune into space. The DoE has developed a new model RTG with a more efficient fuel design called the General Purpose Heat Source (GPHS). The GPHS-RTG operated successfully on the Galileo and Ulysses missions, launched in 1989 and 1990, respectively. DoE program activities in 1994 focused on production of both GPHS components and GPHS-RTG thermoelectric converters to meet the requirements for power of the Cassini mission to Saturn, scheduled for a 1997 launch. The Savannah River Plant in South Carolina processed the majority of the Pu-238 needed to fuel the three new RTG's. In 1994, Oak Ridge National Laboratory in Tennessee completed production of all the iridium parts that will be used to encapsulate the Pu-238 fuel. Los Alamos National Laboratory, New Mexico, pressed the initial flight pellets of Pu-238 and welded these pellets into the iridium capsules. The agency will release the preliminary safety analysis report in late 1994. The Mound Plant of EG&G Mound Applied Technologies in Miamisburg, Ohio, was proceeding according to plan with RTG assembly preparation activities as the fiscal year ended. The prime system contractor, Martin Marietta Astrospace, completed the production of all thermoelectric elements for all three RTG's during the year, and fabrication activities on other portions of the RTG's remained on schedule. The DoE also developed new conceptual designs for smaller and lighter-weight RTG's for the Pluto Fast Flyby mission, whose specifications call for it to be powered by RTG's. Later in 1994, the DoE will issue a comprehensive report responding to a General Accounting Office inquiry regarding the long-term production capability of RTG's. DoE intends to retain its unique capabilities to provide special nuclear power sources for other agencies' needs.

The DoE has continued to pursue **advanced converter technologies** in support of other agency needs. In 1994, the DoE fabricated 6 special heat sources that will be used in a dynamic Stirling generator capable of producing 10 watts of electricity for several years. Successful testing of the Stirling generator with an electrically heated unit in 1994 demonstrated a system efficiency of more than 20 percent. This compares very favorably with the approximate 7 percent efficiency of the present RTG's. The DoE was also investigating the viability of the Thermo Photovoltaic (TPV) conversion technology as the year ended; TPV uses proven solar cell technology with a shift in spectrum. In 1994, engineering tests demonstrated an efficiency of 13 percent with existing hardware; hardware optimization is expected to result in efficiencies in the range of 20 percent or more.

The DoE supported the Air Force during FY 1994 in conducting preliminary assessments of concepts for space reactor systems that would produce both power and propulsion for spacecraft in the DoE/Air Force **Bimodal Power and Propulsion Program**. A primary objective of these preliminary assessments was to determine whether nuclear bimodal (power and propulsion) systems could satisfy requirements while enabling the launch of large payloads on smaller, less costly launch vehicles and at the same time increase maneuverability of the satellite on orbit. The Air Force determined that several nuclear bimodal system concepts may be feasible and during FY 1995 will generate preliminary conceptual designs for further evaluation. The DoE also supported the Air Force with some of its termination activities on the Space Nuclear Propulsion Program.

The **SP-100 Space Reactor Power System** program was terminated in FY 1994. Initiated in 1983 as a DoE, DoD, and NASA program to develop space reactor power in the 10's to 100's of kilowatts of electrical (kWe) power for emerging civil and military missions in the 1990's and the next century, the SP-100 featured a fast reactor design of high-temperature refractory niobium alloys with uranium nitride ceramic fuel. The reactor was to be cooled by a set of pumped liquid metal (lithium) loops to transport heat to solid-state thermoelectric-power conversion packages. The DoE archived data from the program in its Office of Science and Technical Information for future applications. In addition, the DoE and the JPL in California have initiated an effort to transfer to industry the technologies developed under the SP-100 program. A sampling of those technologies includes self-lubricating bearings, heat pipes, high-temperature electric motors, thermoelectric power converters, techniques for bonding brittle materials to metals, and a device to separate gases from liquids. More than 150 companies have shown an interest in applications, ranging from ball bearings for the Space Shuttle to electric motors for aircraft actuators and to the use of the gas-separator concept to remove gases from liquids in the manufacture of syrup for soft drinks.

Progress has continued on in-core **Thermionic Space Nuclear Power Systems**. The Thermionic Space Nuclear Power System Design and Technology Development program began in 1992 under the sponsor-ship of the DoE, the BMDO, and the Air Force's Phillips Laboratory. Funding constraints in 1994 limited progress to technical development of key technologies and critical components identified from early design efforts for a thermionic reactor system meeting mission requirements in the range of 5 to 40 kWe. Industrial contractors under this program have subcontracts with Russian entities that have allowed Russian expertise and facilities to be integrated into the 1994 activities of this program.

The Thermionic Fuel Element Verification Program (TFEVP) was terminated in FY 1994. During the year, TFEVP focused on closing out the program activities and completing final reports. The post-irradiation examinations of the TFE test articles and components will continue into FY 1995.

During 1994, the DoE sponsored a number of studies to assess how nuclear power and propulsion systems might enhance and reduce the cost of **space operations**. These studies included the evaluation of power options for high-power communications satellites; the potential of a reusable space tug to reduce the cost of space operations and increase the payload capabilities of existing launch vehicles; and the benefits that increased power could provide for outer-planet, robotic science missions. In FY 1994, the DoE also continued, at a limited level, nuclear studies to advance knowledge that might be required for future space and terrestrial nuclear power applications. Work to be accomplished next year under several awards issued by the DoE in 1994 includes technical research and testing of thermionic-related technologies and fuels, space reactor applications, and facility/ground-testing issues related to safety and environmental containment. A few of the grant awardees have subcontracts with Russian entities that will promote the transfer of Russian space-power technology to U.S. industry.

Safety and Mission Assurance

The eight successful and one aborted Shuttle launches during FY 1994 were all a testimony to NASA's safety procedures. The successful engine shutdown on the launch pad during the attempted launch of Endeavour on August 18, 1994, followed an engine temperature that exceeded the red-line launch commit criteria. Once the engine was replaced, Endeavour flew successfully on September 30. During the year, NASA also developed a model of the risk associated with the Shuttle systems and subsystems to determine which investments in new technology will bring the largest returns in terms of safety and reliability for Shuttle missions. More generally, NASA continued during FY 1994 to explore more efficient ways of assessing and managing risk, targeting specific areas of individual programs where the reward is greatest. The Agency applied this program in FY 1994 to the Small Satellite Technology Initiatives, identifying mission success criteria and ensuring that there was adequate definition of risks to performance, cost, and schedule. Workshops on the cost of quality have provided another tool for project managers to use in improving overall performance at reduced cost. NASA's Office of Safety and Mission Assurance has also been leading an Agency-wide evaluation of a National Performance Review reinvention laboratory, eliminating bureaucracy and empowering people to provide more effective reviews of safety, reliability, and quality assurance processes at the field installation level. NASA has also begun a transition to apply the 9000 series of generic quality management standards of the International Organization for Standardization to products from NASA's suppliers. Additionally, NASA established an independent assessment function at JSC in Houston for the international Space Station to ensure that safety, reliability, and quality assurance were being fully implemented. An assessment panel from major Centers, contractors, and international partner representatives was chartered and began meeting quarterly to this end.

In other areas, NASA assisted in the remediation of the earthquake on January 17, 1994, at Northridge, California. By coordinating the efforts of the Ames Research Center and its aerial surveillance aircraft (C-130 and ER-2) to collect and disseminate aerial photographs of the area around Northridge, the Agency was able to provide information to the Federal Emergency Management Agency that helped minimize the effects of the earthquake. Other safety efforts included a planned space flight demonstration of an interferometric, fiber optic gyroscope with improved reliability over mechanical systems; guidance and reference documentation in pyrotechnic devices, including a laser-initiated system to enhance launch vehicle safety; technology such as optically stimulated electron emission sensors and automatic optical scanners that provide early identification of defects; and advanced wiring systems for safe flight operations. NASA issued a new safety standard on an interim basis to incorporate software into the Agency's overall approach to safety engineering. Relatedly, the NASA Software Independent Verification and Validation Facility opened this year in West Virginia. There, software experts from NASA, industry, and the academic community began working to improve software processes for such projects as the international Space Station, remote sensing applications, and software reuse for NASA and the DoD.

Other Space Technology

Also during FY 1994, the BMDO's **Space and Missile Tracking System** (Brilliant Eyes) was slowed due to funding reductions (necessitating a restructuring of its contract) and because of a major DoD study that led to the combination of all nonimaging, space-based infrared systems into an integrated program known as SBIRS. While design progressed, there were performance tests of the system's focal-plane arrays; cryocoolers; critical sensor algorithms; sensor pointing, stabilization, and control algorithms; 32-bit processors and application-specific integrated circuits; communications; electrical power system; ground and space software; simulation; and sensor end-to-end demonstration. Other development work in conjunction with the Air Force Phillips Laboratory and the JPL included delivery and testing of cryocoolers from four contractors as well as successful space flight testing of a thermal storage unit.

During FY 1994, NASA made significant progress in measuring, modeling, and mitigating the **orbital-debris** environment. This completed the third year that the Haystack Orbital Debris Radar, operated for NASA by MIT's Lincoln Laboratory, has measured and monitored such debris. This powerful radar can detect debris as small as a pea orbiting 400 miles out in space. At low altitudes (250-400 miles), it measured less debris than predicted—good news for the international Space Station. However, at higher altitudes (500-650 miles), the debris population was greater than NASA had predicted. Because objects in higher orbits are not significantly affected by changes in solar activity, their lifetimes can exceed 1,000 years, meaning that they will not pose a hazard to the Space Station, but they are a threat to scientific, Earth observation, weather, and communications satellites. On February 9, 1994, the Orbital Debris Radar Calibration Spheres (ODERACS-1) were deployed from Space Shuttle Discovery. The purpose of these six spheres, ranging in diameter from 2 to 6 inches, is to improve the ability of ground-based radars to detect and track small debris objects. The spheres are expected to remain in orbit, providing valuable calibration data until mid-1995. NASA also developed a portable telescope that is capable of detecting objects as small as one-half inch in diameter at altitudes ranging from that of the Space Station (250-400 miles) through Sun-synchronous altitudes (500-650 miles) and objects as small as 2 to 4 inches at geosynchronous altitude (23,000 miles). This Liquid Metal Mirror Telescope (LMMT) concept is based on the research of Dr. E.F. Borra of Laval University in Quebec, Canada, in the area of liquid mercury mirrors. The prototype 10-foot-diameter LMMT now in operation at NASA's JSC is the 17th largest telescope in the world. It was built at a cost of about $500,000—1/100th the cost of comparable Earth-based astronomical telescopes. To reduce construction costs, NASA designed the LMMT to be housed in a grain silo purchased on the commercial market. Operational software costs were minimized by modifying software previously developed for JSC's Charge Coupled Device Debris Telescope.

In a somewhat related effort to forecast **space weather** and thus to assess the likelihood of damage to satellite components, scientists at Rice University developed sophisticated computer models to calculate the density and energy of particles at any point in space. They constructed maps similar to those used by meteorologists showing the flow of plasma in the ionosphere and the characteristics of ions and electrons precipitating into the atmosphere. Using high-time resolution, the scientists calculated the way in which the plasma flow changed in response to conditions in the solar wind. They displayed the results graphically as a movie. More than 50 scientists then carried out coordinated observational campaigns to validate the results of the model.

The Department of Commerce's (DoC's) National Institute of Standards and Technology (NIST) has applied its expertise in measurement science, developed through its mission to help industry with measurements, standards, and evaluated data, to assist NASA in 74 different project areas during the fiscal year. For example, NIST worked on a project to **measure critical point viscosity**. The object is to test the theory of transport properties of fluids very near the liquid-vapor critical point. To date, a definitive test of the theory has not been possible on the Earth because of the very weak divergence of the viscosity as the critical point is approached and because the approach to the critical point is limited by the Earth's gravity. Fluids within 4 percent of the critical density and 0.01 percent of the critical temperature are so compressible that the density near the bottom of a 1-mm-high sample exceeds the density near the top of the sample by 8 percent or more. In recent years, a series of viscometers were developed that achieve the necessary combination of low frequency (1-5 hertz), extremely low shear rate and fluid flow (0.1 to 1 s^{-1}), precise temperature control (0.1 millikelvin), and high-viscosity resolution (0.1 percent). Measurements have been completed near the critical points of xenon, carbon dioxide, four binary liquid mixtures of small molecules, polymer solutions, and microemulsions. The results of the NIST research have stimulated theoretical work to recalculate the exponent characterizing the divergence of the viscosity. NIST recently developed a new viscometer that not only meets the criteria mentioned above but will be able to do so in the vibrationally noisy environment of the Space Shuttle. On the Shuttle, gravity-induced stratification will be negligible, and meaningful measurements will be made to within 0.6 millikelvin of the critical temperature of xenon. In FY 1994, a novel, accurate calibration procedure based on hydrodynamic similarity was developed and tested successfully in the new viscometer. The design of the sample cell of the viscometer was improved, and NASA began construction of the flight apparatus, scheduled to be flown in 1997.

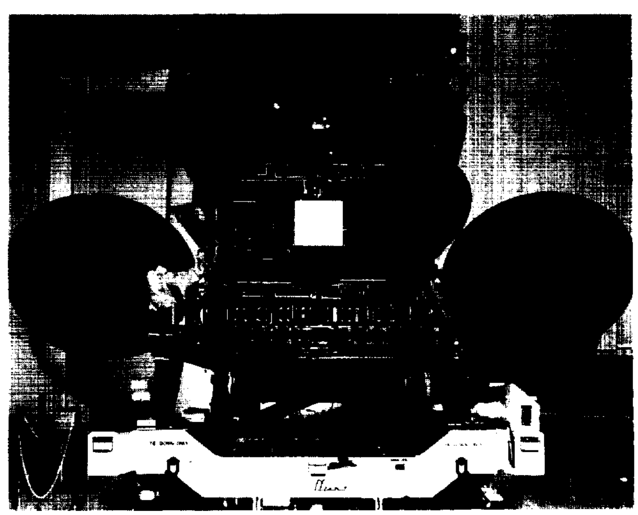
Another example of the projects NIST was working on for NASA during the fiscal year involved **materials processing**. During the directional solidification of a binary alloy, solute inhomogeneities can arise from both fluid flow and morphological instability. In microgravity, buoyancy-driven fluid flow is reduced, and experiments to study the evolution of morphological patterns without the interference of fluid flow may be possible. NIST researchers have performed calculations to predict fluid flows and evolution rates to aid in the planning and analysis of space flight experiments on these effects. Many semiconductors and some metals such as bismuth have highly anisotropic interface kinetics and solidify with faceted interfaces. In FY 1994, morphological stability theory has been extended to treat these anisotropic materials. Anisotropic kinetics give rise to traveling waves along the crystal-melt interface and can lead to a significant enhancement of morphological stability. The stability enhancement increases as the orientation approaches a singular orientation and as the solidification velocity increases, thus tending to produce homogeneous materials. Shear flows interact with the traveling waves and, depending on the direction of the flow, may either stabilize or destabilize the interface.

Space Communications

Communications Satellites

There were three new commercial **domestic fixed satellites** launched for the United States during FY 1994. Galaxy 1R(S), launched on February 19, 1994, will provide video services into the next decade. The satellite replaced another one that was nearing the end of its useful life; it is located at longitude 133° W. General Dynamics Commercial Launch Services successfully launched the Telstar 401 communications satellite from Cape Canaveral aboard an Atlas IIAS on December 15, 1993. The satellite completed systems checkout and in-orbit testing at longitude 89° W. in January 1994 and was then moved to longitude 97° W. to begin providing television and data communications services for U.S. customers in early February. Unfortunately, the September 9, 1994, launch of Telstar 402 by an Ariane launch vehicle from Kourou, French Guiana, was not as successful. The launch itself went fine, but operators lost contact with the satellite after it evidently began spinning as it passed over the Indian Ocean. Customers such as Fox Broadcasting and ABC will continue to use Telstar 401 until Telstar 403, redesignated Telstar 402R, is launched.

Two **other communications satellites** that were not in the domestic fixed category but did provide domestic service were the first Direct Broadcast Satellites (DBS's). Launched by an Ariane booster from Kourou, French Guiana, on December 17, 1993, DBS-1, as the satellite is designated by its co-owners, DirecTv and United States Satellite Broadcasting, offered some 75-80 channels of television service after April 1994 to U.S. subscribers or those purchasing the equipment necessary for reception. Located at longitude 101° W., the HS 601 satellite built by Hughes Space and Communications Company provided broadcasting to all of the contiguous 48 states. It was followed on August 3, 1994, by DBS-2, successfully launched from Cape Canaveral AFS



DBS-1 before assembly.

PanAmsSat's first Pacific Ocean satellite, the PAS-2, was launched on July 8, 1994. The FCC refers to this satellite as the PAS-4.

by a Martin Marietta Atlas IIA. It increased the number of channels available on the service to 150. Still another communications satellite placed into orbit during the fiscal year was PanAmSat's PAS-2—designated PAS-4 by the Federal Communications Commission (FCC). An Ariane 4 rocket launched it into space from Kourou, French Guiana, on July 8, 1994. The 2,920-kilogram satellite was built by Hughes Aircraft Company and became PanAmSat's first private international satellite for the Pacific Ocean region, providing television coverage from the Western United States to the Asian mainland. It marks the second of four satellites scheduled to constitute PanAmSat's Global Satellite System, begun with PAS-1 launched in June 1988 and providing services to the Atlantic Ocean Region. Also a Hughes HS 601 satellite, PAS-4 can carry more than 320 digital channels transmitted on 16 63-watt Ku-band and 16 34-watt C-band transponders.

For the military, the **Defense Satellite Communications System** (DSCS) continued to serve as the long-haul, high-capacity communications system supporting the worldwide command and control of the U.S. Armed Forces and other Government agencies. The DSCS program successfully launched a DSCS III satellite in November 1993; it was cut over to operational traffic in mid-1994 as a replacement for an older DSCS III. Six other DSCS III satellites in storage at the end of FY 1994 have been scheduled for launch between FY's 1995 and 2003. The DSCS control segment continued to provide semi-automated management of DSCS resources to maintain the satellite communications network in alignment with the needs of the operational commanders. As of the end of FY 1994, there were five DSCS operations centers and three auxiliary satellite control terminals operated and maintained by the U.S. Army Space Command worldwide. Proficient network management of DSCS space and ground resources enabled support of a wide variety of contingencies and high-priority requirements, including various Presidential trips and military activities in Bosnia.

The **Milstar** program, the cornerstone of the DoD's military satellite communications network, launched its first satellite in February 1994. Although the satellite was still undergoing on-orbit testing at the end of the fiscal year, when operational it will be a multichannel, extremely high frequency/ultra high frequency (EHF/UHF) satellite communications system providing survivable, enduring, and jam-resistant secure voice data communication for the Armed Forces and other users. The Air Force remained the lead service for procuring the Milstar satellites, a dispersed mission control network, airborne terminals, and ground command post terminals. The Army and Navy also continued to have programs for terminal development and procurement. Satellite number two was complete and in testing as the year ended. Satellite number three was being prepared for medium-data-rate payload.

The **Fleet Satellite Communications System** (FLTSATCOM) provided worldwide UHF satellite communications for the DoD and other agencies through a constellation composed of four Navy FLTSAT satellites, two Leased Satellites (LEASATs) that had been purchased by the Navy, and one still-leased LEASAT, all positioned in geosynchronous orbit at four locations around the Earth. The two newest FLTSAT spacecraft carry an EHF package added to their UHF payloads. This mixed FLTSAT/LEASAT constellation is being replaced by the UHF Follow-On satellites produced by Hughes Aircraft Company under contract with the Navy. The second UHF Follow-On satellite, launched on September 3, 1993, aboard a General Dynamics Commercial Launch Services Atlas-Centaur I ELV, began operational service over the Indian Ocean on December 3, 1993, thus achieving initial operational capability for the UHF Follow-On constellation. The third UHF Follow-On satellite launch, on June 24, 1994, was the first Atlas launch conducted by Martin Marietta following its purchase of the Atlas business from General Dynamics in March-April 1994. UHF Follow-On satellite number three began operational service over the Atlantic Ocean in October 1994. The 1994 Defense Appropriations Act authorized the Navy to use the $199 million in contract remedies from the failure of the first UHF Follow-On launch in March 1993 to fund the purchase and launch of a replacement satellite. With that purchase, a total of 10 UHF Follow-On satellites the will be produced, with satellites 4 through 10 incorporating both UHF and EHF communications capabilities.

The U.S. Army Space and Strategic Defense Command's **Space Applications Technology program** successfully demonstrated an ability to communicate at 128 kilobits per second (voice, data, and video) to and from a moving High Mobility Multipurpose Wheeled Vehicle (HMMWV), using NASA's Advanced Communications Technology Satellite (ACTS) and the JPL's ACTS mobile terminal. The mobile terminal's algorithms partially alleviated the impact of multipath and rain attenuation effects on communicating in the EHF frequencies. ACTS operates in the K/Ka bands (20/30 gigahertz) and will be used as a testbed to demonstrate and evaluate technologies and concepts suitable for application to Milstar 3 and Milstar 4. Follow-on efforts will attempt to increase the data rates to 1.5 milobits per second, and the testbed will also be used to identify and quantify requirements to influence future communications satellites. Also, analyses will identify performance degradation (if any) related to converting ACTS mobile terminal technologies to the lower-power Milstar wave form.

The International Telecommunications Satellite Organization (INTELSAT), a consortium established in 1964 and consisting (in September 1994) of 134 member nations that owned and operated the world's most extensive global communications satellite system with service in more than 200 countries and territories, successfully launched its **INTELSAT 701** satellite on October 22, 1993, aboard an Ariane 44LP rocket. The first in its series of high-powered INTELSAT VII spacecraft, INTELSAT 701 began commercial service on January 15, 1994, with the transfer of traffic from the INTELSAT 510 satellite launched in March 1985. Situated at longitude 174° E., the Space Systems/ Loral satellite began providing expanded telephone, television, and other services to INTELSAT customers in the Pacific Ocean region, including the west coast of North America, the islands in the Pacific, and the east coast of Asia. Most long-distance carriers of telephone service in North America and the Asia-Pacific region began using the new satellite, which handles 90,000 telephone calls at once versus the 75,000 transmitted by the 510 satellite. In addition, the 701 transmits three television channels at a time instead of the two channels transmitted by INTELSAT 501.

On June 17, 1994, INTELSAT successfully launched the second of nine VII-VII-A satellites ordered from Space Systems/Loral aboard an Ariane 44LP launch vehicle from Kourou, French Guiana. After moving from its in-orbit test location, **INTELSAT 702** began commercial service on August 13, 1994, at longitude 359° E., replacing the lower-capacity INTELSAT 512. Serving as the only direct one-hop communications link between the Indian subcontinent and America (North and South), INTELSAT 702 provides expanded communications services to INTELSAT's customers in Africa, Europe, the Indian subcontinent, the Middle East, the Eastern United States, and South America. The new satellite is the 50th that INTELSAT has launched; 22 of these remain in operation, providing customers such business services as international video, teleconferencing, facsimile, data, and telex.

The International Maritime Satellite Organization (**INMARSAT**), a London-based international entity with 75 member countries as the fiscal year ended, did not add to its complement of four INMARSAT II and seven older satellites providing mobile satellite communications in the air, on land, and at sea for almost 40,000 users of mobile terminals in more than 165 countries. Among the organization's accomplishments during the year was the world's first satellite voice connection to a cellular-sized phone, announced by INMARSAT in March 1994. The event occurred during trials for a future global handheld phone system to test the power margins needed to provide voice service between 1998 and 2000. Meanwhile, in September 1994, a London department store began selling the INMARSAT-M briefcase satellite telephone. The lid of the briefcase serves as the antenna for the telephone inside. Also during the year, the U.S. Communications Satellite (Comsat) Corporation, which holds (roughly) a 23-percent share in INMARSAT, opened a new station in Kuantan, Malaysia, on July 1, 1994. This new station plus existing ones in Santa Paula, California, and Southbury, Connecticut, made Comsat the first INMARSAT service provider to operate digital mobile satellite services around the globe.

Space Network

On November 29, 1993, NASA repositioned its first Tracking and Data Relay Satellite (TDRS-1), launched in 1983 and already serving beyond its 10-year lifetime, to recover scientific data from the Compton Gamma Ray Observatory (GRO), launched in 1991. A significant portion of the GRO data would otherwise have been lost because of the failure of a tape recorder on the spacecraft. NASA installed a highly automated ground terminal, **GRO Remote Terminal System** (GRTS), at its Deep Space Network location in Australia to control TDRS-1. This terminal is remotely operated from the TDRS System (TDRSS) ground stations in New Mexico. TDRS-1 started relaying data operationally on December 6, 1993, during the shift from its former to its new location, a year from project start. TDRS-1 was in position at longitude 85° E. over the Indian Ocean by February 7, 1994, and NASA declared GRTS to be operational on April 1, 1994, with a proficiency of over 97 percent. With TDRS-1 and GRTS, NASA has extended real-time data retrieval to the full orbit for the GRO, which is studying the evolution of the universe, the nature of puzzling astronomical objects, and the processes that produce very-high-energy radiation.

NASA has begun making TDRSS available to U.S. industry to conduct experiments and demonstrations of innovative satellite communications technologies and concepts free of charge. The intent of this **Mobile Satellite Communications via the TDRSS** (MOST) program is to enhance the competitiveness of the U.S. industry in the global satellite communications arena. TDRSS enables testing of lightweight, mobile, handheld satellite communication terminals in a variety of environmental conditions. Already, the tracking system has been used to demonstrate satellite broadcast of compact disk (CD)-quality radio to conduct measurements of path diversity for commercial mobile satellite communications. Applications of the technologies validated by MOST include, for example: listening to CD-quality radio while driving across the country; communicating by handheld, wireless devices anywhere in the world, no matter how remote; and communicating (by hikers) in remote areas during emergencies. The MOST activity does not interfere with the primary TDRSS mission of relaying commands to and data from scientific spacecraft.

Ground Networks

NASA uses ground-based telecommunications facilities to provide telemetry, command, and navigation services to a number of NASA, other U.S., and international spacecraft such as the Space Shuttle; other Earth-orbiting spacecraft; planetary orbiters; and international spacecraft. These spacecraft include the Space Shuttle and Earth orbiters, planetary orbiters such as Galileo and Magellan; and the Voyager and Pioneer spacecraft traveling to the outer reaches of our Solar System. Other uses of ground network facilities include tracking and data acquisition services to sounding rocket, high-altitude balloon, and aeronautical research missions. This worldwide capability has enabled mission operators to navigate their spacecraft, configure them for scientific observations, and recover the resulting scientific data. During the past year, the recovery of additional image data from the 1993 encounter of the Galileo spacecraft with the asteroid Ida showed that the asteroid had a moon. Magellan, which had been providing scientific data about Venus for several years, concluded its mission in a final experiment as its orbit decreased and it entered the planet's atmosphere. In addition, radar image data received from the Clementine spacecraft provided detailed maps of the Moon's surfaces, and data from the international solar mission, Ulysses, provided unique observations of the southern hemisphere of the Sun.

Aeronautical Activities

Technological Developments

In the field of aeronautics, the DoD, NASA, and the FAA all engaged in the development of new and improved technologies. A good example of the ways in which the agencies cooperated in this endeavor was the joint **X-31 Enhanced Fighter Maneuverability** program, a cooperative effort involving the U.S. Navy, the U.S. Air Force, NASA, ARPA, Rockwell International, and Germany's Ministry of Defense, as well as Deutsche Aerospace (formerly Messerschmidt-Bolkow-Blohm). The aim is to determine the overall utility of thrust vectoring and advanced control concepts during slow-speed, poststall maneuvering. This highly productive program includes two aircraft built under sponsorship of ARPA and the German government. The X-31 features three lightweight, carbon-carbon external thrust deflection paddles and a movable inlet lip to minimize inlet flow distortion at high angles of attack. It also incorporates a flight control system that provides superior control during poststall maneuvering. During the past year, the program successfully completed its original program goals, compiling an impressive array of technically significant "firsts" in aeronautics, demonstrating: (1) significant agility at extremely high angles of attack (70°), well beyond the aerodynamic stall limit; (2) the significant combat value of its advanced technologies in close-in combat with F/A-18 Hornets and F-14 Tomcats by winning 117 of 129 engagements featuring computer-simulated guns and missiles; (3) the effectiveness of thrust vectoring for stability and control at supersonic speed (Mach 1.2), including a successful simulation of flight without a vertical tail; (4) the successful use of the advanced lightweight helmet during simulated close-in combat, permitting the pilot to see critical flight information on the helmet visor, thereby promoting safety and combat effectiveness by keeping a maneuvering foe in constant view; and (5) the highest flight rate and total number of flights ever achieved for a fixed-wing X-aircraft. This technology, integrated into new designs, would provide significant reductions in aircraft weight, aerodynamic drag, fuel consumption, and radar signature. It could even permit more efficient and less complex subsonic and supersonic transport aircraft designs for the future. The program's significance is suggested by its winning *Aviation Week and Space Technology*'s Laurels Award in December 1993 and the American Institute of Aeronautics and Astronautics' Aircraft Design Award in September 1994.

As Congress mandated, FY 1994 marked the last year of another joint program, the **National Aero-Space Plane** (NASP). NASP was a joint DoD-NASA effort to demonstrate technologies for air-breathing, SSTO, hypersonic vehicles that take off and land horizontally. Since 1986, the NASP program has developed significant advances in structures, materials, propulsion, aerodynamics, computational design tools, and national hypersonic test facilities. Those efforts have established a broad and sound foundation of national hypersonic expertise. Advances include high-temperature carbon-carbon materials, lightweight titanium and beryllium-aluminum alloys, and high-strength, corrosion-resistant titanium-alloy composites. In the area of propulsion, the program vigorously pursued the development of supersonic-combustion ramjet (scramjet) technology in FY 1994. A one-third scale Concept Demonstrator Engine underwent initial testing at Mach 6.8 in the 8-foot High-Temperature Tunnel at NASA's Langley Research Center in Virginia. During the past year, the program has made a major effort to document progress made to date and transfer NASP technology to other aerospace industries. Applications of this technology are emerging in the automotive, energy, computer, and medical industries as well. The hypersonic community will focus its efforts over the next 5 years on the most critical technology, the scramjet propulsion system, as the most cost-effective way to reduce the technical risks for air-breathing aerospace planes. The resulting Air Force/NASA Hypersonic System Technology Program will combine rocket-boosted scramjet experiments (with nominal test points at Mach 15) with related ground tests and analyses.

Relatedly, the **External Vision Display** (EVD) program—a joint effort between NASA, the NASP joint Program, Lockheed, Kaiser Optical Electronics, and Systems Technologies, Inc.—developed a system of lenses and mirrors that provides the pilot a view on the cockpit display of the runway under the nose of the aircraft. A flight of the system on an F-104 aircraft at the Dryden Flight Research Center in January 1994 showed that it allowed the pilot to see the runway during nose-high landings typical of a High-Speed Civil Transport (HSCT)-type aircraft, without the need for heavy nose-drop machinery used in the Concorde and the Russian Tu-144 aircraft.

Another joint program between the DoD and NASA is the X-32 Short Take-off and Vertical Landing/Conventional Take-off and Landing (**STOVL/CTOL**) Affordable Lightweight Fighter Technology Demonstration program. ARPA conceived this joint program with the British Ministry of Defense, NASA, and the Joint Advanced Strike Technology Program to investigate the technical feasibility of designing both a STOVL aircraft and an Air Force CTOL strike fighter aircraft to conduct missions currently performed by the AV-8B, F-18, and F-16. The keystone to this concept is affordability to be achieved by employing integrated product/process development and acquisition reform; specifying a single engine; setting an upper weight limit of 24,000 pounds empty; and maximizing avionics, airframe, and engine commonality for the Air Force, Navy, and Marine Corps versions of the aircraft—i.e., 95 percent of the Air Force CTOL aircraft parts common to the Naval Services' Advanced STOVL (ASTOVL) version. The X-32 was in Phase II of a three-phase program as the fiscal year ended. Phase I consisted of studies of the propulsion system and airframe design. Phase II consists of the validation of critical technology, studies of common airframe design, and analyses of affordability. Phase III will consist of the design of demonstrator aircraft, fabrication, and flight testing. The NASA portion of the program included tests conducted in a Harrier aircraft equipped with an integrated flight propulsion control system and cockpit display system. During 1994, NASA completed most of the planned flight research.

Close participation of industry engineers and pilots during the tests resulted in beneficial exchanges of information and data. NASA also conducted flight simulations in the Ames Fixed-Base and Vertical Motion Simulators, with industry engineers and pilots participating. This work served as a basis for their control system designs, which will then be simulated in FY's 1995-96. Finally, aerodynamic testing of the various STOVL configurations and components took place at three NASA research facilities.

Another project for ARPA has been the **Special Operations Forces (SOF) Transport Program**. This concept exploration effort, initiated in FY 1994, aimed at determining the feasibility and appropriate characteristics of an affordable transport capable of performing the SOF infiltration/exfiltration mission. During the course of the 2-year program, the contractor will conduct trade studies to identify concepts with potential military multipurpose and/or military-civil dual-use applications. Conceptual designs will be refined in terms of weight, performance, and costs. The contractor will also address key technical issues and risks through analysis and ground testing.

ARPA has also been involved jointly with the Air Force and Army in the **Miniature Air-Launched Decoy** (MALD) program to develop a small, self-protection and offensive air-launched decoy system designed to saturate surface threat radars and aid in establishing air superiority by diluting and confusing surface-based and airborne threat systems. This program is a follow-on to ARPA's Small Engine Applications Program (SENGAP) that resulted in the development of a low-cost, 4-inch-diameter turbojet engine capable of developing 50 pounds of thrust for up to 30 minutes. The current phase of the MALD program will integrate this engine with an airframe, conduct flight demonstrations, and verify full-envelope flight performance of a MALD flight vehicle. If successful, this could lead to further efforts to refine the air vehicle concept and to develop prototype decoy payloads for flight testing in an operational environment.

Another ARPA effort is a congressionally directed study of the possible use of very large, ocean-skimming aircraft to transport large military payloads quickly over long distances. Referred to as **wingships**, these unique vehicles would be 5 to 10 times larger than the biggest conventional aircraft, such as the Boeing 747, and would be built to take advantage of favorable aerodynamic forces.

ARPA also had a **Tier III Minus Program** to develop and demonstrate a low-observable, high-altitude-endurance, unmanned air vehicle specifically designed for wide area surveillance of areas to which conventional aircraft are denied access by the enemy. Two such vehicles will comprise part of a system, currently under development by Lockheed Advanced Development Company and Boeing Defense and Space Group, consisting of the vehicles, one electric optical sensor, one synthetic aperture radar sensor, two sets of communications equipment, and one launch and recovery control station. This system will be procured and tested during FY's 1995-96. The air vehicle will be capable of carrying the radar or optical sensor payload and will communicate with the ground station through a UHF Satellite Communication (UHF SATCOM) link, a 1.5-megabits-per-second sensor SATCOM link, and a wideband line-of-sight link. This program is integral to the overall reconnaissance architecture being developed by the Defense Airborne Reconnaissance Office.

In the BMDO's gasoline-powered **RAPTOR Demonstrator Unmanned Aerial Vehicle** (UAV) program, the UAV built by Scaled Composites, Inc., completed 19 flights during FY 1994 before crashing in February 1994. A replacement UAV completed two flights before October in preparation for high-altitude, long-endurance missions later in the calendar year. The solar-powered Pathfinder UAV, built by AeroVironment, Inc., flew 10 missions at low altitude in FY 1994 to explore basic flight stability and control issues. This UAV was upgraded during the year. Plans called for it to be moved in the spring of 1995 to NASA's Dryden Flight Research Center in California to resume high-altitude flight testing. Because of budget restrictions in the BMDO, the DoD could no longer fund these activities and was in the process at the end of the fiscal year of transferring these assets to NASA and the DoE for continued joint flight operations to support future civil and commercial initiatives.

The Army had a project, **Rotorcraft Pilot's Associate Advanced Technology Demonstration**, to revolutionize the mission effectiveness of combat helicopters. It has focused on critical pilotage and mission management technologies, including the use of artificial intelligence for cognitive decision making to optimize crew workload; advanced command and control techniques necessary to meet new mission requirements and situational-awareness needs; advanced pilotage sensors, displays, and controls; and advanced weapon systems to support both air-to-air and air-to-ground engagements. The new technology will contribute greatly to DoD/Army rotorcraft pilots' abilities to "see and comprehend the battlefield" in all conditions; rapidly collect, synthesize, and disseminate battlefield information; and take immediate and effective actions. Compared with a "Commanche-like" baseline, this is expected to reduce mission losses by 30 to 60 percent, increase targets destroyed by 50 to 150 percent, and reduce mission time lines by 20 to 30 percent. Projected plans for transition include support of the RAH-66 Commanche, AH-64 Longbow Apache, Special Operations aircraft, DoD/Army system upgrades, and potential future systems beyond the year 2000.

The Army was also involved in two related, joint programs, the **Integrated High Performance Turbine Engine Technology** (IHPTET) and **Joint Turbine Advanced Gas Generator** (JTAGG). The IHPTET initiative is a joint DoD/NASA/industry effort to provide revolutionary advancement in aircraft propulsion performance and operational capability. The goals of JTAGG—which is jointly sponsored by the Army, Navy, and Air Force and has two contractors, Textron Lycoming of Stratford, Connecticut, and General Electric of Lynn, Massachusetts (teamed 50/50 with Allied Signal Engines of Phoenix, Arizona)—are fully aligned with the three phases of IHPTET. JTAGG will focus on improvements in turboshaft/turboprop (TS/TP) core engine technology with a long-range goal of achieving a 40-percent decrease in specific fuel consumption and a 120-percent increase in power-to-weight for a given size engine. The JTAGG program was demonstrating TS/TP core engines as the fiscal year ended, employing advanced aerodynamics and materials technology that will allow the IHPTET Phase I goals to be achieved. Demonstrator engines that can greatly exceed the Phase I goals and meet those of Phase II were being fabricated as of the end of September 1994, with component testing to begin soon.

At NASA, the **F-18 High Alpha Technology** program sought to achieve an understanding of high angle-of-attack aerodynamics, including the effects of two advanced control concepts: thrust vectoring and vortices shed from the nose. The program was using flight research, wind-tunnel research, Computational Fluid Dynamics (CFD) modeling, and correlation among the resultant sets of data to produce this understanding. The flight research has employed a highly instrumented F-18 aircraft outfitted with an external-paddle thrust-vectoring system. Plans called for a mechanical nose-strake vortex-control system to be added in FY 1995. During 1994, flights with the thrust-vectoring system produced performance and dynamic data to a 70° angle of attack to help establish specification criteria for the future design of a Navy aircraft. Flights with an instrument rake documented engine-inlet distortion patterns during maneuvering and measured the effects of engine compressor stalls on the aerodynamic flow field external to the aircraft.

U.S. companies and other Government agencies used NASA's **F-18 Systems Research Aircraft** (SRA) as a testbed to help identify and flight test advanced concepts and technologies. The Electrically Powered Actuation Design (EPAD) program installed and successfully flew a "smart actuator" in place of a conventional aileron actuator. The Air Force, Navy, and NASA jointly sponsored the EPAD program as part of the drive toward the "more electric aircraft" concept. A test of a 10-horsepower electromechanical actuator for an aileron will be the next element in the EPAD flight test program. A second focus of the F-18 SRA testbed is its use in an element of the Advanced Subsonic Technology (AST) program called "Fly-by-Light/Power-by-Wire" (FBL/PBW), which aims to reduce aircraft weight substantially by using glass fiber to replace a large amount of electrical wiring. The F-18 flew successfully in FY 1994, equipped with a package of 10 airframe fiber optic control sensor integration sensors. The aircraft will test a package of 10 engine sensors in FY 1995. Also initiated later in the calendar year will be the fly-by-light aircraft closed-loop tests, which will demonstrate fiber optic technology in the critical paths of the flight control system. The expected result will be to build the knowledge and confidence necessary to begin applying this technology to new aircraft designs.

The goals of NASA's **FBL/PBW** program are to provide technology for lightweight, highly reliable, electromagnetically immune control and power-management systems for advanced subsonic civil transport aircraft and to develop the technology for application to and certification of future transport aircraft systems. NASA assists industry in accomplishing these goals by reducing research and development risks associated with cost, safety, and certification. Optical technologies are immune to electromechanical interference and eliminate the threat of electrical sparking. PBW eliminates the need for centralized hydraulic and pneumatic systems, variable engine-bleed air systems, and variable-speed, constant-frequency drive systems found in secondary power systems. The use of FBL/PBW results in significant weight savings, more efficient engine operation, and reduced complexity. Studies also indicate improvements in reliability, which translate into less downtime for maintenance and faster turnaround at the gate. Several studies by industry have confirmed these advantages, and the NASA-Navy Fiber-Optic Control System Integration has begun to evaluate FBL technology in high-performance aircraft.

Relatedly, in FY 1994, the FAA continued to study the airworthiness resulting from improvements in flight safety for new aircraft employing advanced displays, flight management systems and procedures, and modified operational profiles. The agency focused efforts on the collection of updated flight test data and analyses of computer-based, **fly-by-wire** automated flight control systems and equipment. The FAA will use that information to address the issues of flight safety and certification raised by incorporating the emerging, highly complex, software-based digital systems into aircraft and avionics system design. The research is especially crucial in cases where this technology is applied to flight-critical applications, such as fly-by-wire, FBL, and PBW. In coordination with NASA, the agency proceeded during FY 1994 in designing, developing, and validating fault-tolerant software and hardware to assist the U.S. aviation industry in acquiring the competitive advantages associated with this advanced technology while simultaneously promoting flight safety.

Another area in which NASA and the FAA cooperated was in **aircraft noise reduction**. Aircraft noise has become a national and international issue that prompts airports to operate within strict noise budgets and curfews, restricting airline operations. International treaty organizations are actively considering even more stringent noise standards. They will limit the growth of the air transportation system and the U.S. aircraft industry's competitiveness in the world market. The FAA has been participating with NASA in a series of joint noise and emission reduction initiatives. The two agencies continued implementation of the joint subsonic airplane noise reduction technology research program. The FAA released version 2.2 of the Heliport Noise Model, featuring more helicopter performance data and improved methods of track definition and taxi procedures. The development of computer models included the release of Integrated Noise Model 4.11 with capabilities for analyzing terrain, runup operations, and varying airport temperature and elevation. In addition, the FAA established a broad Government-industry review committee to oversee future FAA noise modeling. The overall goal of NASA's noise reduction program is to provide ready noise reduction technologies to help industry achieve present and future noise reduction goals and thereby facilitate market growth, increased U.S. market share, and compliance with international environmental requirements. To achieve that goal, NASA has established an objective of 10 decibels of noise reduction over 1992 levels. A group of industry, university, and Government technologists is working to achieve this goal and help provide the competitive impetus for U.S. industry in the design of the next generation of subsonic transport aircraft. Specifically, the program will enhance reductions in source noise, improve nacelle aeroacoustics, enhance engine-airframe integration, reduce interior noise, and help create flight procedures to reduce airport community noise and still maintain high efficiency. Two specific major accomplishments of the program in FY 1994 were the completion of the first integrated fan noise source and propagation prediction code and the active control of interior aircraft noise using active trim control panels. The prediction capability will define and optimize concepts for technology to reduce noise. The active trim panel is a promising concept that can be used by airframe manufacturers to reduce aircraft cabin noise.

Another NASA initiative that will assist the U.S. civil transport industry to remain competitive in an environment of increased worldwide competition is the **integrated wing** element of the AST program. Its goal is to develop and validate new wind tunnel test procedures and cost-effective aerodynamic concepts that will improve overall aircraft performance while reducing the length of the aerodynamic design cycle. The result will be an aircraft that performs better and is cheaper for the airlines to operate. Areas being investigated include simpler and more cost-effective high-lift systems, cost-effective methods for integrating engines on aircraft wings, and new wind tunnel test techniques and technologies that will provide design data more quickly and accurately. One result of studies surrounding the integrated wing has been a pressure-sensitive paint system that, when fully developed, will result in a significant reduction in the aerodynamic portion of the wing design time, thus reducing cost.

NASA's **Advanced Composites Technology** program can also help U.S. transport aircraft recoup recent losses in market share of world sales by reducing ownership and direct operating costs by 16 percent. The program is specifically tailored to demonstrate the capability to scale up existing technology by designing, fabricating, and testing full-scale fuselage and wing sections under simulated flight loads and by verifying a composite-structure fuselage and wing design that will have an acquisition cost 20 to 25 percent less and weigh 30 to 50 percent less than the current aluminum aircraft with the same payload and mission. While this is a challenging goal, significant savings can be attained by using automated fabrication methods and by reducing the numbers of parts required in composite structures. During FY 1994, the program produced and tested subscale components in both wing and fuselage areas. A NASA-industry team manufactured and strength-tested fuselage keel panels made of laminated composite skins bonded to a composite-honeycomb core. Engineers developed and used cost-analysis software in the analysis of the engineering and manufacturing process. Its use led to a focus on a honeycomb core sandwich substance as the material of choice for the fuselage side panels as well as the keel. In the wing area, McDonnell Douglas and its subcontractors, along with their team members from the Langley Research Center, manufactured a number of wing cover panels to increase confidence in the resin-film-infusion process of impregnating and curing dry fabric layers stitched together. Once the process was perfected, the team fabricated, assembled, and prepared for strength testing an inboard portion of wing structure with stiffened upper and lower panels, called a wing stub box.

The **propulsion element** of NASA's AST program, in cooperation with U.S. industry, has been developing propulsion technology that will increase the competitiveness and market share of the U.S. propulsion industry, helping to recover some of the 50,000 jobs recently lost due to industry downsizing, as well as reduce the environmental impact of future commercial engines through decreased exhaust emissions. The improved propulsion systems will lower overall direct operating costs of future commercial transports of all sizes by 3 percent—a figure that currently represents the profit/loss margin for a U.S. airline. The systems will reduce nitrogen oxide emissions by at least 70 percent over current levels and will improve fuel efficiency by at least 8 percent. Engineers also made progress in FY 1994 in the development of robust computer design codes to help U.S. industry decrease development test time and cost on new or derivative engines. During FY 1994, the NASA-industry partnership with major U.S. engine manufacturers (General Electric Co., Pratt and Whitney, and Alison Engine Co.) completed several studies of low-emission combustors. The companies identified promising concepts and barrier technology issues, and the partnership was also studying higher-temperature disk materials, lightweight composites, and film-riding seals.

Relatedly, to develop a scientific basis for analyzing the impacts of subsonic aviation on the atmosphere, NASA has established an **environmental assessment** element in its AST program. The goals are to determine the impacts over time of aviation on the atmosphere and to provide assistance to future international ozone and climate assessments. The successful scientific and management model of the Atmospheric Effects of Stratospheric Aircraft element of the High-Speed Research (HSR) program was in the process of being applied to this program as of the end of the fiscal year to establish collaborative relationships with existing atmospheric science programs. NASA's HSR program also continued to emphasize the resolution of environmental issues for, as well as the determination of the economic viability of, the next-generation HSCT during FY 1994. The National Academy of Sciences conducted a review of the "Interim Assessment of Atmospheric Effects of Stratospheric Aircraft" released by NASA. It commended NASA for enhancing the understanding of atmospheric chemistry. NASA's ER-2 high-altitude scientific aircraft completed a series of atmospheric observations for the Stratospheric Photo Chemistry Aerosols and Dynamics Expedition. These in-situ measurements tested concepts that underlie the stratospheric models used for assessment of HSCT aircraft effects in the stratosphere. As the year ended, the program was conducting atmospheric observations in collaboration with the NASA Office of Mission to Planet Earth.

In related engine technology, the development of the low oxides of nitrogen (NO_x) combustor technology for **HSCT engines** continued with successful tests of experimental fuel combustion chamber sectors. Initial results achieved or exceeded the goal of generating no more than 5 grams of NO_x per kilogram of fuel burned at supersonic cruise conditions. The results indicate that practical combustor hardware has been developed that emits the ultralow levels previously obtained under highly controlled laboratory conditions. The "mixed flow turbofan" and "fan-on-blade" technologies showed significant benefits in reducing engine take off noise while maintaining good performance at supersonic speeds. Both approaches will continue to be studied for approximately 2 years.

Along these same lines, the FAA began participation in NASA's **Atmospheric Effects of Aviation** project involving some of the efforts just discussed. The goal was to develop a scientific basis for the assessment of atmospheric impacts of subsonic and supersonic aviation, particularly commercial aircraft emissions during cruise. The FAA also completed a joint EPA/FAA study concerning the control of NO_x emissions from uninstalled aircraft engines in enclosed test cells. The agency released Version 94.4 of the Emissions and Dispersion Modeling System with enhancements to meet requirements of the Clean Air Act Amendments of

1990 and the California Federal Implementation Plan. Among these enhancements is the ability to assess emissions from aircraft ground support equipment.

In a separate area related to the **HSCT**, synthetic vision will improve the operational flexibility necessary for an economically successful HSCT to take off and land in all weather conditions. NASA has combined a variety of sensor data, including millimeter wave and infrared, into a single display to provide visibility for pilots in any type of weather. A future decision by industry to develop an HSCT would require that the aircraft meet stringent certification standards. The advanced technologies that would be incorporated into an HSCT pose new challenges for the current process and requirements of aircraft certification. During FY 1994, NASA addressed these challenges by initiating discussions with the FAA on the potential airworthiness standards that would be required to develop the certification for a supersonic civilian transport. NASA and the FAA prepared a memorandum of agreement that identified responsibilities for developing new certification processes and standards for supersonic transports. A team comprised of members of each agency released a Long-Range Plan for Certification of High-Speed Civil Transports.

In a related connection, NASA's **SR-71 Aircraft Testbed** program conducted several aeronautical research flights to assist industry in making key decisions about developing an HSCT. The SR-71 is particularly well suited for this research because of its ability to meet and exceed the projected HSCT operating conditions of Mach 2.4 at 60,000 to 65,000 feet. Pilots successfully completed baseline flights to verify flight test methods for sonic boom propagation. In addition, there were numerous scientific and technical experiments completed using the SR-71, including a high-speed flying qualities experiment; a dynamic auroral viewing experiment sponsored by UCLA, the JPL, and the Navy; a JPL validation of a Near Ultraviolet Spectrometer; in-flight shock wave photographs; and validation of the communication performance of Motorola's IRIDIUM low-Earth-orbit satellite intended to make voice, data, facsimile, and paging services available on pocket-sized telephones.

At the recommendation of a task force, NASA began during FY 1994 to enter into joint sponsored research agreements with the FAA and industry. In an effort to revitalize the U.S. **general aviation industry**, NASA made available to industry its "world-class tools," including wind tunnels, computer simulations, engine test cells, and material property labs. The goals of this effort are to support the expansion of the national economy by better serving the vast infrastructure of more than 5,200 public-use airports for general aviation. Included in the program are cockpit systems for improved safety and utility, design and manufacturing for improved affordability, propulsion systems for environmental compatibility, and icing protection systems. The Advanced General Aviation Transport Experiments (AGATE) program is developing the foundation for general aviation to expand to meet the needs of the U.S. and foreign general aviation market.

In a different area, NASA's achievements in advanced technology concepts for development, fabrication, and testing of lightweight, high-strength airframe materials continued in FY 1994. NASA fabricated and tested an array of composite metal and organic matrix composite panels. NASA also demonstrated a process capable of fabricating up to 10 feet per minute of fiber/resin composite material, suitable for high-temperature use.

Also during the year, the **United States and Russia** reached an agreement to use the Russian Tu-144 supersonic civil transport as a flying testbed for conducting flight research to develop enabling technologies for NASA's HSR program. The flights will provide data on aerodynamic, flight environment, structural, and handling qualities for a supersonic passenger aircraft. The decision to use the Tu-144 was based on a study conducted by a team of engineers from the United States and Russia. It concluded that use of the Tu-144 would be effective and economical. Its size, performance characteristics, and availability made it ideal for this purpose. The Tu-144 supersonic research will establish direct working relationships between aircraft manufacturers in the United States and Russia and will enhance the relationship between the aeronautical agencies of the two countries.

In a different area, NASA's **Flight Research Instrumentation and Test Techniques** program continued to emphasize the transition of new concepts into products and processes that will improve the productivity of flight testing. In 1994, the program achieved in-flight imaging of jet flow for the first time, using laser visualization between Mach 0.8 and 1.8. These tests yielded important information that will aid in understanding and developing improved combustion processes for a vehicle accelerating through the transonic flight regime.

Also, Aurora Flight Sciences Corporation has been developing the **Small High Altitude Science Aircraft**, known as Perseus A, for NASA to use in gathering atmospheric readings at 65,000 to 82,000 feet. These data will fill in a gap between measurements from current research aircraft and space-based instruments. Perseus A is an unpiloted, propeller-driven aircraft. It uses a single internal combustion engine and a novel exhaust recirculation concept with liquid oxygen and gasoline fuel to operate in the rarified stratosphere. Two of the aircraft had been built by the end of the fiscal year, with the first flight occurring on December 21, 1993. By August 1994, Perseus A had demonstrated flight operation to 50,000 feet.

Additionally during 1994, NASA initiated the **Airborne Coherent Lidar for Advanced In-flight Measurements** (ACLAIM) program through a research announcement issued by the Office of Aeronautics. As conceived, the ACLAIM program will use a high-power, solid state laser device with a high repetition rate for aircraft application. The proposed laser represents more than a 10-fold increase in laser capability over the currently available diode laser. NASA signed a contract for the laser development with Coherent Technologies, Inc., in August 1994. The planned use of the laser is to acquire reflected energy from naturally occurring atmospheric aerosols. Potential high-value applications include sensors to indicate interruptions of supersonic airflow through engine inlets, detection of turbulence that follows in the wake of landing aircraft, and detection of turbulence that arises in the otherwise clear air.

NASA designed the **Environmental Research Aircraft and Sensor Technology** (ERAST) program to create a partnership between the UAV industry and Government. The purpose of the partnership is to foster commercial applications of UAV's, to address the Government's needs for UAV's in support of scientific and military requirements, and to address expected regulatory issues associated with the flight operations of these aircraft. NASA held three meetings with industry in 1994 to define the research and development tasks necessary to achieve flight demonstrations in support of scientific missions. On September 9, 1994, NASA signed a joint sponsored research agreement with industry to develop UAV technology.

NASA's efforts in the field of **High Performance Computing and Communications** (HPCC) contributed to the Federal HPCC program by leading the development of applications software and algorithms for scalable parallel computing systems that will increase systems performance to the sustained teraFLOPS (10^{12} floating point operations per second) level for NASA applications and also by transferring those technologies for application to other national needs. NASA will use those technologies to solve its "grand challenges," including improvement in the design and simulation of advanced aerospace vehicles, enabling people at remote locations to communicate more effectively and share information, increasing scientists' abilities to model the Earth's climate and forecast global environmental trends, and improving the capabilities of advanced spacecraft to explore the Earth and Solar System. In this connection, the Information Infrastructure Technology and Applications (IITA) program applies HPCC technology to developing programs not only for aerospace design and manufacturing but also for use in elementary and secondary education, experiments in packet video over the Internet, digital library technologies, and data base applications for remote sensing. In FY 1994 the IITA started several projects in data base applications for remote-sensing and digital-library technologies, and it established a public access center for the products of remote sensing. During the fiscal year, the Computational AeroSciences component of the HPCC program installed 128 of the 160 planned processors for a new IBM SP-2 at Ames Research Center, California. The new system will greatly augment other scalable parallel computers to provide research platforms for systems software, virtual wind tunnels, critical disciplines research, and other projects beneficial to the aerospace and manufacturing industries. The projects will lead to significant enhancements in design support and in computer simulation of aerodynamic performance. These will produce more efficient and cost-effective aircraft and spacecraft design. The HPCC program has also started research into the use of high-performance workstations so as to decrease dramatically the costs of many high-performance computing requirements while ensuring reliable performance on workstations in diverse geographical locations. Finally, the Numerical Aeronautics Simulation (NAS) facility at Ames underwent major improvements during 1994 to support the requirements of the aeronautics community, 170 of whose representatives attended a workshop titled "Distributed Computing of Aerospace Applications" sponsored by the NAS facilities. Many aerospace industry leaders have already attributed major cost savings to the NAS facilities.

Air Traffic Control and Navigation

Among many projects and programs of the FAA in the area of air traffic control, the **Traffic Alert and Collision Avoidance System** (TCAS) uses air-to-air interrogations of transponder-equipped aircraft to provide pilots with traffic advisories indicating the range, attitude, and bearing of other planes posing potential threats. The agency will require TCAS I, a low-power system that provides alerting but does not recommend escape maneuvers, in turbine-powered commercial airplanes with 10 to 30 passenger seats by the mid- to late 1990's. Public Laws 100-223 and 101-236 require that all air carrier aircraft with more than 30 passenger seats operating in U.S. airspace be equipped with TCAS II. It alerts pilots to traffic and advises whether to climb or descend when a potential conflict occurs. At the end of FY 1994 there were more than 6,000 air carrier and business aircraft equipped with TCAS II, and more than 25 million flight hours have been accumulated with the equipment worldwide. In addition, pilot reports show that the system has already prevented midair collisions. During FY 1994, the FAA continued to monitor the performance of TCAS I and II and to make adjustments as necessary.

The FAA's **Advanced Traffic Management System** (ATMS) sought to develop enhanced automation capabilities for air traffic flow management. In FY 1994, the agency implemented a new automation function, Delay Manager, that provides the traffic flow manager with the capability to estimate the operational impact of alternative air traffic control flow management actions.

During the fiscal year, the FAA delivered the first **Voice Switching and Control System** (VSCS) to the Seattle Air Route Traffic Control Center (ARTCC). On June 29, 1994, the agency accepted delivery of its second unit at the Salt Lake ARTCC. The VSCS is an automated communication system that provides flexible, digital air-to-ground and ground-to-ground voice communications links between controllers and enroute aircraft. When fully operational, the VSCS will be responsible for communications among controllers at ARTCCs. The new digital system will allow the FAA to begin planning for eventual decommissioning of the presently owned and leased voice switching equipment, which is over 30 years old. Eight additional operational VSCS's were on order at the end of the fiscal year. The software baselines have undergone evaluation and testing at the FAA's Technical Center in Atlantic City, New Jersey.

An essential part of aircraft movement on airport surfaces is proper guidance during taxiing. Hence, it is necessary that the FAA design and maintain the **visual guidance systems** (lighting, marking, and signs) to avoid any ambiguity in intended operational use. During FY 1994, the FAA revised a draft specification for a U.S. standard stop-bar lighting system based on testing at Seattle Tacoma International Airport and on ICAO recommendations. A stop-bar lighting system is intended to prevent aircraft from entering the runway area without proper approval, and it improves safety for low-visibility operations below 600 feet runway visual range. The agency completed an inservice evaluation of the system at Seattle during the fiscal year. The FAA has also completed a study on improved pavement marking materials. This included an evaluation of different sizes of retroflective beads added to the marking materials.

The FAA's **Terminal Area Surveillance System** (TASS), chartered to provide a single-system replacement for the existing mix of multiple aircraft and weather terminal surveillance systems, has been conducting research and technology demonstrations of design concepts expected to increase capacity and efficiency while maintaining safety. The effort has focused on seamless coverage from gate to gate and timely hazardous weather detection and prediction integrated with surface and enroute data. The selected design will provide lower maintenance costs through emphasis on solid-state technology and the modularity and upgradability of the system to accommodate site-specific needs. During FY 1994, the FAA (1) evaluated the results of exploratory work in various pulse-compression processing techniques, methods to detect and track wake vortices, capabilities of phased-array radars, and simulated displays of weather and aircraft tracking data; (2) completed initial simulations that demonstrated that a 5-percent increase in capacity is achievable with wind data from TASS sensors; (3) completed two milestones of a cooperative agreement with the DoD on an ARPA technology reinvestment project for the building and demonstration of an advanced airport radar system based on dual-use monolithic microwave integrated circuit technologies; (4) conducted a TASS industry day forum and released to industry all nonproprietary TASS program reports and documentation to provide interested parties an opportunity to contribute to the formulation of the TASS program strategy; (5) completed an Air Traffic Terminal Surveillance Requirements Report documenting controllers' needs in the terminal area, a baseline for the program's initial operational requirement document; and (6) initiated a cost-benefit analysis of alternative concepts identified during the concept exploration phase of the program.

The FAA's **Terminal Air Traffic Control Automation** (TATCA) program provides software tools to aid controllers in traffic flow management in the airspace surrounding major airports. The FAA previously completed the development of a converging runway display aid. Successfully deployed at four airports, this technology for use during instrument meteorological conditions (bad weather) is planned for additional terminal facilities nationwide. The Center-TRACON Automation System (CTAS), jointly developed by the FAA and NASA, is also a part of the TATCA program. During this fiscal year, CTAS design strategy shifted from individual tool development to a combined approach of producing four software components. Future CTAS capabilities will include integration with other ground-based and onboard systems technologies, including the flight management system, data link, aircraft communications addressing and reporting system, next-generation air traffic management, and automated enroute air traffic control. As the year ended, a cooperative team of airframe users, onboard avionics manufacturers, and air traffic management system engineers was discussing interoperability issues and benefits to users.

In June 1991, the FAA awarded a production contract for 26 **Microwave Landing Systems** (MLS's) for use in Category I conditions. In FY 1994, all 26 systems completed production, factory testing, and FAA factory acceptance. Seven systems had been installed at airports at the end of the fiscal year, with engineering and site preparation under way at 17 additional locations. On June 2, 1994, in a move designed to focus on the adoption of satellite technology and to save money, the FAA decided to halt further development of Category II and III MLS's. The FAA terminated two existing development contracts. If Category II or III MLS's are required by any international treaty, the agency will acquire the systems on the open market.

Predeparture Clearance (PDC) **data link service** continued at 30 airports with participation growing to include eleven carriers. General aviation participation increased to 324 aircraft. During FY 1994, the FAA continued development work on the Tower Data Link Service, which included PDC Phase II, flight data input and output emulation, and the Digital Automatic Terminal Information Service, with expansion planned to 57 airports during FY 1995. The FAA also worked toward the development of U.S. and international standards for controller/pilot data link communications, which will be used to standardize interfaces for digital messages for air traffic communications services, helping to relieve pilot and controller workload while reducing voice channel congestion. In addition, the agency supported the development of the context management application, which enables aircraft and ground systems to maintain up-to-date addressing information while the aircraft traverses airspace.

The FAA identified and documented Oceanic Data Link (ODL) requirements in a system segment specification and an interface requirements specification. During the fiscal year, the agency began ODL development and conducted testing of the prototype ODL for use by controllers; it also tested the related prototype Boeing datalink avionics package, which will be installed in aircraft. The FAA designed an Air Traffic Services Interfacility Data Communications (AIDC) system and developed a prototype for testing ground-to-ground data link communications between adjacent flight information regions. Initial testing took place between the New York ARTCC and the Area Control Center at Piarco, Republic of Trinidad and Tobago. Additionally, the Russian Department for Air Transport agreed to permit the FAA to install a prototype AIDC in the Russian Far East and connect it to the Anchorage ARTCC. The agency also participated in the development of Dynamic Aircraft Route Planning (DARP) capability in the South Pacific. That capability provides the structure, procedures, and processes necessary for the rerouting of aircraft in midflight. During the fiscal year, the FAA completed several studies and collected the data used to generate scenarios for the end-to-end system simulation of DARP, and the FAA Technical Center performed the simulation. The agency also finalized the Dynamic Oceanic Track System (DOTS) training plan. Efforts were under way at the end of the year to rehost the DOTS onto a new hardware platform with an open operating system. The maintenance plan was also in development, and all existing documentation was being revised to reflect the new hardware and open architecture.

In other areas related to air traffic and navigation, in FY 1994 the FAA approved a new oceanic intrail climb procedure; it allows a trailing aircraft to climb to a more fuel-efficient altitude with less horizontal separation from a leading aircraft than previously required. The procedure is currently limited to use by United and Delta Airlines' aircraft under the control of the Oakland ARTCC. The FAA also, in cooperation with the user community, formed a new operational concepts working group to coordinate modeling and analysis of a range of procedural and policy matters. The group conducted initial analysis in support of the RTCA (formerly, Radio Technical Commission for Aeronautics) Task Force on Free Flight. In addition, the FAA is supporting NASA's free-flight initiatives as outlined in a memorandum of agreement. Finally, after conducting an assessment of the five architectural options, the National Airspace System precision approach and landing system study group recommended as the future precision approach and landing architecture the wide area augmentation system/local differential GPS for Category I approach procedures and a GPS-based system for Categories II and III approach procedures.

Following a series of independent reviews of the **Advanced Automation System** (AAS) program in FY 1994, the FAA restructured the program to contain cost growth and minimize delays. When completed, the restructured program will provide the same functions and benefits as the original program but with a different implementation approach. The new system will upgrade the capacity and reliability of the airspace system, increase controller productivity, provide greater fuel efficiency, minimize delays, and give the flexibility needed for future enhancements. The FAA was planning to replace the equipment used at the end of the fiscal year by controllers with new computer software, processors, tower position consoles, and controller workstations. In the enroute environment, the most pressing need was the replacement of antiquated controller displays and the computers that drove them. The new plan called for a display system replacement that will provide controllers with a new workstation and peripherals. Initial deployment of the automated enroute air traffic control project will enable controllers to begin a major transition to more flexible routing and more fuel-efficient aircraft operations. In the terminal environment, the plan includes short-term projects to replace or upgrade aging and inflexible subsystems of the automated radar terminal system. The longer-term solution requires proceeding with a stand-alone TRACON replacement project, based on commercial products and technology, to remove functional limitations and facilitate the phased introduction of user benefit capabilities. The tower program will provide technical enhancements, a computer-human interface, and consolidation of various automated capabilities into a single, efficient system. This will ease the problem of limited physical space, enhance safety, and provide a platform for further automation.

This program was especially important because an increase in air traffic has led to congestion at major airports with a corresponding increase in delays and inconvenience for passengers as well as in costs and time to operators. Unless system capacity is increased, the annual delay of 20,000 hours at a number of airports is estimated to grow to 39,000 hours by 1997. **Civil tiltrotor** offers a unique opportunity to create a new aircraft market and simultaneously reduce a large portion of short-haul traffic at major airports. Studies conducted by the U.S. aircraft industry, NASA, the FAA, and various state and local transportation authorities have shown that the civil tiltrotor can be a viable solution for relieving air traffic congestion. A commercially viable, U.S.-manufactured tiltrotor can provide an increase of approximately $5 to $7 billion in sales revenue as well as an increase in aviation jobs. Furthermore, it will substantially relieve our overcrowded major airports and increase U.S. aviation exports. NASA's civil tiltrotor research has begun building the technological foundation for a vertical take off and landing commuter airliner of the future that will operate from conveniently located, inner city vertiports. The civil tiltrotor element focuses on noise reduction, cockpit integration, proprietor efficiency, contingency power, and technology integration. Major accomplishments in FY 1994 included the first wind-tunnel test of a four-bladed proprotor, the most comprehensive tiltrotor test to date. The test data will substantially add to the understanding of the acoustic improvements inherent in the four-bladed proprotor. NASA also completed the critical design review for the TiltRotor Aero-acoustic Model (TRAM), a critically important proprotor test stand for use in the 40-by-80-foot wind tunnel at Ames. Its successful implementation will greatly facilitate full-scale aerodynamics testing of future proprotors. Additionally, this year NASA published the first Government and industry characteristics standard for tiltrotor performance. The standard represents current tiltrotor technology that will be used as a baseline for comparison with future designs.

In a separate program, NASA initiated the **Terminal Area Productivity** (TAP) program. Its goal is to achieve clear-weather capability in instrument weather conditions and do so safely and affordably. TAP consists of reduced separation requirements, air traffic management, low-visibility landing and surface operations, and aircraft-air traffic control systems integration. Wake vortex systems research has begun to reduce separation standards for runway operations safely through investigations, tests, and documentation. The wake vortex systems effort consists of identifying and modeling wake vortices mathematically. The goal is to develop models that will predict wake vortex hazards and to develop sensor concepts to detect wake vortex hazards on final approach.

Weather-Related Aeronautical Activities

NASA applied a similar process to the NASA-FAA **Airborne Wind Shear Advanced Technology program**. The Terminal Area Simulation System (TASS), a model of the atmosphere with cloud microphysics incorporated, provided an unprecedented capability to the NASA and FAA research program to study wind shear. After extensive evaluation of the candidate sensors in the simulated microburst environment of the TASS, there were flight tests of candidate wind-shear sensors. TASS also provided the foundation for the certification and test criteria to be applied to commercial wind-shear radar systems. Relatedly, in FY 1994, the FAA certified a forward-look wind-shear detection device that provides the aircrew with advanced warning of hazardous wind shear, enabling pilots to avoid the hazard. The agency has required the air carrier community to have "reactive" warning devices onboard civil air transports since early 1994. The FAA has completed a wind-shear research program addressing commuter and air taxi operators, extending previously acquired knowledge to this important segment of the air transportation system. A computer-based training program is available to the entire aviation community through the National Technical Information Service.

To achieve TAP's goals and meet the challenges of modern-day air traffic, NASA replaced its outdated Transport Systems Research Vehicle (TSRV) with a new Boeing 757 (B-757) that incorporated more advanced electronic systems than its predecessor, the 30-year-old TSRV-I. The TSRV supports field experiments to test reduced separation requirements for aircraft under TAP. For example, a series of tests is projected in Memphis, Tennessee, as a cooperative effort with MIT's Lincoln Laboratory in support of the NASA-FAA **Integrated Wake Vortex Program** (IWVP). These field experiments will provide a field capability for testing candidate predictor algorithms and operational wake vortex sensors, as well as provide an interface between meteorological and air traffic systems for testing demonstrations. During these field experiments, NASA will deploy lidar and supplemental meteorological sensors to record vortex and other atmospheric data. During the year, the FAA completed and implemented its wake vortex program plan, which includes a joint effort with NASA through a memorandum of agreement. This joint program will permit increases in airport capacity and will stress avoidance of wake turbulence through improved knowledge of vortex behavior. As the year ended, a Wake Vortex Training Aid was undergoing development through joint efforts of the FAA and the aviation community. Additionally, work had already begun to collect take off and landing data at John F. Kennedy International Airport in New York to validate sensor performance and determine meteorological effects on vortex behavior in the vicinity of the runway. The international community has also provided data regarding vortex encounters through an established reporting system located in the United Kingdom. France, Germany, and The Netherlands have been participants in this effort.

The FAA also continued its development of the Integrated Terminal Weather System which will provide short-range forecasts and warning notices for pilots and air traffic controllers. The agency conducted prototype tests at the Orlando and Memphis airports. Among other improvements in **aviation weather services**, the FAA and NOAA's Forecast Systems Laboratory continued testing the improvements in the analysis and forecasting of weather data at Denver's Stapleton Airport, using the Aviation Gridded Forecast System (AGFS), which provides more accurate and timely weather information. The National Center for Atmospheric Research also continued assisting the FAA in developing aviation weather products, which will be tailored for enroute application. NOAA and the FAA continued evaluations of prototype aviation user products at the Denver airport and NOAA's National Aviation Weather Advisory Unit in Kansas City.

During the year, the FAA completed the report, "Other Ways to Characterize the **Icing** Atmosphere," which facilitates the use of icing-related variables for the design of aircraft ice protection systems, computer modeling, icing tunnel settings, and evaluation of flight test results with regard to icing. The agency continued the assessment and verification of commuter aircraft with potential susceptibility to ice-induced stalls of the tail. In cooperation with NASA, the FAA initiated efforts to develop techniques to recognize this susceptibility during icing certification testing. Also in cooperation with NASA, the FAA has been developing simulation methodologies and analytical techniques from which to design and test ice protection systems. The FAA incorporated much of this and related information on ice protection into its FY 1994 update to the *Aircraft Icing Handbook*. The agency continued its investigation of technologies associated with aircraft ground deicing and anti-icing fluids, optimal application procedures, holdover-time guidelines, and associated aerodynamic effects. The FAA also undertook research, development, and evaluation of surface ice detectors and related technologies. One surface ice detector system will be evaluated in a cooperative effort with United Airlines.

The FAA and the manufacturer installed all 190 federally procured **automated weather observing systems**, with nearly all having been commissioned. Forty-two automated surface observing systems, the result of a cooperative program of the FAA and the National Weather Service (NWS), have been commissioned, 40 by the NWS and 2 by the FAA.

During FY 1994, the FAA developed a research and development data base to address the **electrical hazards** associated with lightning. In addition, the agency continued its joint programs with NASA's Langley Research Center, the DoE's Lawrence Livermore National Laboratory in California, and the DoC's National Institute of Standards and Technology to study the effectiveness of shielding aircraft and airframes from lightning and high-intensity radiated fields, emissions that could interfere with electronic systems.

The FAA's Terminal Doppler Weather Radar (TDWR) provides timely detection of **hazardous wind shear** in and near airport terminal approach and departure corridors, and it reports that information to pilots and controllers. FAA plans call for acquiring 47 systems for deployment at 45 airports. During FY 1994, the agency commissioned a TDWR at Houston and installed the system at Denver, Memphis, New Orleans, Orlando, and St. Louis. A related system, the enhanced Low-Level Wind shear Alert System (LLWAS), was on hold at the end of the fiscal year while the FAA analyzed the need for sustaining LLWAS another 15 years at 38 airports not scheduled to receive either a TDWR or an airport surveillance radar wind shear processor.

Also during FY 1994, the FAA completed development, testing, and installation of a modification to integrate data from the **Next Generation Weather Radar** (NEXRAD) into the Meteorologist Weather Processor I (MWP I)—an existing system that provides meteorologists located in ARTCC's with weather data, processing, and display capabilities to support real-time air traffic control operations across the United States. The NEXRAD modification provides access to individual radar products from all operational NEXRAD's as well as regional and national weather radar mosaics. The agency completed installation of the modification in all 21 ARTCC's and the new Air Traffic Control System Command Center in Herndon, Virginia, in May 1994.

Flight Safety and Security

In the area of **advanced materials and structural safety**, the FAA published two reports on delamination methodology for composite structures, describing how to assess size and location of delaminations on composite airframes to determine their effects on strength and service life. The FAA used recently developed software to assess the structural integrity of all composite Learfan aircraft. Nondestructive inspection and analysis in the field have shown that the delaminations found were smaller than the allowable damage sizes. The agency also published a report exploring the use of an ultrasonic resonance technique to find weak bonds. The technique proved to be 97-percent effective in detecting known weak bonds but was subject to a range between 14 and 31 percent of false reject errors depending on the evaluation criteria. In-house research resulted in two completed chapters for a handbook on bonded and bolted joints in composite structures. The program office also presented three papers on advanced materials and bolted joints at conferences during this fiscal year. Also during the year, the FAA conducted a vertical drop test of a 10-foot section of a narrowbody fuselage to determine the reactions experienced by the fuselage, onboard overhead bins, and the auxiliary fuel tank system. NASA, in conjunction with the FAA, conducted a pendulum swing test of a Learfan 2100 to determine the reaction of the composite-material fuselage. The FAA had experimental energy-absorbing seats installed on this airplane to determine its reactions. In addition, the agency upgraded the computer program "KRASH" with an algorithm for aircraft impacts into soft soil. The FAA published a report that reviewed and analyzed worldwide impact and ditching performance into water for transport aircraft for the years 1959 to 1991 to determine the adequacy of current ditching requirements. Also, the agency published a report that surveyed and analyzed current rotorcraft flotation systems.

In cooperation with NASA, the FAA sponsored an international symposium on methods for maintaining the structural integrity of **aging aircraft** during 1994. The two agencies also conducted numerous technical workshops on this increasing problem in the U.S. commercial air transport fleet. The FAA published a revised program plan on research in this area in October 1993, as well as a quarterly newsletter during the fiscal year and a draft advisory circular. The FAA developed a prototype immersion device for focused ultrasonic inspections in the vertical and reverse horizontal positions, then tested the device both in the laboratory and in a field demonstration at Northwest Airlines. Also, the agency integrated its self-compensating ultrasonic technique for the detection of fatigue cracks and corrosion with commercially available hardware and software and conducted laboratory and field tests of the resulting system on manufactured samples provided by Northwest Airlines. Under an international agreement with Transport Canada, the FAA developed an enhanced visual inspection device for rapid surface corrosion detection called D-Sight. It tested that system on the Boeing 737 belonging to its Aging Aircraft Nondestructive Validation Center as well as on an Air Canada aircraft. Other achievements of the FAA during the year included publishing a damage-tolerance handbook and video for engineering and maintenance personnel; a prototype software package on aircraft and fuselage repairs; a 2-week video survey of landing parameters undertaken with Navy personnel at Kennedy International Airport; and a prototype safety performance analysis that it has installed in 24 regional and field offices, FAA headquarters, the FAA Technical Center, and the DoD's Air Mobility Command. Meanwhile, NASA experimentally verified its two-dimensional models to predict the residual strength and fatigue-crack growth of aging structures. It developed software and transferred user-friendly computer codes to industry. NASA completed successful field demonstrations of several prototype, portable instruments for detecting corrosion and small fatigue cracks in aircraft structures. These led to product licensing agreements and cooperative partnerships with industry to develop commercial equipment for use by airline maintenance personnel. A novel, self-nulling eddy-current instrument developed by scientists at Langley Research Center is capable of detecting fatigue cracks as small as 0.05 inches. It can map corrosion damage to accuracies within 3 percent of wall thinning in aluminum sheet material. Under a new licensing agreement with NASA, the Kraut Kramer Corporation will develop and build several advanced prototypes for industry and FAA evaluation, including a battery-powered, handheld instrument for field inspections. The advanced technology being developed by NASA in this area has many dual-use applications. Under a recently implemented memorandum of understanding between NASA and the Air Force, these technologies will be specialized and transferred to air logistics centers to assist in the safe and economical operation of aging military weapons systems well into the next century.

In another area related to flight safety, the production of halon fire extinguishing agents, used extensively in commercial transport cargo compartments, engine nacelles, lavatory trash receptacles, and portable extinguishers, ceased on January 1, 1994, because of their contributions to the depletion of the ozone layer. During the fiscal year, the FAA initiated a test program to develop certification criteria for halon replacement agents, evaluating water spray, pyrotechnically generated aerosol, and a hydrochlorofluorocarbon gas on cargo compartment fires; it found them not as effective as halon. As a result of this and tests to determine flight attendants' effectiveness in fighting cargo compartment fires, the FAA will develop new cargo compartment **fire protection** requirements for commuter airplanes. In FY 1994, the agency completed testing to ensure greater survivability of flight data and cockpit voice recorders subjected to postcrash fire. Since 1989, six accidents have occurred worldwide in which vital flight recorder data were lost because of the thermal degradation of the magnetic tape recording media. Based in part on the completed testing, the FAA will propose new fire test certification criteria. The new test will double the exposure time of the current fuel fire simulation test and add a new fire test requirement to simulate a long-duration, smoldering fire that may occur at a remote accident site.

The FAA also completed tests at a number of large airports to evaluate and develop a Drivers' Enhanced Vision System (DEVS) for **Aircraft Rescue and Firefighting** (ARFF) vehicles to improve response capability under conditions of poor visibility. DEVS consists essentially of a forward-looking infrared system for enhanced driver visibility and a GPS/Geographic Information System (GIS) for vehicle positioning on a map display. The FAA also completed fire extinguishing tests on two halon replacement agents, perfluorohexane and Halotron I, for application in flightline extinguishers and ARFF vehicle extinguishing equipment. Halotron I with improved discharge characteristics proved to be the more effective of the two in extinguishing aircraft and fuel fires.

The FAA Technical Center continued working on the development of an unleaded **aviation gasoline** for use in the existing fleet of general aviation aircraft with piston engines. This program is primarily concerned with issues of safety certification and eventually will culminate in a new fuel specification, but it has generated data on environmental and maintenance issues as well. The principal research topics include octane requirements, emissions, and endurance. The FAA, various oil companies, and engine manufacturers have been working together to develop standard testing procedures to identify the minimum octane requirements of the existing piston aircraft engines. In support of the octane requirement study, the FAA compiled surveys identifying the properties of autogas that is currently used in light aircraft, as well as an aircraft registry summary showing the number of single-engine piston aircraft certified on each fuel grade. The emission tests compared a base fuel to a similar fuel containing various percentages of methyl tertiary butyl ether (MTBE), with fuel flows adjusted to obtain equivalent energy densities. The results showed a decrease in carbon monoxide and NO_x in exhaust gases. In addition, more power was generated using increasing amounts of MTBE. Tests in late September 1994 identified the octane requirements of current test engines before use in a flight test program.

The FAA continued to develop and research technologies and methodologies to mitigate and **prevent catastrophic failure** of aircraft. As the year ended, studies and tests were ongoing in areas of flight control technologies, lightweight material barriers for high-energy rotor fragment mitigation, and aircraft loads. Grants and small business innovation research awards have further expanded research in aircraft control, load technology, and rotor fragment mitigation. During FY 1994, the agency and NASA's Lewis Research Center in Ohio completed evaluation tests of a Health Usage Monitoring System (HUMS) for rotorcraft. This evaluation will help the FAA develop certification and regulatory criteria for HUMS operation on rotorcraft.

The recent advent of larger and heavier civil transport aircraft has necessitated advanced technology for proper assessment of whether **airport pavements** remain safe. The FAA continued its comprehensive Airport Pavement Research Program, including the development of advanced pavement design methodologies. In August 1994, the FAA signed an agreement with the Army Corps of Engineers for construction of the first National Airport Pavement Test Machine facility. It will provide full-scale testing data urgently needed to investigate the performance of airport pavements subjected to the complex gear loads of the new generation of aircraft. The FAA also completed the construction of the first fully instrumented runway section at the Denver International Airport. Using planes of various sizes and tire configurations, the agency completed the calibration of a system of almost 500 sensors to collect data in real time, providing the first source of accurate information on pavement performance. Also during the fiscal year, the FAA introduced a layered elastic design method with guidelines to permit airports to cope with the Boeing 777's impact on their pavement once it begins commercial flight in 1995. Also, as a part of its efforts to develop an index of runway roughness, the FAA completed a field study at 10 selected airports. The study will determine appropriate limits and corrective measures for irregular runway profiles.

The FAA continued efforts to identify, initiate, and coordinate actions to promote technology applicable to **general aviation and vertical flight** in the national airspace system. The agency initiated work to improve coordination and cooperation with NASA on general aviation programs of mutual interest, such as innovative aircraft design, new cockpit display and control technologies, enhanced ground/cockpit information systems, noise reduction, and situational awareness for safety. Research continued with NASA's Ames Research Center to develop steep-angle approach profiles to reduce rotorcraft noise. The FAA continued to conduct flight tests for development of criteria for GPS nonprecision-approach, terminal instrument procedures for use at heliports across the Nation. Such tests are part of a program to improve safety for rotorcraft instrument flights in poor weather conditions. The agency is participating with NASA, the DoD, and industry as part of the National Rotorcraft Technology Center to promote and expand the U.S. rotorcraft technology base as well.

During FY 1994, the FAA continued its efforts to strengthen **civil aviation security** through research and development, initiating extensive tests at its Security Research Laboratory. These included the evaluation of a resonance device for explosive detection in baggage and of two commercially available, trace-explosives-detection devices, as well as the development of standards for explosive detection devices. The FAA also deployed agency-owned, commercially available explosives-detection equipment at three U.S. airports for test periods of 3 to 6 months each. Another airport test/demonstration evaluated a tomography x-ray device to detect explosives in baggage. The manufacturer of this device became the first company to apply for certification testing under the FAA's criteria for explosives-detection systems. Additional research included the evaluation of two prototype personnel portal screening devices and of two explosives-detection devices for baggage at Glasgow International Airport, Scotland. The agency also completed its first series of characterization tests for luggage containers. The completed testing of an enhanced airport security system at Baltimore/Washington International Airport yielded more than 70 reports being made available to industry. During the fiscal year, the FAA held security awareness gaming exercises at three domestic airports and conducted an operational test and evaluation of an improvised explosive device using black-and-white and color-enhanced x-ray machines, both before and after specialized screener training. Also, the agency developed the functional requirements for a screener proficiency evaluation and reporting system. In addition, the FAA developed, operationally tested, and evaluated a profiling technique for domestic passengers to highlight passengers categorized as high-security risks.

Aviation Medicine and Human Factors

The FAA completed final details concerning the procurement of a reconfigurable advanced general aviation research simulator, with installation at the Civil Aeromedical Institute scheduled for the first quarter of FY 1995. Work has continued on enhancing the capability of a system used to recreate air traffic controller incidents with the objective of developing controller and sector-task-load measures. During the fiscal year, the agency also initiated joint international research projects with The Netherlands and Sweden to evaluate and validate a computerized test as a selection instrument for air traffic controllers. An extensive field study in several FAA regions evaluated a "pen-based" computerized job aid that allows information to be entered into a computer by using a stylus to write directly on the computer screen. The FAA aviation inspectors were provided with these systems and specially developed software in a study of methods for improving the efficiency and quality of the inspectors' work. The FAA also evaluated human blood and tissue samples for toxicologic analysis from over 80 percent of all pilots in civil aviation accidents. Positive chemical or pharmaceutical findings were noted in 34 percent of these cases. The FAA's forensic capabilities were enhanced by the introduction of a Deoxyribo-Nucleic Acid (DNA) laboratory that facilitates specimen identification and by more sensitive methods to detect newer cardiovascular and tranquilizer medications.

The FAA completed a study on the effect of automation on corporate aircraft pilots; it suggests that errors made by pilots could be alleviated by redesigning cockpit computer programs. The FAA's study of flight deck information management resulted in preliminary guidelines outlining functional control and display requirements as well as procedures for the classification and prioritization of information on future flight deck systems. Research also showed that human performance would be improved by functionally grouping flight deck information and integrating displays. During the fiscal year, the FAA also designed a handbook on improving the presentation of instrument-approach-procedure charts. The agency studied the human-factor problems associated with the operation of the Loran-C and GPS systems, focusing on input controls, software logic, viability and order of displayed data, and the complexity of all available functions. Problems in these areas have limited the use of these systems and affected the operational integration of the systems into the national aerospace system; they may pose a safety problem if uncorrected.

Additionally, agency research on crew resource management and decisionmaking focused on reviewing existing empirical information on the variables affecting situational awareness, identifying individual and team-level behavioral skills, and developing a model to test and validate these skills. The FAA supported NASA in its aeronautical decisionmaking research by reviewing current knowledge about it and related research, developing preliminary criteria for effectiveness, and investigating decisionmaking scenarios. The FAA also conducted research dealing specifically with aeronautical decisionmaking in general aviation settings. That research dealt with improving the decisionmaking skills of inexperienced pilots in such areas as weather avoidance and risk assessment. To support this effort, the agency conducted a national survey of pilots to determine typical experience levels, training activities, and attitudes toward safety issues. The agency also initiated a study of the automated performance measurement system, designed to measure when and why crew performance diminishes in the cockpit. Although the benefits of the system range from improved flight safety to validation of air traffic control procedures and air carrier training, the FAA discovered problems such as difficulty in converting data into useful information. Agency researchers concluded that the system must be affordable, goal-directed, and tailored to the immediate use of airlines. The FAA's investigations of shift schedules for air traffic controllers resulted in the completion of both laboratory and field studies to determine the effects of the rapidly rotating shift schedule on sleep and performance. The agency used the findings to develop strategies for coping with sleep loss often associated with shift work. The FAA also initiated research to evaluate the effectiveness of fatigue countermeasures. The effects of fatigue while monitoring a simulated air traffic control display revealed a number of significant changes in eye movement that could serve as possible indicators of loss of alertness. The agency initiated a follow-on study to determine the feasibility of using noninvasive techniques to assess changes in eye movements as potential measures of a loss of attention or a decline in alertness.

Studies of the Planet Earth

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

Terrestrial Studies and Applications

Terrestrial studies themselves encompass a broad range of activities. Among them was NASA's demonstration during FY 1994 of two new techniques for observing the environment from space. The first of these was a multifrequency, multipolarization radar—the most complex civilian radar ever flown in space—to study ecology, water cycles, vegetative cover, oceanography, geology, and volcanology. In cooperation with Italy and Germany, the **Space Radar Laboratory** flew on the Space Shuttle Endeavour during April (SRL-1) and September-October 1994 (SRL-2). These missions have enabled a team of 52 scientists and ground teams around the world to observe the shifting boundaries between temperate and boreal (northern) forests, plus other natural phenomena. The results will be used for mapmaking, study, and interpretation. For example, the USGS has begun studying the Sahara in North Africa, the southern part of Africa, Asia, and the southwestern United States using images from the SRL. Because radar signals penetrate dry sand and produce images of geologic features otherwise concealed by windblown sand in desert regions, the radar laboratory's images are being used to map the distribution of various geologic indicators of climate change and of untapped resources, particularly those related to old, dry river systems.

During April and May 1994, NASA and the Canadian government conducted a campaign known as the **Boreal Ecosystem-Atmosphere Study** (BOREAS)—a large-scale, ground-based and remote-sensing investigation of how the forests and the atmosphere exchange energy, heat, water, carbon dioxide, and other trace gases. SRL-1 repeatedly imaged BOREAS ground sites, allowing scientists to compare the spaceborne data with their readings from ground and aircraft investigations. Sample results indicate that water evaporation rates in the boreal (northern) forests of central Canada are extremely low. These data will correct current models that overpredict atmospheric moisture. In a tangentially related development, in August 1994 NASA, NOAA, and the Canadian Space Agency reached final agreement on the data policy for the Canadian Radarsat spacecraft. Once launched, Radarsat will map the world, collecting all-weather data of particular value over ice and oceans. The program plan calls for tilting the satellite to provide a complete mapping of Antarctica as one of the mission objectives.

The second of NASA's new techniques for environmental observation was lidar—using a laser in a manner similar to radar by bouncing it off objects (e.g., clouds, pollutants, the Earth's surface) and then making environmental measurements from the reflected energy. The **LIDAR In-Space Technology Experiment** (LITE) flew on the Space Shuttle Discovery in September and observed clouds invisible to conventional weather satellites, dust clouds over Africa, and the structure of a super typhoon in the Pacific, including the top level of clouds and the storm's eye.

In June 1994, meanwhile, NASA announced that it had competitively selected two industry-led teams to build, launch, and operate two **experimental satellites**—each no bigger than a console television set and commonly referred to as "Lewis and Clark"—as part of NASA's small spacecraft technology demonstration. The entire contract process lasted only 70 days instead of the standard 6 months to a year. "Lewis" will be the first-ever space-based "hyper-spectral" imaging system, with wide applications in Earth science and new commercial business opportunities. "Clark" will help city planners and developers evaluate sites and construction needs through the use of an optical element with very high spatial resolution and capabilities for stereo imaging. Both spacecraft will carry additional instruments that will provide information on the dynamics of global atmospheric pollution for NASA's Mission to Planet Earth (MTPE).

MTPE has included education and public awareness as part of its vision to ensure that the public has sufficient information and understanding to support the development of prudent policy in the future regarding global environmental change. Significant efforts are under way at the Federal and agency levels and within MTPE to coordinate and convey program results more effectively. In this connection, so as to be a catalyst for progress, NASA has begun addressing educational challenges at several levels—training the next generation of Earth scientists who will approach global change from an interdisciplinary perspective, training teachers at the undergraduate level to provide the tools to teach Earth system science, and educating the public at the societal level to build confidence in and understanding of scientific methods. One of the priorities of the **U.S. Global Change Research Program** (USGCRP) is to address and contribute to scientific education and communications. In April 1994, Vice President Albert Gore, Jr., announced Global Learning and Observations to Benefit the Environment (GLOBE), a major new initiative to have students from around the world make measurements, submit them to a central source for processing, and analyze the collective findings. Scientists will be able to use the results in their environmental research. NOAA and NASA have been leading this effort with contributions from the NSF, EPA, the State Department, and other agencies. The agencies of the USGCRP made significant progress during the year in improving coordination in education and outreach, including the development of teacher training materials, the provision of fellowships in environmental research, and contributions to new national standards for the teaching of science.

NASA-sponsored analysis of **data from Landsat**-4 and -5 for 1978 and 1988 showed that deforestation in the Brazilian Amazon Basin was lower than some previous estimates had suggested. However, the fragmentation of the rain forest and the "edge effects" on the perimeters of these fragments were greater than had been believed, potentially increasing the threat of species extinction. Tropical forests are home to nearly half of all plant and animal species on the Earth. Researchers concluded that while the area of deforestation had nearly tripled in the 10-year period, the total deforested area was smaller than predicted by many other studies. Working in close cooperation with researchers from Brazil, the authors of the study validated the use of Landsat data for estimating deforestation in the Amazon, previously an issue of substantial controversy. Other researchers also demonstrated Landsat's effectiveness by combining its imagery with GIS technology to identify types and location of landscape elements associated with the risk of Lyme disease in Westchester County, New York. Also, analysis of data from a combination of Landsat, airborne, and ground-based scanners continued to be used to battle pest damage to California's $10 billion-a-year wine industry. About 65 percent of Napa and Sonoma Counties' vineyards are planted with a grape rootstock vulnerable to a new variety of phylloxera, an aphid-like insect that kills grapevines by sucking juice from their roots. The spatial and spectral analysis from Landsat's scanners can detect problems before they become visible to vintners.

Relatedly, the USGS **EROS Data Center** is the Distributed Active Archive Center (DAAC) for data about land processes to be acquired and distributed in support of the Earth Observing System (EOS). Its functions include storage, management, and distribution of data from the Moderate Resolution Imaging Spectrometer and Advanced Spaceborne Thermal Emission and Reflection Radiometer, which will fly on the first EOS platform in 1998, and from Landsat-7. The EROS Data Center was also planning to archive and distribute other data sets through its Land Processes DAAC, including data from the Advanced Very High Resolution Radiometer (AVHRR) on NOAA's polar-orbiting satellites, digital aircraft scanner data, digital topography, and associated ancillary data. The EROS Data Center DAAC component of the EOS Data and Information System (EOSDIS) Version 0 became operational in FY 1994, providing user access to electronic networks, interoperable catalogs, and data distribution capabilities at the EROS Data Center as well as at the other DAAC's. The center was in the process of converting historical Landsat data from aging magnetic media to new cassette tapes to preserve them for future use. It completed the conversion of 352,000 Landsat Multispectral Scanner scenes acquired since 1979, and it also converted about 30 percent of the Landsat Thematic Mapper (TM) data in the archive.

The **National Geophysical Data Center** (NGDC) within NOAA had a fully operational center for processing, archiving, and disseminating data from the DMSP. It became fully operational during the fiscal year, processing data within 48 hours of collection by the Air Force and provided browse images routinely on the Internet. Also available on the Internet, NGDC's geophysical online data were accessed by an order of magnitude more users than just a year before. Also, NGDC employees visited more than 30 different classrooms in local schools throughout the year to present workshops on such subjects as earthquakes, volcanoes, and geomagnetism.

Information management is one of the main program elements of NOAA's **Climate and Global Change** (C&GC) program. It provides the scientific community with the data and information necessary to evaluate the variability of the global environment, distinguish between natural and human-induced change, and perform integrated assessments of changes in climate and their societal impacts. Foci of the program include data base development (rescue, digitization, and assembly of high-priority data sets); data access and archive management, which provide the means to make the data sets available to scientists; and Pathfinder, which is developing community-consensus algorithms for the reprocessing and dissemination of large-volume, multidecadal, global-scale, operational-satellite data sets. In FY 1994, the program supported governmental and academic researchers in 31 projects.

As part of the Landsat **Pathfinder** program, the USGS has been producing standardized Landsat Multispectral Scanner data sets from three periods (1973, 1986, and 1992) to support the EPA's North American Landscape Characterization Program. In FY 1994, it produced about 400 out of a total of 4,000 scenes for parts of the United States, Mexico, and Central America. The USGS has also been cooperating with NASA plus the Universities of New Hampshire and Maryland to produce similar three-date-time-series Landsat data sets for the Humid Tropical Forest Inventory Project, which is studying the tropical forest regions of the Amazon Basin, Central Africa, and Southeast Asia. These data sets will serve to monitor changes in land cover over these areas during the 20-year period since the beginning of the Landsat program. In a separate project using lower-resolution satellite data, since 1992 the USGS has been working with NASA, NOAA, ESA, and more than 31 foreign ground receiving stations to collect AVHRR data (1-km resolution) for each afternoon pass of the NOAA polar-orbiting satellite over the Earth's land surface. This Pathfinder project had collected over 93,000 AVHRR scenes by the end of the fiscal year. They were being used to produce a global land-cover map and to monitor vegetation conditions (greenness) on a periodic basis throughout the year. Routine production of cloud-free composite data for a vegetation index of all global land areas was also under way at the end of the year. The USGS was cooperating with the EPA, NOAA, and the U.S. Fish and Wildlife Service to prepare a baseline of global, multiscale data on environmental characteristics and to develop mechanisms for identifying, monitoring, and assessing environmental change. The resulting Multi-Resolution Land Characteristics Monitoring System will be essential for understanding the dynamics of the Earth as a system.

Through a directive from OSTP, an interdisciplinary, interagency Scientific Assessment and Strategy Team formed to provide scientific advice to Federal officials making decisions about recovery and **river-basin management** following the severe flooding of the Upper Mississippi and Missouri River basins in 1993. The team included specialists from the USGS, U.S. Fish and Wildlife Service, National Biological Survey, Soil Conservation Service, Army Corps of Engineers, EPA, and Federal Emergency Management Agency. Working at the EROS Data Center, the team produced numerous maps and analyses, as well as a substantial environmental information system for the two basins using remotely sensed, map, and environmental data. This includes a wide variety of data made available on the Internet. The team's preliminary report documents the data and analysis provided to the Interagency Floodplain Management Review Committee, which was providing policy recommendations to the Administration.

In other DoI activities, the **Bureau of Reclamation** used remote sensing and GIS's to aid in the management of water resources. During FY 1994, it used aerial photographs and multispectral data from the Landsat TM and SPOT to map irrigated lands, riparian vegetation, and open water at a number of locations in the Western United States. It used these maps and other spatial data in a GIS with environmental models to estimate consumptive water use. Airborne video and thermal infrared scanner imagery were used to map river habitat for endangered fish in the Colorado River system, enabling managers to release water from reservoirs in such a way as to maximize survival of the endangered species.

The **Bureau of Indian Affairs** continued to conduct natural resource inventories, image mapping projects, and GPS training services to support its Indian Integrated Resource Information Program. Analysts used Landsat TM data to classify land use on several Indian Reservations for forestry and wildlife management applications. The Bureau continued land cover inventories on reservations in New Mexico and Arizona with emphasis on modeling the potential burn rate of different vegetation types in response to fires. Landsat TM and SPOT panchromatic data enabled the Bureau to prepare image maps for three reservations, while GPS training supported resource inventory programs.

The **Bureau of Land Management** used remotely sensed data and GPS to monitor the health of public lands and the effectiveness of ecosystem-based management practices. Landsat, SPOT, and AVHRR satellite data plus aerial photographs supported ecosystem-based management of mineral resources, land-use planning, fire fuels mapping, characterization of wildlife habitat, and delineation of hazardous materials and their impacts at a number of sites on public lands throughout the United States. GIS and GPS technology supported much of this analysis.

The **National Biological Survey**, now 1 year old, has continued a wide variety of remote sensing projects transferred from other DoI bureaus. The Gap Analysis Program, a statewide and national program to identify land areas not being protected and managed to maintain biological diversity, was one such program transferred from the U.S. Fish and Wildlife Service. The program is based on mapping of actual natural vegetation from Landsat TM and other data using a nationwide classification system for vegetation. Standardized mapping methods and data formats permit the aggregation of State-level data for comparison at regional and national levels. At the end of the year, projects were under way in 36 States, with data from Nevada and Washington nearing completion. With adequate funding, complete national-level data sets will be available by 1999.

The **National Park Service** initiated a comprehensive, multiyear program in FY 1994 to map vegetation in 235 units of the National Park System, excluding Alaska. The program will provide consistent baseline digital data about the composition and distribution of vegetation to support the National Park Service Inventory and Monitoring program. Mapping will be done through the interpretation of medium-scale (1:20,000) natural color and color-infrared aerial photographs using a nationwide standardized classification system. The National Biological Survey is working closely with the Park Service to plan and direct the project, beginning with pilot studies in a variety of selected park environments.

With transfer of research activities to the National Biological Survey in FY 1994, the U.S. **Fish and Wildlife Service** began emphasizing use of computerized mapping, aerial photographs, and Landsat and SPOT data for day-to-day operations, especially managing wildlife habitat from an ecosystem perspective. It has used remotely sensed data and GIS technology to evaluate the effects of habitat changes on migratory birds, assess threats of environmental contaminants to biological resources such as endangered species, and identify the most valuable lands for inclusion in new refuges such as Canaan Valley, West Virginia. The Service also led a Federal Geographic Data Committee effort to develop national standards for mapping wetlands and was active in a similar attempt to define a standard for mapping upland vegetation. These activities will reduce costs for acquiring remotely sensed data and increase the consistency of the resultant maps of these resources.

The U.S. **Bureau of Mines** has directed its remote sensing research to the development of applications to abandoned mine land areas. This innovative technology will address the identification and characterization of mineralogy of waste materials and the associated potential for the development of acid mine drainage and occurrence of heavy metals at these sites. The applications utilize Landsat TM satellite images and airborne multispectral scanner data and were field tested in the Cripple Creek Mining District in central Colorado. The successful completion of this research will provide a quick procedure for inventorying and initial characterization of noncoal mine waste materials, providing land management agencies with an increased ability to focus on the remediation of these sites.

Within the U.S. Department of Agriculture (USDA), the remote sensing program of the **Foreign Agricultural Service** (FAS) continued to be a critical element in the analysis of domestic and foreign agricultural production, supply, and demand—providing timely, accurate, and unbiased estimates of global area, yield, and production. The agency used satellite imagery, crop models, and remotely sensed weather data to support State Department assessments of food needs in the states of the former Soviet Union, particularly the drought-affected Ukraine. The FAS also prepared detailed analyses of the performance of India's summer monsoon, frost damage to Brazil's coffee crop, and drought in Australia's eastern wheat regions. Satellite-derived early warning of unusual crop conditions allowed for price adjustments in commodity markets and helped maximize U.S. farmers' returns. In addition, the FAS used satellite imagery to monitor domestic crop production areas in support of work carried out by the Agricultural Stabilization and Conservation Service (redesignated the Farm Service Agency in October 1994).

The National Agricultural Statistics Service (NASS) used remote sensing data in constructing area frame samples (using data from small sample areas as an aid to estimating crops and acreages), crop-specific land cover mapping, direct estimation of planted crop area, and assessment of crop conditions. Products from the first three areas were mainly based on Landsat-5 TM and SPOT Multispectral Scanner data. Crop condition assessment used data from the NOAA-11 satellite. In 1994, NASS completed a California area frame for conducting 1994 surveys, and New York and South Carolina frames for survey use in 1995, and it initiated work on a Kansas frame. Among a host of other activities, NASS improved biweekly vegetative index map products for the 1994 crop season, based on NOAA-11 AVHRR data, and distributed them to NASS offices and USDA policy makers for their use. Starting in the fall of 1993, NASS entered into a cooperative agreement with the Intertribal Agricultural Council to collect pilot-level data on Native American farm operator production. One result of the agreement was a crop-specific land-cover map of the Crow and Northern Cheyenne Reservations in Montana, delivered in September 1994. Another satellite data application was the Delta Remote Sensing Project in Arizona. It regressed multitemporal, computer-classified Landsat TM data against ground information to provide estimates with reduced sampling error for rice, cotton, and soybean acreage. The resulting data provided county acreage estimates for the 1993 season in tabular form and in colored theme-map and tabular form. NASS continued to produce biweekly vegetative index map products based on NOAA-11 AVHRR data during the 1994 crop season. It distributed the maps to USDA decisionmakers and to various NASS state statistical offices to aid in assessments of crop conditions. In 1994, NASS improved the maps in several ways, such as adding the capability to compare the current value with a meridian of several previous years. However, due to the aging NOAA-11 satellite, on which one AVHRR ceased to function in September, and a relatively unstressed crop year, the 1994 maps contained less information than those of 1993 when the Midwest flood and the Southeast drought were featured in the maps.

The **Agricultural Research Service** (ARS) used remote sensing and GIS technologies to provide information about the extent and spatial dynamics of leafy spurge, a troublesome weed, in the Theodore Roosevelt National Park, North Dakota, among many other applications. The results contributed to the development of a management plan for leafy spurge in the park and provided insight into the application of integrated spatial technologies for natural resource management. Other uses of remote imaging together with data from the ground included maps of soil salinity, biomass, crop management, and crop yields. For example, a cooperative program was undertaken examining commercial cotton fields in the San Joaquin Valley of California, aimed at developing integrated tools to produce crops that maximize economic return, support efficient use of natural resources, and minimize detrimental impacts on the environment. ARS researchers also developed fluorescence techniques and a prototype fluorescent instrument to discriminate and quantify crop residues. The effective management of these remains from the harvest minimizes soil erosion and improves water quality. In the area of hydrology, ARS scientists, in close cooperation with NASA and the DoC, used ground-based and remotely sensed data to aid in understanding how conditions in river basins influence climate and climate change. ARS also is using space signals to help develop "precision farming systems" that permit land managers to adjust the treatment (with fertilizers, pesticides, or seeding rates) continuously across a field based on detailed local knowledge.

In 1994, the **Forest Service** (FS) used remote-sensing and associated technologies to assist in fighting fires throughout the Western United States as well as to detect high-risk fire zones, assess damage, monitor national and foreign ecosystems, and administer/manage more than 191 million acres of National Forest System land. The number of wildfires reached a record high in 1994, with more than 66,000 fires and over 3.8 million acres burned. To combat these blazes, the FS employed airborne scanners, including Firefly developed by the JPL, to help map and determine both the speed and direction of the fires. Throughout the year, the FS used such remote sensing technology as AVHRR imagery from NOAA satellites to implement early-warning measures. Once fires started, the FS shifted to greater use of imagery from aircraft. When fires had been suppressed, the FS employed satellite imagery to map and assess changes in the landscape caused by the fires. Other uses for remote sensing included mapping, vegetation classification, the rehabilitation and restoration of ecosystems, research for global greenhouse gas emissions, land management, identification of critical wildlife habitat, support of law enforcement, and inventory programs. The FS initiated partnerships with international, Federal, State, and private organizations for ecosystem assessment, leading to greater use of satellite data and increased understanding of global ecological processes. For example, technical exchanges continued with Russia, Brazil, Indonesia, Mexico, Canada, Australia, and Kenya, among other countries. FS research and development of airborne video, digital cameras, radar, and GPS systems continued to address numerous ecosystem management applications. Integration of remotely sensed data into GIS's proved to be cost effective in supporting land management decisions.

The **Soil Conservation Service** (redesignated the Natural Resources Conservation Service or NRCS in October

1994) adopted digital orthophotography as the common framework for collecting and managing natural resource geospatial databases. The Service cooperated with other Federal and State agencies to acquire aerial photography and digital orthophotography. In addition, it and other USDA agencies agreed with the DoD to purchase GPS units to collect georeferences for natural resource data to be included in a GIS.

The U.S. **Environmental Protection Agency** (EPA), primarily through its Environmental Monitoring Systems Laboratory in Las Vegas, Nevada (EMSL-LV), with assistance from its Atmospheric Research and Exposure Assessment Laboratory in Research Triangle Park, North Carolina, also routinely conducted research and provided technical support using remote sensing as part of its overall environmental monitoring program. The EPA used large-scale aerial photography to develop site characterization data during the remedial actions under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), as well as to support site selection and monitoring at hazardous waste facilities operated under the Resource Conservation and Recovery Act (RCRA). It developed and used remote-sensing systems to support the provisions of the Clean Water Act. In FY 1994, the EMSL-LV completed approximately 150 aerial-photographic site-characterization projects under CERCLA and RCRA, and satellite imagery played a part in helping engineers develop detailed site characterizations. Aerial photography and satellite data also supported a broad variety of pollution, global change, pollution prevention, compliance, and other ecosystem monitoring studies in FY 1994, such as those of critical-habitat areas for wildlife. In support of activities associated with the identification of the impacts and hazards resulting from severe flooding along the Mississippi River and its tributaries in FY 1993, the EPA's Environmental Photographic Interpretation Center (EPIC—a branch of EMSL-LV) analyzed aerial photographs acquired, in cooperation with the Army Corps of Engineers, to identify flood impacts on industrial and agricultural facilities for the assessment of hazardous and toxic waste movement and containment. Additional analysis of pre- and postflood aerial photographs by EPIC in FY 1994 identified and mapped changes that have occurred at known waste disposal sites affected by the flooding.

Atmospheric Studies

NASA's and NOAA's efforts to monitor **ozone depletion** continued to reflect the effects of the Mount Pinatubo eruption in June 1991. Data from NASA instruments such as the Total Ozone Mapping Spectrometer aboard the Russian Meteor-3 satellite (launched in 1991) as well as NOAA instruments aboard balloons and the NOAA-9 satellite have enabled scientists to study the global cooling effects and loss of ozone that resulted from the eruption. These are the first unambiguous, direct measurements of large-scale changes in the Earth's radiation budget caused by a volcanic eruption. Ozone, a molecule made up of three atoms of oxygen, forms a thin layer of the atmosphere that absorbs harmful ultraviolet radiation from the Sun. The term "ozone hole" describes a large area of intense ozone depletion that occurs over Antarctica during late August through early October and typically breaks up in late November. Scientists have determined that chlorine products from human activities, such as electronics manufacturing, air conditioning, and refrigeration, are a primary cause of ozone hole formation. The Antarctic ozone levels for 1994 were nearly as small as the record lows from October 1993. The slight recovery in 1994 probably resulted from fewer sulfuric acid particles remaining from the eruption of Mount Pinatubo. The NSF's Office of Polar Programs continued during the year to support researchers studying the cause and effects of the Antarctic ozone hole at each of three year-round stations. Both balloons for in situ measurements and remote sensing instruments were used. There was a particularly strong effort during the late austral winter and early spring of 1994 to support the NASA-sponsored ER-2 aircraft flights from Christchurch, New Zealand, to study the ozone levels. The Microwave Limb Sounder (MLS) on the Upper Atmosphere Research Satellite (UARS—launched in 1991) continued, meanwhile, to make unprecedented measurements of global chlorine monoxide (ClO) concentration, observing the spatial relationships of ClO, ozone, temperature, and other atmospheric variables. These measurements provide the first global picture of the reactive form of chlorine that destroys ozone. Even though regulations will phase out the production of chlorofluorocarbons in the future, the removal of chlorine from the stratosphere is a very slow process (taking decades or centuries), and stratospheric chlorine will continue to increase for at least the next few years, as chlorine already released into the lower atmosphere reaches the stratosphere. The MLS is providing the only global monitoring of this process during the critical period in which stratospheric chlorine is increasing to record levels.

A major focus of the Upper Atmosphere Research Program (UARP) in 1994 was the Airborne Southern Hemisphere Ozone Experiment/Measurements for Assessing the Effect of Stratospheric Aircraft campaign. The goal of this effort in the Pacific was to obtain in-situ measurements of atmospheric trace gases related to stratospheric ozone. Full analysis of the data combined with model calculations will improve our understanding of the chemistry and processes of midlatitudes. Scientists from NASA and NOAA contributed to the recently completed "Assessment of Ozone Depletion: 1994," developed under the auspices of the World Meteorological Organization and the United Nations Environment Programme. This periodically issued report provides the scientific basis for policy decisions by parties to the Montreal Protocol (the international agreement limiting the use and production of chlorofluorocarbons) and its amendments. NASA's ozone measurements are part of the Agency's **MTPE program**, which includes measurements from instruments on free-flying spacecraft and the Space Shuttle; aircraft, in situ, and ground-based observations; a comprehensive data and information system to process and distribute the findings; and a modeling effort designed to help understand, and eventually predict, the behavior of and changes in the Earth's system as well as to distinguish the effects of natural and human-induced global climatic change. The first phase of MTPE includes the flight by NASA and partners of more than two dozen missions through 1998. Data from MTPE and other global change research efforts will enable policymakers to formulate prudent policies regarding the future of the global environment.

The second phase of MTPE is the **EOS program**, a series of spacecraft planned to carry a variety of sophisticated instruments to make the most comprehensive measurements ever of the interrelated elements of the global environment. NASA's program is part of the international Earth Observing System, in which satellites and instruments from the United States, Europe, Japan, and Canada are being closely coordinated to provide complementary data on different aspects of the Earth's environment. In support of NOAA's GOES program, NASA participated in the successful launch of the GOES-8 satellite in April 1994. GOES-8 and subsequent GOES satellites (J-M) are the prime observational platforms for dynamic weather and the near-Earth environment for the 1990s and beyond. In mid-1994, the EOS program was redesigned to respond to a reduction in program budget through the year 2000. NASA's objectives were to preserve the scientific integrity of EOS as a global change program and to maintain the target launch schedule for core EOS missions. Realigning the EOS program meant placing greater reliance on both domestic and foreign partners, in addition to deferring some data products and measurements. However, some high-priority scientific items were added to the program or scheduled sooner, such as the flight of an additional Stratospheric Aerosol and Gas Experiment (SAGE) instrument in the year 2000 and the incorporation of a Landsat-type instrument on the EOS AM-2 spacecraft (AM indicating a morning crossing time over the Equator). In September, NASA released a major solicitation seeking proposals for a "common" spacecraft bus for several of the subsequent EOS flights, with selection expected in 1995. Meanwhile, development continued on the EOSDIS, the means by which information from MTPE observations and analysis will be archived and made available to researchers and other worldwide users; NASA modified its planning for EOSDIS architecture, making it more extensible and accessible. In August 1994, NASA released Version 0, a working prototype for EOSDIS, designed for the general Earth science community for use in scientific research.

Pathfinders constitute a recent application of Earth-science and other data sets, developed specifically to study global environmental change. They focus on processing, reprocessing, archiving, maintaining, and distributing existing data sets to make them more useful to researchers. In FY 1994, the focus of the joint NASA-NOAA Pathfinder was on generating data for the benchmark period April 1987 to November 1988, but additional data sets included TOPEX/Poseidon, an educational CD-ROM, the First International Satellite Cloud Climatology Regional Experiment, and the UARS. Using Pathfinder data sets, NASA scientists combined NOAA-7, -9, and -11 data on vegetation dating back to 1981 to predict the likelihood of famine and locust plagues in Africa, for use by the U.S. Agency for International Development to locate drought areas and locust swarms. NASA also solicited broadened application of its scientific and technological assets via the Internet. A significant number of the resultant proposals and awards involved using the Internet to make environmental information more readily available for educational purposes.

The NSF also studied global change. Under the **Coupling, Energetics, and Dynamics of Atmospheric Regions** (CEDAR) program, scientists at the University of

Tennessee, Urbana, organized a campaign referred to as ALOHA-93 (Airborne Lidar and Observations of the Hawaiian Airglow). Involving experimenters from several academic and commercial research institutions, its purpose was to study the source and dynamics of gravity waves over the mid-Pacific in October 1993. Gravity waves are a major source of energy and momentum coupling between different layers of the atmosphere from the troposphere to the lower thermosphere. In ALOHA-93, a sodium lidar, optical imager, and spectrometer gathered data from an aircraft, the flights being coordinated with selective overpasses of NASA's UARS (launched in 1991). The campaign obtained important information on midocean storms and generation, propagation, and filtering of gravity waves in the mesosphere and stratosphere. This should lead to better parameterization of gravity waves in global circulation models. The airborne observations also revealed rich horizontal structure in sporadic sodium layers observed in conjunction with substantial increases in mesopause temperature. These metal layers, formed through meteoric ablation, appear to be sensitive to global atmospheric changes related to changing levels of atmospheric carbon dioxide and methane. Also, the CEDAR program sponsored a special competition to encourage the development of innovative technical approaches, resulting in a number of projects to improve instrumentation and techniques.

The NSF has supported studies of how variations in the energy output from the Sun and anthropogenic effects contribute variously to **global change**. The SunRISE (Radiative Inputs of the Sun to Earth) program supports the development and deployment of a precision photometric telescope designed for measurements of sunspots, faculae, and other features thought to be sources of variations in solar brightness. The program also supports measurements of the solar diameter and analysis of the historical measurements of the plage phenomena (bright, granular areas in the chromosphere of the Sun), which are possible indicators of changes in radiance. A second area of emphasis in the last year has been space weather, conditions on the Sun and in the solar wind, magnetosphere, ionosphere, and thermosphere that can significantly influence the performance and integrity of civilian, commercial, and military spaceborne and ground-based technological systems. The NSF supported a study conducted by scientists at Johns Hopkins University in which they used data from a Swedish satellite to predict electrical currents induced in a power grid at Chalk Point, Maryland; they successfully correlated intense electrical currents in the ionosphere with the induced currents on the ground. Other studies of ionospheric currents used magnetometer arrays deployed by scientists from Boston College, Augsburg College, and the University of Michigan. The scientists will use data from these newly created arrays in Canada and Greenland to study dynamic variations in ionospheric currents that originate from the entry of energetic particles from the Sun into the Earth's atmosphere.

Another atmospheric and environmental concern in recent years has been **global warming**. In the first international, interdisciplinary effort to discuss this issue broadly, 37 scientists from 10 countries met near the beginning of the fiscal year at a conference sponsored by the DoE and NOAA. Among the findings of the conference were that while the global average temperature has been rising in recent decades, the warming has not been truly global and has occurred mainly at night. Scientists believe that the cause of higher nighttime temperatures may be the combined result of an increase in greenhouse gases and cloud cover over continents combined with increased sulfur emissions produced by the burning of fossil fuels. A climatic model developed by James Hansen of NASA that took all three factors into account came closer to simulating observed temperature changes than had previous models. While nighttime warming may lengthen the growing season and reduce killing frosts, it might increase insect infestations, reduce crop-growing areas, and raise heat-related death rates among humans. In a study relevant to this issue, NIST has been studying isotropic measurements for NASA to identify and quantify the presence of tropospheric methane (CH_4), which is second only to carbon dioxide (CO_2) in its effects on global warming. Although the tropospheric CH_4 concentration is a small fraction (5 percent) of that of CO_2, CH_4 accounts for about 12 percent of the global temperature rise, due to strong absorption in a relatively transparent part of the infrared. Intensive CH_4 measurement and modeling are under way because of significant uncertainties in both anthropogenic and natural emission data that are critical for estimating the global CH_4 budget. To serve these needs, NIST has compiled a data base of global source and ambient isotropic measurements.

Oceanographic Studies

TOPEX/Poseidon, a satellite jointly sponsored by the French Space Agency, Centre National d'Etudes Spatiales (CNES), and NASA (launched in August 1992) continued to provide valuable information during 1994. The satellite uses a radar altimeter to yield precise measurements of sea-surface height. Data analysis shows that the seasonal change in sea level in the Northern Hemisphere is about 50 percent larger than in the southern half of the globe. This was a previously unknown asymmetry and indicates the air-sea heat exchange is much stronger in the Northern Hemisphere. Data from the satellite have also enabled scientists to track disturbances caused by the lingering effects of the El Niño event of 1991-93, the longest one in the last 40 years. El Niño is a warm inshore current annually flowing south along the coast of Ecuador around the end of December and extending about every 7 to 10 years down the coast of Peru; it can bring devastating weather to several global regions, including heavy rains and flooding as well as colder than normal winters across the United States and severe droughts and dust storms in Australia. Observations made by TOPEX/Poseidon in the North Pacific revealed a northward shift of the Kuroshio, the swift current southeast of Japan, which has been traced back to the El Niño event of 1982-83. Meteorologists believe that the position of the Kuroshio is drastically affecting the weather of North America. NASA, CNES, and NOAA held discussions in 1994 on a TOPEX/Poseidon Follow-On (TPFO) mission, in which NOAA, the new partner, would provide the ground segment. TPFO would meet both operational and research needs.

NASA also participated in the international Tropical Ocean Global Atmosphere (TOGA)-Coupled Ocean-Atmosphere Response Experiment (COARE) program. Measurements from NASA's ER-2 and DC-8 aircraft have produced significant improvements in our understanding of precipitation, convection, clouds and radiation, air-sea interaction, and oceanographic processes. Results from the 1993 **TOGA-COARE** field exercise in oceanography and long-term atmospheric effects will be presented in Melbourne, Australia, in April 1995.

Meanwhile, the NIST Radiometric Physics Division has been continuing its collaboration with the NASA Sea-viewing Wide Field-of-view Sensor (SeaWiFS) project and associated investigators. SeaWiFS, scheduled for launch in 1995, is designed to provide global observations of photosynthetic pigment concentrations contained in the microscopic marine plants called phytoplankton. Among other things, these measurements will help assess how much carbon dioxide transferred to the ocean from the atmosphere is being transformed into oceanic plant biomass. Accurate calibration of the SeaWiFS instrument is critical to the mission's success. Also, sea-based optical measurements for validation of the post-launch calibration and various products derived from the satellite observations must be equally accurate. NIST's role is to help ensure that these observations are traceable to radiometric standards and that instrument calibrations are performed properly. NIST has designed, constructed, and characterized a portable, multichannel spectroradiometer (**SeaWiFS Transfer Radiometer** or SXR) to compare the calibrations of field instruments and to check the calibration sources at different institutions. The device was used during the second and third SeaWiFS Round Robins in June 1993 and September 1994. NIST also used the device during a NASA/NOAA field experiment in February 1994 at the Marine Optical Buoy (MOBY) support facility in Hawaii. MOBY will be used to verify the postlaunch SeaWiFS calibration and other future ocean color satellite instruments to be launched later in this decade under the EOS program.

Near the end of the fiscal year, NOAA announced the completion of initial flight tests of a new system for mapping coastal ocean salinity. Called the **scanning low-frequency microwave radiometer**, the new system is smaller than older ones and can be operated from small, single-engine aircraft rather than the four-engine C-130. Consisting of a microwave radiometer, an infrared radiometer, a GPS instrument for locating measurements, and a computer, the new system can produce salinity maps at the rate of 100 square kilometers per hour. NOAA's National Environmental Satellite, Data, and Information Service (NESDIS) anticipated collaborating with other NOAA and Federal agencies and academia in coastal-ecosystem health, hydrological, and coastal forecasting activities where data on salinity are critical, such as in studies of the distribution of brown shrimp in the Mississippi Delta and Gulf of Mexico.

Additionally, NOAA/NESDIS's Office of Satellite Data Products and Distribution forged a partnership with NASA for the development and joint funding of a U.S. ground system to support real-time collection of high-priority **scatterometer and ocean color data** from the Japanese Advanced Earth Observing Satellite, scheduled for launch in 1996.

Finally, in the area of tactical oceanography, Ball Aerospace Corporation has been developing the **Geodetic/Geophysical** (GEOSAT) **Follow-on** (GFO) satellites for the Navy. The Navy expects to launch the first of these radar altimeter satellites in 1996, with up to two additional satellites as needed to provide an operational capability until a radar altimeter can be placed aboard a future environmental satellite (such as the converged DMSP and NOAA satellites). GFO is expected to provide timely, worldwide, and extremely accurate measurements of ocean topography via direct readout to ships at sea and selected shore sites. The Navy completed the preliminary design review in October 1993 and the critical design review in August 1994. As the fiscal year ended, the first satellite was in production for the 1996 launch date on a Lockheed LLV-1 launch vehicle.

Other Aeronautical and Space Activities

Discussions Concerning Arms Control of Space-Related Weaponry

In the wake of the breakup of the Soviet Union, and with the end of the Cold War, there has been an unprecedented wave of projects for cooperation between the United States and Russia in the areas of civil and commercial space. It is U.S. policy to support such cooperation actively, to employ Russian scientific and technical personnel who might otherwise work on military projects or migrate abroad to work on projects that might promote the proliferation of technology applicable to missiles. Even as we increase our cooperation with Russia, the United States must ensure that militarily useful technology is not transferred to Russian missile programs and that such programs are not supported indirectly, e.g., by funding Russian production facilities that conduct both commercial and missile-related work. The Arms Control and Disarmament Agency (ACDA), as the only U.S. agency specifically charged with responsibilities for arms control, endeavors to ensure that cooperation with Russia in the areas of civil and commercial space is carried out in accordance with our treaty obligations and nonproliferation standards.

There are several ways in which commercial space activities interact with interests in arms control and nonproliferation. One is technology transfers relating to cooperation in commercial space. In each U.S.-Russian project for cooperation in space, the U.S. export-control community examines the flow of technology in both directions. The United States does not authorize transfers that could contribute to Russia's still formidable missile capability or that would assist Russia financially to continue the production of a missile by allowing it or modifications of it to be sold as commercial launch vehicles. Another area of interaction is ballistic missiles used as space launch vehicles. With the inventories of ballistic missiles being reduced or eliminated under the Strategic Arms Reduction Treaty (START) signed in July 1991, the United States, Russia, and the Ukraine are considering the use of ballistic missiles or their derivatives as space launch vehicles. Both START and the Missile Technology Control Regime (MTCR) control such use. The ACDA participated in U.S. policy formulation on this issue as a member of the Excess Ballistic Missile Working Group, chaired by the National Security Council. Under START, any such use must be in accordance with the counting rules in the treaty, must not allow the flight testing of missiles under the guise of space-launch vehicles, and must not result in the transfer of strategic arms to third countries. MTCR restrictions pertain to the export of missiles and missile technology, providing that member countries and adherents may support the space programs of other nations as long as such programs could not contribute to the delivery systems for weapons of mass destruction. The United States and its MTCR partners exchange information and coordinate their control processes to prevent any such contribution.

During FY 1994, the Conference on Disarmament (CD), based in Geneva, Switzerland, again discussed the subject of preventing an arms race in outer space. Substantive discussions in the CD's Outer Space Ad Hoc Committee focused on appropriate, multilateral confidence-building measures, and the United States maintained its position that negotiations should not be initiated unless meaningful issues can be identified. The United Nations General Assembly's First Committee (UNFC) passed its annual resolution on preventing the arms race in outer space, with the United States abstaining. ACDA is the lead agency for the United States in both the CD and the UNFC.

Cooperation With Russia and Other Foreign Policy Issues

With the President's decision in June 1993 to pursue a redesigned **Space Station** and seek ways to involve Russia in the program, the Department of State (DoS) and NASA were tasked to evaluate potential options for Russian participation. In support of this direction, NASA initiated in-depth technical discussions with RSA on the feasibility of Russian involvement in the program and provided the results of this joint technical assessment to the White House on November 1, 1993, indicating that significant programmatic benefits could be gained from Russian participation. Bringing Russia into the program also required agreement by the existing Space Station partners. To achieve this agreement, the DoS and NASA initiated discussions with Canada, Europe, and Japan at the intergovernmental and cooperating agency levels. In early November, the heads of the Space Station cooperating agencies invited RSA's Director General to participate in a meeting to begin charting the technical parameters of potential Russian cooperation in the program. The Russians confirmed their strong desire to participate in the international Space Station program on an equal basis with the existing international partners, recognizing the preeminent U.S. role in managing the program. Working closely with technical and political representatives of the existing partners, representatives of participating agencies extended an invitation from the partnership to Russia at the intergovernmental level and developed an integrated plan with programmatic milestones for bringing Russia into the partnership at the cooperating agency level. Russia accepted both the invitation and the plan by diplomatic note on December 17, 1993.

On February 10-11, 1994, the existing Space Station partners held a preparatory meeting to discuss approaches to revising the legal framework of the 1988 Space Station agreements and to propose negotiating modalities for bringing Russia into the partnership. While the partners accepted in principle the U.S. approach of minimizing changes to the 1988 agreements, the Europeans sought to preserve flexibility to allow them later to revise their contributions to the program. The legal framework advanced by the DoS after extensive coordination within the U.S. Government called for a protocol amending the 1988 Intergovernmental Agreement (IGA), a new provisional arrangement for the period between signature of the protocol and the time it went into effect, and, at the cooperating agency level, a NASA-RSA memorandum of understanding paralleling those already in effect with the cooperating agencies of the existing partners. To cover the period up to the the signature of the protocol and provisional arrangement, NASA would conclude an interim agreement with RSA. The proposed negotiating modalities called for establishing a negotiating body below the IGA-level representation that could employ legal and drafting groups as required. Each of the four existing partners, plus Russia, would participate on an equal basis in plenary sessions and subgroups. The existing partners met in Paris on March 17-18 at the intergovernmental level, initially to agree among themselves on the legal framework and negotiating modalities proposed by the United States, and then with representatives of the Russian Federation and RSA participating. As a result of the meeting, Russia accepted the legal framework and negotiating modalities the existing partners proposed. In June 1994, NASA and RSA signed an "Interim Agreement for the Conduct of Activities Leading to Russian Partnership in the Permanently Manned Civil Space Station." It established bilateral management mechanisms that are fully consistent with existing managing mechanisms used by the international Space Station partners. It also provides for Russian participation in the mechanisms for management within the existing multilateral Space Station partnership. NASA and RSA also signed a separate $400 million contract for Russian space hardware, services, and data. Under this contract, NASA will purchase hardware and services from RSA and its subcontractors for approximately $100 million per year through 1997 in support of a joint program involving the U.S. Space Shuttle and the Russian Mir space station. The contract also covers early international Space Station activities. Relatedly, the DoS chaired or provided secretariat support for three rounds of intergovernmental negotiations between the existing partners and Russia in Washington on April 27-28, in Moscow on May 30-31, and again in Washington on August 30-31, 1994. In parallel, NASA initiated discussions with RSA on the development of a NASA-RSA memorandum of understanding on Space Station and bilateral discussions with each of the existing partners regarding modifications of their memoranda of understanding as appropriate to reflect Russian involvement in the program and modifications to the respective contributions by partners. The aim is to complete all agreements for concurrent signature during 1995. In parallel with the effort to bring Russia into the Space Station program, the partnership faced a difficult challenge posed by budget-cutting pressures in Canada. Arguing that the addition of a new partner, Russia, was not an appropriate time to lose an existing partner in Canada, the DoS coordinated U.S. efforts to ensure that Canada remained in the partnership, albeit at lower funding levels.

In September 1994, **Germany** hosted the 10th annual meeting of the Committee on Earth Observation Satellites (CEOS) in Berlin. CEOS members are national and international governmental organizations with responsibility for conducting Earth observation programs. Other organizations with a focus on Earth observation or Earth science participate in CEOS as affiliates and observers. The primary goal of CEOS is to coordinate the Earth observation missions of its members. Also, on September 22, 1994, NASA and German space officials recognized 30 years of cooperation in space at a celebration in Bonn.

Japan is becoming an increasingly important partner of the United States in space. The DoS worked closely with NASA throughout the year on several **agreements with Japan** on joint space activities. To facilitate enhanced cooperation between NASA and Japanese agencies, the United States and Japan have begun discussing a government-level agreement waiving liability for damages resulting from cooperative or reimbursable space activities.

The DoS also worked closely with Government and private organizations to promote space cooperation at all levels with **Latin America**. The Government of Chile hosted an air show in Santiago from March 20-27, 1994, during which the American Institute of Aeronautics and Astronautics (AIAA) organized, with support from the DoS, a highly successful program on using space technology for development. Before an audience of over 300 people, representatives from various U.S. firms reviewed opportunities for collaboration in using space technology for environmental monitoring and communications. Another U.S.-sponsored event was the first meeting on the use of COSPAS-SARSAT in the Latin American region. In conjunction with the DoS, NOAA organized a 2-day meeting to examine distribution procedures for COSPAS-SARSAT alert data among search and rescue authorities in Latin America. Representatives from 13 countries and 3 international organizations participated in the meeting and agreed on measures to expand the use of this important program.

Relatedly, in connection with a joint statement issued at the June 1994 meeting of the U.S.-Russian Joint Commission on Economic and Technological Cooperation, NOAA Administrator D. James Baker and Director General Yuri N. Koptev of RSA agreed to closer cooperation in the use of geostationary satellites for sea, air, and land search and rescue services. For more than a decade, the United States and **Russia** have used polar-orbiting satellites to support the search and rescue of maritime, aviation, and land-based users in distress. The two countries, plus France and Canada, provide satellites, instruments, and ground-receiving capabilities for the COSPAS-SARSAT system. In addition, NOAA collaborated with the DoS, OSTP, and other Federal agencies in negotiating with Russian counterpart agencies a "Statement of General Principles for U.S.-Russian Exchange of Scientific and Technological Data and Information," which Vice President Albert Gore, Jr., and Russian Prime Minister Victor Chernomyrdin signed in June 1994.

In FY 1994, the DoS continued to provide foreign policy oversight of **U.S. Government involvement in international space science, satellite remote sensing, and related applications programs**. The DoS participated in interagency forums addressing the convergence of NOAA and DoD Polar Orbiting Environmental Satellite systems; development of U.S. components in a global EOS supporting global change research and other related initiatives; licensing for operation and export of high-resolution U.S. private remote sensing systems; review of U.S. Government data policy in the United Nations (UN) World Meteorological Organization; and technical planning for the follow-on U.S. Landsat-7 program. The DoS also coordinated interagency review of several space-based Earth observation agreements involving data management, export licensing, cross-waiver of liability, intellectual property, and bilateral regulatory issues.

During FY 1994, the DoS also led efforts to advance U.S. interests in multilateral discussions concerning international space cooperation. The General Assembly of the UN adopted, without a vote, Resolution 48/39 renewing the mandate of the **Committee on the Peaceful Uses of Outer Space** (COPUOS) and setting the program of work for COPUOS and its Legal and Scientific and Technical Subcommittees (LSC and STSC, respectively). In 1993, COPUOS and the subcommittees continued their work on questions relating to international cooperation in areas such as meteorology, astronomy and astrophysics, space transportation, human space flight, planetary exploration, and environmental monitoring. There has been a growing awareness among member states of the need for further international research concerning orbital debris and its potential impact on space exploration. In this regard, the DoS played a leading role in reaching agreement to add to the agenda of the 1994 session of the STSC an item dealing with the scientific aspects of orbital debris. The year 1993 marked the 35th anniversary of the establishment of the 53-member COPUOS, established as an ad hoc committee in 1958 with 20 members to consider international cooperation in the exploration of outer space. Since that time, the committee and its subcommittees have made significant progress in promoting international understanding of the potential uses of outer space for science and engineering, communications, transportation, meteorology, environmental monitoring, and medicine. COPUOS has also been responsible for the elaboration and adoption by consensus of five multilateral treaties governing space activities and two sets of nonbinding principles concerning the use of nuclear power sources in outer space and remote sensing of the Earth from space. These treaties form the basis for international law in the use and exploration of outer space.

In connection with the President's May 1994 announcement of the convergence of NOAA and DoD Polar Orbiting Environmental Satellite systems into a single operational program under NOAA leadership, NOAA Administrator D. James Baker invited EUMETSAT—together with involvement as appropriate of ESA—to consider a joint polar system, taking into account on the U.S. side a converged U.S. system and assuming that key U.S. mission requirements can be met. This invitation complements longstanding plans by NOAA and EUMETSAT, as supported by NASA and ESA, to provide U.S. instruments for flight on the European METOP satellite series. Activities under this proposed cooperation would be an important asset in the international effort to better understand the global environment. With DoS international authorization, NOAA, with the involvement of the DoD and NASA, is in the process of negotiating an agreement with EUMETSAT for an initial joint polar system covering the initial METOP satellites, as well as continued contribution of European instruments to the remaining NOAA missions prior to the advent of the converged U.S. system.

Commercial Development and Regulation of Space Technology

The five **commercial launches** completed during FY 1994 brought to 40 the total number carried out by the U.S. commercial space transportation industry, since inception in 1989. Of these launches, 18 have carried foreign or internationally owned payloads, many of them satellites purchased from U.S. manufacturers. This international launch and satellite sales business has contributed more than $2 billion to the U.S. balance of trade. The industry has more than 60 more launch or reentry events scheduled over the next several years. The DoT's OCST is responsible for regulating this growing industry. It grants licenses to launch providers based on their presenting evidence that they are in compliance with all safety regulations and other requirements and have sufficient insurance or financial resources to cover any probable losses from a launch mishap. The OCST is also responsible for the regulation of any future commercial launch sites, such as those proposed by Alaska, Florida, Hawaii, New Mexico, California, and Virginia. Working with the OCST, Hawaii completed its State Environmental Impact Statement for a proposed commercial launch site, and the office also coordinated efforts with the other states involved. The OCST also has the responsibility to oversee commercial reentry vehicles and recovery sites. The office had seven applications for commercial launch licenses that were in process during FY 1994, including amendments, renewals, maximum probable loss determinations (in case of launch mishaps, none of which have occurred so far), and transfers. It issued four licenses, amendments, or transfers during FY 1994 and made the same number of maximum probable loss determinations. The OCST continued to support the development of voluntary standards for the commercial launch industry, especially those in the area of safety, reliability, and quality assurance. Work sponsored by the OCST with the participation of the AIAA should lead to the acceptance and accreditation of an industry standard. The office has continued discussions with a number of companies interested in the development for commercial applications of reusable SSTO vehicles. At least two companies are building or have built subscale prototypes of reusable vehicles, including McDonnell Douglas's DC-X discussed below. The OCST is a member of the National Spacelift Requirement Process group, whose charter is to establish a common set of requirements for the U.S. spacelift system. The office has maintained communications with members of the commercial space industry to ensure that industry inputs have been considered.

In FY 1994, the OCST was instrumental in developing the **National Space Transportation Policy** (see appendix F-6 of this report). This Presidential directive established policy, guidelines, and implementing actions for the conduct of national space transportation programs that will sustain and revitalize U.S. space transportation capabilities by providing a coherent strategy for supporting and strengthening U.S. space launch capabilities to meet the growing needs of the civilian and national security sectors. The DoS and the Office of Air and Space Commercialization (OASC) in the DoC also made contributions to this directive, which recognizes the importance of private-sector input into Government space launch policies and activities and will support increasing commercial activity in space, thereby promoting growth in satellite manufacturing, launch services, and space application operations. The policy commits the Nation to a two-track strategy of maintaining and improving the current fleet of expendable launch vehicles as necessary to meet civil, commercial, and national security requirements, and of investing research and development resources in developing and demonstrating next-generation, reusable space transportation systems with the potential to reduce greatly the cost of access to space.

The OCST also played a significant role in supporting the U.S. Trade Representative (USTR) by chairing the Interagency Working Group on Information, which is charged with gathering data that enable the USTR to conduct negotiations about **commercial space launch agreements** with both the Russians and Chinese. In this connection, the United States and Russia held two special and one annual consultation under the U.S.-Russian Commercial Space Launch Agreement. Both sides exchanged information on specific Geosynchronous Earth Orbit (GEO) and Low-Earth Orbit (LEO) competitions and LEO market prospects (see also OASC coverage below). Meanwhile, the United States and the People's Republic of China (PRC) held negotiations to renew a follow-on commercial space launch agreement. The current agreement, signed in 1989, will expire on December 31, 1994. On September 21-23, 1994, a USTR-led negotiating team (made up of representatives from the DoS, DoC, DoT, NASA, and OSTP) held its first round of consultations in Beijing with the Chinese National Space Administration on the possible renewal of the existing agreement regarding international trade in commercial launch services. U.S. discussions with the PRC reflect the U.S. belief that China's transition toward a market economy is ongoing and that transitional rules are therefore desirable to ensure China's participation in the international commercial launch market does not disrupt normal competition among Western launch providers. The new agreement, if successfully negotiated, will continue to provide rules of the road for Government involvement in the commercial launch market regarding subsidies, marketing inducements, and nondiscriminatory treatment. The U.S. believes the existing agreement should serve as the basis for a renewed agreement. The current agreement consists of two basic disciplines: (1) a quantitative limit allowing the Chinese to launch up to nine space vehicles over the period of the agreement (1989-1994) and (2) a pricing discipline that obligates the PRC to offer launch services "on a par with those prices, terms and conditions prevailing in the international market for comparable commercial launch services." As FY 1994 ended, the United States continued working off the existing agreement to refine quantitative and pricing disciplines to respond to new developments in the market and to improve the functioning of the agreement. With regard to the GEO and LEO launch markets, the United States proposes to treat them separately to spur the development of these different markets. The United States also seeks to address concerns created with respect to Chinese implementation of the pricing provision and to clarify provisions pertaining to directed procurement and leasing transponders on orbiting satellites, based on past experience. The consultations drew on extensive analysis of PRC launch contracts conducted by the OCST and the Interagency Working Group it chairs.

Per Presidential directive, the DoS continued to chair an interagency working group that reviewed the coverage of spacecraft and related components on various lists. The **Space Technical Working Group** had the mission of identifying and recommending removal from the U.S. munitions list commercial satellites and related articles covered by the coordinating committee industrial list, except where such movement would jeopardize U.S. national security interests. The working group developed language to transfer the Space Station to the commodity control list under the DoC's jurisdiction.

The role of the OASC is to ensure that U.S. **commercial space interests** are represented in Government policy making and programmatic activities and to provide the U.S. commercial space sector and related sectors with timely, reliable data and analysis regarding commercial space activities, investment, and trade opportunities. It further develops policy and undertakes initiatives that seek to assure and support a policy environment in which commercial space activities prosper. During FY 1994, besides the work on the National Space Transportation Policy, the OASC and NOAA contributed to a new Presidential policy on commercial remote sensing announced March 10, 1994 (see appendix F-2) that allows private firms to build and operate high-resolution satellite imaging systems. Development of these systems will result in more jobs in manufacturing and operations and will also produce geographic information that will greatly advance emergency management and rescue, disaster relief, mineral exploration, map making, and a variety of other commercial endeavors. As a result of the new policy, NESDIS, the line office within NOAA responsible for administering the policy, has already issued licenses to a number of aerospace companies planning to build remote-sensing satellite systems. In 1994 it issued licenses to Lockheed Corp., Orbital Sciences Corporation, Ball Corporation, and a consortium consisting of Orbital Sciences Corporation, GDE Systems, and Litton Itek. The OASC was also instrumental in promoting a launch-services agreement between the United States and Russia that creates a policy environment under which introduction of nonmarket Russian launchers on the international scene will cause minimal disruption, allowing U.S. and foreign launch service providers to compete fairly for international business and aiding Russia's transition to a market-based economy. In addition, the OASC had direct input into the administration of U.S. Air Force grants for the study, design, and construction of launch pads and facilities to be used by both the Government and the private sector. These dual-use grants for launch infrastructure have fostered the growth of privately owned and operated spaceports across the Nation. To ensure U.S. commercial access to space and to promote growth in U.S. space applications, the OASC was also involved in the ongoing development of policy supporting commercial activity in several other areas. These included the renewal of the U.S.-China launch services agreement, GPS navigation satellite and ground system technology, present- and future-generation high-power communications satellites, and satellite remote sensing.

In a separate area having to do with commercial development and the regulation of space technology, the FCC adopted rules and policies governing the nonvoice, nongeostationary **Mobile Satellite Service** that will facilitate granting the applications for licenses in this service that are pending before the agency. The FCC also adopted a notice of proposed rulemaking for the Mobile Satellite Service operating above 1 gigahertz, which is the first step in granting authorizations to provide this service.

In related developments, following a year of intense negotiations, a special working party of the **INTELSAT Assembly of Parties** made recommendations on a number of significant policy issues. It raised the limit on public switched telephone circuit capacity, below which private international systems could receive streamlined international approval, from the 1,250-circuit limit established at the Assembly meeting in 1992 to 8,000 circuits. This recommendation was expected to receive routine approval at an Assembly meeting after the end of the fiscal year. The working party focused much of the remainder of its work on the future structure of the INTELSAT organization and whether it would not be appropriate to "privatize" it in the face of a new, more competitive market environment. The party recommended that the Assembly work out further details for a subsequent working party.

During FY 1994, the **INMARSAT Council** devoted considerable attention to whether it should proceed with the INMARSAT-P program to identify and deploy a pocket telephone. The council was divided between those members who wished to undertake the project within INMARSAT and those who were unwilling to assume the liability for a venture that had become risky because of numerous competing systems. The council compromised by proposing the creation of an independent affiliate in which INMARSAT will invest. The affiliate will implement a handheld, global, mobile telephone service expected to be fully operational by 2000. A 12-satellite system in intermediate circular orbit will provide the service.

The U.S. Government has also been involved in a process to formulate policy regarding the future structure of both **INTELSAT and INMARSAT**. An interagency task force, chaired by the DoS Coordinator for International Communications and Information Policy, met several times to consider the merits of various options. As part of the process, the DoS held a public meeting to elicit the views of industry and consumer groups. The United States has announced that it will support privatization of the organizations as the best means to achieve competition, which it views as the best way to assure the best service at the lowest cost.

NASA was also involved in the development of commercial space technology. For example, late in the fiscal year, NASA's Marshall Space Flight Center in Alabama signed a cooperative agreement with McDonnell Douglas Aerospace to reconfigure the **Delta Clipper experimental vehicle** (DC-X), using advanced lightweight materials and advanced auxiliary propulsion systems. The agreement covers a 28-month period beginning in August 1994 with total estimated Government funding at $17.6 million and cost sharing by McDonnell Douglas of $7.6 million. Originally developed under a DoD contract (see above), the DC-X will allow NASA to test new technologies needed to develop a reusable launch vehicle that could assist the Agency's ultimate goal of gaining low-cost access to space.

This is only one of the ways NASA sought to implement the President's policy to invest in U.S. technology and thus in the Nation's future and to work cooperatively with U.S. industry in areas of mutual interest. NASA is one of six Federal agencies managing the **Technology Reinvestment Project** (TRP), promoting risk-sharing investment partnerships based on mutual interests rather than the buyer-seller relationship that used to exist between the Federal Government and private industry. It is a fully collaborative project of NASA, ARPA, DoC, DoE, DoT, and NSF, with ARPA acting as the lead agency. NASA is contributing technical expertise and program management to the TRP. NASA helped plan the first "general" competition for TRP partnerships, and 57 NASA personnel helped evaluate about 2,800 proposals in FY 1993-94, of which 212 projects worth around $605 million were selected for negotiation. NASA is the lead "agent" in managing 28 of these projects. They are estimated to cost the Government about $71.5 million—less than half of the total cost because of the TRP's cost-sharing requirements. NASA is managing technology development projects in such areas as hybrid rockets, virtual reality simulations, phased-array satellite antennas, and millimeter-wave cameras for all-weather pilot-vision systems. In the area of technology deployment, a NASA-managed project links NASA's National Technology Transfer Network and the Federal Lab Consortium to improve the transfer of technology from the Federal labs, leveraging NASA's mission and structure in technology transfer. In the area of manufacturing education and training, NASA is the agent for a project that will develop a junior college curriculum centered around the design and manufacture of microsatellites and Get Away Specials (low-cost, experimental payloads for the Space Shuttle).

Two examples will illustrate the way the TRP has been working. On April 7, 1994, NASA's Marshall Space Flight Center signed a TRP agreement with a consortium of three U.S. aerospace companies to develop hybrid-rocket-motor technology. Hybrid rocket motors consist of elements from both solid- and liquid-propellant rockets. The **Hybrid Technology Project** (HyTOP) consortium consists of Martin Marietta Manned Space Systems, United Technologies Corporation's Chemical Systems Division, and the American Rocket Company. The TRP will provide $10.4 million during the 30-month duration of the project with the consortium furnishing approximately $12 million. The agreement calls for the consortium to build and test two H250K hybrid qualification motors with 250,000 pounds of thrust. The manager of this initiative in technology development, the director of Marshall's recently established Technology Transfer Office, stated that this agreement was "an important step in stimulating the transition of technology to the private sector and enhancing U.S. competitiveness."

The second example of TRP agreements featured one between NASA and Hi-Shear Technology Corporation in California to develop a new generation of portable **emergency rescue equipment**. This equipment will use NASA-developed pyrotechnical technology to modernize current hydraulic-powered cutters that fire and rescue teams employ to free accident victims from wreckages. The new-generation cutters will replace umbilical connections to cumbersome hydraulic pumps with pyrotechnic cartridges, saving an estimated 50 percent in weight and 70 percent in costs. This will make the cutters available to smaller fire departments as well as civil and military search and rescue helicopters. It should also generate millions of dollars in cost savings for local, State, and Federal rescue services.

NASA's many **other activities in developing commercial space technology** and promoting technology transfer included TECHNOLOGY 2003, the fourth annual national technology transfer conference on December 7-9, 1993, in Anaheim, California. At the event, sponsored by *NASA Tech Briefs* magazine and the Technology Utilization Foundation, more than 200 Federal labs, universities, and high-technology companies from across America exhibited their latest inventions and products available for license or sale. Other efforts included Phase A awards to develop flight experiments in a 1992 In-Space Technology Experiments Program. NASA selected 51 studies from more than 350 proposals, of which 15-20 will receive Phase B awards for continued hardware development and, eventually, flight testing. NASA also selected 21 proposals of 159 submissions for 1-year Phase I contracts under the Small Business Technology Transfer Pilot Program to develop products that will involve technological innovation. About half of the Phase I products are expected to evolve into Phase II efforts geared toward product commercialization. NASA's budget for this program in FY 1994 was about $3.4 million.

Space and Public Diplomacy Abroad

The **U.S. Information Agency** (USIA) joined the world in celebrating the 25th anniversary of the Apollo 11 Moon landing in July 1994. Numerous posts abroad held special events that included exhibits (some featuring Moon rocks), seminars, and video programs. Invited guests in several Asian cities had live conversations via televised Worldnet Dialogue with former Apollo astronaut David Scott and NASA Associate Administrator for Space Science, Dr. Wesley T. Huntress. Posts in 70 countries distributed more than 5,000 commemorative Apollo 11 posters, designed and produced by the USIA. The Voice of America radio, the Wireless File print service, and Worldnet television produced special commemorative features in dozens of languages. Additionally, the USIA covered the collision of Comet Shoemaker-Levy 9 with the planet Jupiter and provided information on Shuttle launches and space probes to interested foreign audiences.

APPENDIXES

APPENDIX A-1

U.S. Government Spacecraft Record

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

Calendar Year	Earth Orbit[a]		Earth Escape[a]	
	Success	Failure	Success	Failure
1957	0	1	0	0
1958	5	8	0	4
1959	9	9	1	2
1960	16	12	1	2
1961	35	12	0	2
1962	55	12	4	1
1963	62	11	0	0
1964	69	8	4	0
1965	93	7	4	1
1966	94	12	7	1[b]
1967	78	4	10	0
1968	61	15	3	0
1969	58	1	8	1
1970	36	1	3	0
1971	45	2	8	1
1972	33	2	8	0
1973	23	2	3	0
1974	27	2	1	0
1975	30	4	4	0
1976	33	0	1	0
1977	27	2	2	0
1978	34	2	7	0
1979	18	0	0	0
1980	16	4	0	0
1981	20	1	0	0
1982	21	0	0	0
1983	31	0	0	0
1984	35	3	0	0
1985	37	1	0	0
1986	11	4	0	0
1987	9	1	0	0
1988	16	1	0	0
1989	24	0	2	0
1990	40	0	1	0
1991	32[c]	0	0	0
1992	26[c]	0	1	0
1993	28[c]	1	1	0
1994 *(through September 30)*	27[c]	1	1	0
TOTAL	1,314	146	85	15

[a] The criterion of success or failure used is attainment of Earth orbit or Earth escape rather than judgment of mission success. "Escape" flights include all that were intended to go to at least an altitude equal to lunar distance from the Earth.

[b] This Earth-escape failure did attain Earth orbit and therefore is included in the Earth-orbit success totals.

[c] This excludes commercial satellites. It counts separately spacecraft launched by the same launch vehicle, as on Mar. 13, 1994, when a single Taurus launch vehicle placed two satellites in orbit. (See Appn. A-3.)

World Record of Space Launches Successful in Attaining Earth Orbit or Beyond

(Enumerates launches rather than spacecraft; some launches orbited multiple spacecraft.)

Calendar Year	United States	USSR/ CIS	France[a]	Italy[a]	Japan	People's Republic of China	Australia	United Kingdom[a]	European Space Agency	India	Israel
1957		2									
1958	5	1									
1959	10	3									
1960	16	3									
1961	29	6									
1962	52	20									
1963	38	17									
1964	57	30									
1965	63	48	1								
1966	73	44	1								
1967	57	66	2	1			1				
1968	45	74									
1969	40	70									
1970	28	81	2	1[b]	1	1					
1971	30	83	1	2[b]	2	1		1			
1972	30	74		1	1						
1973	23	86									
1974	22	81		2[b]	1						
1975	27	89	3	1	2	3					
1976	26	99			1	2					
1977	24	98			2						
1978	32	88			3	1					
1979	16	87			2				1		
1980	13	89			2					1	
1981	18	98			3	1			2	1	
1982	18	101			1	1					
1983	22	98			3	1			2	1	
1984	22	97			3	3			4		
1985	17	98			2	1			3		
1986	6	91			2	2			2		
1987	8	95			3	2			2		
1988	12	90			2	4			7		
1989	17	74			2				7		1
1990	27	75			3	5			5		1
1991	20[c]	62			2	1			9	1	
1992	31[c]	55			2	3			7[b]	2	
1993	24[c]	45			1	1			7[b]		
TOTAL	998	2,418	10	8	46	32	1	1	58	6	2
1994 *(through Sept. 30)*	20[c]	32			2	4			4[b]	1	
TOTAL	1,018	2,450	10	8	48	36	1	1	62	7	2

[a]Since 1979 all launches for ESA member countries have been joint and are listed under ESA.

[b]Includes foreign launches of U.S. spacecraft.

[c]This includes commercial expendable launches and launches of the Space Shuttle, but because this table records launches rather than spacecraft, it does not include separate spacecraft released from the Shuttle.

Successful U.S. Launches
October 1, 1993–September 30, 1994

Launch Date (GMT). Spacecraft Name, COSPAR Designation, Launch Vehicle	Mission Objectives, Spacecraft Data	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
Oct. 5 Landsat-6 63A Titan II	*Objective:* To monitor Earth resources in support of global change research, coastal zone monitoring, timber management, environmental monitoring, and other programs. *Spacecraft:* Landsat-6	813.0 786.0 100.6 98.5	Satellite's kick motor failed to place it in final orbit and communications with it ceased (i.e., launch was successful but not satellite).
Oct. 18 Space Shuttle Columbia (STS-58) 65A	*Objective:* To determine the effects of microgravity on human and animal subjects using the Spacelab Life Sciences-2 payload. *Spacecraft:* Shuttle orbiter carrying SLS-2.	291.0 282.0 90.2 39.0	Fifty-eighth flight of STS. Piloted by John E. Blaha and Richard A. Searfoss. Payload Commander M. Rhea Seddon, MD. Mission Specialists Shannon W. Lucid, PhD; David A. Wolf, MD; William S. McArthur, Jr. Payload Specialist, Martin J. Fettman, DVM, PhD. Launched from KSC, 10:53 a.m. EDT. Landed at EAFB 11:22 a.m. EDT, Nov. 1. Mission duration: 14 days, 29 min.
Oct. 26 GPS 68A Delta II	*Objective:* To provide radio positioning and navigation, including position, velocity, and timing data to DoD and civilian users. *Spacecraft:* A Block IIA satellite in the NAVSTAR Global Positioning System.	20,268.0 20,093.0 717.9 55.2	Twenty-third in a series of operational GPS satellites. System to be composed of 24 satellites in inclined, semi-synchronous orbit. In orbit.
Nov. 28 DSCS III 74A Atlas II	*Objective:* To provide long-haul, high capacity communications system supporting the worldwide command and control of the U.S. Armed Forces and other Government agencies. *Spacecraft:* Improved, third-generation Defense Satellite Communications System (DSCS) satellite.	35,533.0 160.0 623.3 26.5	Cut over to operational traffic in mid-1994. In orbit.
Dec. 2 Space Shuttle Endeavour (STS-61) 75A	*Objective:* To restore the planned scientific capabilities and reliability of the Hubble Space Telescope and to validate the on-orbit servicing concept for HST. *Spacecraft:* Shuttle orbiter equipped with HST replacements.	594.0 588.0 96.5 28.4	Fifty-ninth flight of STS. Piloted by Richard O. Covey and Kenneth D. Bowersox. Mission Specialists Tom Akers, Jeffrey A. Hoffman, Kathryn C. Thornton, Claude Nicollier (Switzerland), and F. Story Musgrave. Launched from KSC at 4:27 a.m. EST. Landed at KSC 26 minutes after midnight on Dec. 13. Mission duration: 10 days, 19 hours, 58 min.
Dec. 8 NATO IVB 76A Delta II	*Objective:* To provide secure and reliable military communications between NATO member nations and NATO military forces. *Spacecraft:* Military communications satellite built by British Aerospace.	35,914.0 762.0 644.5 23.3	Launched commercially by McDonnell Douglas. In orbit.

Successful U.S. Launches
October 1, 1993–September 30, 1994

Launch Date (GMT). Spacecraft Name, COSPAR Designation, Launch Vehicle	Mission Objectives, Spacecraft Data	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
Dec. 16 Telstar 401 77A Atlas II	*Objective:* To provide television and data communications services for U.S. customers. *Spacecraft:* AT&T communications satellite.	35,804.0 188.0 631.2 23.9	Launched commercially by General Dynamics. In orbit.
Jan. 25 Clementine 4A Titan II	*Objective:* To test in space 23 advanced technologies for high-tech, lightweight missile defense. *Spacecraft:* A deep space probe consisting of newly developed hardware, such as lightweight imaging sensors, all developed since 1990.	409,886.0 801.0 6,158.8 63.8	Conceived, built, and launched in 22 months, the satellite, whose position changed over the course of the year, also provided 1.8 million images of the surface of the Moon.
Feb. 3 Space Shuttle Discovery (STS-60) 6A	*Objective:* To deploy and retrieve a free-flying disk designed to generate new semiconductor films for advanced electronics and provide the second flight of a commercially developed research facility. *Spacecraft:* Shuttle orbiter carrying the Wake Shield Facility, a 12-foot-diameter, stainless steel disk, and SPACEHAB.	386.0 358.0 91.7 59.9	Sixtieth flight of the STS. Piloted by Charles F. Bolden and Kenneth S. Reightler, Jr. Mission Specialists N. Jan Davis, PhD; Ronald M. Sega, PhD; Franklin R. Chang-Diaz, PhD, who also was Payload Commander; and Sergei Konstantinovich Krikalev (Russia), whose presence signified a new era in cooperation in space between the U.S. and Russia. Launched from KSC 7:10 a.m. EST. Landed at KSC 2:19 p.m. EST on Feb. 11. Mission duration: 8 days, 7 hours, 9 min.
Feb. 7 Milstar 9A Titan IV	*Objective:* To begin a multichannel, EHF/UHF satellite communications system providing survivable, enduring, and jam-resistant secure voice data communication for the Armed Forces and other users. *Spacecraft:* A communications satellite using extremely high-frequency radio and encription technology to prevent jamming.	Elements not available.	Launch included first use of Titan IV with Centaur upper stage. First Milstar satellite. In orbit.
Feb. 9 ODERACS 6B-6G Space Shuttle	*Objective:* To improve the ability of ground-based radars to detect and track small debris objects. *Spacecraft:* Six spheres ranging in diameter from two to six inches.	Elements vary.	Deployed from the orbiter's payload bay. In orbit at end of FY but ODERACS A & B (COSPAR designations 6B & 6C) decayed Oct. 2 & 4 respectively.
Feb. 9 BREMSAT 6H Space Shuttle Discovery	*Objective:* To study various phenomena in space including heat conductivity, the forces of acceleration, and atomic forces. *Spacecraft:* The University of Bremen Satellite, built by that institution's Center of Applied Space Technology and Microgravity; weight: 140 lbs. (63 kilograms); length: 19 inches (480 mm).	320.0 302.0 90.8 57.0	Spring-ejected from its canister in the orbiter's bay. In orbit.

Successful U.S. Launches

October 1, 1993–September 30, 1994

Launch Date (GMT), Spacecraft Name, COSPAR Designation, Launch Vehicle	Mission Objectives, Spacecraft Data	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
Feb. 19 Galaxy 1R 13A Delta II	*Objective:* To provide video communications. *Spacecraft:* A geostationary communications satellite with 24 C-band transponders, owned by Hughes Communications, Inc.	37,300.0 2,933.0 715.3 25.1	Launched commercially by McDonnell Douglas. In orbit.
Mar. 9 Space Shuttle Columbia (STS-62) 15A	*Objective:* To conduct dozens of experiments in such areas as materials processing, biotechnology, advanced technology, and environmental monitoring. *Spacecraft:* Shuttle orbiter equipped with the U.S. Microgravity Payload-2, the Office of Aeronautics and Space Technology-2, the Shuttle Solar Backscatter Ultraviolet instrument, and other payloads.	309.0 296.0 90.4 39.0	Sixty-first flight of the STS. Piloted by John H. Casper and Andrew M. Allen. Mission Specialists Pierre J. Thuot, Charles D. Gemar, and Marsha S. Ivins. Launched from KSC at 8:53 a.m. EST. Landed at KSC 8:10 a.m. EST on Mar. 18. Mission duration: 13 days, 23 hours, 17 min.
Mar. 10 GPS 16A Delta II	*Objective:* To provide radio positioning and navigation, including position, velocity, and timing data to DoD and civilian users. *Spacecraft:* A Block IIA satellite in the NAVSTAR Global Positioning System.	20,348.0 20,016.0 718.0 55.0	Twenty-fourth and final satellite in the GPS constellation. In orbit.
Mar. 10 SEDS-II 16B Delta II	*Objective:* To suspend a tether in space with a minimum of swing and to determine the resistance of its braided polyethelene to micrometeoroids, space debris, and atomic oxygen. *Spacecraft:* A 23-kilogram mini-satellite.	358.0 344.0 91.3 32.3	Ejected by the Delta's second stage using a spring-loaded device. At 20 kilometers, the longest object ever placed in space. Severed on March 15, but the remaining 10-12 kms. remained attached to the rocket's second stage until it decayed May 8.
Mar. 13 ARPASAT 17A Taurus	*Objective:* To demonstrate a low-cost, classified space capability, validate advanced technologies, and assess the operational utility of direct user tasking and collection of payload data. *Satellite:* A 400-lb. satellite developed by Ball Aerospace Corporation for the Advanced Research Projects Agency of DoD.	Specific elements not available.	Launched by the first Taurus standard small launch vehicle. In a 290-nautical-mile, 105-degree-inclination orbit.
Mar. 13 STEP-TAOS 17B Taurus	*Objective:* To demonstrate and validate state-of-the-art spacecraft technologies to ensure autonomy and survivability in an operational space environment. *Satellite:* Space Test Program Experimental Platform-Technology for Autonomous Operational Survivability, also known as STEP-0.	Specific elements not available.	Launched by the first Taurus standard small launch vehicle. In a 290-nautical-mile, 105-degree-inclination orbit.
Mar. 13 Not announced 17C-17J	*Objective:* Not announced. *Satellite:* Not announced.	No elements available.	In orbit.

Successful U.S. Launches

October 1, 1993–September 30, 1994

Launch Date (GMT), Spacecraft Name, COSPAR Designation, Launch Vehicle	Mission Objectives, Spacecraft Data	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
Apr. 9 Space Shuttle Endeavour (STS-59) 20A	*Objective:* To gather Earth images from Space Radar Laboratory-1 to improve the understanding of our planet's carbon, water, and energy cycles and the effects humans have on them. *Spacecraft:* Shuttle orbiter carrying SRL-1 and other payloads.	218.0 204.0 88.7 56.9	Sixty-second flight of the STS. Piloted by Sidney M. Gutierrez and Kevin P. Chilton. Mission Specialists Jerome Apt, Michael R. Clifford, Linda M. Godwin (also Payload Commander), and Thomas D. Jones. Launched from KSC at 7:05 a.m. EDT. Landed at EAFB 12:54 p.m. EDT on Apr. 20. Mission duration: 11 days, 5 hours, 50 min.
Apr. 13 GOES-8 22A Atlas I	*Objective:* To provide more precise and timely weather observation and data on the atmosphere. *Spacecraft:* Geostationary Operational Environmental Satellite-8 with three-axis stabilization to permit continuous observation of the Earth.	35,805.0 35,773.0 1,436.2 0.2	Satellite positioned at 90° West Longitude during checkout, but plans called for it to be moved to 75° West Longitude once it became operational. In orbit.
May 3 DSP 26A Titan IV	*Objective:* To provide DoD with enhanced missile warning and surveillance capabilities. *Spacecraft:* The 17th Defense Support Program satellite, in geostationary orbit.	No elements available.	In orbit.
May 9 MSTI-2 28A Scout	*Objective:* To provide ballistic missile launch detection and environmental/ecological monitoring. *Spacecraft:* Miniature Sensor Technology Integration-2 satellite with short-wave and mid-wave infrared sensors.	433.0 415.0 93.1 97.1	Launched by the last Scout into Sun-synchronous orbit.
May 19 STEP-2 29A Pegasus	*Objective:* To evaluate unusual detection techniques for the DoD so as to separate adjacent, overlapping co-channel communications transmitted at a low signal level. *Spacecraft:* Space Test Program Experimental Platform.	817.0 600.0 99.0 82.0	In orbit.
Jun. 24 UFO-3 35A Atlas I	*Objective:* To provide UHF communications for DoD. *Spacecraft:* Third Ultra High Frequency Follow-on satellite built by Hughes Aircraft Company for the Navy to replace the FLTSATCOM system.	15,457.0 383.0 283.6 27.1	First Atlas launch conducted by Martin Marietta following its purchase of the Atlas business from General Dynamics. In orbit, became operational over the Atlantic Ocean in October 1994.

Successful U.S. Launches

October 1, 1993–September 30, 1994

Launch Date (GMT), Spacecraft Name, COSPAR Designation, Launch Vehicle	Mission Objectives, Spacecraft Data	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
Jul. 8 Space Shuttle Columbia (STS-65) 39A	*Objective:* To conduct research into the behavior of materials and life in the nearly weightless environment of low Earth orbit. *Spacecraft:* Shuttle orbiter equipped with the International Microgravity Laboratory-2 and other payloads.	304.0 300.0 90.5 28.4	Sixty-third flight of the STS. Piloted by Robert D. Cabana and James D. Halsell, Jr. Mission Specialists Richard J. Hieb (also Payload Commander); Carl E. Walz; Leroy Chiao, PhD; and Donald A. Thomas, PhD. Payload Specialist Chiaki Naito-Mukai, MD, PhD (Japan). Launched from KSC at 12:43 p.m. EDT. Landed at KSC on July 23 following a record duration flight of 14 days, 17 hours, 55 min.
Aug. 3 APEX 46A Pegasus	*Objective:* To test the impact of radiation in the Van Allen belt on two target instruments. *Spacecraft:* Advanced Photovoltaic Experiment, a test spacecraft carrying three diagnostic instruments.	2,538.0 362.0 114.9 70.0	Pegasus launch vehicle carried by a B-52 bomber that took off from EAFB. In orbit.
Aug. 3 DBS-2 47A Atlas IIA	*Objective:* To provide commercial television service to the 48 contínguous states in the United States. Increases channel capacity from DBS-1 (alone) to 150 channels. *Spacecraft:* Geostationary communications satellite owned by DirecTv and United States Satellite Broadcasting. Named Direct Broadcast Satellite-2 or DIRECTV-2.	39,445.0 196.0 703.4 26.9	Launched commercially by Martin Marietta. In orbit.
Aug. 27 USA 105 54A Titan IV	*Objective:* Classified DoD mission. *Spacecraft:* Not announced.	No elements available.	In orbit along with 54B, about which no information is available.
Aug. 29 DMSP F-12 57A Atlas E	*Objective:* To provide specialized meteorological data in support of DoD operations, including cloud coverage, wind speed, and precipitation. *Spacecraft:* Defense Meteorological Satellite Program Satellite F-12 (indicating the 12th satellite in Block 5D) with 8 sensors to measure ocean surface wind speed, areas and intensity of precipitation, cloud water content, land surface moisture, and space environmental data.	856.0 838.0 101.9 98.9	In orbit.
Aug. 29 Not announced 57B-57E	*Objective:* Not announced. *Spacecraft:* Not announced.	Elements vary.	In orbit.

Successful U.S. Launches

October 1, 1993–September 30, 1994

Launch Date (GMT), Spacecraft Name, COSPAR Designation, Launch Vehicle	Mission Objectives, Spacecraft Data	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
Sept. 9 Space Shuttle Discovery (STS-64) 59A	*Objective:* To perform atmospheric research using a laser, conduct robotic processing of semiconductor materials, deploy and retrieve a free-flying astronomical sub-satellite, and perform the first untethered spacewalk by astronomers in over ten years. *Spacecraft:* Shuttle orbiter equipped with LIDAR In-Space Technology Experiment, the Robot Operated Processing System, Shuttle Pointed Autonomous Research Tool, and Simplified Aid for EVA (Extra Vehicular Activity) Rescue, among other items.	269.0 259.0 89.5 56.9	Sixty-fourth flight of the STS. Piloted by Richard N. Richards and L. Blaine Hammond, Jr. Mission Specialists J. M. Linenger, MD, PhD; Susan J. Helms; Carl J. Meade; and Mark C. Lee. Launched at 6:23 p.m. EDT and landed at 5:13 EDT at EAFB on Sept. 20. Mission duration: 10 days, 22 hours, 50 min.
Sept. 13 SPARTAN-201 59B Space Shuttle Discovery	*Objective:* To explain how the solar wind is generated by the Sun. *Spacecraft:* Shuttle Pointed Autonomous Research Tool-201, a battery-powered sub-satellite equipped with a pointing system and recorder for capturing data about the acceleration and velocity of the solar wind plus aspects of the Sun's corona.	50 miles behind Discovery.	Released from Discovery's payload bay and recovered on Sept. 15.
Sept. 30 Space Shuttle Endeavour (STS-68) 62A	Objective: To refly the Space Radar Laboratory and provide scientists with detailed information to help distinguish between human-induced environmental changes and other natural forms of change. *Spacecraft:* Shuttle orbiter equipped with Space Radar Laboratory-2, Get Away Special experiments, and a number of in-cabin payloads.	226.0 213.0 88.9 57.0	Sixty-fifth flight of STS. Piloted by Michael A. Baker and Terrence W. Wilcutt. Commander and Mission Specialist Thomas D. Jones. Mission Specialists Steven L. Smith, Daniel W. Bursch, and Peter J. K. Wisoff. Launched (after an initial abort on August 18) at 7:16 a.m. EDT from Cape Canaveral. Landed at EAFB on October 11.

U.S.-Launched Applications Satellites, 1988–Sept. 1994

Date	Name	Launch Vehicle	Remarks
			COMMUNICATIONS
Sept. 29, 1988	TDRS-3	Space Shuttle	Space-based communications and tracking satellite.
Mar. 13, 1989	TDRS-4	Space Shuttle	Space-based communications and tracking satellite.
Sept. 25, 1989	Fltsatcom F-8	Atlas/Centaur	Sixth, and last, in series of geosynchronous satellites for U.S. Navy.
Jan. 1, 1990	Skynet 4A	Titan III	Launched for British Ministry of Defense.
Jan. 1, 1990	JCSAT 2	Titan III	Second of dual Titan III launch for Japanese Communications Satellite Co.
Jan. 9, 1990	Syncom IV-5	Space Shuttle	Leasat 5, fourth in series of satellites for U.S. Navy.
Mar. 14, 1990	Intelsat 6 F-3	Titan III	Launched for INTELSAT.
Apr. 13, 1990	Palapa-B2R	Delta	Launched for Indonesia.
Jun. 23, 1990	Intelsat 6 F-4	Titan III	Launched for INTELSAT.
Aug. 18, 1990	BSB-2R	Delta	Launched for British Satellite Broadcasting.
Aug. 2, 1991	TDRS-5	Space Shuttle	Space-based communications and tracking satellite.
Feb. 10, 1992	DSCS III	Atlas II	Launched by the Air Force for DoD.
Mar. 14, 1992	Galaxy 5	Atlas I	Commercial communications satellite.
May 14, 1992	Palapa-B4	Delta	Launched for Indonesia.
Jun. 10, 1992	INTELSAT K	Atlas IIA	Launched for INTELSAT.
Jul. 2, 1992	DSCS III	Atlas II	Launched by the Air Force for the DoD.
Aug. 31, 1992	Satcom C4	Delta II	Commercial communications satellite.
Oct. 12, 1992	DFS-3	Delta II	Launched by McDonnell Douglas for German communications.
Jan. 13, 1993	TDRS-6	Space Shuttle	Space-based communications and tracking satellite.
Feb. 9, 1993	OXP-1	Pegasus	Experimental, demonstration satellite for transmitting brief messages with hand-held communicators.
Mar. 25, 1993	UFO-1	Atlas-Centaur I	Launched for the Navy but to a useless orbit.
Jul. 19, 1993	DSCS III	Atlas II	Defense Satellite Communications System satellite.
Sept. 3, 1993	UFO-2	Atlas-Centaur I	Second of nine UHF satellites to replace the Navy's Fleet Satellite Communications System.
Sept. 12, 1993	ACTS	Space Shuttle	Test of advanced communications satellite technology.
Nov. 28, 1993	DSCS III	Atlas II	Defense Satellite Communications System satellite.
Dec. 8, 1993	NATO IVB	Delta II	NATO communications satellite for communications with NATO military forces and between NATO nations.
Dec. 16, 1993	Telstar 401	Atlas II	AT&T television and data communications satellite.
Feb. 7, 1994	Milstar	Titan IV	Initial Milstar EHF/UHF secure voice satellite for the U.S. Armed Forces.
Feb. 19, 1994	Galaxy 1R	Delta II	Hughes video communications satellite.
May 19, 1994	STEP-2	Pegasus	Test satellite to separate adjacent, overlapping co-channel communications.
Jun. 24, 1994	UFO-3	Atlas I	Third of nine UHF satellites to replace the Navy's Fleet Satellite Communications System.
Aug. 3, 1994	DBS-2	Atlas IIA	Commercial television satellite owned by DIRECTV and United States Satellite Broadcasting.
			WEATHER OBSERVATION[a]
Feb. 2, 1988	DMSP F-9	Atlas E	DoD Meteorological satellite.
Sept. 24, 1988	NOAA-11	Atlas E	Launched for NOAA, to repair NOAA-9.
Dec. 1, 1990	DMSP F-10	Atlas E	DoD meteorological satellite.
May 14, 1991	NOAA-12	Atlas E	Launched for NOAA.
Nov. 28, 1992	DMSP F-11	Atlas E	DoD meteorological satellite.
Feb. 9, 1993	SCD 1	Pegasus	Satellite to monitor cloud cover, rainfall, flood and tide levels, and air quality over Brazil.
Aug. 9, 1993	NOAA-13	Atlas E	Launched for NOAA but communications lost Aug. 21, 1993.
Apr. 13, 1994	GOES-8	Atlas I	Satellite to provide data on weather and the atmosphere.
Aug. 29, 1994	DMSP F-12	Atlas E	Meteorological satellite for DoD.

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

U.S.-Launched Applications Satellites, 1988–Sept. 1994

Date	Name	Launch Vehicle	Remarks
		EARTH OBSERVATION AND GEODESY[b]	
Oct. 23, 1992	LAGEOS II	Space Shuttle	Joint NASA-Italian satellite for a variety of Earth observation and geodetic missions.
Oct. 5, 1993	Landsat-6	Titan II	Launched to monitor Earth resources but communications lost.
May 9, 1994	MSTI-2	Scout	Satellite to detect ballistic missile launches and also perform environmental and ecological monitoring.
		NAVIGATION[a]	
Apr. 25, 1988	SOOS-3	Scout	Dual satellites, part of Navy navigation system.
Jun. 16, 1988	NOVA-2	Scout	Third of improved Transit System satellites for DoD.
Aug. 25, 1988	SOOS-4	Scout	Dual Satellites, part of Navy navigation system.
Feb. 14, 1989	GPS-1 (Block II)	Delta	Global Positioning System satellite.
June 10, 1989	GPS-2 (Block II)	Delta	Global Positioning System satellite.
Aug. 18, 1989	GPS-3 (Block II)	Delta	Global Positioning System satellite.
Oct. 21, 1989	GPS-4 (Block II)	Delta	Global Positioning System satellite.
Dec. 11, 1989	GPS-5 (Block II)	Delta	Global Positioning System satellite.
Jan. 24, 1990	GPS-6 (Block II)	Delta	Global Positioning System satellite.
Mar. 26, 1990	GPS-7 (Block II)	Delta	Global Positioning System satellite.
Aug. 2, 1990	GPS-8 (Block II)	Delta	Global Positioning System satellite.
Oct. 1, 1990	GPS-9 (Block II)	Delta	Global Positioning System satellite.
Nov. 16, 1990	GPS-10 (Block II)	Delta	Global Positioning System satellite.
Jul. 4, 1991	GPS-11 (Block II)	Delta	Global Positioning System satellite.
Feb. 23, 1992	GPS-12 (Block II)	Delta	Global Positioning System satellite.
Apr. 10, 1992	GPS-13 (Block II)	Delta	Global Positioning System satellite.
Jul. 7, 1992	GPS-14 (Block II)	Delta	Global Positioning System satellite.
Sept. 9, 1992	GPS-15 (Block II)	Delta	Global Positioning System satellite.
Nov. 22, 1992	GPS-16 (Block II)	Delta II	Global Positioning System satellite.
Dec. 18, 1992	GPS-17 (Block II)	Delta II	Global Positioning System satellite.
Feb. 3, 1993	GPS-18 (Block II)	Delta II	Global Positioning System satellite.
Mar. 30, 1993	GPS-19 (Block II)	Delta II	Global Positioning System satellite.
May 13, 1993	GPS-20 (Block II)	Delta II	Global Positioning System satellite.
Jun. 26, 1993	GPS-21 (Block II)	Delta II	Global Positioning System satellite.
Aug. 30, 1993	GPS-22 (Block II)	Delta II	Global Positioning System satellite.
Oct. 26, 1993	GPS (Block II)	Delta II	Global Positioning System satellite.
Mar. 10, 1994	GPS (Block II)	Delta II	Global Positioning System satellite.

[a]Does not include Department of Defense satellites that are not individually identified at launch.
[b]Previously separate categories. See also Weather Observation for satellites with multiple missions including Earth observation.

U.S.-Launched Scientific Satellites, 1988–Sept. 1994

Date	Name	Launch Vehicle	Remarks
Mar. 25, 1988	San Marco D/L	Scout	International satellite to study Earth's lower atmosphere.
Nov. 18, 1989	COBE	Delta	Measurement of cosmic background.
Feb. 14, 1990	LACE	Delta II	Low-powered atmospheric compensation experiment for DoD.
Feb. 14, 1990	RME	Delta II	Second payload, relay mirror experiment satellite for DoD.
Apr. 5, 1990	PEGSAT	Pegasus	Chemical release experiment satellite for NASA and DoD.
Apr. 25, 1990	Hubble Space Telescope	Space Shuttle	Long-term astronomical observations.
June 1, 1990	ROSAT	Delta II	Measurement of x-ray and extreme ultraviolet sources.
Jul. 25, 1990	CRRES	Atlas/Centaur	Chemical release experiment.
Apr. 7, 1991	Compton Gamma Ray Observatory	Space Shuttle	Measurement of celestial gamma-rays.
Sep. 15, 1991	Upper Atmosphere Research Satellite	Space Shuttle	Measurement of Earth's atmosphere and ozone layer.
Jun. 7, 1992	Extreme Ultra-violet Explorer	Delta II	Spectroscopic and wide-band observations over the entire extreme ultraviolet spectrum.
Jul. 3, 1992	Solar, Anomalous and Magnetospheric Particle Explorer	Scout	Investigation of cosmic rays and other phenomena of space physics.
Jul. 24, 1992	Geotail	Delta II	Investigation of geomagnetic tail region of the magnetosphere.
Aug. 2, 1992	Eureka-1	Space Shuttle	Research in the fields of material and life sciences.
Mar. 30, 1993	SEDS-I	Delta II	Comparison of actual tether dynamics with model.
Apr. 11, 1993	SPARTAN-201	Space Shuttle	Study solar wind and the Sun's corona.
Jun. 26, 1993	Plasma Motor Generator	Delta II	Demonstrate ability of tether to generate electrical current in space.
Sep. 13, 1993	ORFEUS-SPAS	Space Shuttle	Study very hot and very cold matter in universe.
Oct. 5, 1993	Landsat-6	Titan II	Satellite to support global change research but communications lost after successful launch by Titan II after kick motor failed to place it in final orbit.
Jan. 25, 1994	Clementine	Titan II	Satellite to test missile defense technologies and also provide mages of the Moon.
Feb. 9, 1994	BREMSAT	Space Shuttle	Satellite to study such phenomena in space as heat conductivity, the forces of acceleration, and atomic forces.
Mar. 10, 1994	SEDS-II	Delta II	Suspend a tether in space with a minimum of swing.
Sept. 13, 1994	SPARTAN-201	Space Shuttle	Second release of sub-satellite to study the solar wind and the Sun's corona.

U.S.-Launched Space Probes, 1975–Sept. 1994

Date	Name	Launch Vehicle	Remarks
Aug. 20, 1975	Viking 1	Titan IIIE-Centaur	Lander descended, landed safely on Mars on Plains of Chryse, Sept. 6, 1976, while orbiter circled planet photographing it and relaying all data to Earth. Lander photographed its surroundings, tested soil samples for signs of life, and took measurements of atmosphere.
Sept 9, 1975	Viking 2	Titan IIIE-Centaur	Lander descended, landed safely on Mars on Plains of Utopia, July 20, 1976, while orbiter circled planet photographing it and relaying all data to Earth. Lander photographed its surroundings, tested soil samples for signs of life, and took measurements of atmosphere.
Jan. 15, 1976	Helios 2	Titan IIIE-Centaur	Flew in highly elliptical orbit to within 41 million km. of the Sun, measuring solar wind, corona, electrons, and cosmic rays. Payload had some West German and U.S. experiments as Helios 1 plus cosmic-ray burst detector.
Aug. 20, 1977	Voyager 2	Titan IIIE-Centaur	Jupiter and Saturn flyby mission. Swung around Jupiter in July 1979, arrived at Saturn in 1981, going on to Uranus by 1986, Neptune by 1989.
Sept. 5, 1977	Voyager 1	Titan IIIE-Centaur	Jupiter and Saturn flyby mission. Passing Voyager 2 on the way, swung around Jupiter in Mar. 1979, arrived at Saturn in Nov. 1980, headed for outer solar system.
May 20, 1978	Pioneer Venus 1	Atlas-Centaur	Venus orbiter, achieved Venus orbit Dec. 4, returning imagery and data.
Aug. 8, 1978	Pioneer Venus 2	Atlas-Centaur	Carried 1 large, 3 small probes plus spacecraft bus; all descended through Venus atmosphere Dec. 9, returned data.
May 4, 1989	Magellan	Space Shuttle	Venus orbiter, achieved Venus orbit Aug. 10, 1990, returning radar image of surface.
Oct. 18, 1989	Galileo	Space Shuttle	Planetary exploration spacecraft, composed of probe to enter Jupiter's atmosphere and orbiter to return scientific data.
Oct. 6, 1990	Ulysses	Space Shuttle	Solar exploration spacecraft, to explore interstellar space and the Sun.
Sept. 25, 1992	Mars Observer	Titan III	Planetary exploration spacecraft to study the geology, geophysics, and climate of Mars; ceased communicating with Earth Aug. 21, 1993.
Jan. 25, 1994	Clementine	Titan II	Experimental deep space probe that entered lunar orbit on Feb. 19, 1994, and took 1.8 million images of the surface of the Moon during the next 2 1/2 months.

U.S. and Russian Human Spaceflights, 1961–Sept. 1994

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Vostok 1	Apr. 12, 1961	Yury A. Gagarin	0:1:48	First human flight.
Mercury-Redstone 3	May 5, 1961	Alan B. Shepard, Jr.	0:0:15	First U.S. flight; suborbital.
Mercury-Redstone 4	July 21, 1961	Virgil I. Grissom	0:0:16	Suborbital; capsule sank after landing; astronaut safe.
Vostok 2	Aug. 6, 1961	German S. Titov	1:1:18	First flight exceeding 24 hrs.
Mercury-Atlas 6	Feb. 20, 1962	John H. Glenn, Jr.	0:4:55	First American to orbit.
Mercury-Atlas 7	May 24, 1962	M. Scott Carpenter	0:4:56	Landed 400 km. beyond target.
Vostok 3	Aug. 11, 1962	Andriyan G. Nikolayev	3:22:25	First dual mission (with Vostok 4).
Vostok 4	Aug. 12, 1962	Pavel R. Popovich	2:22:59	Came within 6 km. of Vostok 3.
Mercury-Atlas 8	Oct. 3, 1962	Walter M. Schirra, Jr.	0:9:13	Landed 8 km. from target.
Mercury-Atlas 9	May 15, 1963	L. Gordon Cooper, Jr.	1:10:20	First U.S. flight exceeding 24 hrs.
Vostok 5	June 14, 1963	Valery F. Bykovskiy	4:23:6	Second dual mission (withVostok 6).
Vostok 6	June 16, 1963	Valentina V. Tereshkova	2:22:50	First woman in space; within 5 km. of Vostok 5.
Voskhod 1	Oct. 12, 1964	Vladimir M. Komarov Konstantin P. Feoktistov Boris G. Yegorov	1:0:17	First 3-person crew.
Voskhod 2	Mar. 18, 1965	Pavel I. Belyayev Aleksey A. Leonov	1:2:2	First extravehicular activity (Leonov, 10 min.).
Gemini 3	Mar. 23, 1965	Virgil I. Grissom John W. Young	0:4:53	First U.S. 2-person flight; first manual maneuvers in orbit.
Gemini 4	June 3, 1965	James A. McDivitt Edward H. White, II	4:1:56	21-min. extravehicular activity (White).
Gemini 5	Aug. 21, 1965	L. Gordon Cooper, Jr. Charles Conrad, Jr.	7:22:55	Longest-duration human flight to date.
Gemini 7	Dec. 4, 1965	Frank Borman James A. Lovell, Jr.	13:18:35	Longest human flight to date.
Gemini 6-A	Dec. 15, 1965	Walter M. Schirra, Jr. Thomas P. Stafford	1:1:51	Rendezvous within 30 cm. of Gemini 7.
Gemini 8	Mar. 16, 1966	Neil A. Armstrong David R. Scott	0:10:41	First docking of 2 orbiting spacecraft (Gemini 8 with Agena target rocket).
Gemini 9-A	June 3, 1966	Thomas P. Stafford Eugene A. Cernan	3:0:21	Extravehicular activity; rendezvous.
Gemini 10	July 18, 1966	John W. Young Michael Collins	2:22:47	First dual rendezvous (Gemini 10 with Agena 10, then Agena 8).
Gemini 11	Sept. 12, 1966	Charles Conrad, Jr. Richard F. Gordon, Jr.	2:23:17	First initial-orbit docking; first tethered flight; highest Earth-orbit altitude (1,372 km.).
Gemini 12	Nov. 11, 1966	James A. Lovell, Jr. Edwin E. Aldrin, Jr.	3:22:35	Longest extravehicular activity to date (Aldrin, 5 hrs.)
Soyuz 1	Apr. 23, 1967	Vladimir M. Komarov	1:2:37	Cosmonaut killed in reentry accident.
Apollo 7	Oct. 11, 1968	Walter M. Schirra, Jr. Donn F. Eisele R. Walter Cunningham	10:20:9	First U.S. 3-person mission.
Soyuz 3	Oct. 26, 1968	Georgiy T. Beregovoy	3:22:51	Maneuvered near uncrewed Soyuz 2.
Apollo 8	Dec. 21, 1968	Frank Borman James A. Lovell, Jr. William A. Anders	6:3:1	First human orbit(s) of Moon; first human departure from Earth's sphere of influence; highest speed attained in human flight to date.
Soyuz 4	Jan. 14, 1969	Vladimir A. Shatalov	2:23:23	Soyuz 4 and 5 docked and transferred 2 cosmonauts from Soyuz 5 to Soyuz 4.
Soyuz 5	Jan. 15, 1969	Boris V. Volynov Aleksey A. Yeliseyev Yevgeniy V. Khrunov	3:0:56	
Apollo 9	Mar. 3, 1969	James A. McDivitt David R. Scott Russell L. Schweickart	10:1:1	Successfully simulated in Earth-orbit operation of lunar module to landing and takeoff from lunar surface and rejoining with command module.
Apollo 10	May 18, 1969	Thomas P. Stafford John W. Young Eugene A. Cernan	8:0:3	Successfully demonstrated complete system including lunar module to 14,300 m. from the lunar surface.

Appendix C
(continued)

U.S. and Russian Human Spaceflights, 1961–Sept. 1994

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Apollo 11	July 16, 1969	Neil Armstrong Michael Collins Edwin E. Aldrin, Jr.	8:3:9	First human landing on lunar surface and safe return to Earth. First return of rock and soil samples to Earth, and human deployment of experiments on lunar surface.
Soyuz 6	Oct. 11, 1969	Georgiy Shonin Valery N. Kubasovf	4:22:42	Soyuz 6, 7, and 8 operated as a group flight without actually docking. Each conducted certain experiments, including welding and Earth and celestial observation.
Soyuz 7	Oct. 12, 1969	A. V. Filipchenko Viktor N. Gorbatko Vladislav N. Volkov	4:22:41	
Soyuz 8	Oct. 13, 1969	Vladimir A. Shatalov Aleksey S. Yeliseyev	4:22:50	
Apollo 12	Nov. 14, 1969	Charles Conrad, Jr. Richard F. Gordon, Jr. Alan L. Bean	10:4:36	Second human lunar landing Explored surface of Moon and retrieved parts of Surveyor 3 spacecraft, which landed in Ocean of Storms on Apr. 19, 1967.
Apollo 13	Apr. 11, 1970	James A. Lovell, Jr. Fred W. Haise, Jr. John L. Swigert, Jr.	5:22:55	Mission aborted; explosion in service module. Ship circled, Moon, with crew using LEM as "lifeboat" until just before reentry.
Soyuz 9	June 1, 1970	Andriyan G. Nikolayev Vitaliy I. Sevastyanov	17:16:59	Longest human spaceflight to date.
Apollo 14	Jan. 31, 1971	Alan B. Shepard, Jr. Stuart A. Roosa Edgar D. Mitchell	9:0:2	Third human lunar landing. Mission demonstrated pinpoint landing capability and continued human exploration.
Soyuz 10	Apr. 22, 1971	Vladimir A. Shatalov Aleksey S. Yeliseyev Nikolay N. Rukavishnikov	1:23:46	Docked with Salyut 1, but crew did not board space station launched Apr. 19. Crew recovered Apr. 24, 1971.
Soyuz 11	June 6, 1971	Georgiy T. Dobrovolskiy Vladislav N. Volkov Viktor I. Patsayev	23:18:22	Docked with Salyut 1 and Soyuz 11 crew occupied space station for 22 days. Crew perished in final phase of Soyuz 11 capsule recovery on June 30, 1971.
Apollo 15	July 26, 1971	David R. Scott Alfred M. Worden James B. Irwin	12:7:12	Fourth human lunar landing and first Apollo "J" series mission, which carried Lunar Roving Vehicle. Worden's inflight EVA of 38 min. 12 sec was performed during return trip.
Apollo 16	Apr. 16, 1972	John W. Young Charles M. Duke, Jr. Thomas K. Mattingly II	11:1:51	Fifth human lunar landing, with Lunar Roving Vehicle.
Apollo 17	Dec. 7, 1972	Eugene A. Cernan Harrison H. Schmitt Ronald E. Evans	12:13:52	Sixth and final Apollo human lunar landing, again with roving vehicle.
Skylab 2	May 25, 1973	Charles Conrad, Jr. Joseph P. Kerwin Paul J. Weitz	28:0:50	Docked with Skylab 1 (launched uncrewed May 14) for 28 days. Repaired damaged station.
Skylab 3	July 28, 1973	Alan L. Bean Jack R. Lousma Owen K. Garriott	59:11:9	Docked with Skylab 1 for more than 59 days.
Soyuz 12	Sept. 27, 1973	Vasiliy G. Lazarev Oleg G. Makarov	1:23:16	Checkout of improved Soyuz.
Skylab 4	Nov. 16, 1973	Gerald P. Carr Edward G. Gibson William R. Pogue	84:1:16	Docked with Skylab 1 in long-duration mission; last of Skylab program.
Soyuz 13	Dec. 18, 1973	Petr I. Klimuk Valentin V. Lebedev	7:20:55	Astrophysical, biological, and Earth resources experiments.
Soyuz 14	July 3, 1974	Pavel R. Popovich Yury P. Artyukhin	15:17:30	Docked with Salyut 3 and Soyuz 14 crew occupied space station.
Soyuz 15	Aug. 26, 1974	Gennady V. Sarafanov Lev. S. Demin	2:0:12	Rendezvoused but did not dock with Salyut 3.
Soyuz 16	Dec. 2, 1974	Anatoly V. Filipchenko Nikolay N. Rukavishnikov	5:22:24	Test of ASTP configuration.
Soyuz 17	Jan. 10, 1975	Aleksay A. Gubarev Georgiy M. Grechko	29:13:20	Docked with Salyut 4 and occupied station.

U.S. and Russian Human Spaceflights, 1961–Sept. 1994

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Anomaly	Apr. 5, 1975	Vasiliy G. Lazarev Oleg G. Makarov	0:0:20	Soyuz stages failed to separate; crew recovered after abort.
Soyuz 18	May 24, 1975	Petr I. Klimuk Vitaliy I. Sevastyanov	62:23:20	Docked with Salyut 4 and occupied station.
Soyuz 19	July 15, 1975	Aleksey A. Leonov	5:22:31	Target for Apollo in docking and joint experiments of ASTP mission.
Apollo	July 15, 1975	Thomas P. Stafford Vance D. Brand	9:1:28	Docked with Soyuz 19 in joint (ASTP) experiments of ASTP mission.
Soyuz 21	July 6, 1976	Boris V. Volynov Vitaliy M. Zholobov	48:1:32	Docked with Salyut 5 and occupied station.
Soyuz 22	Sept. 15, 1976	Valery F. Bykovskiy Vladimir V. Aksenov	7:21:54	Earth resources study with multispectral camera system.
Soyuz 23	Oct. 14, 1976	Vyacheslav D. Zudov Valery I. Rozhdestvenskiy	2:0:6	Failed to dock with Salyut 5.
Soyuz 24	Feb. 7, 1977	Viktor V. Gorbatko Yury N. Glazkov	17:17:23	Docked with Salyut 5 and occupied station.
Soyuz 25	Oct. 9, 1977	Vladimir V. Kovalenok Valery V. Ryumin	2:0:46	Failed to achieve hard dock with Salyut 6 station.
Soyuz 26	Dec. 10, 1977	Yury V. Romanenko Georgiy M. Grechko	37:10:6	Docked with Salyut 6. Crew returned in Soyuz 27; crew duration 96 days 10 hrs.
Soyuz 27	Jan. 10, 1978	Vladimir A. Dzhanibekov Oleg G. Makarov	64:22:53	Docked with Salyut 6. Crew returned in Soyuz 26; crew duration 5 days, 22 hrs., 59 min.
Soyuz 28	Mar. 2, 1978	Aleksey A. Gubarev Vladimir Remek	7:22:17	Docked with Salyut 6. Remek was first Czech cosmonaut to orbit.
Soyuz 29	June 15, 1978	Vladimir V. Kovalenok Aleksandr S. Ivanchenkov	9:15:23	Docked with Salyut 6. Crew returned in Soyuz 31; crew duration 139 days, 14 hrs, 48 min.
Soyuz 30	June 27, 1978	Petr I. Klimuk Miroslaw Hermaszewski	7:22:4	Docked with Salyut 6. Hermaszewski was first Polish cosmonaut to orbit.
Soyuz 31	Aug. 26, 1978	Valery F. Bykovskiy Sigmund Jaehn	67:20:14	Docked with Salyut 6. Crew returned in Soyuz 29; crew duration 7 days, 20 hrs, 49 min. Jaehn was first German Democratic Republic cosmonaut to orbit.
Soyuz 32	Feb. 25, 1979	Vladimir A. Lyakhov Valery V. Ryumin Nikolay N. Rukavishnikov	108:4:24	Docked with Salyut 6. Crew returned in Soyuz 34; crew duration 175 days, 36 min.
Soyuz 33	Apr. 10, 1979	Georgi I. Ivanov	1:23:1	Failed to achieve docking with Salyut 6 station. Ivanov was first Bulgarian cosmonaut to orbit.
Soyuz 34	June 6, 1979	(unmanned at launch)	7:18:17	Docked with Salyut 6, later served as ferry for Soyuz 32 crew while Soyuz 32 returned without a crew.
Soyuz 35	Apr. 9, 1980	Leonid I. Popov Valery V. Ryumin	55:1:29	Docked with Salyut 6. Crew returned in Soyuz 37. Crew duration 184 days, 20 hrs, 12 min.
Soyuz 36	May 26, 1980	Valery N. Kubasov Bertalan Farkas	65:20:54	Docked with Salyut 6. Crew returned in Soyuz 35. Crew duration 7 days, 20 hrs, 46 min. Farkas was first Hungarian to orbit.
Soyuz T-2	June 5, 1980	Yury V. Malyshev Vladimir V. Aksenov	3:22:21	Docked with Salyut 6. First crewed flight of new-generation ferry.
Soyuz 37	July 23, 1980	Viktor V. Gorbatko Pham Tuan	79:15:17	Docked with Salyut 6. Crew returned in Soyuz 36. Crew duration 7 days, 20 hrs, 42 min. Pham was first Vietnamese to orbit.
Soyuz 38	Sept. 18, 1980	Yury V. Romanenko Arnaldo Tamayo Mendez	7:20:43	Docked with Salyut 6. Tamayo was first Cuban to orbit.
Soyuz T-3	Nov. 27, 1980	Leonid D. Kizim Oleg G. Makarov Gennady M. Strekalov	12:19:8	Docked with Salyut 6. First 3-person flight in Soviet program since 1971.
Soyuz T-4	Mar. 12, 1981	Vladimir V. Kovalenok Viktor P. Savinykh	74:18:38	Docked with Salyut 6.
Soyuz 39	Mar. 22, 1981	Vladimir A. Dzhanibekov Jugderdemidiyn Gurragcha	7:20:43	Docked with Salyut 6. Gurragcha first Mongolian cosmonaut to orbit.

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Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Space Shuttle Columbia (STS 1)	Apr .12, 1981	John W. Young Robert L. Crippen	2:6:21	First flight of Space Shuttle, tested spacecraft in orbit. First landing of airplane-like craft from orbit for reuse.
Soyuz 40	May 14, 1981	Leonid I. Popov Dumitru Prunariu	7:20:41	Docked with Salyut 6. Prunariu first Romanian cosmo naut to orbit.
Space Shuttle Columbia (STS-2)	Nov. 12, 1981	Joe H. Engle Richard H. Truly	2:6:13	Second flight of Space Shuttle, first scientific payload (OSTA 1). Tested remote manipulator arm. Returned for reuse.
Space Shuttle Columbia (STS-3)	Mar. 22, 1982	Jack R. Lousma C. Gordon Fullerton	8:4:49	Third flight of Space Shuttle, second scientific payload (0SS 1). Second test of remote manipulator arm. Flight extended 1 day because of flooding at primary landing site; alternate landing site used. Returned for reuse.
Soyuz T-5	May 13, 1982	Anatoly Berezovoy Valentin Lebedev	211:9:5	Docked with Salyut 7. Crew duration of 211 days. Crew returned in Soyuz T-7.
Soyuz T-6	June 24, 1982	Vladimir Dzhanibekov Aleksandr Ivanchenkov Jean-Loup Chrétien	7:21:51	Docked with Salyut 7. Chrétien first French cosmonaut to orbit.
Space Shuttle Columbia (STS-4)	June 27, 1982	Thomas K. Mattingly II Henry W. Hartsfield, Jr.	7:1:9	Fourth flight of Space Shuttle, first DoD payload, additional scientific payloads. Returned July 4. Completed testing program. Returned for reuse.
Soyuz T-7	Aug. 19, 1982	Leonid Popov Aleksandr Serebrov Svetlana Savitskaya	7:21:52	Docked with Salyut 7. Savitskaya second Soviet woman to orbit. Crew returned in Soyuz T-5.
Space Shuttle Columbia (STS-5)	Nov. 11, 1982	Vance D. Brand Robert F. Overmyer Joseph P. Allen William B. Lenoir	5:2:14	Fifth flight of Space Shuttle, first operational flight; launched 2 commercial satellites (SBS 3 and Anik C- 3); first flight with 4 crew members. EVA test canceled when space suits malfunctioned.
Space Shuttle Challenger (STS-6)	Apr. 4, 1983	Paul J. Weitz Karol J. Bobko Donald H. Peterson Story Musgrave	5:0:24	Sixth flight of Space Shuttle, launched TDRS 1.
Soyuz T-8	Apr. 20, 1983	Vladimir Titov Gennady Strekalov Aleksandr Serebrov	2:0:18	Failed to achieve docking with Salyut 7 station.
Space Shuttle Challenger (STS-7)	June 18, 1983	Robert L. Crippen Frederick H. Hauck John M. Fabian Sally K. Ride Norman T. Thagard	6:2:24	Seventh flight of Space Shuttle, launched 2 commercial satellites (Anik C-2 and Palapa B-l), also launched and retrieved SPAS 01; first flight with 5 crewmembers, including first woman U.S. astronaut.
Soyuz T-9	June 28, 1983	ladimir Lyakhov Aleksandr Aleksandrov	149:9:46	Docked with Salyut 7 station.
Space Shuttle Challenger (STS-8)	Aug. 30, 1983	Richard H. Truly Daniel C. Brandenstein Dale A. Gardner Guion S. Bluford, Jr. William E. Thornton	6:1:9	Eighth flight of Space Shuttle, launched one commercial satellite (Insat l-B), first flight of U.S. black astronaut.
Space Shuttle Columbia (STS-9)	Nov. 28, 1983	John W. Young Brewster W. Shaw Owen K. Garriott Robert A. R. Parker Byron K. Lichtenberg Ulf Merbold	10:7:47	Ninth flight of Space Shuttle, first flight of Spacelab 1, first flight of 6 crew members, one of whom was West German, first non-U.S. astronaut to fly in U.S. space program (Merbold).
Space Shuttle Challenger (STS-41B)	Feb. 3, 1984	Vance D. Brand Robert L. Gibson Bruce McCandless Ronald E. McNair Roben L. Stewart	7:23:16	Tenth flight of Space Shuttle, two communication satellites failed to achieve orbit. First use of Manned Maneuvering Unit (MMU) in space.
Soyuz T-10	Feb. 8, 1984	Leonid Kizim Vladimir Solovev Oleg Atkov	62:22:43	Docked with Salyut 7 station. Crew set space duration record of 237 days. Crew returned in Soyuz T-ll.

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Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Soyuz T-11	Apr. 3, 1984	Yury Malyshev Gennady Strekalov Rakesh Sharma	181:21:48	Docked with Salyut 7 station. Sharma first Indian in space. Crew returned in Soyuz T-10.
Space Shuttle Challenger (STS-41C)	Apr. 6, 1984	Robert L. Crippen Frances R. Scobee Terry J. Hart George D. Nelson James D. van Hoften	6:23:41	Eleventh flight of Space Shuttle, deployment of LDEF-l, for later retrieval, Solar Maximum Satellite retrieved, repaired, and redeployed.
Soyuz T-12	July 17, 1984	Vladimir Dzhanibekov Svetlana Savistskaya Igor Volk	11:19:14	Docked with Salyut 7 station. First female extravehicular activity.
Space Shuttle Discovery (STS-41D)	Aug. 30, 1984	Henry W. Hartsfield Michael L. Coats Richard M. Mullane Steven A. Hawley Judith A. Resnik Charles D. Walker	6:0:56	Twelfth flight of Space Shuttle. First flight of U.S. non-astronaut.
Space Shuttle Challenger (STS-41G)	Oct. 5, 1984	Robert L. Crippen Jon A. McBride Kathryn D. Sullivan Sally K. Ride David Leestma Paul D. Scully-Power Marc Garneau	8:5:24	Thirteenth flight of Space Shuttle, first of 7 crew members, including first flight of two U.S. women and one Canadian (Garneau).
Space Shuttle Discovery (STS-51A)	Nov. 8, 1984	Frederick H. Hauck David M. Walker Joseph P. Allen Anna L. Fisher Dale A. Gardner	7:23:45	Fourteenth flight of Space Shuttle, first retrieval and return of two disabled communications satellites. (Westar 6, Palapa B2) to Earth.
Space Shuttle Discovery (STS-51C)	Jan. 24, 1985	Thomas K. Mattingly Loren J. Shriver Ellison S. Onizuka James F. Buchli Gary E. Payton	3:1:33	Fifteenth STS flight. Dedicated DoD mission.
Space Shuttle Discovery (STS-51D)	Apr. 12, 1985	Karol J. Bobko Donald E. Williams M. Rhea Seddon S. David Griggs Jeffrey A. Hoffman Charles D. Walker E. J. Garn	6:23:55	Sixteenth STS flight. Two communications satellites. First U.S. Senator in space (Garn).
Space Shuttle Challenger (STS-51B)	Apr. 29, 1985	Robert F. Overmyer Frederick D. Gregory Don L. Lind Norman E. Thagard William E. Thornton Lodewijk van den Berg Taylor Wang	7:0:9	Seventeenth STS flight. Spacelab-3 in cargo bay of shuttle.
Soyuz T-13	June 5, 1985	Vladimir Dzhanibekov Viktor Savinykh	112:3:12	Repair of Salyut-7. Dzhanibekov returned to Earth with Grechko on Soyuz T-13 spacecraft, Sept. 26, 1985.
Space Shuttle Discovery (STS-51G)	June 17, 1985	Daniel C. Brandenstein John O. Creighton Shannon W. Lucid John M. Fabian Steven R. Nagel Patrick Baudry Sultan bin Salman bin Abdul-Aziz Al-Saud	7:1:39	Eighteenth STS flight. Three communications satellites. One reusable payload, Spartan-l. First U.S. flight with French and Saudi Arabian crewmembers.

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Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Space Shuttle Challenger (STS-51F)	July 29, 1985	Charles G. Fullerton Roy D. Bridges Karl C. Henize Anthony W. England F. Story Musgrave Loren W. Acton John-David F. Bartoe	7:22:45	Nineteenth STS flight. Spacelab-2 in cargo bay.
Space Shuttle Discovery (STS-51I)	Aug. 27, 1985	Joe H. Engle Richard O. Covey James D. van Hoften William F. Fisher John M. Lounge	7:2:18	Twentieth STS flight. Launched three communications satellites. Repaired Syncom IV-3.
Soyuz T-14	Sept. 17, 1985	Vladimir Vasyutin Georgiy Grechko Aleksandr Volkov	64:21:52	Docked with Salyut 7 station. Viktor Savinykh, Aleksandr Volkov and Vladimir Vasyutin returned to Earth Nov. 21, 1985, when Vasyutin became ill.
Space Shuttle Atlantis (STS-51J)	Oct. 3, 1985	Karol J. Bobko Ronald J. Grabe Robert A. Stewart David C. Hilmers William A. Pailes	4:1:45	Twenty-first STS flight. Dedicated DOD mission.
Space Shuttle Challenger (STS-61A)	Oct. 30, 1985	Henry W. Hartsfield Steven R. Nagel Bonnie J. Dunbar James F. Buchli Guion S. Bluford, Jr. Ernst Messerschmid Reinhard Furrer (FRG) Wubbo J. Ockels (ESA)	7:0:45	Twenty-second STS flight. Dedicated German Spacelab D-1 in shuttle cargo bay.
Space Shuttle Atlantis (STS-61B)	Nov. 27, 1985	Brewster H. Shaw Bryan D. O'Connor Mary L. Cleve Sherwood C. Spring Jerry L. Ross Rudolfo Neri Vela Charles D. Walker	6:22:54	Twenty-third STS flight. Launched three communications satellites. First flight of Mexican astronaut (Neri Vela).
Space Shuttle Columbia (STS-61C)	Jan. 12, 1986	Robert L. Gibson Charles F. Bolden, Jr. Franklin Chang-Diaz Steve A. Hawley George D. Nelson Roger Cenker Bill Nelson	6:2:4	Twenty-fourth STS flight. Launched one communications satellite. First member of U.S. House of Representatives in space (Bill Nelson).
Soyuz T-15	Mar. 13, 1986	Leonid Kizim Vladimir Solovyov	125:1:1	Docked with Mir space station on May 5/6 transferred to Salyut 7 complex. On June 25/26 transferred from Salyut 7 back to Mir.
Soyuz TM-2	Feb. 5, 1987	Yury Romanenko Aleksandr Laveykin	174:3:26	Docked with Mir space station. Romanenko established long distance stay in space record of 326 days.
Soyuz TM-3	July 22, 1987	Aleksandr Viktorenko Aleksandr Aleksandrov Mohammed Faris	160:7:16	Docked with Mir space station. Aleksandr Aleksandrov remained in Mir 160 days, returned with Yury Romanenko. Viktorenko and Faris returned in Soyuz TM-2, July 30 with Aleksandr Laveykin who experienced medical problems. Mohammed Faris first Syrian in space.
Soyuz TM-4	Dec. 21, 1987	Vladimir Titov Musa Manarov Anatoly Levchenko	180:5	Docked with Mir space station. Crew of Yury Romakenko Aleksandr Aleksandrov, and Anatoly Levchenko returned Dec. 29 in Soyuz TM-3.
Soyuz TM-5	June 7, 1988	Viktor Savinykh Anatoly Solovyev Aleksandur Aleksandrov	9:20:13	Docked with Mir space station, Aleksandrov first Bulgarian in space. Crew returned June 17 in Soyuz TM-4.

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Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Soyuz TM-6	Aug. 29, 1988	Vladimir Lyakhov Valery Polyakov Abdul Mohmand	8:19:27	Docked with Mir space station, Mohmand first Afghanistani in space. Crew returned Sept. 7, in Soyuz TM-5.
STS-26	Sept. 29, 1988	Frederick H. Hauck Richard O. Covey John M. Lounge David C. Hilmers George D. Nelson	4:1	Twenty-sixth STS flight. Launched TDRS 3.
Soyuz TM-7	Nov. 26, 1988	Aleksandr Volkov Sergey Krikalev Jean-Loup Chrétien	151:11	Docked with Mir space station. Soyuz TM-6 returned with Chrétien, Vladimir Titov, and Musa Manarov. Titov and Manarov completed 366-day mission Dec. 21. Crew of Krikalev, Volkov, and Valery Polyakov returned Apr. 27, 1989 in Soyuz TM-7.
STS-27	Dec. 2, 1988	Robert "Hoot" Gibson Guy S. Gardner Richard M. Mullane Jerry L. Ross William M. Shepherd	4:9:6	Twenty-seventh STS flight. Dedicated DoD mission.
STS-29	Mar. 13, 1989	Michael L. Coats John E. Blaha James P. Bagian James F. Buchli Robert C. Springer	4:23:39	Twenty-eighth STS flight. Launched TDRS-4.
STS-30	May 4, 1989	David M. Walker Ronald J. Grabe Nomman E. Thagard Mary L. Cleave Mark C. Lee	4:0:57	Twenty-ninth STS flight. Venus orbiter Magellan launched.
STS-28	Aug. 8, 1989	Brewster H. Shaw Richard N. Richards James C. Adamson David C. Leestma Mark N. Brown	5:1	Thirtieth STS flight. Dedicated DoD mission.
Soyuz TM-8	Sept. 5, 1989	Aleksandr Viktorenko Aleksandr Serebrov	166:6	Docked with Mir space station. Crew of Viktorenko and Serebrov returned in Soyuz TM-8, Feb. 9, 1990.
STS-34	Oct. 18, 1989	Donald E. Williams Michael J. McCulley Shannon W. Lucid Franklin R. Chang-Diaz Ellen S. Baker	4:23:39	Thirty-first STS flight. Launched Jupiter probe and orbiter Galileo.
STS-33	Nov. 23, 1989	Frederick D. Gregory John E. Blaha Kathryn C. Thornton F. Story Musgrave Manley L. "Sonny" Carter	5:0:7	Thirty-second STS flight. Dedicated DoD mission.
STS-32	Jan. 9, 1990	Daniel C. Brandenstein James D. Wetherbee Bonnie J. Dunbar Marsha S. Ivins G. David Low	10:21	Thirty-third STS flight. Launched Syncom IV-5 and retrieved Long-Duration Exposure Facility (LDEF).
Soyuz TM-9	Feb. 11, 1990	Anatoly Solovyov Aleksandr Balandin	178:22:19	Docked with Mir space station. Crew returned Aug. 9, 1990, in Soyuz TM-9.
STS-36	Feb. 28, 1990	John O. Creighton John H. Casper David C. Hilmers Richard H. Mullane Pierre J. Thuot	4:10:19	Thirty-fourth STS flight. Dedicated DoD mission.

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Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
STS-31	Apr. 24, 1990	Loren J. Shriver Charles F. Bolden, Jr. Steven A. Hawley Bruce McCandless II Kathryn D. Sullivan	5:1:16	Thirty-fifth STS flight. Launched Hubble Space Telescope (HST).
Soyuz TM-10	Aug. 1, 1990	Gennady Manakov Gennady Strekalov	130:20:36	Docked with Mir space station. Crew returned Dec. 10, 1990, with Toyohiro Akiyama, Japanese astronaut.
STS-41	Oct. 6, 1990	Richard N. Richards Robert D. Cabana Bruce E. Melnick William M. Shepherd Thomas D. Akers	4:2:10	Thirty-sixth STS flight. Ulysses spacecraft to investigate interstellar space and the Sun.
STS-38	Nov. 15, 1990	Richard O. Covey Frank L. Culbertson, Jr. Charles "Sam" Gemar Robert C. Springer Carl J. Meade	4:21:55	Thirty-seventh STS flight. Dedicated DoD mission.
STS-35	Dec. 2, 1990	Vance D. Brand Guy S. Gardner Jeffrey A. Hoffman John M. "Mike" Lounge Robert A. R. Parker	8:23:5	Thirty-eighth STS flight. ASTRO-1 in cargo bay.
Soyuz TM-11	Dec. 2, 1990	Viktor Afanasyev Musa Manarov	175:01:52	Docked with Mir space station. Toyohiro Akiyama returned Dec. 10, 1990, with previous Mir crew of Gennady Manakov and Gennady Strekalov.
STS-37	Apr. 5, 1991	Steven R. Nagel Kenneth D. Cameron Linda Godwin Jerry L. Ross Jay Apt	6:0:32	Thirty-ninth STS flight. Launched Gamma Ray Observatory to measure celestial gamma-rays.
STS-39	Apr. 28, 1991	Michael L. Coats Blaine Hammond, Jr. Gregory L. Harbaugh Donald R. McMonagle Guion S. Bluford, Jr. Lacy Veach Richard J. Hieb	8:7:22	Fortieth STS flight. Dedicated DoD mission.
Soyuz TM-12	May 18, 1991	Anatoly Artsebarskiy Sergei Krikalev Helen Sharman (UK)	144:15:22	Docked with Mir space station. Helen Sharman first from United Kingdom to fly in space. Crew of Viktor Afanasyev, Musa Manarov, and Helen Sharman returned May 20, 1991. Artsebarskiy and Krikalev remained on board Mir, with Artsebarskiy returning Oct. 10, 1991, and Krikalev doing so Mar. 25, 1992.
STS-40	June 5, 1991	Bryan D. O'Conner Sidney M. Gutierrez James P. Bagian Tamara E. Jernigan M. Rhea Seddon Francis A. "Drew" Gaffney Millie Hughes-Fulford	9:2:15	Forty-first STS flight. Carried Spacelab Life Sciences (SLS-1) in cargo bay.
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).

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Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
STS-48	Sept. 12, 1991	John Creighton Kenneth Reightler, Jr. Charles D. Gemar James F. Buchli Mark N. Brown	5:8:28	Forty-third STS flight. Launched Upper Atmosphere Research Satellite (UARS).
Soyuz TM-13	Oct. 2, 1991	Aleksandr Volkov Toktar Aubakirov (Kazakh Republic) Franz Viehboeck (Austria)	90:16:00	Docked with Mir space station. Crew returned Oct. 10, 1991, with Anatoly Artsebarsky.
STS-44	Nov. 24, 1991	Frederick D. Gregory Tom Henricks Jim Voss Story Musgrave Mario Runco, Jr. Tom Hennen	6:22:51	Forty-fourth STS flight. Launched Defense Support Program (DSP) satellite.
STS-42	Jan. 22, 1992	Ronald J. Grabe Stephen S. Oswald Norman E. Thagard David C. Hilmers William F. Readdy Roberta L. Bondar Ulf Merbold (ESA)	8:1:12	Forty-fifth STS flight. Carried International Microgravity Laboratory-1 in cargo bay.
Soyuz TM-14	Mar. 17, 1992	Alexandr Viktorenko Alexandr Kaleri Klaus-Dietrich Flade (Germany)	145:15:11	First manned CIS space mission. Docked with Mir space station Mar. 19. The TM-13 capsule with Flade, Aleksandr Volkov, and Sergei Krikalev returned to Earth Mar. 25. Krikalev had been in space 313 days. Viktorenko and Kaleri remained in the TM-14 spacecraft.
STS-45	Mar . 24, 1992	Charles F. Bolden, Jr. Brian Duffy Kathryn D. Sullivan David C. Leestma Michael Foale Dirk D. Frimout Byron K. Lichtenberg	9:0:10	Forty-sixth STS flight. Carried Atmospheric Laboratory for Applications and Science (ATLAS-1).
STS-49	May 7, 1992	Daniel C. Brandenstein Kevin P. Chilton Richard J. Hieb Bruce E. Melnick Pierre J. Thuot Kathryn C. Thornton Thomas D. Akers	8:16:17	Forty-seventh STS flight. Reboosted a crippled INTELSAT VI communications satellite.
STS-50	June 25, 1992	Richard N. Richards Kenneth D. Bowersox Bonnie J. Dunbar Ellen S. Baker Carl Meade	13:19:30	Forty-eighth STS flight. Carried U.S. Microgravity Laboratory-1.
Soyuz TM-15	July 27, 1992	Anatoly Solovyov Sergei Avdeyev Michel Tognini (France)	189:17:43[a]	Docked with Mir Space Station Jul. 29. Tognini returned to Earth in TM-14 capsule with Alexandr Viktorenko and Alexandr Kaleri. Solovyov and Avdeyev spent over six months in the Mir orbital complex and returned to Earth in the descent vehicle of the TM-15 space craft on 1 February 1993.

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

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Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
STS-46	July 31, 1992	Loren J. Shriver Andrew M. Allen Claude Nicollier (ESA) Marsha S. Ivins Jeffrey A. Hoffman Franklin R. Chang-Diaz Franco Malerba (Italy)	7:23:16	Forty-nineth STS flight. Deployed Tethered Satellite System-1 and Eureka-1.
STS-47	Sept. 12, 1992	Robert L. Gibson Curtis L. Brown, Jr. Mark C. Lee Jerome Apt N. Jan Davis Mae C. Jemison Mamoru Mohri (Japan)	7:22:30	Fiftieth STS flight. Carried Spacelab J. Jemison first African American woman to fly in space. Mohri first Japanese to fly on NASA spacecraft. Lee and Davis first married couple in space together.
STS-52	Oct. 22, 1992	James D. Wetherbee Michael A. Baker William M. Shepherd Tamara E. Jernigan Charles L. Veach Steven G. MacLean	9:20:57	Fifty-first STS flight. Studied influence of gravity on basic fluid and solidification processes using U.S. Microgravity Payload-1 in an international mission. Deployed second Laser Geodynamics Satellite and Canadian Target Assembly.
STS-53	Dec. 2, 1992	David M. Walker Robert D. Cabana Guion S. Bluford, Jr. James S. Voss Michael Richard Clifford	7:7:19	Fifty-second STS flight. Deployed the last major DoD classified payload planned for Shuttle (DoD 1) with ten different secondary payloads.
STS-54	Jan. 13, 1993	John H. Casper Donald R. McMonagle Gregory J. Harbaugh Mario Runco, Jr. Susan J. Helms	6:23:39	Fifty-third STS flight. Deployed Tracking and Data Relay Satellite-6. Operated Diffused X-ray Spectrometer Hitchhiker experiment to collect data on stars and galactic gases.
Soyuz TM-16	Jan. 24, 1993	Gennady Manakov Aleksandr Poleshchuk	179:0:44[a]	Docked with Mir space station Jan. 26. On July 22, 1993, the TM-16 descent cabin landed back on Earth with Manakov, Poleschuk, and French cosmonaut Jean-Pierre Haignere from Soyuz TM-17 on board.
STS-56	Apr. 8, 1993	Kenneth D. Cameron Stephen S. Oswald C. Michael Foale Kenneth D. Cockerell Ellen Ochoa	9:6:9	Fifty-fourth STS flight. Completed second flight of Atmospheric Laboratory for Applications and Science and deployed SPARTAN-201.
STS-55	Apr. 26, 1993	Steven R. Nagel Terence T. Henricks Jerry L. Ross Charles J. Precourt Bernard A. Harris, Jr. Ulrich Walter (Germany) Hans W. Schlegel (Germany)	9:23:39	Fifty-fifth STS flight. Completed second German microgravity research program in Spacelab D-2.

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U.S. and Russian Human Spaceflights, 1961–Sept. 1994

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
STS-57	June 21, 1993	Ronald J. Grabe Brian J. Duffy G. David Low Nancy J. Sherlock Peter J. K. Wisoff Janice E. Voss	9:23:46	Fifty-sixth STS flight. Carried Spacelab commercial payload module and retrieved European Retrievable Carrier in orbit since August 1992.
Soyuz TM-17	July 1, 1993	Vasiliy Tsibliyev Aleksandr Serebrov Jean-Pierre Haignere	196:17:45[a]	Docked with Mir space station July 3. Haignere returned to Earth with Soyuz TM-16. Serebrov and Tsibliyev landed in TM-17 space craft on Jan. 14, 1994, after colliding with the Mir space station the same day, having spent 2 1/2 months longer in space than originally planned.
STS-51	Sept. 12, 1993	Frank L. Culbertson, Jr. William F. Readdy James H. Newman Daniel W. Bursch Carl E. Walz	9:20:11	Fifty-seventh STS flight. Deployed ACTS satellite to serve as testbed for new communications satellite technology and U.S./German ORFEUS/SPAS.
STS-58	Oct. 18, 1993	John E. Blaha Richard A. Searfoss M. Rhea Seddon Shannon W. Lucid David A. Wolf William S. McArthur Martin J. Fettman	14:0:29	Fifty-eighth STS flight. Carried Spacelab Life Sciences-2 payload to determine the effects of microgravity on human and animal subjects.
STS-61	Dec. 2, 1993	Richard O. Covey Kenneth D. Bowersox Tom Akers Jeffrey A. Hoffman Kathryn C. Thornton Claude Nicollier F. Story Musgrave	10:19:58	Fifty-ninth STS flight. Restored planned scientific capabilities and reliability of the Hubble Space Telescope.
Soyuz TM-18	Jan. 8., 1994	Viktor Afanasyev Yuri Usachev Valery Polyakov	182:0:27[a]	Docked with Mir space station Jan. 10. Afanasyev and Usachev landed in the TM-18 spacecraft on July 9, 1994. Polyakov remained aboard Mir in the attempt to establish a new record for endurance in space.
STS-60	Feb. 3, 1994	Charles F. Bolden, Jr. Kenneth S. Reightler, Jr. N. Jan Davis Ronald M. Sega Franklin R. Chang-Diaz Sergei K. Krikalev (Russia)	8:7:9	Sixtieth STS flight. Carried the Wake Shield Facility to generate new semi-conductor films for advanced electronics. Also carried SPACEHAB. Krikalev's presence signified a new era in cooperation in space between Russia and the U.S.
STS-62	Mar. 9, 1994	John H. Casper Andrew M. Allen Pierre J. Thuot Charles D. Gemar Marsha S. Ivins	13:23:17	Sixty-first STS flight. Carried U.S. Microgravity Payload-2 to conduct experiments in materials processing, biotechnology, and other areas.
STS-59	Apr. 9, 1994	Sidney M. Gutierrez Kevin P. Chilton Jerome Apt Michael R. Clifford Linda M. Godwin Thomas D. Jones	11:5:50	Sixty-second STS flight. Carried the Space Radar Laboratory-1 to gather data on the Earth and the effects humans have on its carbon, water, and energy cycles.

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

U.S. and Russian Human Spaceflights, 1961–Sept. 1994

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Soyuz TM-19	July 1, 1994	Yuri I. Malenchenko Talgat A. Musabayev	125:22:53[a]	Docked with Mir space station July 3. Both Malenchenko and Musabayev returned to Earth with the Soyuz TM-19 spacecraft, landing in Kazakhstan on Nov. 4 together with Ulf Merbold of Germany, who went up aboard Soyuz TM-20 on Oct. 3, 1994. Merbold gathered biological samples on the effects of weightlessness on the human body in the first of two ESA missions to Mir to prepare for the international Space Station.
STS-65	July 8, 1994	Robert D. Cabana James D. Halsell, Jr. Richard J. Hieb Carl E. Walz Leroy Chiao Donald A. Thomas Chiaki Naito-Mukai (Japan)	14:17:55	Sixty-third STS flight. Carried International Microgravity Laboratory-2 to conduct research into the behavior of materials and life in near weightlessness.
STS-64	Sept. 9, 1994	Richard N. Richards L. Blaine Hammond, Jr. J. M. Linenger Susan J. Helms Carl J. Meade Mark C. Lee	10:22:50	Sixty-fourth STS flight. Used LIDAR In-Space Technology Experiment to perform atmospheric research. Included the first untethered space walk by astronauts in over ten years.
STS-68	Sept. 30, 1994	Michael A. Baker Terrence W. Wilcutt Thomas D. Jones Steven L. Smith Daniel W. Bursch Peter J. K. Wisoff	11:5:36	Sixty-fifth STS flight. Used Space Radar Laboratory-2 to provide scientists with data to help distinguish human-induced environmental change from other natural forms of change.

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

U.S. Space Launch Vehicles

Vehicle	Stages: Engine/Motor	Propellant[a]	Thrust (kilonewtons)[bc]	Max. Dia x Height (m)	Max. Payload (kg)[d]: 185-Km Orbit	Max. Payload (kg)[d]: Geosynch. Transfer Orbit	Max. Payload (kg)[d]: Sun-Synch. Orbit[e]	First Launch[f]
Pegasus				6.71x15.5[h]	380 280[e]	—	210	1990
	1. Orion 50S	Solid	484.9	1.28x8.88				
	2. Orion 50	Solid	118.2	1.28x2.66				
	3. Orion 38	Solid	31.9	0.97x1.34				
Pegasus XL				6.71x16.93	460 350[e]	—	335	1994[g]
	1. Orion 50S-XL	Solid	743.3	1.28x10.29				
	2. Orion 50-XL	Solid	201.5	1.28x3.58				
	3. Orion 38	Solid	31.9	0.97x1.34				
Taurus				2.34x28.3	1400 1080[e]	255	1020	Not scheduled[f]
	0. Castor 120	Solid	1687.7	2.34x11.86				
	1. Orion 50S	Solid	580.5	1.28x8.88				
	2. Orion 50	Solid	138.6	1.28x2.66				
	3. Orion 38	Solid	31.9	0.97x1.34				
Delta II (7920, 7925)				2.44x29.70	5089 3890[e]	1842[i]	3175	1990, Delta-7925 [1960, Delta]
	1. RS-27A	LOX/RP-1	1043.0 (SL)	3.05x38.1				
	Hercules GEM (9)	Solid	487.6 (SL)	1.01x12.95				
	2. AJ10-118K	N_2O_4/A-50	42.4	2.44x5.97				
	3. Star 48B[l]	Solid	66.4	1.25x2.04				
Atlas E				3.05x28.1	820[e] 1860[ek]	—	910[k]	1968, Atlas F [1958, Atlas LV-3A]
	1. Atlas: MA-3	LOX/RP-1	1739.5 (SL)	3.05x21.3				
Atlas I				4.2x43.9	—	2255	—	1990, Atlas I [1966, Atl Centaur]
	1. Atlas: MA-5	LOX/RP-1	1952.0 (SL)	3.05x22.16				
	2. Centaur I: RL10A-3-3A (2)	LOX/LH_2	73.4	3.05x9.14				
Atlas II				4.2x47.5	6580 5510[e]	2810	4300	1991, Atlas II [1966, Atl Centaur]
	1. Atlas: MA-5A	LOX/RP-1	2110.0 (SL)	3.05x24.9				
	2. Centaur II: RL10A-3-3A (2)	LOX/LH_2	73.4	3.05x10.05				
Atlas IIA				4.2x47.5	7280 6170[e]	3039	4750	1992, Atlas IIA [1966, Atl Centaur]
	1. Atlas: MA-5A	LOX/RP-1	2110.0 (SL)	3.05x24.9				
	2. Centaur II: RL10A-4 (2)	LOX/LH_2	92.53	3.05x10.05				
Atlas IIAS				4.2x47.5	8640 7300[e]	3606	5800	1993, IIAS [1966, Atl Centaur]
	1. Atlas: MA-5A	LOX/RP-1	2110.0 (SL)	3.05x24.9				
	Castor IVA (4)[j]	Solid	478.3 (SL)	1.01x11.16				
	2. Centaur IIA: RL10A-4 (2)	LOX/LH_2	92.53	3.05x10.05				

U.S. Space Launch Vehicles

Vehicle	Stages: Engine/Motor	Propellant[a]	Thrust (kilonewtons)[bc]	Max. Dia x Height (m)	Max. Payload (kg)[d] 185-Km Orbit	Geosynch. Transfer Orbit	Sun-Synch. Orbit[e]	First Launch[f]
Titan II				3.05x42.9	1905[e]	—	—	1988, Titan II SLV [1964, Titan II Gemini]
	1. LR-87-AJ-5 (2)	N_2O_4/A-50	1045.0	3.05x21.5				
	2. LR-91-AJ-5	N_2O_4/A-50	440.0	3.05x12.2				
Titan III				3.05x47.3	14515	5000[l]	—	1989, Titan III [1964, Titan IIIA]
	0. Titan III SRM (2) (5-1/2 segments)	Solid	6210.0	3.11x27.6				
	1. LR87-AJ-11 (2)	N_2O_4/A-50	1214.5	3.05x24.0				
	2. LR91-AJ-11	N_2O_4/A-50	462.8	3.05x10.0				
Titan IV				3.05x62.2	17700	6350[m]	—	1989, Titan IV
	0. Titan IV SRM (2) (7 segments)	Solid	7000.0	3.11x34.1	14110[e]			
	1. LR87-AJ-11 (2)	N_2O_4/A-50	1214.5	3.05x26.4				
	2. LR91-AJ-11	N_2O_4/A-50	462.8	3.05x10.0				
Titan IV/ Centaur				4.3x62.2	—	5760[q]	—	1994, Titan IV Centaur
	0. Titan IV SRM (7 segments)	Solid	7000.0	3.11x34.1				
	1. LR87-AJ-11	N_2O_4/A-50	1214.5	3.05x26.4				
	2. LR91-AJ-11	N_2O_4/A-50	462.8	3.05x10.0				
	3. Centaur: RL-10A-3-3A	LOX/LH_2	73.4	4.3x9.0				
Space Shuttle[n]				23.79x56.14[h]	24900[o]	5900[p]	—	1981, Columbia
	1. SRB: Shuttle SRB (2)	Solid	11790.0(SL)	3.70x45.46				
	2. Orbiter/ET:SSME (3)	LOX/LH_2	1668.7(SL)	8.41x47.00 (ET) 23.79x37.24[h] (orbiter)				
	3. Orbiter/OMS: OMS engines (2)	N_2O_4/MMH	26.7	23.79x37.24[h]				

NOTES:

[a] Propellant abbreviations used are as follows:
A-50=Aerozine 50 (50% Monomethyl Hydrazine, 50% Unsymmetrical Dimethyl Hydrazine)
RP-1=Rocket Propellant 1 (kerosene)
Solid=Solid Propellant (any type)
LH_2=Liquid Hydrogen
LOX=Liquid Oxygen
MMH=Monomethyl Hydrazine
N_2O_4=Nitrogen Tetroxide

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

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

[d] Inclination of 28.5° except where indicated.

[e] Polar launch from Vandenberg AFB, CA.

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

[g] First launch was a failure.

[h] Diameter dimension represents vehicle wing span.

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

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

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

[l] With Transfer Orbit Stage (TOS).

[m] With appropriate upper stage.

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

[o] 204 km circular orbit.

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

[q] TitanIV/Centaur is designed for 3 burns directly to geosynchronous orbit.

[r] The first Taurus launch used a Peacekeeper first stage as stage 0 in 1994.

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

C-2

Space Activities of the U.S. Government

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

Fiscal Year	NASA Total	NASA Space[a]	Defense	Other[f]	Energy	Com-merce	Inter-ior	Agri-culture	NSF	DOT	EPA[g]	Total Space
1959	331	261	490	34	34	...	...	...	...	...	...	785
1960	524	462	561	43	43	...	...	...	0.1	...	...	1,066
1961	964	926	814	69	68	...	...	...	1	...	...	1,809
1962	1,825	1,797	1,298	200	148	51	...	...	1	...	...	3,295
1963	3,673	3,626	1,550	259	214	43	...	...	2	...	...	5,435
1964	5,100	5,016	1,599	216	210	3	...	...	3	...	...	6,831
1965	5,250	5,138	1,574	244	229	12	...	...	3	...	...	6,956
1966	5,175	5,065	1,689	217	187	27	...	...	3	...	...	6,971
1967	4,966	4,830	1,664	216	184	29	...	...	3	...	...	6,710
1968	4,587	4,430	1,922	177	145	28	0.2	1	3	...	...	6,529
1969	3,991	3,822	2,013	141	118	20	0.2	1	2	...	...	5,976
1970	3,746	3,547	1,678	115	103	8	1	1	2	...	...	5,340
1971	3,311	3,101	1,512	127	95	27	2	1	2	...	...	4,741
1972	3,307	3,071	1,407	97	55	31	6	2	3	...	...	4,575
1973	3,406	3,093	1,623	109	54	40	10	2	3	...	...	4,825
1974	3,037	2,759	1,766	116	42	60	9	3	2	...	...	4,640
1975	3,229	2,915	1,892	107	30	64	8	2	2	...	...	4,914
1976	3,550	3,225	1,983	111	23	72	10	4	2	...	...	5,320
TQ*	932	849	460	31	5	22	3	1	1	...	...	1,341
1977	3,818	3,440	2,412	131	22	91	10	6	2	...	...	5,983
1978	4,060	3,623	2,738	157	34	103	10	8	2	...	...	6,518
1979	4,596	4,030	3,036	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	444	97	301	17	21	...	3	5	28,448
1990	13,073	12,142	15,616	387	79	243	31	25	...	4	5	28,145
1991	14,004	13,036	14,181	566	251	251	29	26	...	4	5	27,783
1992	14,316	13,199	15,023	624	223	327	34	29	...	4	7	28,845
1993	14,323	13,077	14,106	559	165	324	33	25	...	4	8	27,742
1994	14,568	13,022	13,166	465	78	312	31	31	...	5	8	26,653

[a]Excludes amounts for air transportation (subfunction 402).
[b]Includes $33.5 million for unobligated funds that lapsed.
[c]Includes $37.6 million for reappropriation of prior year funds.
[d]NSF funding of balloon research transferred to NASA.
[e]Includes $2.1 billion for replacement of shuttle orbiter Challenger.
[f]"Other" column is the total of the non-NASA, non-DoD budget authority figures that appear in succeeding columns. The total is sometimes different from the sum of the individual figures because of rounding. The "Total Space" column does not include the "NASA Total" column because it includes budget authority for aeronautics as well as space.
[g]EPA has recalculated its aeronautic and space expenditures since 1989, making them significantly higher than reported in previous years.
*Transit Quarter

SOURCE: Office of Management and Budget.

Space Activities of the U.S. Government

BUDGET AUTHORITY IN MILLIONS OF EQUIVALENT FY 1994 DOLLARS
(adjusted for inflation)

Fiscal Year	GDP Inflator to 1993 $	NASA Total	NASA Space	Defense	Other	Energy	Com- merce	Inter- ior	Agri- culture	NSF	DOT	EPA	Total Space
1959	4.9141	1,627	1,283	2,408	167	167	0	0	0	0	0	0	3,858
1960	4.8613	2,547	2,246	2,727	210	209	0	0	0	0	0	0	5,183
1961	4.8170	4,644	4,461	3,921	330	328	0	0	0	3	0	0	8,712
1962	4.7326	8,637	8,504	6,143	948	700	241	0	0	6	0	0	15,595
1963	4.6510	17,083	16,865	7,209	1,202	995	200	0	0	7	0	0	25,276
1964	4.5838	23,377	22,992	7,329	990	963	14	0	0	14	0	0	31,312
1965	4.4849	23,546	23,043	7,059	1,095	1,027	54	0	0	14	0	0	31,198
1966	4.3540	22,532	22,053	7,354	946	814	118	0	0	14	0	0	30,353
1967	4.2095	20,904	20,332	7,005	908	775	122	0	0	12	0	0	28,245
1968	4.0573	18,611	17,974	7,798	718	588	114	1	2	13	0	0	26,490
1969	3.8633	15,418	14,766	7,777	544	456	77	1	3	7	0	0	23,086
1970	3.6646	13,728	12,998	6,149	423	377	29	4	3	9	0	0	19,570
1971	3.4835	11,534	10,803	5,268	443	330	95	7	3	8	0	0	16,515
1972	3.3107	10,947	10,167	4,658	320	183	104	19	5	9	0	0	15,145
1973	3.1543	10,744	9,757	5,119	343	171	125	32	6	8	0	0	15,219
1974	2.9305	8,900	8,084	5,175	339	122	176	26	9	5	0	0	13,598
1975	2.6657	8,608	7,771	5,045	284	79	172	22	6	5	0	0	13,100
1976	2.4753	8,788	7,984	4,909	275	58	177	26	9	6	0	0	13,168
TQ*	2.3895	2,226	2,029	1,100	74	11	53	6	2	1	0	0	3,203
1977	2.2902	8,744	7,879	5,524	299	50	208	22	14	5	0	0	13,702
1978	2.1291	8,645	7,714	5,830	334	73	219	21	16	5	0	0	13,878
1979	1.9591	9,003	7,896	5,947	348	115	193	19	16	5	0	0	14,191
1980	1.7970	9,417	8,411	6,916	288	71	166	21	25	4	0	0	15,614
1981	1.6311	9,001	8,143	7,874	257	66	142	20	25	4	0	0	16,275
1982	1.5180	9,175	8,391	10,139	356	92	219	18	23	3	0	0	18,886
1983	1.4575	10,021	9,223	13,145	352	57	259	7	30	0	0	0	22,720
1984	1.3961	10,119	9,281	14,233	408	48	329	4	27	0	0	0	23,923
1985	1.3447	10,183	9,312	17,169	637	46	569	3	20	0	0	0	27,118
1986	1.3059	10,142	9,357	18,448	481	45	403	3	30	0	0	0	28,286
1987	1.2683	13,326	12,441	20,657	447	60	352	10	23	0	1	0	33,545
1988	1.2239	11,047	10,161	21,637	766	295	430	17	22	0	2	0	32,564
1989	1.1719	12,854	11,834	20,984	520	114	353	20	25	0	4	6	33,338
1990	1.1257	14,716	13,668	17,579	436	89	274	35	28	0	5	6	31,683
1991	1.0832	15,169	14,121	15,361	613	272	272	31	28	0	4	5	30,095
1992	1.0537	15,085	13,908	15,830	657	235	345	36	31	0	4	7	30,394
1993	1.0270	14,710	13,430	14,487	574	169	333	34	26	0	4	8	28,491
1994	1.0000	14,568	13,022	13,166	465	78	312	31	31	0	5	8	26,653

*Transit Quarter

SOURCE: Office of Management and Budget.

APPENDIX E-2

Federal Space Activities Budget

(in millions of dollars by fiscal year)

Federal Agencies	Budget Authority			Budget Outlays		
	1992 actual	1993 actual	1994 estimated	1992 actual	1993 actual	1994 estimated
NASA	13,199	13,077	13,022	12,838	13,092	12,363
Defense	15,023	14,106	13,166	14,437	13,779	10,973
Energy	223	165	78	223	165	82
Commerce	327	324	312	298	308	307
Interior	34	33	31	31	31	31
Agriculture	29	25	31	29	25	30
Transportation	4	4	5	4	4	5
EPA	7	8	8	5	7	8
TOTAL	28,845	27,742	26,653	27,865	27,411	23,799

SOURCE: Office of Management and Budget.

APPENDIX E-3

Federal Aeronautics Budget

(in millions of dollars by fiscal year)

Federal Agencies	Budget Authority			Budget Outlays		
	1992 actual	1993 actual	1994 estimated	1992 actual	1993 actual	1994 estimated
NASA[a]	1,117	1,246	1,546	1,122	1,212	1,330
Defense[b]	7,366	7,601	6,763	6,790	7,165	6,895
Transportation[c]	2,627	2,532	2,309	2,099	2,378	2,604
TOTAL	11,110	11,379	10,618	10,011	10,755	10,829

[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 WHITE HOUSE

Office of the Press Secretary

For Immediate Release   November 3, 1993

STATEMENT BY THE PRESS SECRETARY

The President has signed the United States instrument of ratification of the Treaty on Open Skies. This multilateral aerial observation regime represents the broadest and most flexible effort to date to promote openness and transparency of military forces and activities.

The Treaty responds to the new demands of the post-Cold War world and the desire of many states to find innovative means of strengthening confidence and predictability. It will give all participants an agreed way to obtain information about foreign military forces and activities of concern to them. Under the Treaty, each participating state may conduct a certain number of unarmed flights anywhere over the territory of the other participants, using approved observation techniques. The data collected during these flights will be available to all participants. This combination of breadth of coverage, flexibility of use and availability of information enables the Open Skies regime to make a unique contribution to building confidence and enhancing stability.

Present signatories include all NATO Allies, the East European members of the former Warsaw Pact, Russia, Ukraine, Belarus, Georgia and Kyrgyzstan. The states of the former Soviet Union, and all CSCE states are eligible to join on an accelerated basis. The Treaty is open to any nation by consensus approval. The model developed in the Treaty could also be important to the reduction of local tensions and the prevention of conflict in regions beyond the scope of current signatories.

The Open Skies concept was first put forward by President Eisenhower in 1955, and then revived in a Treaty proposal by President Bush in 1989. It was signed on March 24, 1992 and received the unanimous advice and consent of the U.S. Senate on August 6, 1993. Ratification in several countries has been completed and in others is underway. The United States looks forward to ratification soon by all signatories and the Treaty's early entry into force.

THE WHITE HOUSE
Office of the Press Secretary

FOR IMMEDIATE RELEASE

March 10, 1994

STATEMENT BY THE PRESS SECRETARY

The President today announced that the Administration will allow for the expansion of the sale of images taken from space and the export of the systems themselves. This decision is expected to expand American jobs and business opportunities by enabling U.S. firms to compete aggressively in the growing international market for remote sensing, which already accounts for nearly $400 million worldwide and is expected to grow to more than $2 billion by the turn of the century.

Under the policy, U.S. companies will be licensed by the Secretary of Commerce to operate private remote sensing systems and sell those images to domestic and foreign entities. The export of turn-key remote sensing systems will also be considered under this policy on a case-by-case basis under an export license issued by the State Department. National security and international obligations will be protected through specific licensing conditions. Export of sensitive technologies will be considered on a restricted basis.

Vice President Gore also highlighted the decision's importance to maintaining the competitiveness of America's aerospace industry. "Removing some of our barriers to the sale of space-based remote sensing systems and data products is a major contribution to the ability of U.S. industry, which sets the world standard for these systems, to compete successfully in this rapidly emerging global commercial market," he said. Equally important, the Vice President said, is the contribution which data from such satellites will make to our knowledge of the planet: "Timely, high quality data which we expect to become available from these systems will include global change and environmental information which will form a vital part of this country's National Information Infrastructure."

Space-based images and imaging systems are increasingly being recognized by commercial entities as a means of dramatically improving their productivity and business operations. Farmers, city planners, environmentalists, news organizations, map makers, surveyors, geologists, mining companies, oil companies, timber harvesters, taxing authorities, as well as foreign governments have all recognized the utility of high quality, space-based images for purely commercial purposes.

This new policy should also aid the U.S. defense industry in its efforts to find new commercial applications for defense technologies and enhance U.S. global competitiveness in the international remote sensing market. Including the market for images incorporating demographic or technical data with digital maps, or geographic information systems, the market for space-based imagery could be up to $15 billion by the year 2000.

FACT SHEET

FOREIGN ACCESS TO REMOTE SENSING SPACE CAPABILITIES

Background

Remote sensing from space provides scientific, industrial, civil governmental, military and individual users with the capacity to gather data for a variety of useful purposes. The US Government operates very high resolution space-based reconnaissance systems for intelligence and military purposes. These systems are among the most valuable US national security assets because of their high quality data collection, timeliness, and coverage and the capability they provide to monitor events around the world on a near real-time basis. More nations have discovered the value of these satellites and are developing their own indigenous capabilities, or are seeking the purchase of data or systems.

Policy Goal

The fundamental goal of our policy is to support and to enhance US industrial competitiveness in the field of remote sensing space capabilities while at the same time protecting US national security and foreign policy interests. Success in this endeavor will contribute to maintaining our critical industrial base, advancing US technology, creating economic opportunities, strengthening the US balance of payments, enhancing national influence, and promoting regional stability.

Scope of Policy

The policy covers foreign access to remote sensing space systems, technology, products, and data. With respect to commercial licenses, this would include operating licenses granted under the Land Remote Sensing Policy Act of 1992 and export licenses for certain items controlled on the US Munitions List (USML). While the policy will define certain restrictions for export of items on the USML, export of items on either the USML or the Commerce Control List (CCL) would continue to be licensed in accord with existing law and regulations.

Licensing and Operation of Private Remote Sensing Systems

License requests by US firms to operate private remote sensing space systems will be reviewed on a case-by-case basis in accordance with the Land Remote Sensing Policy Act of 1992 (the Act). There is a presumption that remote sensing space systems whose performance capabilities and imagery quality characteristics are available or are planned for availability in the world marketplace (e.g., SPOT, Landsat, etc.) will be favorably considered, and that the following conditions will apply to any US entity that receives an operating license under the Act.

1. The licensee will be required to maintain a record of all satellite tasking for the previous year and to allow the USG access to this record.

2. The licensee will not change the operational characteristics of the satellite system from the application as submitted without formal notification and approval of the Department of Commerce, which would coordinate with other interested agencies.

3. The license being granted does not relieve the licensee of the obligation to obtain export license(s) pursuant to applicable statutes.

4. The license is valid only for a finite period, and is neither transferable nor subject to foreign ownership, above a specified threshold, without the explicit permission of the Secretary of Commerce.

5. All encryption devices must be approved by the US Government for the purpose of denying unauthorized access to others during periods when national security, international obligations and/or foreign policies may be compromised as provided for in the Act.

6. A licensee must use a data downlink format that allows the US Government access and use of the data during periods when national security, international obligations and/or foreign policies may be compromised as provided for in the Act.

7. During periods when national security or international obligations and/or foreign policies may be compromised, as defined by the Secretary of Defense or the Secretary of State, respectively, the Secretary of Commerce may, after consultation with the appropriate agency (ies), require the licensee to limit data collection and/or distribution by the system to the extent necessitated by the given situation. Decisions to impose such limits only will be made by the Secretary of Commerce in consultation with the Secretary of Defense or the Secretary of State, as appropriate. Disagreements between Cabinet Secretaries may be appealed to the President. The Secretaries of State, Defense and Commerce shall develop their own internal mechanisms to enable them to carry out their statutory responsibilities.

8. Pursuant to the Act, the US Government requires US companies that have been issued operating licenses under the Act to notify the US Government of its intent to enter into significant or substantial agreements with new foreign customers. Interested agencies shall be given advance notice of such agreements to allow them the opportunity to review the proposed agreement in light of the national security, international obligations and foreign policy concerns of the US Government. The definition of a significant or substantial agreement, as well as the time frames and other details of this process, will be defined in later Commerce regulations in consultation with appropriate agencies.

Transfer of Advanced Remote Sensing Capabilities

1. Advanced Remote Sensing System Exports: The United States will consider requests to export advanced remote sensing systems whose performance capabilities and imagery quality characteristics are available or are planned for availability in the world marketplace on a case-by-case basis.

   The details of these potential sales should take into account the following:

   > the proposed foreign recipient's willingness and ability to accept commitments to the US Government concerning sharing, protection, and denial of products and data; and constraints on resolution, geographic coverage, timeliness, spectral coverage, data processing and exploitation techniques, tasking capabilities, and ground architectures.

   Approval of requests for exports of systems would also require certain diplomatic steps be taken, such as informing other close friends in the region of the request, and the conditions we would likely attach to any sale; and informing the recipient of our decision and the conditions we would require as part of the sale.

   Any system made available to a foreign government or other foreign entity may be subject to a formal government-to-government agreement.

Transfer of Sensitive Technology

The United States will consider applications to export sensitive components, subsystems, and information concerning remote sensing space capabilities on a restricted basis. Sensitive technology in this situation consists of items of technology on the US Munitions List necessary to develop or to support advanced remote sensing space capabilities and which are uniquely available in the United States. Such sensitive technology shall be made available to foreign entities only on the basis of a government-to-government agreement. This agreement may be in the form of end-use and retransfer assurances which can be tailored to ensure the protection of US technology, Government-to-Government Intelligence and Defense Partnerships.

Proposals for intelligence or defense partnerships with foreign countries regarding remote sensing that would raise questions about US Government competition with the private sector or would change the US Government's use of funds generated pursuant to a US-foreign government partnership arrangement shall he submitted for interagency review.

THE WHITE HOUSE

WASHINGTON

May 5, 1994

THE TEXT OF PRESIDENTIAL DECISION DIRECTIVE/NSTC-2 WAS AS FOLLOWS:

SUBJECT: **Convergence of U.S.-Polar-Orbiting Operational Environmental Satellite Systems**

I. Introduction

The United States operates civil and military polar-orbiting environmental satellite systems which collect, process, and distribute remotely-sensed meteorological, oceanographic, and space environmental data. The Department of Commerce is responsible for the Polar-orbiting Operational Environmental Satellite (POES) program and the Department of Defense is responsible for the Defense Meteorological Satellite Program (DMSP). The National Aeronautics and Space Administration (NASA), through its Earth Observing System (EOS-PM) development efforts, provides new remote sensing and spacecraft technologies that could potentially improve the capabilities of the operational system. While the civil and military missions of POES and DMSP remain unchanged, establishing a single, converged, operational system can reduce duplication of efforts in meeting common requirements while satisfying the unique requirements of the civil and national security communities. A converged system can accommodate international cooperation, including the open distribution of environmental data.

II. Objectives and Principles

The United States will seek to reduce the cost of acquiring and operating polar-orbiting environmental satellite systems, while continuing to satisfy U.S. operational requirements for data from these systems. The Department of Commerce and the Department of Defense will integrate their programs into a single, converged, national polar-orbiting operational environmental satellite system. Additional savings may be achieved by incorporating appropriate aspects of NASA's Earth Observing System.

The converged program shall be conducted in accordance with the following principles:

- Operational environmental data from polar-orbiting satellites are important to the achievement of U.S. economic, national security, scientific, and foreign policy goals.

- Assured access to operational environmental data will be provided to meet civil and national security requirements and international obligations.

- The United States will ensure its ability to selectively deny critical environmental data to an adversary during crisis or war yet ensure the use of such data by U.S. and Allied military forces. Such data will be made available to other users when it no longer has military utility.

- The implementing actions will be accommodated within the overall resource and policy guidance of the President.

III. Implementing Actions

a. Interagency Coordination

1. Integrated Program Office (IPO)

The Departments of Commerce and Defense and NASA will create an Integrated Program Office (IPO) for the national polar-orbiting operational environmental satellite system no later than October 1, 1994. The IPO will be responsible for the management, planning, development, fabrication, and operations of the converged system. The IPO will be under the direction of a System Programs Director (SPD) who will report to a triagency Executive Committee via the Department of Commerce's Under Secretary for Oceans and Atmosphere.

2. Executive Committee (EXCOM)

The Departments of Commerce and Defense and NASA will form a convergence EXCOM at the Under Secretary level. The members of the EXCOM will ensure that both civil and national security requirements are satisfied in the converged program, will coordinate program plans, budgets, and policies, and will ensure that agency funding commitments are equitable and sustained. The three member agencies of the EXCOM will develop a process for identifying, validating, and documenting observational and system requirements for the national polar-orbiting operational environmental satellite system. Approved operational requirements will define the converged system baseline which the IPO will use to develop agency budgets for research and development, system acquisitions, and operations.

b. Agency Responsibilities

1. Department of Commerce

The Department of Commerce, through NOAA, will have lead agency responsibility to the EXCOM for the converged system. NOAA will have lead agency responsibility to support the IPO for satellite operations. NOAA will nominate the System Program Director who will be approved by the EXCOM. NOAA will also have the lead responsibility for interfacing with national and international civil user communities, consistent with national security and foreign policy requirements.

2. Department of Defense

The Department of Defense will have lead agency responsibility to support the IPO in major system acquisitions necessary to the national polar-orbiting operational environmental satellite system. DOD will nominate the Principal Deputy System Program Director who will be approved by the System Program Director.

3. National Aeronautics and Space Administration

NASA will have lead agency responsibility to support the IPO in facilitating the development and insertion of new cost effective technologies that enhance the ability of the converged system to meet its operational requirements.

c. International Cooperation

Plans for and implementation of a national polar-orbiting operational environmental satellite system will be based on U.S. civil and national security requirements. Consistent with this, the United States will seek to implement the converged system in a manner that encourages cooperation with foreign governments and international organizations. This cooperation will be conducted in support of these requirements in coordination with the Department of State and other interested agencies.

d. Budget Coordination

Budgetary planning estimates, developed by the IPO and approved by the EXCOM, will serve as the basis for agency annual budget requests to the President. The IPO planning process will be consistent with agencies' internal budget formulation.

IV. Implementing Documents

a. The "Implementation Plan for a Converged Polar-orbiting Environmental Satellite System" provides greater definition to the guidelines contained within this policy directive for creating and conducting the converged program.

b. By October 1, 1994, the Departments of Commerce and Defense and NASA will conclude a triagency memorandum of agreement which will formalize the details of the agencies' integrated working relationship, as defined by this directive, specifying each agency's responsibilities and commitments to the converged system.

V. Reporting Requirements

a. By November 1, 1994, the Department of Commerce, the Department of Defense, and NASA will submit an integrated report to the National Science and Technology Council on the implementation status of the national polar-orbiting operational environmental satellite system.

b. For the fiscal year 1996 budget process, the Departments of Commerce and Defense and NASA will submit agency budget requests based on the converged system, in accordance with the milestones established in the Implementation Plan.

c. For fiscal year 1997 and beyond, the IPO will provide, prior to the submission of each fiscal year's budget, an annual report to the National Science and Technology Council on the status of the national polar-orbiting operational environmental satellite system.

THE WHITE HOUSE

Office of the Press Secretary

For Immediate Release May 10, 1993

FACT SHEET

LANDSAT REMOTE SENSING STRATEGY

1. Introduction

The Landsat program has provided over 20 years of calibrated data to a broad user community including the agricultural community, global change researchers, state and local governments, commercial users, and the military. The Landsat 6 satellite, which failed to reach orbit in 1993, was intended to replace the existing Landsat satellites 4 and 5. Landsat 4 and 5, which were launched in 1982 and 1984 respectively and are operating well beyond their three year design lives, represent the only source of a global calibrated high spatial resolution measurement of the Earth's surface that can be compared to previous data records.

In 1993, the joint Department of Defense and National Aeronautics and Space Administration Landsat 7 program was being reevaluated due to severe budgetary constraints. This fact, coupled with the advanced age of Landsat satellites 4 and 5, resulted in a reassessment of the Landsat program by representatives of the National Science and Technology Council. The outcome of the National Science and Technology Council's assessment is a new strategy which is designed to continue the Landsat program and extend the 20-year Landsat data set. The details of the strategy are provided below.

II. Policy Goals

A remote sensing capability, such as is currently being provided by Landsat satellites 4 and 5, benefits the civil, commercial, and national security interests of the United States and makes contributions to the private sector which are in the public interest. For these reasons, the United States Government will seek to maintain the continuity of Landsat-type data. The U.S. Government will:

(a) Provide unenhanced data which are sufficiently consistent in terms of acquisition geometry, coverage characteristics, and spectral characteristics with previous Landsat data to allow quantitative comparisons for change direction and characterization;

(b) Make government-owned Landsat data available to meet the needs of all users at no more than the cost of fulfilling user requests consistent with data policy goals of P.L. 102-555; and,

(c) Promote and not preclude private sector commercial opportunities in Landsat-type remote sensing.

III. Landsat Strategy

a. The Landsat strategy is composed of the following elements:

(1) Ensuring that Landsat satellites 4 and 5 continue to provide data as long as they are technically capable of doings so.

(2) Acquiring a Landsat 7 satellite that maintains the continuity of Landsat-type data, minimizes development risk, minimizes cost, and achieves the most favorable launch schedule to mitigate the loss of Landsat 6.

(3) Maintaining an archive within the United States for existing and future Landsat-type data.

(4) Ensuring that unenhanced data from Landsat 7 are available to all users at no more than the cost of fulfilling user requests.

(5) Providing data for use in global change research in a manner consistent with the Global Change Research Policy Statements for Data Management.

(6) Considering alternatives for maintaining continuity of data beyond Landsat 7.

(7) Fostering the development of advanced remote sensing technologies, with the goal of reducing the cost and increasing the performance of future Landsat-type satellites to meet U.S. Government needs, and potentially, enabling substantially greater opportunities for commercialization.

b. These strategy elements will be implemented within the overall resource and policy guidance provided by the President.

IV. Implementing Guidelines

Affected agencies will identify funds necessary to implement the National Strategy for Landsat Remote Sensing within the overall resource and policy guidance provided by the President. {In order to effectuate the strategy enumerated herein, the Secretary of Commerce and the Secretary of the Interior are hereby designated as members of the Landsat Program Management in accordance with section 101(b) of the Landsat Remote Sensing Policy Act of 1992, 15 U.S.C. 5602(6) and 5611(b).} Specific agency responsibilities are provided below.

a. The Department of Commerce/NOAA will:

(1) In participation with other appropriate government agencies arrange for the continued operation of Landsat satellites 4 and 5 and the routine operation of future Landsat satellites after their placement in orbit.

(2) Seek better access to data collected at foreign ground stations for U.S. Government and private sector users of Landsat data.

(3) In cooperation with NASA, manage the development of and provide a share of the funding for the Landsat 7 ground system.

(4) Operate the Landsat 7 spacecraft and ground system in cooperation with the Department of the Interior.

(5) Seek to offset operations costs through use of access fees from foreign ground stations and/ or the cost of fulfilling user requests.

(6) Aggregate future Federal requirements for civil operational land remote sensing data.

b. The National Aeronautics and Space Administration will:

(1) Ensure data continuity by the development and launch of a Landsat 7 satellite system which is at a minimum functionally equivalent to the Landsat 6 satellite in accordance with section 102, P.L. 102-555.

(2) In coordination with DOC and DOI, develop a Landsat 7 ground system compatible with the Landsat 7 spacecraft.

(3) In coordination with DOC, DOI, and DOD, revise the current Management plan to reflect the changes implemented through this directive, including programmatic, technical, schedule, and budget information.

(4) Implement the joint NASA/DOD transition plan to transfer the DOD Landsat 7 responsibilities to NASA.

(5) In coordination with other appropriate agencies of the U.S. Government develop a strategy for maintaining continuity of Landsat-type data beyond Landsat 7.

(6) Conduct a coordinated technology demonstration program with other appropriate agencies to improve the performance and reduce the cost for future unclassified earth remote sensing systems.

c. The Department of Defense will implement the joint NASA/DOD transition plan to transfer the DOD Landsat 7 responsibilities to NASA.

d. The Department of Interior will continue to maintain a national archive of existing and future Landsat-type remote sensing data within the United States and make such data available to U.S. Government and other users.

e. Affected agencies will identify the funding, and funding transfers for FY 1994, required to implement this strategy that are within their approved fiscal year 1994 budgets and subsequent budget requests.

V. Reporting Requirements

U.S. Government agencies affected by the strategy guidelines are directed to report no later than 30 days following the issuance of this directive, to the National Science and Technology Council on their implementation. The agencies will address management and funding responsibilities, government and contractor operations, data management, archiving, and dissemination, necessary changes to P.L. 102-555 and commercial considerations associated within the Landsat program.

THE WHITE HOUSE

Office of the Press Secretary

August 3, 1994

WHITE HOUSE RELEASES NATIONAL SCIENCE POLICY REPORT

In a report on national science policy released by the White House today, President Clinton and Vice President Gore called for investment in science as a national priority, and linked scientific research and education to national goals and the future well-being of the country.

"The return from our public investment in fundamental science has been enormous. The principal sponsors and beneficiaries are the American people," said President Clinton. "Our scientific investments are an important national resource which we must sustain and build on for the future."

The science policy report, "*Science in the National Interest*," is the first major post-Cold War review of national science policy by the White House, and the first formal Presidential statement on science policy since 1979. The report represents the Administration's vision and roadmap for putting science to work on behalf of a broadened set of national goals to benefit the American people: health, prosperity, national security, environmental responsibility, and improved quality of life.

The report, which was released by the Vice President at a White House ceremony, presents a new view of fundamental science research and technological advances as interdependent elements that underpin the nation's economy. "Today's science and technology enterprise is more like an ecosystem than a production line," said Vice President Gore. "Technology is the engine of economic growth; science fuels technology's engine."

The Vice President acknowledged that the new focus on a broadened set of post-Cold War goals will require the most efficient and effective use of scarce resources. "Over the long term, U.S. investment in fundamental research must be commensurate with our national goals," he said.

The document proposes a series of actions to meet five broad goals for world leadership in science, mathematics, and engineering:

Maintain leadership across the frontiers of scientific knowledge;
Enhance connections between fundamental research and national goals;
Stimulate government, industry, and academic partnerships that promote investment in fundamental science and engineering and effective use of physical, human, and financial resources;
Produce the finest scientists and engineers for the twenty-first century;
Raise the scientific and technology literacy of all Americans.

The report calls for full and equal participation of all Americans, as both contributors to and benefactors of the nation's scientific investment, and recommends a number of actions to increase diversity in the science and technology workforce. "America derives great strength from its diversity, yet the country has not had a coherent policy for developing all our human resources for science and technology," said Gore. He underscored the importance of role models and mentoring by announcing a new Presidential awards program to recognize such activities at the state and local level.

The report also calls on scientists to become directly and actively involved in the "critically important national challenge" to increase literacy and to meet the Administration's "Goals 2000" education agenda. "Our economic strength will depend more than ever on the ability of the American people to deal with new challenges and rapid change," said Vice President Gore. "Our scientific community must contribute more strongly to broad public understanding of scientific issues and information."

Highlighting an emphasis on partnerships, the policy calls for the "creative participation of industry and academia" in helping to ensure the prosperity, security, and social well-being of the nation. At the same time, the policy acknowledges that the societal applications of fundamental science are not always immediately apparent and require sustained support to yield benefits. "We must not allow a short-term focus to limit the long-term potential benefits," said Vice President Gore.

"These policies and actions are significant steps in a proactive, ongoing process," said the President's Science Advisor, John Gibbons, who joined the Vice President for the release of the report. "This vision belongs to the many agencies and institutions which will use it as a roadmap to the future. But more importantly, it belongs to the American people, whose support is essential if we are to build a secure foundation for our nation and our children."

The 31-page policy document, as issued by President Clinton's National Science and Technology Council, is available for electronic dissemination on FedWorld and through the Internet at whitehouse.gov, sunsite.unc.edu, and other major online sites.

THE WHITE HOUSE

Office of the Press Secretary

August 3, 1994

PRESIDENT CLINTON APPOINTS SCIENCE AND TECHNOLOGY ADVISORS

Washington—President Clinton today announced the membership of a private-sector committee to advise him on major science and technology issues and to help guide federal investments in science and technology toward national goals. The 18-member President's Committee of Advisors on Science and Technology (PCAST) is composed of top-level representatives from industry, education and research institutions, and nongovernmental organizations.

"I am very pleased to name these eminent scientists, engineers, business leaders, and educators as some of my key advisors," the President said. "Drawn from a cross-section of America, they will help ensure that our science and technology policies reflect our nation's needs: health; prosperity based on long-term economic growth and technological investment; national security; environmental responsibility; and improved quality of life.

The appointment of private-sector advisors to the President highlights the Administration's goal of fostering public/private partnerships to achieve national science and education goals. "To achieve our goals, we must strengthen partnerships with industry, with state and local governments, and with schools, colleges and universities across the country," said President Clinton. "My goal for this committee is to help encourage those partnerships."

President Clinton established the PCAST by Executive Order in November 1993. Its members have established track records of significant achievement and represent the diverse perspectives and expertise in the U.S. science and technology establishment. The committee is co-Chaired by John H. Gibbons, Assistant to the President for Science and Technology, and by John A. Young, former President and CEO of the Hewlett-Packard Company.

The PCAST will advise the President both directly and through the Assistant to the President for Science and Technology. The committee will also serve as a formal channel for private sector advice to the National Science and Technology Council. The NSTC is a cabinet-level council, chaired by the President, that coordinates science and technology policies and programs across federal agencies. The PCAST will ensure the private sector perspective is included in that policy-making process.

Attachment: List of PCAST members

THE PRESIDENT'S COMMITTEE OF ADVISORS ON SCIENCE AND TECHNOLOGY

Chairs

John H. Gibbons
Assistant to the President for Science and Technology
Director, Office of Science and Technology Policy

John A. Young
Former President and CEO
Hewlett-Packard Co.

Members

Norman R. Augustine
Chairman and CEO
Martin Marietta Corporation

Francisco J. Ayala
Donald Bren Professor of Biological Sciences
Professor of Philosophy
University of California, Irvine

Murray Gell-Mann
Professor, Santa Fe Institute
R. A. Millikan Professor Emeritus of Theoretical Physics
California Institute of Technology

David A. Hamburg
President, Carnegie Corporation of New York

John P. Holdren
Class of 1935 Professor of Energy
University of California, Berkeley

Diana MacArthur
Chair and CEO
Dynamac Corporation

Shirley M. Malcom
Head
Directorate for Education and Human Resources Programs
American Association for the Advancement of Science

Mario J. Molina
Lee and Geraldine Martin Professor of Environmental Sciences
Massachusetts Institute of Technology

Peter H. Raven
Director, Missouri Botanical Garden
Engelmann Professor of Botany
Washington University in Saint Louis

Sally K. Ride
Director, California Space Institute
Professor of Physics
University of California, San Diego

Judith Rodin
President, University of Pennsylvania

Charles A. Sanders
Chairman and CEO, Glaxo Inc.

Phillip A. Sharp
Professor of Biology
Head, Department of Biology
Massachusetts Institute of Technology

David E. Shaw
CEO, D. E. Shaw and Co.

Charles M. Vest
President
Massachusetts Institute of Technology

Virginia V. Weldon
Senior Vice President for Public Policy
Monsanto Company

Lilian Shiao-Yen Wu
Member, Research Staff
Thomas J. Watson Research Center
IBM

THE WHITE HOUSE

WASHINGTON

August 5, 1994

THE TEXT OF PRESIDENTIAL DECISION DIRECTIVE/NSTC-4 WAS AS FOLLOWS:

SUBJECT: National Space Transportation Policy

This directive establishes national policy, guidelines, and implementing actions for the conduct of National space transportation programs that will sustain and revitalize U.S. space transportation capabilities. This directive supersedes portions of previous National Space Policy Directives that pertain, in whole or in part, to U.S. space transportation policy and programs. Relevant portions of National Space Policy, National Security, and Presidential Decision Directives dealing with technology transfer guidelines and definition of terms are unaffected by this policy and remain in force.

The United States space program is critical to achieving U.S. national security, scientific, technical, commercial, and foreign policy goals. Assuring reliable and affordable access to space through U.S. space transportation capabilities is a fundamental goal of the U.S. space program. In support of this goal, the U.S. Government will:

(1) Balance efforts to sustain and modernize existing space transportation capabilities with the need to invest in the development of improved future capabilities;

(2) Maintain a strong space transportation capability and technology base, including launch systems, infrastructure, and support facilities, to meet the national needs for space transport of personnel and payloads;

(3) Promote the reduction in the cost of current space transportation systems while improving their reliability, operability, responsiveness, and safety;

(4) Foster technology development and demonstration to support future decisions on the development of next generation reusable space transportation systems that greatly reduce the cost of access to space;

(5) Encourage the cost-effective use of commercially provided U.S. products and services, to the fullest extent feasible, that meet mission requirements; and

(6) Foster the international competitiveness of the U.S. commercial space transportation industry, actively considering commercial needs and factoring them into decisions on improvements in launch facilities and launch vehicles.

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

I. Implementation Guidelines

To ensure successful implementation of this policy, U.S. Government agencies will cooperate to take advantage of the unique capabilities and resources of each agency.

This policy shall be implemented as follows:

(1) The Department of Defense (DoD) will be the lead agency for improvement and evolution of the current U.S. expendable launch vehicle (ELV) fleet, including appropriate technology development.

(2) The National Aeronautics and Space Administration (NASA) will provide for the improvement of the Space Shuttle system, focusing on reliability, safety, and cost-effectiveness.

(3) The National Aeronautics and Space Administration will be the lead agency for technology development and demonstration for next generation reusable space transportation systems, such as the single-stage-to-orbit concept.

(4) The Departments of Transportation and Commerce will be responsible for identifying and promoting innovative types of arrangements between the U.S. Government and the private sector, as well as State and local governments, that may be used to implement applicable portions of this policy. U.S. Government agencies will consider, where appropriate, commitments to the private sector, such as anchor tenancy or termination liability, commensurate with the benefits of such arrangements.

(5) The Department of Defense and the National Aeronautics and Space Administration will plan for the transition between space programs and future launch systems in a manner that ensures continuity of mission capability and accommodates transition costs.

(6) The Department of Defense and the National Aeronautics and Space Administration will combine their expendable launch service requirements into single procurements when such procurements would result in cost savings or are otherwise advantageous to the Government. A Memorandum of Agreement will be developed by the Agencies to carry out this policy.

II. National Security Space Transportation Guidelines

(1) The Department of Defense will be the launch agent for the national security sector and will maintain the capability to evolve and operate those space transportation systems, infrastructure, and support activities necessary to meet national security requirements.

(2) The Department of Defense will be the lead agency for improvement and evolution of the current expendable launch vehicle fleet, including appropriate technology development. All significant ELV technology-related development associated with medium and heavy-lift ELVs will be accomplished through the DoD. In coordination with the DoD, NASA will continue to be responsible for implementing changes necessary to meet its mission-unique requirements.

(3) The objective of DoD's effort to improve and evolve current ELVs is to reduce costs while improving reliability, operability, responsiveness, and safety. Consistent with mission requirements, the DoD, in cooperation with the civil and commercial sectors, should evolve satellite, payload, and launch vehicle designs to achieve the most cost-effective and affordable integrated satellite, payload, and launch vehicle combination.

    (a) ELV improvements and evolution plans will be implemented in cooperation with the Intelligence Community, the National Aeronautics and Space Administration and the Departments of Transportation and Commerce, taking into account, as appropriate, the needs of the commercial space launch sector.

    (b) The Department of Defense will maintain the Titan IV launch system until a replacement is available.

(4) The Department of Defense, in cooperation with NASA, may use the Space Shuttle to meet national security needs. Launch priority will be provided for national security missions as governed by appropriate NASA/DoD agreements. Launches necessary to preserve and protect human life in space shall have the highest priority except in times of national emergency.

(5) Protection of space transportation capabilities employed for national security purposes will be pursued commensurate with their planned use in crisis and conflict and the threat. Civil and commercial space transportation capabilities identified as critical to national security may be modified at the expense of the requesting agency or department. To the maximum extent possible, these systems, when modified, should retain their normal operational utility.

III. Civil Space Transportation Guidelines

(1) The National Aeronautics and Space Administration will conduct human space flight to exploit the unique capabilities and attributes of human access to space. NASA will continue to maintain the capability to operate the Space Shuttle fleet and associated facilities.

(a) The Space Shuttle will be used only for missions that require human presence or other unique Shuttle capabilities, or where use of the Shuttle is determined to be important for national security, foreign policy or other compelling purposes.

(b) The National Aeronautics and Space Administration will maintain the Space Shuttle system until a replacement is available.

(c) As future development of a new reusable launch system is anticipated, procurement of additional Space Shuttle orbiters is not planned at this time.

(2) The National Aeronautics and Space Administration will be the lead agency for technology development and demonstration of next generation reusable space transportation systems.

(a) The objective of NASA's technology development and demonstration effort is to support government and private sector decisions by the end of this decade on development of an operational next-generation reusable launch system.

(b) Research shall be focused on technologies to support a decision no later than December 1996 to proceed with a sub-scale flight demonstration which would prove the concept of single-stage-to-orbit.

(c) Technology development and demonstration, including operational concepts, will be implemented in cooperation with related activities in the Department of Defense.

(d) It is envisioned that the private sector could have a significant role in managing the development and operation of a new reusable space transportation system. In anticipation of this role, NASA shall actively involve the private sector in planning and evaluating its launch technology activities.

IV. Commercial Space Transportation Guidelines

(1) The United States Government is committed to encouraging a viable commercial U.S. space transportation industry.

(a) The Departments of Transportation and Commerce will be responsible for identifying and promoting innovative types of arrangements between the U.S. Government and the private sector, as well as State and local governments, that may be used to implement applicable portions of this policy.

(b) The Department of Transportation will license, facilitate, and promote commercial launch operations as set forth in the Commercial Space Launch Act, as amended, and Executive Order 12465. The Department of Transportation will coordinate with the Department of Commerce where appropriate.

(c) U.S. Government agencies shall purchase commercially available U.S. space transportation products and services to the fullest extent feasible that meet mission requirements and shall not conduct activities with commercial applications that preclude or deter commercial space activities, except for national security or public safety reasons.

(d) The U.S. Government will provide for the timely transfer to the private sector of unclassified Government-developed space transportation technologies in such a manner as to protect their commercial value.

(e) The U.S. Government will make all reasonable efforts to provide stable and predictable access to appropriate space transportation-related hardware, facilities, and services; these will be on a reimbursable basis. The U.S. Government reserves the right to use such facilities and services on a priority basis to meet national security and critical civil sector mission requirements.

(f) U.S. Government agencies shall work with the U.S. commercial space sector to promote the establishment of technical standards for commercial space products and services.

(2) U.S. Government agencies, in acquiring space launch-related capabilities, will, to the extent feasible and consistent with mission requirements:

(a) Involve the private sector in the design and development of space transportation capabilities and encourage private sector financing, as appropriate.

(b) Emphasize procurement strategies that are based on the use of commercial U.S. space transportation products and services.

(c) Provide for private sector retention of technical data rights, limited only to the extent necessary to meet government needs.

(d) Encourage private sector and State and local government investment and participation in the development and improvement of U.S. launch systems and infrastructure.

V. Trade in Commercial Space Launch Services

(1) A long term goal of the United States is to achieve free and fair trade. In pursuit of this goal, the U.S. Government will seek to negotiate and implement agreements with other nations that define principles of free and fair trade for commercial space launch services, limit certain government supports and unfair practices in the international market, and establish criteria regarding participation by space launch industries in countries in transition from a non-market to a market economy.

(a) International space launch trade agreements in which the U.S. is a party must allow for effective means of enforcement. The range of options available to the U.S. must be sufficient to deter and, if necessary, respond to non-compliance and provide effective relief to the U.S. commercial space launch industry. Agreements must not constrain the ability of the United States to take any action consistent with U.S. laws and regulations.

(b) International space launch trade agreements in which the U.S. is a party must be in conformity with U.S. obligations under arms control agreements, U.S. nonproliferation policies, U.S. technology transfer policies, and U.S. policies regarding observance of the Guidelines and Annex of the Missile Technology Control Regime (MTCR).

VI. Use of Foreign Launch Vehicles Components and Technologies

(1) For the foreseeable future, United States Government payloads will be launched on space launch vehicles manufactured in the United States, unless exempted by the President or his designated representative.

(a) This policy does not apply to use of foreign launch vehicles on a no-exchange-of-funds basis to support the following: flight of scientific instruments on foreign spacecraft, international scientific programs, or other cooperative government-to-government programs. Such use will be subject to interagency coordination procedures.

(2) The U.S. Government will seek to take advantage of foreign components or technologies in upgrading U.S. space transportation systems or developing next generation space transportation systems. Such activities will be consistent with U.S. nonproliferation, national security, and foreign policy goals and commitments as well as the commercial sector guidelines contained in this policy. They will also be conducted in a manner consistent with U.S. obligations under the MTCR and with due consideration given to dependence on foreign sources and national security.

VII. Use of U.S. Excess Ballistic Missile Assets

(1) U.S. excess ballistic missile assets that will be eliminated under the START agreements shall either be retained for government use or be destroyed. These assets may be used within the U.S. Government in accordance with established DoD procedures, for any purpose except to launch payloads into orbit. Requests from within the Department of Defense or from other U.S Government agencies to use these assets for launching payloads into orbit will be considered by the DoD on a case-by-case basis and require approval by the Secretary of Defense.

Mindful of the policy's guidance that U.S. Government agencies shall purchase commercially available U.S. space transportation products and services to the fullest extent feasible, use of excess ballistic missile assets may be permitted for launching payloads into orbit when the following conditions are met:

(a) The payload supports the sponsoring agency's mission.

(b) The use of excess ballistic missile assets is consistent with international obligations, including the MTCR guidelines and the START agreements.

(c) The sponsoring agency must certify the use of excess ballistic missile assets results in a cost savings to the U.S. Government relative to the use of available commercial launch services that would also meet mission requirements, including performance, schedule, and risk.

VIII. Implementing Actions

(1) Within 90 days of approval of this directive, United States Government agencies are directed to prepare the following for submission to the Assistant to the President for Science and Technology and the Assistant to the President for National Security Affairs:

(a) The Secretaries of Defense, Commerce, Transportation, and the Administrator of the National Aeronautics and Space Administration, with appropriate input from the Director of Central Intelligence, will provide a report that will include a common set of requirements and a coordinated technology plan that addresses the needs of the national security, civilian, and commercial space launch sectors.

(b) The Secretary of Defense, with the support of other agencies as required, will provide an implementation plan that includes schedule and funding for improvement and evolution of the current U.S. ELV fleet.

(c) The Administrator of the National Aeronautics and Space Administration, with the support of other agencies as required, will provide an implementation plan that includes schedule and funding for improvements of the Space Shuttle system and technology development and demonstration for next generation reusable space transportation systems.

(d) The Secretaries of Transportation and Commerce, with the support of other agencies as required and U.S. industry, will provide an implementation plan that will focus on measures to foster an internationally competitive U.S. launch capability. In addition, the Secretaries will provide recommendations to the Department of Defense and the National Aeronautics and Space Administration that promote the full involvement of the commercial sector in the NASA and DoD plans.

THE WHITE HOUSE

Office of Science and Technology Policy

For Immediate Release **August 5, 1994**

STATEMENT ON

NATIONAL SPACE TRANSPORTATION POLICY

The White House today released a new National Space Transportation Policy document, as developed by the National Science and Technology Council and approved by President Clinton. The policy sets a clear course for the nation's space program, providing a coherent strategy for supporting and strengthening U.S. space launch capability to meet the growing needs of the civilian, national security and commercial sectors.

The policy commits the nation to a two-track strategy of: (1) maintaining and improving the current fleet of expendable launch vehicles as necessary to meet civil, commercial, and national security requirements; and (2) investing R&D resources in developing and demonstrating next generation reusable space transportation systems with the potential to greatly reduce the cost of access to space.

The new policy accomplishes four fundamental objectives:

1) **Establishes new national policy for federal space transportation spending, consistent with current budget constraints and the opportunities presented by emerging technologies.** Under the new policy, DoD will assume the lead responsibility for modernization of the current expendable launch vehicle fleet. NASA will assume the lead responsibility for research and development of next generation reusable systems. NASA will focus their investments on technologies to support a decision no later than December 1996 on whether to proceed with a flight demonstration program. This program would, in turn, provide the basis for deciding by the end of the decade whether to proceed with a new launch system to replace the aging Shuttle fleet.

2) **Establishes policy on federal agencies' use of foreign launch systems and components.** With the end of the Cold War, it is important for the U.S. to be in a position to capitalize on foreign technologies — including Russian technologies — without, at the same time, becoming dependent on them. The policy allows the use of foreign components, technologies and (under certain conditions) foreign launch services, consistent with U.S. national security, foreign policy and commercial space guidelines in the policy.

3) **Establishes policy on federal agencies' use of excess U.S. ballistic missile assets for space launch, to prevent adverse impacts on the U.S. commercial space launch industry.** Under START, these assets may be used in certain circumstances for civilian space launch. A serious concern in developing the policy was the possible impact that widespread government use of these assets could have on U.S. commercial launch companies. The policy obliges the government to fully consider commercial services as part of the decision making process and imposes specific criteria on the use of excess assets.

4) **Provides for an expanded private sector role in the federal space transportation R&D decision making processes.** In contrast with previous national policy on space transportation, this policy specifically directs the Departments of Transportation and Commerce to identify opportunities for government-industry cooperation and to factor these into NASA's and DoD's implementation plans.

These steps will help keep America at the forefront of space transportation technology, while ensuring that we have a robust and reliable expendable launch vehicle fleet.

Glossary

AADSF	Advanced Automated Directional Solidification Furnace
AAS	Advanced Automation System
AASE	Airborne Arctic Stratospheric Expedition
ABM	Anti-Ballistic Missile
ACDA	Arms Control and Disarmament Agency
ACLAIM	Airborne Coherent Lidar for Advanced In-flight Measurements
ACRIM	Active Cavity Radiometer Irradiance Monitor
ACRV	Advanced Crew Return Vehicle
ACT	Advanced Composites Technology
ACTS	Advanced Communications Technology Satellite
Ada	A programming language used by the DoD
ADAS	AWOS Data Acquisition System
ADEOS	(Japanese) Advanced Earth Observing Satellite
ADP	Advanced Ducted Propeller; Automated Data Processing
AEM	Animal Enclosure Modules
AESA	Atmospheric Effects of Stratospheric Aircraft
AESOP	ARGOS Environmental Shipboard Observer Platform
AFB	Air Force Base
AFS	Air Force Station
AFSC	Alaska Fisheries Science Center
AFSCN	Air Force Satellite Control Network
AFTI	Advanced Fighter Technology Integration
AFW	Active Flexible Wing
AGATE	Advanced General Aviation Transport Experiments
AGFS	Aviation Gridded Forecast System
AGRHYMET	AGRiculture, HYdrology, and METeorology
AIAA	American Institute of Aeronautics and Astronautics
AIDA	Arecibo Initiative on Dynamics of the Atmosphere
AIDC	Air Traffic Services Interfacility Data Communications
AIDS	Acquired Immune Deficiency Syndrome
AKM	Apogee Kick Motor
albedo	The ratio of the amount of electromagnetic radiation reflected by a body to the amount incident upon it
ALEXIS	Array of Low Energy X-ray Imaging Sensors
ALOHA	Airborne Lidar and Observations of Hawaiian Airglow
Alpha	Former name of the international Space Station
AMASS	Airport Movement Area Safety System
AMOS	Air Force Maui Optical System

AMSC	American Mobile Satellite Corporation
anechoic	Neither having nor producing an echo
angle of attack	The acute angle between the chord of an airfoil and its direction of motion relative to the air, often referred to as "alpha"; when an airfoil's angle of attack exceeds the one that provides maximum lift, it goes into a stall, losing airspeed, and potentially, the capability of the pilot to control the airplane
anisotropy	A phenomenon whereby properties of different values are exhibited when measured along different axes
AOA	Angle of Attack
APCG	Advanced Protein Crystal Growth
APE-B	Auroral Photography Experiment-B
APEX	Advanced Photovoltaic Experiment
APM	Ascent (or Atmospheric) Particle Monitor
APT	Automatic Picture Transmission—a low-cost ground terminal for receiving data from polar orbiting satellites, developed by NASA
ARFF	Aircraft Rescue and Firefighting
Arinc	Aeronautical Radio, Inc.
ARPA	Advanced Research Projects Agency (formerly Defense Advanced Research Projects Agency)
ARS	Agricultural Research Service
ARTCC	Air Route Traffic Control Center
ASAT	Anti-Satellite
ASCA	Advanced Satellite for Cosmology and Astrophysics
ASD	Aircraft Situation Display
ASF	Area Sampling Frames
ASI	Acronym for the Italian Space Agency
ASOS	Automated Surface Observing System
ASR	Airport Surveillance Radar
ASRM	Advanced Solid Rocket Motor
AST	Advanced Subsonic Technology
ASTOVL	Advanced Short Take-Off and Vertical Landing (aircraft)
ASTP	Advanced Space Technology Program; Apollo-Soyuz Test Project
Astro	Astronomy Observatory
astronomical unit	A measure for distances in space, equal to the mean distance of the Earth from the Sun, i.e., 93,000,000 miles (149,599,000 kilometers)
ATCSCC	Air Traffic Control System Command Center
ATIS	Automatic Terminal Information Service
ATLAS	Atmospheric Laboratory for Applications and Science
ATMS	Advanced Traffic Management System
ATN	Aeronautical Telecommunications Network
ATP	Advanced Turboprop

Auto GCAS	Automatic Ground Collision Avoidance System
AVHRR	Advanced Very High Resolution Radiometer
AWOS	Automated Weather Observing System
AXAF	Advanced X-ray Astrophysics Facility
baseband processor	A computer processor similar in function to a telephone switching office
BATSE	Burst and Transient Source Experiment
BBXRT	Broad Band X-Ray Telescope
BIMDA	Bioserve ITA Materials Dispersion Apparatus
black hole	A completely collapsed, massive dead star whose gravitational field is so powerful that no radiation can escape from it; because of this property, its existence must be inferred rather than recorded from radiation emissions
BMDO	Ballistic Missile Defense Organization, formerly SDIO
boreal	Northern
BOREAS	Boreal Ecosystem-Atmosphere Study
boundary layer	A layer of fluid, close to the surface of a body placed in a moving stream, that is distinguishable from the main airflow by distinctive flow characteristics of its own caused by friction
Brilliant Eyes	Space and missile tracking system
canard	An aircraft or aircraft configuration having its horizontal stabilizing and control surfaces in front of the wing or wings
C&GC	Climate & Global Change
CARA	(NSF's) Center for Astrophysical Research in Antarctica
carbon-carbon	In one application, an improved form of disk brakes featuring carbon rotors and carbon stators in place of the beryllium formerly used
CAS	Computational AeroScience
CASA	Controller Automation Spacing Aid
CASS	Computer Aided Stratification and Sampling
Cassini	A Saturn Orbiter/Titan Probe
CAT	Clear Air Turbulence
Category I	An aircraft approach procedure that provides for approach to a height above touchdown of no less than 200' and with runway visual range of no less than 1,800'
Category II	An aircraft approach procedure with a height no less than 100' and visual range no less than 1,200'
Category III	An aircraft approach procedure involving no minimal decision height and three different minimal visual ranges—at least 700' for IIIA, 150' for IIIB, and no minimum visual range for Category IIIC
CCAFS	Cape Canaveral Air Force Station
C-CAP	CoastWatch-Change Analysis Program
CCDS	Center for the Commercial Development of Space
CCL	Commodity Control List
CCSDS	Consultative Committee for Space Data Systems
CD	Compact Disk; Conference on Disarmament

CD-ROM	Compact Disk-Read Only Memory
CEDAR	Coupling, Energetics, and Dynamics of Atmospheric Regions
CEES	Committee on Earth and Environmental Sciences
CELLS	Controlled Ecological Life Support System
CEOS	Committee on Earth Observation Satellites
CEPS	Center for Earth and Planetary Studies
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFC	Chlorofluorocarbon
CFD	Computational Fluid Dynamics
CGF	Crystal Growth Facility
CGMS	Coordination Group for Meteorological Satellites (formerly, the Coordination of Geostationary Meteorological Satellites Group)
CGRO	Compton Gamma Ray Observatory
CINC	Commander-in-Chief
CIP	Capital Investment Plan
CIRA	Cooperative Institute for Research in the Atmosphere
CIRRIS	Cryogenic Infrared Radiance Instrumentation for Shuttle
CIS	Commonwealth of Independent States, a grouping of independent states formerly part of the Soviet Union
CITE	Cargo Interface Test Equipment
CLAES	Cryogenic Limb Array Etalon Spectrometer
ClO	Chlorine monoxide
CMB	Cosmic Microwave Background
CMC	Center for Macromolecular Crystallography (at the University of Alabama at Birmingham)
CMOS	Complimentary Metal Oxide Semiconductor
CNES	Centre National d'Etudes Spatiales—the French Space Agency
COARE	Coupled Ocean-Atmosphere Response Experiment
COBE	Cosmic Background Explorer
COCOM	Coordinating Committee
COF	Columbus Orbital Facility
COMET	COMmercial Experiment Transporter, a NASA program whose funding was terminated in 1994
COMPTEL	Compton Telescope
Comsat	Communications Satellite Corporation
CONUS	Continental United States
COPUOS	(UN) Committee on the Peaceful Uses of Outer Space
corona	The outer atmosphere of the sun, extending about a million miles above the surface
COSMIC	Computer Software Management Information Center
cosmic rays	Not forms of energy, like X-rays or gamma rays, but particles of matter
COSPAS	Russian acronym meaning Space System for Search of Vessels in Distress

COSTR	Collaborative Solar-Terrestrial Science
CRAF	Comet Rendezvous Asteroid Flyby
CRDA	Converging Runway Display Aid
CREAM	Cosmic Radiation Effects and Activation Monitor
CRO	Chemical Release Observation
CRRES	Combined Release and Radiation Effects Satellite
CRS	CoastWatch Regional Site
CSA	Canadian Space Agency
cryogenic	Very low in temperature
CSCC	Concurrent Supercomputing Consortium
CTAS	Center-TRACON Automation System
CTOL	Conventional Take-off and Landing
CTR	Civil Tiltrotor
CTV	Cargo Transfer Vehicle
CWG	Council Working Group (of INMARSAT)
DAAC	Distributed Active Archive Center
DARO	Defense Airborne Reconnaissance Office
DARP	Dynamic Aircraft Route Planning
DARPA	See ARPA
DARPASAT	DARPA Satellite
dB	Decibel
DBS	Direct Broadcast Satellite
DCS	Data Collection System
DC-X	Delta Clipper-Experimental
DE	Directed Energy
Dem/Val	Demonstration/Validation
DEVS	Drivers' Enhanced Vision System
DLC	Diamond-Like-Carbon
DMSP	Defense Meteorological Satellite Program—DoD's polar orbiting weather satellite system
DNA	Defense Nuclear Agency; Deoxyribonucleic Acid
DoC	Department of Commerce
DoD	Department of Defense
DoE	Department of Energy
DoI	Department of the Interior
DOLILU	Day-of-Launch I-Load-Update
DoT	Department of Transportation
DOTS	Dynamic Oceanic Track System
drag	The force, produced by friction, that impedes a body's motion through a fluid
DSCS	Defense Satellite Communication System
DSN	Deep Space Network

DSP	Defense Support Program
DST	Defense and Space Talks
EAFB	Edwards Air Force Base
ECS	EOSDIS Core System
EDFE	EVA Development Flight Experiments
EDMS	Emissions and Dispersion Modeling System—an EPA-approved computer model for the assessment of air quality around airports
EDO	Extended Duration Orbiter
EDOMP	Extended Duration Orbiter Medical Program
EFM	Enhanced Fighter Maneuverability
EGRET	Energetic Gamma Ray Experiment Telescope
EHF	Extremely high frequency, between 30,000 and 300,000 megacycles per second
EIS	Environmental Impact Statement
electromagnetic spectrum	A collective term for all known radiation from the shortest-waved gamma rays through x-rays, ultraviolet, visible light, infrared waves, to radio waves at the long-waved end of the spectrum
El Niño	A warm inshore current annually flowing south along the coast of Ecuador around the end of December and extending about every seven to ten years down the coast of Peru
ELV	Expendable Launch Vehicle
EMAP	Environmental Monitoring and Assessment Program
EMSL-LV	Environmental Monitoring Systems Laboratory in Las Vegas, NV—part of the EPA
enthalpy	The heat content of a system undergoing change
envelope	The operational parameters within which an aircraft can fly
EO	Electric Optical (sensor)
EO-ICWG	Earth Observations-International Coordination Working Group
EOS	Earth Observing System—a series of satellites, part of the Mission to Planet Earth, being designed for launch beginning near the end of the 1990s to gather data on global change
EOSDIS	EOS Data and Information System
EOSAT	Earth Observation Satellite Company
EPA	Environmental Protection Agency
EPAD	Electrically Powered Actuation Design
EPIC	Environmental Photographic Interpretation Center
EPIRB	Emergency Position-Indicating Radio Beacons
EPM	Enabling Propulsion Materials
EPRI	Electric Power Research Institute
ERAST	Environmental Research Aircraft and Sensor Technology (program)
ERBE	Earth Radiation Budget Experiment
ERBS	Earth Resources Budget Satellite
ERIM	Environmental Research Institute of Michigan
EROS	Earth Resources Observation System (or Satellites)
ERS	European Space Agency Remote Sensing Satellite

ERTS	Earth Resources Technology Satellite
ESA	European Space Agency
E-scan	Electronically scanned
ETM	Enhanced Thematic Mapper
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
EURECA	European Retrievable Carrier
EUVE	Extreme Ultraviolet Explorer
EVA	Extravehicular Activity
EVD	External Vision Display
F	Fahrenheit
FAA	Federal Aviation Administration
FAEED	FAA Aircraft Engine Emissions Database, which contains emissions factors for various aircraft engines and data correlating engines to specific aircraft
FAS	Foreign Agricultural Service
FASA	Final Approach Spacing Aid
FAST	Fast Auroral Snapshot
FBL/PBW	Fly-by-light/power-by-wire
FBW/FBL	Fly-by-wire/fly-by-light
FCC	Federal Communications Commission
FCCSET	Federal Coordinating Council on Science, Engineering, and Technology
FDF	Flight Dynamics Facility
Floquet theory	A method of solving a second-order differential equation
FLTSATCOM	Fleet Satellite Communications System
FRED	FAA Research Electromagnetic Database
FS	Forest Service
FSAR	Final Safety Analysis Report
FTS	Flight Telerobotic Servicer
fuel cladding	A coating designed to contain fission products released in nuclear fuel
FY	Fiscal Year
G or g	A symbol used to denote gravity or its effects, in particular the acceleration due to gravity; used as a unit of stress measurement for bodies undergoing acceleration
galactic cosmic rays	Cosmic rays with energy levels as high as tens of billions of electron volts and velocities approaching the speed of light
gamma rays	The shortest of electromagnetic radiations, emitted by some radioactive substances
GAS	Get Away Special
GBI	Ground Based Interceptor
GCDIS	Global Change Data and Information System
GD	General Dynamics
GDR	Geophysical Data Records
GEM	Geospace Environment Modeling

GEO	Geosynchronous Earth Orbit
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
Geosat	Geodetic and Geophysical Satellite
Geostar	A private firm providing a satellite tracking service
geostationary	Travelling about the Earth's equator at an altitude of at least 35,000 km and at a speed matching that of the Earth's rotation, thereby maintaining a constant relation to points on the Earth
geosynchronous	geostationary
Get Away Special	A low-cost, experimental payload for the Space Shuttle
GETSCO	General Electric Technical Services Co., Inc.
GFO	Geodetic/Geophysical Follow-on (program)
GFS	Generic Flight System
GGS	Global Geospace Science
GGSF	Gas-Grain Simulation Facility
GHRS	Goddard High Resolution Spectrograph
GHz	Gigahertz (one billion cycles per second)
GIS	Geographic Information System
GLITeC	Great Lakes Industrial Technology Center
GLOBE	Global Learning and Observations to Benefit the Environment
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
GPHS	General Purpose Heat Source
GPS	Global Positioning System
GRID	Global Resources Information Database
GRO	(Compton) 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
GRTS	GRO Remote Terminal System
GSA	General Services Administration
GSFC	Goddard Space Flight Center
GTS	Global Telecommunications System
GVI	Global Vegetation Index
Hall effect	The development of a transverse electric field in a solid material when it carries an electric current and is placed in a magnetic field perpendicular to the current
HALOE	Halogen Occultation Experiment
HANG	High Alpha Nose-down Guidelines

HAPS	Hydrazine Auxiliary Propulsion System
HARV	High Angle-of-Attack Research Vehicle
HAX	Haystack Auxiliary Radar
HDTV	High Definition Television
HEAO	High Energy Astronomy Observatory
HESP	High-Energy Solar Physics
HIDEC	Highly Integrated Digital Electronic Control
high-alpha	High angle of attack
high-bypass engine	A turbo-engine having a by-pass ratio of more than four to one, the by-pass ratio being the proportion of air that flows through the engine outside the inner case to that which flows inside that case
HIRF	High Intensity Radiation Field
HIRIS	High Resolution Imaging Spectrometer
HLFC	Hybrid Laminar Flow Control
HMMWV	High Mobility Multipurpose Wheeled Vehicle
HPCC	High Performance Computing and Communications
HRDI	High Resolution Doppler Imager
HSCT	High-Speed Civil Transport
HSR	High-Speed Research
HST	Hubble Space Telescope
HUMS	Health Usage Monitoring System
HUT	Hopkins Ultraviolet Telescope
hypersonic	Faster than Mach 4; the borderline between high speed and hypersonic is somewhat fuzzy but lies at about that velocity
HyTOP	Hybrid Technology Project
IBM	International Business Machines Corp.
IBSS	Infrared Background Signature Survey
ICAO	International Civil Aviation Organization
ICBM	Intercontinental Ballistic Missile
ICE	International Cometary Explorer
IELV	Intermediate ELV
IEOS	International Earth Observing System
IFL	Interfacility Fiber Optic Link
IFM	Internal Fluid Mechanics
IFR	Instrument Flight Rules
IGA	Intergovernmental Agreement
IHPTET	Integrated High Performance Turbine Engine Technology
IITA	Information Infrastructure Technology and Applications
I-Lab	(FAA) Integration and Interaction Laboratory
IMI	Inner Magnetosphere Imager

IML	International Microgravity Laboratory
IMO	International Maritime Organization
IMP	Interplanetary Monitoring Platform
INF	Intermediate-Range Nuclear Forces (Treaty)
INM	Integrated Noise Model—a computer tool for simulation of aircraft noise
INMARSAT	International Maritime Satellite (Organization)
IN-STEP	In-Space Technology Experiments Program
INTELSAT	International Telecommunications Satellite (Organization)
interferometry	The production and measurement of interference from two or more coherent wave trains emitted from the same source
Internet	An international computer network that began about 1970 as the NSF Net; very slowly it became a collection of over 40,000 independently managed computer networks worldwide that have adopted common protocols to permit exchange of electronic information
IOC	Initial Operational Capability
ionosphere	That region of the Earth's atmosphere so named because of the presence there of ionized atoms in layers that reflect radio waves and short-wave transmissions
IPMP	Investigations into Polymer Membrane Processing
IPO	Integrated Program Office (for converged polar-orbiting satellites)
IPOMS	International Polar Orbiting Meteorological Satellite Group
IPPD	Integrated Product/Process Development
IR	Infrared
IRAS	Infrared Astronomy Satellite
IRT	Icing Research Tunnel
ISAC	Intelsat Solar Array Coupon
ISAMS	Improved Stratospheric and Mesospheric Sounder
ISAS	(Japanese) Institute of Space and Astronautical Science
ISB, TW/AA	Improved Space-Based, Tactical Warning/Attack Assessment—one of several names for a program to succeed DSP, later integrated into SBIRS
ISTP	International Solar-Terrestrial Program
ISY	International Space Year (1992)
ITA	Instrumentation Technology Associates
ITO	International Test Organization
ITP	Integrated Technology Plan
ITU	International Telecommunication Union, an intergovernmental organization founded in 1865 that became a specialized agency of the United Nations in 1947
ITWS	Integrated Terminal Weather System
IUE	International Ultraviolet Explorer
IUS	Inertial Upper Stage
IV&V	Independent Validation and Verification
IW	Integrated Wing
IWG	Intersessional Working Group (of INMARSAT)

IWVP	Integrated Wake Vortex Program
JAST	Joint Advanced Strike Technology (program)
JEM	Japanese Experiment Module
JGOFS	Joint Global Ocean Flux Study
JHU/APL	Johns Hopkins University's Applied Physics Laboratory
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
JTAG	Joint Turbine Advanced Gas Generator
JTAGS	Joint Tactical Ground Station
K-band	Radio frequencies in the 20 gigahertz range
Ka-band	A radio frequency in the 30 gigahertz range
KaBLE	Ka-band Link Experiment
KAO	Kuiper Airborne Observatory
KE	Kinetic Energy
Kelvin	Temperature scale in which absolute zero is 0°and water freezes at 273.16°
KSC	Kennedy Space Center
Ku-band	Radio frequencies in the 11-12 gigahertz range
Kuiper Airborne Observatory	A NASA C-141 aircraft equipped with a 0.97-meter telescope
kWe	Kilowatts of electrical (power)
LAGEOS	Laser Geodynamic Satellite
laminar	Of fluid flow, smooth, as contrasted with turbulent; not characterized by crossflow of fluid particles
Landsat	Land [remote sensing] Satellite; also known as ERTS, a series of satellites designed to collect information about the Earth's natural resources
LANL	Los Alamos National Laboratory
laser	Light amplified by simulated emission of radiation—a device that produces an intense beam of light that may be strong enough to vaporize the hardest and most heat-resistant materials, first constructed in 1960
LDEF	Long Duration Exposure Facility
leafy spurge	A tall perennial European herb, troublesome as a weed in the northern U.S. and Canada
LEAP	Lightweight Exo-Atmospheric Projectile
LEASAT	Leased Satellite
LEO	Low-Earth Orbit (100 to 350 nautical miles above the Earth)
LEOEX	Low Earth Orbit Experiment
LEX	Leading Edge eXtension
LFC	Laminar Flow Control
LfA	Laboratory for Astrophysics
Lidar	Light radar

LIDAR	Light Intersection Direction and Ranging
lift	The force exerted on an airfoil such as a wing by a flow of air over and around it, causing it to rise perpendicularly to the direction of flight
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
LITE	LIDAR In-Space Technology Experiment
LLWAS	Low Level Windshear Alert System
LMMT	Liquid Metal Mirror Telescope
Loran	Long-range navigation—a two-dimensional, pulse-synchronized radio navigation system to determine position through pulse-time differencing from a master compared to two slave stations; it uses the frequency band 1.7 to 2.0 megacycles
Loran-C	A Loran system that uses transmission at 100 kilocycles; the C stands for Cytac
LOX	Liquid oxygen
low by-pass engine	A turbo-engine having a by-pass ratio of of less than four to one—see high by-pass engine
low-Earth orbit	An orbit of the Earth some 100 to 350 nautical miles above its surface
LSC	Legal Subcommittee (of COPUOS)
LWIR	Long-Wavelength Infrared
M	Mach number—a relative number named after Austrian physicist Ernst Mach (1838-1916) and indicating speed with respect to that of sound in a given medium; in dry air at 32 degrees F and at sea level, for example, Mach 1=approximately 741 mph or 1,192 kilometers per hour
Mach	See M
MACSAT	Multiple Access Communications Satellite
magnetosphere	The region of the Earth's atmosphere where ionized gas plays an important role in the atmospheric dynamics and where consequently, the geomagnetic field also exerts an important influence; other magnetic planets, such as Jupiter, have magnetospheres that are similar in many respects to the Earth's
MALD	Miniature Air-Launched Decoy
maser	Microwave Amplification by Simulated Emission of Radiation—a device introduced in 1953 with multiple applications in physics and chemistry, plus radio and television communication
mbps	megabits per second
MBR	Mars Balloon Relay
mbs	See mbps
MCC	Mission Control Center
MCS	Maritime Communications Subsystem
MELV	Medium ELV
mesopause	The layer of the Earth's atmosphere with the lowest temperature, from 50-53 mi (80-85 km) up
mesosphere	That portion of the Earth's atmosphere located 34-50 mi (55-80 km) up, where temperature decreases with increasing altitude
MESUR	Mars Environmental SURvey (mission)
Meteosat	Meteorological satellite

METOP	Meteorological Operational (satellite)
MIDEX	Middle-Class Explorer
MILSATCOM	Military Satellite Communications
MIT	Massachusetts Institute of Technology
MLS	Microwave Limb Sounder; Microwave Landing System
MMD	Mean Mission Duration
MMIC	Monolithic Microwave Integrated Circuit
MO	Mars Observer
MOA	Memorandum of Agreement
MOBY	Marine Optical Buoy
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
MOST	Mobile Satellite Communications via the TDRSS
MOU	Memorandum of Understanding
MS	Multiple sclerosis
MSS	Multispectral Scanner Sensors; Mobile Satellite Service
MSTI	Miniature Sensor Technology Integration
MSX	Midcourse Space Experiment
MTBE	Methyl tertiary butyl ether
MTCR	Missile Technology Control Regime
MTD	Maneuver Technology Demonstrator
MTPE	Mission to Planet Earth—a program developed by NASA and the world scientific community to provide scientists with data that will allow them to understand the planet as a total system and to measure the effects of the human population upon it
MWP	Meteorologist Weather Processor
NAPP	National Aerial Photography Program
NAS	National Airspace System; National Academy of Sciences; Numerical Aeronautics Simulation
NASA	National Aeronautics and Space Administration
NASCAP	NASA Charging Analysis Program
NASCOM	NASA Communications network
NASDA	(Japanese) National Space Development Agency
NASM	National Air and Space Museum
NASP	National Aero-Space Plane
NASS	National Agricultural Statistics Service
Navier-Stokes (equations)	Three equations that describe conservation of momentum for the motion of a viscous, incompressible fluid; developed in the nineteenth century by French engineer Claude-Louis-Marie Navier and English physicist Sir George Gabriel Stokes, who made the final derivation of the equations

NCAR	National Center for Atmospheric Research
NCC	Network Control Center
NCDC	National Climatic Data Center
NDVI	Normalized Difference Vegetation Index
NERVA	Nuclear Energy for Rocket Vehicle Applications—a program from 1961-72 to develop a nuclear rocket for post-Apollo missions
NESDIS	(NOAA) National Environmental Satellite, Data, and Information Service
NETSTAR	Network System for TV and Radio
neutron star	Any of a class of extremely dense, compact stars thought to be composed primarily of neutrons; see pulsar
NEXRAD	Next Generation Weather Radar
NGDC	National Geophysical Data Center
NHC	National Hurricane Center
NIH	National Institutes of Health
NIST	(DoC) National Institute of Standards and Technology
NIXT	Normal Incidence X-ray Telescope
NMC	National Meteorological Center
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration, also the designation of that administration's sun-synchronous satellites in polar orbit
NOAO	National Optical Astronomy Observatories
NODC	National Oceanographic Data Center
nominal	Functioning as designed
NOS	National Ocean Service
NOx	Any of several compounds of nitrogen and oxygen, including nitrogen oxide
NRAO	National Radio Astronomy Observatory
NRCS	National Resources Conservation Service, formerly the Soil Conservation Service
NRL	Naval Research Laboratory
NSCAT	NASA Scatterometer
NSC	National Security Council
NSCORT	NASA Specialized Center of Research and Training
NSF	National Science Foundation
NSSFC	National Severe Storms Forecast Center
NST	Nuclear and Space Talks
NTB	National Test Bed
NTF	National Test Facility
NTI	National Technology Initiative
NTIA	(DoC) National Telecommunications and Information Administration, the Federal Government's radio spectrum manager, which coordinates the use of LEO satellite networks like those for Landsat, NAVSTAR GPS, the Space Shuttle, and TIROS with other countries of the world

NTTC	National Technology Transfer Center
NUDET	Nuclear Detonation
NWS	National Weather Service
OACT	(NASA) Office of Advanced Concepts and Technology
OASC	(DoC) Office of Air and Space Commercialization
OCTW	Optical Communications Through the Shuttle Window
ODERACS	Orbital Debris Radar Calibration Spheres
ODL	Oceanic Data Link
OLR	Outgoing Longwave Radiation
OMDP	Orbiter Maintenance Down Period
on-orbit	In orbit
order of magnitude	An amount equal to 10 times a given value; thus if some quantity was 10 times as great as another quantity, it was an order of magnitude greater; if 100 times as great, it was larger by 2 orders of magnitude
OSC	(NASA) Office of Space Commerce; Office of Space Communications
OSL	Orbiting Solar Laboratory
OSSE	Oriented Scintillation Spectrometer Experiment
OSTP	Office of Science and Technology Policy
out-of-ground effect	See "ground effect"
OV	Orbiter Vehicle
PAMRI	Peripheral Adapter Module Replacement Item
PAM	Payload Assist Module
PARE	Physiological and Anatomical Rodent Experiment
Pathfinder	A generic term for various unrelated data sets, used separately by NASA, NOAA, USGS, and perhaps other agencies
PCG	Protein Crystal Growth
PDC	Predeparture Clearance
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
plage	Bright, granular areas in the chromosphere of the Sun
plasma	A gas formed when one or more negatively charged electrons escape from an atom's positively charged nucleus, creating an electrically neutral gas composed of positive and negative particles; because it is ionized, plasma interacts with electric and magnetic fields; approximately 99 percent of matter in the Universe is thought to be in the plasma state

plasma sheet	An extensive area of low-energy, ionized gases in the tail region of the magnetosphere that undergoes considerable change during magnetospheric storms
plastic media blasting	A method of removing paint from aircraft skins by propelling plastic beads into them
PLS	Personnel Launch System
PMS	Physiological Monitoring System
POAM	Polar Ozone and Aerosol Measurement
POES	Polar-orbiting Operational Environmental Satellite
polar orbit	The path of an Earth satellite that passes near or over the North and South Poles
PRA	Probabilistic Risk Assessment
PRC	People's Republic of China
PROSPER	PROgramme SPot Et Radar (the SPOT and radar program)
PSC	Performance Seeking Control
PSCN	Program Support Communications Network
PSE	Physiological Systems Experiment
Pu-238	A plutonium isotope
pulsar	A pulsating radio star, which is thought to be a rapidly spinning neutron star; the latter is formed when the core of a violently exploding star called a supernova collapses inward and becomes compressed together; pulsars emit extremely regular pulses of radio waves
PVO	Pioneer Venus Orbiter
quasar	A class of rare cosmic objects of extreme luminosity and strong radio emission; many investigators attribute their high-energy generation to gas spiraling at high velocity into a massive black hole
RAH	Reconnaissance Attack Helicopter
ramjet	A jet engine with no mechanical compressor, consisting of specially shaped tubes or ducts open at both ends, the air necessary for combustion being shoved into the duct and compressed by the forward motion of the engine
R&D	Research and Development
R&T	Research and Technology
RAWS	Remote Automatic Weather Station
RCRA	Resource Conservation and Recovery Act
real-time	Immediate, as an event is occurring
red shift	Shift of spectral lines toward the red end of the spectrum, indicating motion away from the observer in the lines of sight
Resin Transfer Molding	A process for the fabrication of composite parts for aerospace vehicles in which a dry preform of reinforcements is placed in a mold, resin is infused by vacuum or pressure, and the part is cured in the mold
resolution	With reference to satellites, a term meaning the ability to sense an object; thus, an 80 meter resolution indicates the ability to detect an object of at least 80 meters in diameter
REX	Radiation Experiment
Reynolds number	A nondimensional parameter representing the ratio of the momentum forces in fluid flow, named for English scientist Osborne Reynolds (1842-1912); among other applications, the ratio is vital to the use of wind tunnels for scale-model testing, as it provides a basis for extrapolating the test data to full-sized test vehicles

RFI	Request for Information
RFP	Request for Proposals
RHU	Radioisotope Heater Units
RME	Radiation Monitoring Equipment
RMP	Rotorcraft Master Plan
RMS	Remote Manipulator System—a remotely controlled arm, developed by Canada and controlled from the orbiter crew cabin, used for deployment and/or retrieval of payloads from the orbiter payload bay
ROSAT	Roentgen Satellite
Rover	After 1955, a program to develop a nuclear rocket, renamed NERVA in 1961
RSA	Russian Space Agency
RSRM	Redesigned Solid Rocket Motor
RTG	Radioisotope Thermoelectric Generator
RTTC	Regional Technology Transfer Center
RTTM	Real Time Thrust Measurement
s	second
SAGE	Stratospheric Aerosol and Gas Experiment
SAIC	Science Applications International Corporation
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
SAR	Synthetic Aperture Radar
SAREX	Shuttle Amateur Radio Experiment
SARSAT	Search and Rescue Satellite-Aided Tracking (system)
SATCOM	Satellite Communication
SBIR	Small Business Innovation Research
SBIRS	Space-Based Infrared Systems—a program integrating SMTS and the DSP follow-on program, which has had several names
SBUV	Solar Backscatter Ultraviolet (spectral radiometer)
scramjet	Supersonic-combustion ramjet
SCS	Soil Conservation Service (renamed the National Resources Conservation Service in October 1994)
SDI	Strategic Defense Initiative
SDIO	See BMDO
SEALAR	Sea Launch and Recovery
Seasat	Experimental oceanic surveillance satellite launched June 27, 1978; it demonstrated that much useful information about the ocean could be obtained through satellite surveillance
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
SEDS	Small Expendable Tether Deployable System

SEI	Space Exploration Initiative
SEM	Space Environment Monitor
SENGAP	Small Engine Applications Program
S-GCOS	Space-based Global Change Observation System
Sgr A*	Sagittarius A*, a small but very luminous radio source located at the very center of the spiral Milky Way galaxy
SHARE	Space Station Heat Pipe Advanced Radiator Element
SHASA	Small High Altitude Science Aircraft
SIMMOD	Simulation Model
SLBM	Submarine-Launched Ballistic Missile
SMEX	Small Explorer
SIRTF	Space Infrared Telescope Facility
SLAR	Side-Looking Airborne Radar
SLC	Space Launch Complex
SLS	Spacelab Life Sciences
SLV	Space Launch Vehicle
SMTS	Space and Missile Tracking System (Brilliant Eyes)
SNOTEL	SNOWpack TELemetry
SOF	Special Operations Forces
SOFIA	Stratospheric Observatory for Infrared Astronomy
SOHO	Solar and Heliospheric Observatory
solar flare	A sudden, intense brightening of a portion of the Sun's surface, often near a sunspot group; these flares, enormous eruptions of energy that leap millions of miles from the Sun's surface, pose a potential radiation hazard to humans in space
solar maximum	The period in the roughly 11-year cycle of solar activity when the maximum number of sunspots is present
solar wind	A stream of particles accelerated by the heat of the solar corona (outer region of the Sun) to velocities great enough to permit them to escape from the Sun's gravitational field
SOLSTICE	Solar/Stellar Irradiance Comparison Experiment
SOLTIP	SOLar connection to Transient Interplanetary Processes
Space Station Alpha	See Alpha
Space Test Program	A program in existence since 1965 in the DoD to test hardware in space and study the space environment
SPADE	Stratospheric Photochemistry Aerosols and Dynamics Expedition
SPARTAN	Shuttle Pointed Autonomous Research Tool for Astronomy
SPAS	Shuttle Pallet Satellite
SPEAR	Space Power Experiment Aboard Rocket
SPIREX	South Pole Infrared EXplorer (telescope)
SPOT	Satellite Pour l'Observation de la Terre (satellite for the observation of the Earth)
SPPD	Signal Processing Packaging Design
SRA	Systems Research Aircraft

SRAM	Static Random Access Memory
SRL	Space Radar Laboratory
SRM&QA	Safety, Reliability, Maintainability, and Quality Assurance
SRMU	Solid Rocket Motor Upgrade
SSAAC	Space Science and Applications Advisory Committee
SSBUV	Shuttle Solar Backscatter Ultraviolet (spectrometer)
SSCE	Solid Surface Combustion Experiment
SSME	Space Shuttle Main Engine
SSMI	Special Sensor Microwave/Imager
SSMT	Special Sensor Microwave/Temperature
SSRT	Single Stage Rocket Technology (program)
SST	Sea Surface Temperature
SSTO	Single-stage-to-orbit
stall	A loss of lift by an aircraft or airfoil resulting from insufficient airspeed or excessive angle of attack
START	Strategic Arms Reduction Treaty
STDN	Spaceflight Tracking and Data Network
STEP	Solar Terrestrial Energy Programme; Space Test Experiments Platform
STGT	Second TDRSS Ground Terminal
Stirling engine or generator	One in which work is performed by the expansion of gas at high temperature to which heat is supplied through a wall
STME	Space Transportation Main Engine
STOL	Short Takeoff and Landing
STORM-FEST	Storm-Fronts Experiment Systems Test
STOVL	Short Take-off and Vertical Landing (aircraft)
STP	Space Test Program
stratosphere	The atmospheric zone 12-31 mi (20-50 km) up, exhibiting increased temperature with increased altitude
STRV	Space Technology Research Vehicle
STS	Space Transportation System
STSC	Scientific and Technical Subcommittee (of COPUOS)
STV	Space Transfer Vehicle
SunRISE	Radiative Inputs of the Sun to Earth
sunspot	A vortex of gas on the surface of the Sun associated with stray local magnetic activity
SUPER	Name for a survivable solar-power subsystem demonstrator
super high frequency	Any frequency between 3,000 and 30,000 megacycles per second
supernova	An exceptionally bright nova (a variable star whose brightness changes suddenly) that exhibits a luminosity ranging from 10 million to 100 million times that of our Sun
SUSIM	Solar Ultraviolet Spectral Irradiance Monitor
SWAS	Submillimeter Wave Astronomy Satellite

SXR	SeaWiFS Transfer Radiometer
TAAS	Terminal Advanced Automation System
TAOS	Technology for Autonomous Operational Survivability
TAP	Terminal Area Productivity
TASS	Terminal Area Surveillance System; Terminal Area Simulation System
TATCA	Terminal Air Traffic Control Automation (program)
TBM	Theater Ballistic Missile
TCAS	Traffic Alert and Collision Avoidance System
TDLS	Tower Data Link Service
TDP	Telemedicine Demonstration Project
TDRS	Tracking and Data Relay Satellite
TDRSS	TDRS System
TDWR	Terminal Doppler Weather Radar
teraFLOPS	10^{12} floating point operations per second
TFE	Thermionic Fuel Element
thermionics	A field of electronics that uses electrical current passing through a gaseous medium (vacuum tube) instead of a solid state (semi-conductor), permitting use in high-temperature and radiation environments in which other electronic devices fail
thermosphere	The atmospheric zone beginning about 53 mi (85 km) up and characterized by a significant rise in temperature with increased altitude
thrust-vectoring system	A system on a jet engine to vary the direction of its exhaust nozzles so as to change the direction of the thrust
TIMED	Thermosphere-Ionosphere-Mesosphere Energetics and Dynamics
TIROS	Television and Infrared Operational Satellite
TM	Thematic Mapper
TNA	Thermal Neutron Analysis
TOGA	Tropical Ocean Global Atmosphere
TOMS	Total Ozone Mapping Spectrometer
TONS	TDRSS Onboard Navigation System
TOPEX	Ocean Topography Experiment
TOPS	Toward Other Planetary Systems
TOS	Transfer Orbit Stage
TOVS	TIROS Operational Vertical Sounder
TPCE	Tank Pressure Control Experiment
TPFO	TOPEX/Poseidon Follow-On
TPOCC	Transportable Payload Operations Control Center
TPV	Thermo Photovoltaic
TR	Thrust-reversing
TRACON	Terminal Radar Approach Control
TRAM	Tilt Rotor Aeroacoustic Model

tribology	The study of the interaction of sliding surfaces with respect to friction, wear, and lubrication
troposphere	That portion of the atmosphere about 7-10 mi (11-16 km) up where clouds form and convection is active
TRMM	Tropical Rainfall Measuring Mission
TRP	Technology Reinvestment Project
TSRV	Transportation Systems Research Vehicle
TS/TP	turboshaft/turboprop
TSS	Tethered Satellite System
TV	Thrust-vectoring
TVCS	Thrust Vector Control System
UARP	Upper Atmosphere Research Program
UARS	Upper Atmosphere Research Satellite
UAV	Unmanned Aerial Vehicle
UCLA	University of California at Los Angeles
UFO	UHF Follow-On
UHF	Ultra high frequency, any frequency between 300 and 3,000 megacycles per second
UHF SATCOM	UHF Satellite Communication
UIT	Ultraviolet Imaging Telescope
U.K.	United Kingdom of Great Britain and Northern Ireland
UMS	Urine Monitoring System
UN	United Nations
UNEP	United Nations Environment Program
UNFC	United Nations (General Assembly's) First Committee
U.S.	United States
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
USGS	U.S. Geological Survey
USML	U.S. Microgravity Laboratory; U.S. Munitions List
USMP	U.S. Microgravity Payload
USTR	Office of the U.S. Trade Representative
UTTR	Utah Test and Training Range
UV	Ultraviolet
UVCS	Ultraviolet Coronal Spectrometer
VAFB	Vandenberg Air Force Base
VAS	Visible-and-Infrared-Spin-Scan-Radiometer Atmospheric Sounder
VCS	Voice Command System
VFC	Vortex Flow Control
VHF	Very high frequency, any radio frequency between 30 and 300 megacycles per second

viscosity	Resistance to flow or change of shape under pressure
VISSR	Visible and Infrared Spin-Scan Radiometer—an instrument on NOAA's GOES-7 satellite
VLBA	Very Long Baseline Array, a set of 10 radio telescopes in the continental U.S., Hawaii, and St. Crois
VLBI	Very Long Baseline Interferometry
VLSI	Very Large Scale Integration
VoA	Voice of America
VSCS	Voice Switching and Control System
VSRA	V/STOL System Research Aircraft
V/STOL	Vertical/Short Take off and Landing
WARC	World Administrative Radio Conference
WEFAX	Weather Facsimile
WGD	(CEOS) Working Group on Data
white dwarf	Any of a class of faint stars, characterized not only by low luminosity but by masses and radii comparable to that of our Sun
WINDII	Wind Imaging Interferometer
WMO	World Meteorological Organization
WSGT	White Sands Ground Terminal
WSMC	Western Space and Missile Center
WSMR	White Sands Missile Range
WSP	Windshear Processor
WSTF	White Sands Test Facility
WUPPE	Wisconsin Ultraviolet Photopolarimeter Experiment
x-rays	Radiations of very short wavelengths, beyond the ultraviolet in the spectrum
XTE	X-ray Timing Explorer

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