Aeronautics and Space Report of the President

1987 Activities

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Aeronautics and Space Report of the President

1987 Activities

1989
National Aeronautics
and Space Administration
Washington, DC 20546

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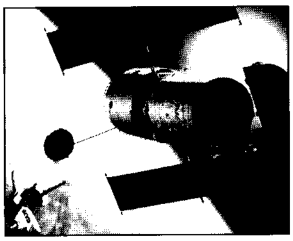
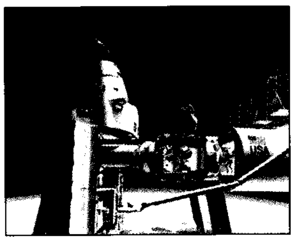
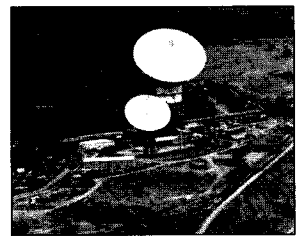
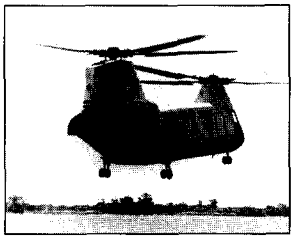
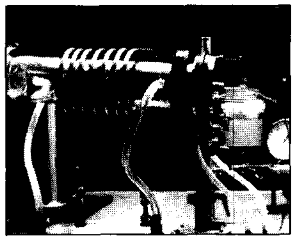
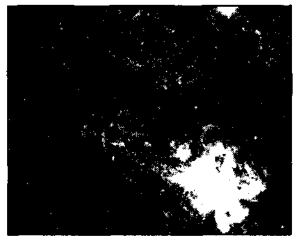
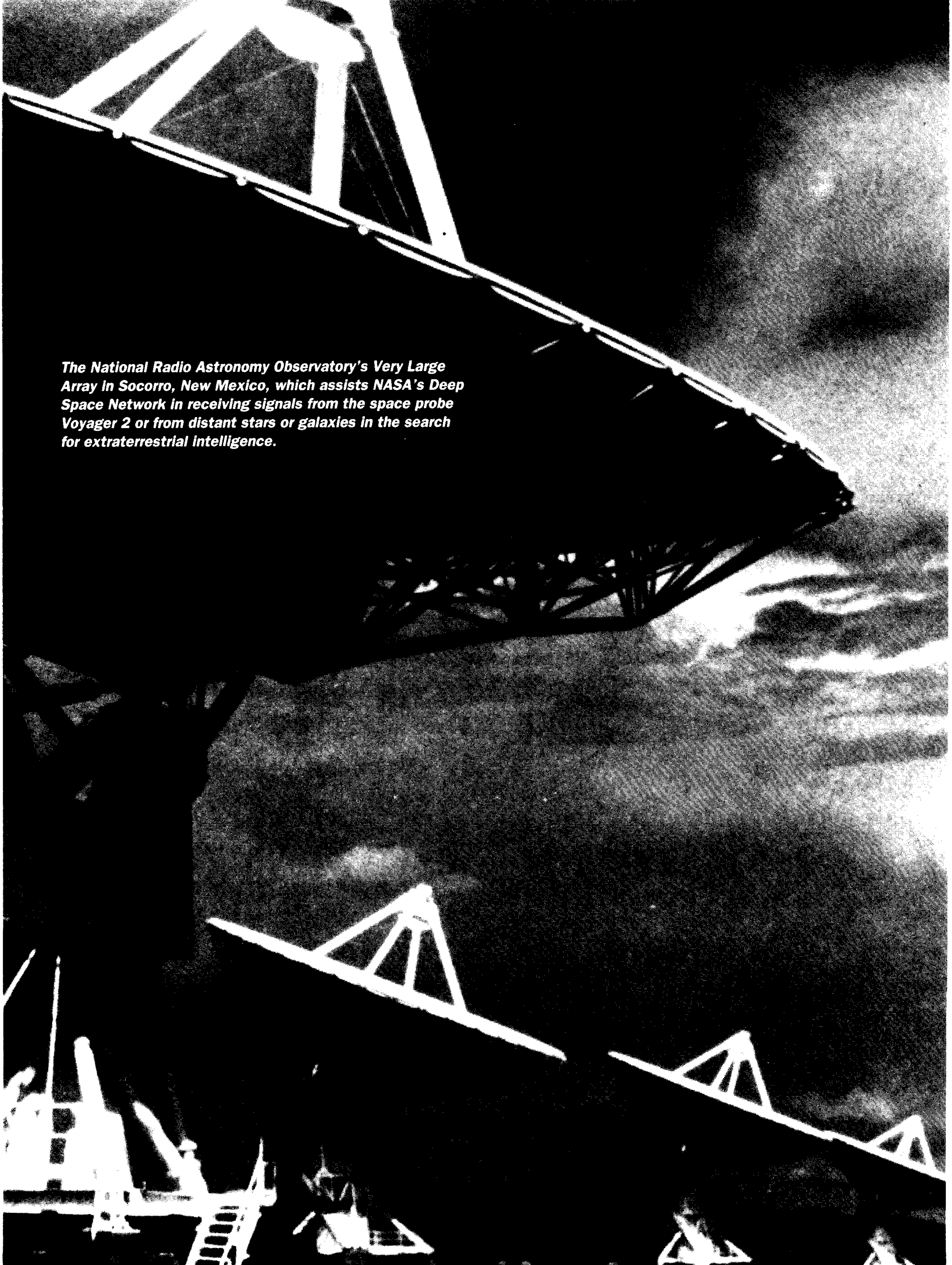
   



The National Radio Astronomy Observatory's Very Large Array in Socorro, New Mexico, which assists NASA's Deep Space Network in receiving signals from the space probe Voyager 2 or from distant stars or galaxies in the search for extraterrestrial intelligence.

Summary

During 1987 research and development in the areas of aeronautics and space, involving several federal agencies, continued to open new horizons for technological understanding and answer numerous questions about how the solar system, including Earth, and the universe were created.

Major efforts continued to focus on returning the space shuttle to flight status. Crew escape and landing system changes recommended by the Presidential Commission on the Space Shuttle Challenger Accident were being incorporated into the orbiter; design changes were made to the Solid Rocket Motor and static test firings of it were conducted; and a program was initiated to address key problems involving the space shuttle main engine that were identified following the Challenger accident on January 28, 1986.

Studies were completed concluding that a mixed fleet, consisting of the space shuttle and expendable launch vehicles, would be required for continued U.S. operations and access to space.

The National Aeronautics and Space Administration (NASA) conducted four spacecraft launches using expendable launch vehicles, three of which were the launch of GOES-H, the last in the current series of Geostationary Operaticnal Environmental Satellites.

In the areas of space observation and exploration, Supernova 1987a, discovered in the Large Magellanic Cloud which is located 160,000 light years from Earth, was observed and studied. Since this was the brightest supernova observed since 1604, astronomers from around the world had an unprecedented opportunity to study the death of a star. In related activity, scientists theorized that the massive black holes (M31 and M32) at the center of two galaxies close to the Milky Way have a mass 10 to 100 times that of the sun, and are favored to explain the energy source of quasars. The Pioneer 10 spacecraft traveled past the orbit of Pluto, and Pioneer 11 approached the orbit of Neptune. Like the Pioneers, the Voyager 1 and 2 spacecraft continued measuring the properties of the interplanetary medium in the outer solar system. Preparations were initiated for Voyager 2's final encounter with Neptune in 1989. Also, after successfully operating for 10 years, the International Sun-Earth Explorers ISEE-1 and -2 reentered Earth's atmosphere.

Based in Antarctica, scientists from U.S. agencies and universities conducted extensive studies to determine the causes of ozone depletion in the atmosphere.

In the area of national security, the Strategic Defense Initiative program demonstrated the ability to intercept targets within the atmosphere and in space. Certain technologies and concepts to be used in this program were approved for analysis of their feasibility as critical elements of the program.

Surveillance and warning systems continued to provide warning capability for attacks by ballistic missiles or threats by air-breathing vehicles. During 1987 two phased-array warning-system radars became operational; two have been in use since 1980. A joint program by the Federal Aviation Administration and the U.S. Air Force was planned for modernizing the Canadian-American Joint Surveillance System radar, in addition to other surveillance and warning systems.

Increased capacity in the 11/12/14-GHz band allowed the Federal Communications Commission to approve applications for several small Earth-based antenna networks that will increase satellite-delivered communications services.

Congress approved a revised Landsat program commercialization plan that called for the release of additional funding to continue the development of the space and ground systems for the Landsat 6 satellite. In addition, the Department of Commerce will direct a study aimed at developing a commercial system more advanced than the Landsat 6 system.

In the international arena, the United States moved closer to agreement with its partners in the multibillion dollar, permanently occupied Space Station program. Secretary of State Shultz signed a new space cooperation agreement between the United States and the Soviet Union that established 16 bilateral cooperative space science projects. The Federal Communications

Commission was involved in international efforts concerning equitable access by all countries to the geostationary satellite orbit and the frequency bands allocated to space services, as well as participating in the examination and revision of the International Telecommunications Union Radio Regulations pertaining to mobile services. The Department of State continued to evaluate and advance U.S. foreign policy interests in the context of space activity. The Arms Control and Disarmament Agency continued to work on multilateral space arms control issues, both in the United Nations General Assembly and in the Conference on Disarmament in Geneva. The Department of Energy worked on developing spaceborne nuclear detonation detector systems in order to support national requirements to verify international compliance with the Limited Test Ban Treaty and the Nonproliferation Treaty. Also, the United States Information Agency distributed articles which examined the prospects for space over the next 25 years and reviewed "Who's Who" in space during the first 25 years of space travel and exploration. Through its information activities, the U.S. Information Agency continued to promote world awareness of U.S. achievements in space research and the development of the peaceful uses of space. The National Science Foundation collaborated with agencies of other nations on an extensive global study of Earth, the oceans, and the atmosphere. The U.S. Geological Survey of the Department of the Interior participated in cooperative work with Norway to analyze Landsat thematic mapper images for surface temperature mapping of an area of Queen Maud Land, Antarctica. Also the Survey is working with 30 other countries to document the areal extent of glacier ice on Earth. The Antarctic volume in this study is being prepared in cooperation with Britain and New Zealand.

The remainder of this chapter is a summary by function of U.S. aeronautics and space activities in calendar year 1987. The succeeding chapters present activities of individual agencies in greater detail.

Space Science and Applications

The Space Science and Applications program of NASA endeavors to increase understanding of basic physical, chemical, and biological processes, Earth and its environment, the other planets, the sun and the other stars, and the rest of the universe. Scientific disciplines included are astrophysics, solar system exploration, space physics, Earth science and applications, life sciences, microgravity science and applications, and communications and information systems

The National Science Foundation has continued to make important contributions to the furtherance of research in atmospheric sciences and ground-based astronomy. The Smithsonian Institution, through its Astrophysical Observatory, contributes to basic research in the space sciences. The Smithsonian's Air and Space Museum provides public exhibits, lectures, and educational programs. The Museum's Center for Earth and Planetary Studies also conducts basic research in planetary geology and terrestrial remote sensing.

Astrophysics

The NASA Astrophysics program studies the origin and evolution of the universe, the fundamental physical laws of nature, stars, planets, and life itself. The program centers on space observatories that are supported by instrument developments, suborbital research activities, data analysis, and theoretical studies.

Supernova 1987a. February 24, 1987 marked the discovery of Supernova 1987a in the Large Magellanic Cloud. The International Ultraviolet Explorer (IUE) detected the initial ultraviolet spectrum of this exploding star and acquires spectral data from it regularly. By comparing ultraviolet spectral data from IUE with pre-explosion measurements of other stars, researchers determined the progenitor of Supernova 1987a to be a blue supergiant star known as Sanduleak-69 202. Data from continued observations could help answer many questions about the birth of a solar system.

Hubble Space Telescope. In 1987 NASA completed assembly and testing of the Hubble Space Telescope (HST), the first of the four Great Observatories. The HST is scheduled for launch into space in 1989, allowing scientists and astronomers to see clearly 10 to 30 times beyond what can be seen in the universe with existing instruments.

Gamma Ray Observatory. NASA neared completion of the manufacturing of the mechanical components and electronic systems for the Gamma Ray Observatory (GRO). Scheduled for launch into space in 1990, the GRO will be used to study extraterrestrial gamma rays, the highest energy radiation in the electromagnetic spectrum.

Proposed Advanced X-ray Astrophysics Facility. Definition phase studies of this proposed facility were completed by two competing contractors. Planned for launch in the 1990's, the Advanced X-ray Astrophysics Facility will be designed to observe celestial sources of x-rays, and to help answer fundamental questions in astronomy and physics.

Proposed Space Infrared Telescope Facility. Detailed studies were made of the Facility and its mirror. Expected to be the fourth of the Great Observatories, the Space Infrared Telescope Facility will make the most sensitive observations yet of infrared radiation from celestial objects.

Solar System Exploration

Pioneer Venus. Orbiting Venus since 1978, the Pioneer Venus spacecraft has made continual observations of the planet and its interaction with the solar wind. During 1987, NASA researchers emphasized collecting data that contributed to understanding the solar cycle effects on the Venusian atmosphere and ionosphere.

The Interplanetary Medium. The Voyager 1 and 2 spacecraft, like the Pioneer 10 and 11 spacecraft, are measuring the interplanetary medium in the outer solar system. Both the Voyager spacecraft are beyond the orbit of Uranus. Pioneer 10 is beyond the orbit of Pluto, and Pioneer 11 is approaching the orbit of Neptune.

Galileo. NASA re-established the launch date, mission trajectory, and upper stage for the Galileo mission to Jupiter. Scheduled for launch on the space shuttle in late 1989, Galileo will conduct investigations of Venus and the asteroids Gaspra and Ida while en route to Jupiter.

Ulysses. The Ulysses mission, a joint endeavor with the European Space Agency (ESA), will provide the first view of the sun and the solar system from above the ecliptic plane. After extensive negotiations with ESA, the launch date for the mission was scheduled for 1990.

Mars Observer. The Mars Observer mission will obtain images of the surface and atmosphere of Mars during the four seasons of one Mars year. The mission was rescheduled for launch in 1992.

Magellan. Development of the Magellan mission to Venus continued toward an expected 1989 launch by the space shuttle. The radar-equipped spacecraft will map the surface of the planet for one Venus year (243 days).

Space Physics

Space Physics programs support investigations of the origin, evolution, and interactions of particulate matter and electromagnetic fields in a variety of space plasmas. Research is conducted in the areas of Ionospheric Physics, Magnetospheric Physics, Solar Physics, and Cosmic and Heliospheric Physics.

Global Geospace Science Program. Planning began for this program that will involve contributions by the United States, Japan, and the European Space Agency. The U.S. contribution to this effort will be in the International Solar Terrestrial Physics Program. These nations plan to launch a series of satellites in the early-to-mid 1990's to provide the measurements and to test models for the study of the interior of the sun; the origin of the solar wind; the cause-and-effect relations of the flow of energy in Earth's key magnetospheric source and storage regions; and the microphysics of plasma interactions in Earth's magnetosphere.

Operational Explorers. Launched in 1980, the Solar Maximum Mission continued to provide valuable observations of the sun and measurements of ozone concentrations in Earth's atmosphere. The data are expected to play a significant role in solving the mystery of Antarctica's "Ozone Hole."

The workhorse of the Explorers, the 14-year-old Interplanetary Monitoring Platform (IMP-8) satellite, continued to function well as the only existing monitor of solar wind interactions with Earth's magnetosphere and to provide crucial information for missions to other planets.

After operating successfully for 10 years, the International Sun-Earth Explorers ISEE-1 and -2 reentered Earth's atmosphere. The data they had provided resulted in the publication of numerous scientific papers. The International Sun-Earth Explorer-3, retargeted and renamed the International Cometary Explorer (ICE), is still operational. Its observations result in over 100 scientific papers published annually that cover the full range of space plasma phenomena.

Earth Science and Applications

During 1987, considerable progress was made in understanding Earth, its atmosphere, and its environment.

Satellite Operations. NASA-developed satellites operated by the National Oceanic and Atmospheric Administration (NOAA) include both geostationary and polar-orbiting spacecraft that are used to forecast weather and issue storm or natural disaster warnings. In February, the last of the current series of Geostationary Operational Environmental Satellites, GOES-H, was launched and became operational as GOES-7, providing primary weather coverage of the east coast of the United States. Launch of the first in the next-generation series of satellites, GOES I through M, is expected in early 1990. NOAA 9 and NOAA 10 satellites continued to provide polar-orbiting service throughout the year. Orbiting 450 miles above Earth's surface, these spacecraft provide total global imaging coverage.

Atmospheric, Oceanic, and Geologic Research. NASA, NOAA, the National Science Foundation, and the Chemical Manufacturers Association sponsored two expeditions to study the Antarctic Ozone Hole, using ER-2 and DC-8 aircraft and ground-based experiments. Preliminary results indicate that it is caused by both human and natural activities. More precise analysis is expected in early 1988.

The second regional experiment in the International Satellite Cloud Climatology Project was conducted off the coast of southern California to study marine stratocumulus clouds. The results of this experiment, along with data taken from the first regional experiment on the role of cirrus clouds in the radiation budget, will help scientists understand the relationships between microphysics and macrophysics and the radiative transfer properties of clouds.

Research continued on both active and passive remote sensing techniques to improve capabilities for observing Earth's atmosphere. Several techniques using lasers to measure aerosols, water vapor, temperature, and wind profiles were tested aboard NASA research aircraft.

NASA and NOAA established a joint panel to study the feasibility of developing a spaceborne lightning sensor. The proposed instrument would be carried on a satellite in geosynchronous orbit, and would be capable of detecting both cloud-to-cloud and cloud-to-ground lightning strokes. The data it would provide is expected to yield new insights into the role of atmospheric electricity, cloud growth, storm development, intensity and precipitation processes, and Earth's global electrodynamic circuit.

The FAA continued to improve the 6-sensor Low Level Wind Shear Alert System, the ground-based wind shear detection system that is used by air traffic controllers to issue advisories to departing and arriving aircraft. New algorithms for the system designed to reduce the impact of false alarms and enhance the system's ability to detect microbursts were developed and tested. Also, the FAA continued to conduct tests using Doppler weather radar capable of "seeing" inside storms to measure rainfall intensity and the speed of winds.

NASA's oceanography program focused on obtaining and analyzing remotely sensed satellite data to study ocean circulation, atmospheric forcing of the ocean surface, biological productivity, and sea ice. Several federal agencies and international organizations are collaborating on ocean research, and a system of satellite sensors is expected to be in use by the early 1990's to support several global experiments. Science teams from NASA and the French Space Agency began developing a science plan for TOPEX/POSEIDON, a satellite altimetry system that will measure sea surface height and allow scientists to determine the ocean response to wind forcing and ocean circulation.

NASA and the University of Alaska continued developing the Alaska Synthetic Aperture Radar Facility in Fairbanks, Alaska, which will allow scientists to receive, process, and archive data about sea ice from the Special Sensor Microwave Imaging Radiometer that was launched into space in June, and from sensors on European, Japanese, and Canadian satellites.

Geodynamics research contributes to the understanding of earthquakes, the evolution of Earth, and the interaction between the solid Earth, the oceans, and the atmosphere. During the year, the United States participated in joint projects and programs with several nations that included not only using fixed and mobile laser ranging systems to measure tectonic plate motion and Earth rotation, but also studying earthquake hazards in the Caribbean basin.

The Department of the Interior's Bureau of Land Management uses data from both the French SPOT satellite and the Landsat Thematic Mapper to assess and monitor mineral development on public lands. Data were used to map areas where mineral materials are extracted and oil and gas are located, and to monitor compliance with U.S. management regulations governing mining claims.

NASA and the U.S. Geological Survey initiated a program to map the surface of Mars using high-resolution images from Viking spacecraft. The resulting geologic maps are expected to show in detail the structure, stratigraphy, and morphologic aspects of the Martian surface.

Life Sciences

NASA's Life Sciences program investigates biological processes and life in the universe and endeavors to promote health and productivity in human space flight.

Space Medicine. NASA initiated planning for the Space Station era, with emphasis on maintaining health and performance during extended exposure to the weightlessness of space. A Health Maintenance Facility under development for the Space Station will incorporate advanced technology and capabilities to monitor space crews.

Gravitational Biology. This program strives to understand the effects of gravity and weightlessness on the biological processes of plants and animals. Ground-based research clarified some mechanisms that control the differential growth and orientation of plants. This research contributes directly to the program to develop a Controlled Ecological Life Support System, which will be designed to recycle the food, air, and water needed to support extended missions with humans in space. Additional studies in the space environment are needed to confirm and complement current developmental and metabolic research.

Microgravity Science and Applications

NASA's Microgravity Science and Applications program strives to foster the development of near-Earth space as a national resource. Research is conducted in the fundamental sciences, materials science, and biotechnology. Experimenting in the microgravity environment increases understanding of the following: the fundamental sciences that govern processes on

Earth, such as those influencing the behavior of fluids; the role of gravity in Earth-based industrial processes, such as those used to produce metals and alloys; and the production of high-value materials, such as protein crystals. During the year, some outdated research hardware was replaced by systems with expanded capabilities.

Communications

Programs in satellite communications are designed to expand the technology base for commercial and military satellite communications systems in today's highly competitive, data-intensive environment.

Advanced Communications Technology Satellite. The Advanced Communications Technology Satellite project essentially completed the design, implementation, and testing of this satellite's communication engineering models (transponders and antennas), the heart of this spacecraft. High-technology items designed for the spacecraft, such as the space-based processor, steerable antenna, and high-powered, fast-hopping, spot-beam antenna system, will contribute to U.S. prominence in the future international telecommunications marketplace.

Mobile Satellite. A mobile satellite system will provide telephone service to rural areas, long-range vehicle dispatch and location service, emergency communications, aeronautical communications, and service to industries operating in remote locations. The Federal Communications Commission allocated 27 MHz of spectrum in the L-Band for mobile service, and concluded that joint ownership of the first-generation system would best serve the public. Eight applicants have reached general agreement on a joint venture, and are expected to submit a system proposal in early 1988.

Search and Rescue. To date, the COSPAS/SARSAT system, an international service which locates aircraft and vessels in distress has been credited with saving over 950 lives (COSPAS, translated literally from Russian means Space System for Search of Distressed Vessels; and SARSAT, is the acronym for Search and Rescue Satellite-Aided Tracking, the U.S. contribution to the system). A final draft of an intergovernmental agreement to extend service beyond the 1990's was completed. Also, plans were under way to expand the ground system network and to test the system using both polar-orbiting and geostationary satellites.

Advanced Technology Satellite (ATS-3). The ATS-3 celebrated its 20th anniversary and continued to support the activities of not only several federal, state, and local agencies, but also a number of domestic and international disaster-relief organizations. Through satellite voice and data links in science and communications application experiments, support is provided to North and South America, most of the Atlantic Ocean, and a large part of the eastern Pacific, including Hawaii and Antarctica.

INTELSAT and INMARSAT. At the end of 1987, the International Telecommunications Satellite Organization (INTELSAT) maintained 13 satellites in geosynchronous orbit: 1 IV-A, 4 V's, and 2 V-A's in the Atlantic Ocean Region; 2 V's and 1 V-A in the Indian Ocean Region; and 1 IV-A and 2 V's in the Pacific Ocean Region. The IV-A satellites have exceeded their estimated maneuver life. During the year, the Federal Communications Commission approved the construction and operation of 19 new Earth station facilities to access the INTELSAT system in the Atlantic and Pacific Ocean Regions.

Second-generation satellites of the 53 member-country International Maritime Satellite Organization (INMARSAT) will have a capacity about triple that of the present leased satellites. The first of these satellites is expected to become operational in 1989. INMARSAT serves over 6,500 vessels; 20 coast stations in 13 countries are in operation, with two more expected by 1988.

Domestic Communications Satellites. At year's end, there were 27 domestic communications satellites in orbit at locations between 69° and 143° west longitude on the orbital arc. In September, 20 applications for new or replacement satellites were filed as part of the next domestic satellite group to be processed.

Direct Broadcast Satellites. Of the eight "first-round" companies previously granted conditional permits in the fall of 1986 to construct Direct Broadcast Satellites, three were actively doing so. They are required to have their satellite systems in operation by the last quarter of 1988. One demonstrated "due diligence" in construction of its satellite system and requested channel and orbital position assignments. One application for a Direct Broadcast Satellite system was filed, and another applicant requested placement in a pending status. Of the six "second-round" applicants previously granted conditional permits, one has demonstrated "due diligence" and was awarded channels, orbital position, and launch authority.

Military Communications Satellites. Military Satellite Communications (MILSATCOM) are provided by several satellite systems. The Fleet Satellite Communications (FLTSATCOM) system consists of government-owned satellites, augmented by leased, contractor-owned satellites (LEASAT). FLTSATCOM provides low-capacity, worldwide command and control communications in the Ultra High Frequency band. Using the same frequency band, the Air Force Satellite Communications system provides specialized command and control capabilities for U.S. nuclear forces. In the Super High Frequency band, the Defense Satellite Communications System provides high-capacity, multi-channel service to a diverse group of strategic, tactical, and non-Defense Department customers. Planning continued on the future deployment of the Milstar satellite communications system, which will use the Extremely High Frequency band to provide highly survivable communications for critical users.

Navigation Satellites. Seven Global Positioning System (GPS) developmental satellites were operating, five of which were performing well. The remaining two were operating substantially beyond their design lifetimes and were performing marginally. Procurement of GPS operational satellites was in its sixth year, under a multiyear, 28 spacecraft contract. The first operational launch is scheduled for 1988 and full operational capability of the GPS network is expected in late 1990 or early 1991.

Defense Meteorological Satellites. The Defense Meteorological Satellite Program continued to be the Department of Defense's most important source of weather data. The Department of Defense continued the development of improved sensing capability to be incorporated into all new satellites of this system.

Space Transportation

Major efforts in NASA's Space Flight program continued to focus on returning the space shuttle to flight status.

Transportation Services

Activity in Transportation Services centered on developing a combined shuttle and expendable launch vehicle manifest. This mixed fleet manifest incorporated major elements of the President's policy on the commercialization of space, which provides that NASA will no longer launch commercial satellites except for those that are shuttle-unique or have foreign policy implications. The policy revised Department of Defense requirements and broadened the definition of secondary payloads to include those up to approximately 8,000 pounds.

Orbiter

Orbiter safety modifications that include crew escape and landing system changes recommended by the Presidential Commission on the Space Shuttle Challenger Accident were being incorporated into the spacecraft. Other safety-related areas under review included the critical items list, launch commit criteria, hazard analyses, and design requirements and certification. The production of an orbiter to replace Challenger was initiated in August when a contract was signed with Rockwell International.

Solid Rocket Booster

All areas of the Solid Rocket Boosters were reviewed for minimum impact on the return-to-flight schedule. Primary design changes were made to the Solid Rocket Motor field joints, nozzle-to-case joints, case insulation, and seals. Several tests of case and nozzle-to-case joints with intentionally flawed insulation and O-rings were completed. Also, two of the four static motor test firings were conducted and were successful.

Subsequent to the Challenger accident, the five major solid-propulsion contractors were funded to study changes to the existing Solid Rocket Motor joint design and to propose new concepts for improving Solid Rocket Motor performance. The results of these studies were reported to Congress, as required by law. Also, NASA submitted a plan to Congress indicating it would initiate Phase B studies for an Advanced Solid Rocket Motor. Subsequently, the five solid propulsion contractors were awarded contracts for preliminary design studies of both a monolithic and segmented Advanced Solid Rocket Motor.

Space Shuttle Main Engine

A program was initiated to address the key problems of the space shuttle main engine identified following the Challenger accident. It resulted in 23 mandatory changes that will be required before flights of the space shuttle resume. The test rate to complete all certification testing was increased from 8 to 12 per month. The engine certification test program reached a major milestone when engine 2105 was tested for 30,000 seconds. A third test stand was completed at the National Space Technology Laboratories and should be activated early in 1988.

Expendable Launch Vehicles

During 1987 the Department of Defense, NASA, and the Department of Transportation developed a Space Launch Recovery Plan, in conjunction with the commercial and scientific communities, which would allow for a balanced use of the shuttle and expendable launch vehicles. NASA conducted four spacecraft launches using expendable launch vehicles, three of which were successful.

Advanced Planning

NASA and DOD continued the Space Transportation Architecture Studies to define future space transportation requirements. Specifically, they coordinated studies to define concepts for heavy-lift launch vehicles that would satisfy both near- and long-term mission requirements. For human space flight, NASA continued efforts to enhance the shuttle's near-term performance, initiated studies for space shuttle evolution, and continued studies of a next-generation (Space Shuttle II) vehicle. To support advanced lunar and Mars missions, studies were conducted on techniques for on-orbit storage of large cargoes and on space transfer vehicles that would be required in the next century.

Safety, Reliability, Maintainability and Quality Assurance

As part of efforts to improve the communication of safety problems, NASA's Office of Safety, Reliability, Maintainability and Quality Assurance established the NASA Safety Reporting System. It is a confidential, voluntary, and independent reporting system through which NASA's 100,000 employees and contractor personnel may directly and anonymously inform the NASA Headquarters Safety Division of their concerns over safety aspects of the space shuttle program. It is intended as a supplementary reporting system to be used when standard reporting methods fail to provide timely or satisfactory resolution.

A Technical Advisory Group, comprising representatives from the Space Transportation System (STS) Centers and the Office of Space Flight, and chaired by the Manager of the STS Safety Program, was formed to investigate concerns reported through the NASA Safety Reporting System. Currently, the Program is handling only STS-related safety issues. However, it will be expanded in the future to include safety issues in all NASA programs and projects.

Commercial Use of Space

The Office of Commercial Programs was established in NASA to encourage private sector investments in commercial space activities.

NASA's Centers for the Commercial Development of Space, which are nonprofit consortia of universities, industry, and government, conduct space-based, high-technology research with commercial potential. During 1987, 7 additional Centers were established, bringing the total number to 16. Over 100 organizations are affiliated with the Centers. Two researchers that received support from the Centers were responsible for the highly publicized breakthrough in high-temperature superconductivity, the fabrication of material superconducting above the temperature of liquid nitrogen.

When the space shuttle resumes flight operations, it will carry a payload developed by the 3M Corporation to study the properties of highly ordered organic materials produced in space. It also will carry equipment to grow protein crystals of a size and quality that will facilitate detailed analysis of their characteristics and that have significant implications for the future manufacture and use of pharmaceuticals.

Two notable spinoffs from NASA-developed technology are the Programmable Implantable Medication (PIM) System which can eliminate the diabetic's need for intravenous insulin and the Automatic Implantable Defibrillator (AID) which can sense the onset of fibrillation and deliver a balanced electric pulse to restore the heart to normal rhythm. During 1987 the PIM System was implanted in a total of 18 diabetic patients and the AID was implanted in approximately 20 heart patients per month.

The Office of Commercial Space Transportation of the Department of Transportation continued to encourage and coordinate the development of commercial expendable launch vehicle operations by private U.S. enterprises. In 1987 the Office worked with the Air Force to develop the terms and conditions that will govern commercial use of the nation's launch facilities. By the end of the year American launch firms had final contracts to launch 12 satellites.

Space Station

NASA took a major step toward establishing a permanently occupied Space Station by selecting four aerospace firms to design and build the orbital research base.

The Space Station will serve, initially, as an orbiting observatory and microgravity laboratory. As it evolves, it is expected to become a servicing center, transportation node, spacecraft assembly facility, manufacturing facility, storage depot, and staging base for lunar and planetary exploration. Plans call for the Space Station to be assembled in orbit beginning in 1994, and serve as the cornerstone for continued exploration of the solar system in the next century.

By the end of the year, negotiations with the Space Station's international partners were nearly complete. Canada informally agreed to develop the facility's Mobile Servicing System; Japan is expected to develop a laboratory module and two logistics carriers; and the European Space Agency's plan to develop a laboratory module and a polar orbiting platform is pending.

A National Research Council committee conducted an independent technical and cost review of the Space Station and concluded that NASA's Phase I baseline configuration was the most practical first step in Space Station development.

In the area of Space Station utilization, the Space Station Operations Task Force completed a 6-month review of the options and concepts for managing and conducting operations aboard the facility; a preliminary draft was completed of a Space Station Users Handbook that will be used as a guide for commercial and government users; and a NASA-sponsored workshop provided the Agency with a commercial perspective on making the Space Station a valuable tool for industry.

Space Operations

In a reorganization, the functions of the former Office of Space Tracking and Data Systems became an integral part of the new Office of Space Operations. This office is responsible for developing a plan for managing NASA's increasingly complex space operations, with initial priority given to man-tended and man-related space operations.

The Space Tracking and Data Systems program continued to provide vital tracking, command, telemetry, communications, data relay, and data processing support to meet the requirements of flight programs. The current orbiting Tracking and Data Relay Satellite (TDRS) supported Landsat, Solar Mesospheric Explorer, and Earth Radiation Budget Satellite missions. Final assembly, test, and launch preparations for two additional TDRS spacecraft were conducted to continue the transition from a ground-based tracking network to a space-based network for low-Earth-orbit missions. The space network will become operational when three fully functioning satellites are in geosynchronous orbit and spacecraft and ground systems have been tested. The next TDRS is scheduled for launch when space shuttle operations resume. Also, a TDRS Replacement Spacecraft program was initiated to replace the satellite lost in the Challenger accident.

The Deep Space Network (DSN) prepared for Voyager II's encounter with Neptune in August 1989. To increase the capabilities of deep space antennas for this and future missions, the diameter of the DSN antennas in Spain and Australia were increased from 64 meters to 70 meters.

Basic elements of the Communications and Data Systems program form the vital link between data acquisition stations and users and provide communications, mission control, and data gathering and processing. During 1987, this program continued to support low-Earth-orbiting spacecraft for both scientific and applications missions.

Aeronautics and Space Research and Technology

New capabilities in aeronautics and significant advances made in space research and technology marked the year 1987 as one of promise in several Federal agencies' endeavors to expand U.S. capabilities in civil and military aviation and to maintain U.S. leadership and security in space.

Aeronautics

The aeronautics research and technology program managed by NASA includes both fundamental disciplinary research and systems (vehicle-specific) research. This program includes joint efforts with both the Federal Aviation Administration and the Department of Defense. In addition to traditional aeronautical research, considerable progress has been made in the application of new disciplines, such as artificial intelligence and advanced computational simulation.

Disciplinary Research and Technology. The disciplinary research and technology activities endeavor to improve understanding of basic physical phenomena and to provide the technological base for new concepts and ideas necessary for future advances. These activities are in the areas of aerodynamics, propulsion, materials and structures, information sciences and human factors, and flight systems.

Aerodynamics—NASA developed the computational fluid dynamics techniques that were applied to the hull and keel design of the America's Cup yacht "Stars and Stripes." In addition, two NASA-developed aerodynamic concepts were applied to the vessel—"riblets," to reduce skin friction drag, and swept wingtips, on the winglets of the keel, to reduce induced drag.

Propulsion—In addition to achievements in research related to computational fluid mechanics analysis and advanced computational analysis in general aviation engine research, the major accomplishment was the start-up of three new facilities for component research that will expand the experimental validation data base.

Materials and structures—A new thermoplastic composite material developed by NASA's Langley Research Center is under evaluation by the aircraft industry for high-temperature composite structures that offer the potential for improved aircraft performance.

Researchers have developed an advanced analytical capability to predict the unsteady aeroelastic response of aircraft configurations. Called the Computational Aeroelasticity Program-Transonic Small Disturbance, this analysis code may also be used to predict flutter boundaries and to simulate hypersonic three-dimensional flow fields and three-dimensional rotor-stator interactions, giving researchers insight and understanding into very complex flow fields.

Information sciences and human factors—NASA and the Federal Aviation Administration are working together to find ways to increase the efficiency of the U.S. Air Traffic Control System. A time-based concept for controlling traffic flow in terminal areas was evaluated in the NASA Ames Research Center's ATC simulation system. It is designed to allow new techniques for fully utilizing runway capacity and improving fleet operational efficiency. Flight evaluation of this concept is planned for the Denver terminal area in 1988-1989.

Flight systems—Research on safety continued in the specific areas of lightning, rain, and icing effects. Accomplishments included the installation at the Aircraft Landing Dynamic Facility of a water spray system that will be able to test sections of full-scale wings; the completion of computer codes for simulating iced airfoil performance whose simulation results were found to compare favorably with experimental data; and the start of the calibration of the completely rehabilitated Icing Research Tunnel. Other safety studies included wind shear computer modeling that was used to develop and evaluate a wind shear hazard warning index.

Systems (vehicle-specific) research and technology—Systems (vehicle-specific) research and technology focuses on areas that have the potential for increasing the capabilities of specific classes of vehicles, such as transports, rotorcraft, high-performance military aircraft, and hypersonic vehicles.

Transports—As part of the Advanced Turboprop Program, NASA and industry continued flight evaluation of a large-scale propfan propulsion system. A 9-foot diameter propfan was installed and flight tested on a Gulfstream II twinjet at speeds up to Mach 0.85 and altitudes of 5,000 to 40,000 feet. All blade stresses were consistently below unlimited life levels, and noise levels agreed closely with model test data and analytical predictions. Unducted Fan Model testing for acoustic and reverse thrust evaluation was completed, providing a data base for a variety of variations in geometry. This model promises to reduce wake swirl and thereby increase propulsive efficiency.

Research continued on laminar (smooth) flow over aircraft surfaces. An important milestone in the technology of active laminar flow control was achieved when simulated commercial airline operations tests on a Jet Star verified the effectiveness and practicality of two different system concepts for maintaining laminar flow over the leading edge of the wing.

Rotorcraft—In NASA's rotorcraft research, developments continued in the key areas of noise reduction, improved rotor performance, and high-speed performance. The research was highlighted with the beginning of flights of the X-Wing Rotor Systems Research Aircraft. The X-Wing points the way to future aircraft that at low speeds can hover like helicopters, yet at high speeds can stop the rotor in a fixed X-Wing configuration for airplane-like speed.

High-performance military aircraft—Several advances were made in this area in 1987. Flight tests on the first system to integrate an aircraft's propulsion and flight control systems, called the Highly Integrated Digital Electronic Control System, were completed in an F-15. A modified and highly instrumented High-Angle-of-Attack Research Vehicle made its first research flight to obtain and assess the aerodynamic characteristics of its design. Investigation was initiated into the effects of ingestion, by an advanced, short takeoff and vertical landing (ASTOVL) aircraft, of its hot exhaust gases. A joint program with the United Kingdom, Department of Defense, and NASA was under way to develop technology for ASTOVL aircraft. NASA conducted an extensive flight test program on vertical and short takeoff and landing (V/STOL) research aircraft to validate control laws. Flight testing was successfully completed in the first phase of flight-envelope expansion for the X-29 Forward Swept Wing research aircraft, expanding the envelope to a Mach number of 1.4 at 40,000 feet. A testbed aircraft called the Advanced Fighter Technology Integration/F-111 Mission Adaptive Wing, with a wing modified so that its camber could be changed in flight, cleared a flight envelope to a Mach number of 1.3 with better than predicted performance.

Hypersonic vehicles—Hypersonic vehicle research focused on the following three areas: vehicle configuration, propulsion, and materials and structures. The National Aerospace Plane (NASP) program, which is jointly sponsored by NASA and the Department of Defense, completed the conceptual design phase for this hypersonic vehicle, the X-30. The NASP program seeks to merge aeronautics and space technologies into a flightworthy vehicle. The requirements imposed by the need to test such a hypersonic vehicle have spawned significant progress in the development of computational methods for analyzing fluid dynamics that will permit extrapolating beyond the limits of testing provided by ground facilities. Other analytical methods were being developed for predicting the length and stability of laminar (smooth) flow over surfaces in the transition from transonic to hypersonic speeds. Significant progress was achieved toward a hypersonic propulsion system through tests on supersonic combustion ramjet (scramjet) engines. In related structures research, an advanced technology fuel-injection side strut for the scramjet engine was developed and determined to be a feasible approach. A high-temperature superalloy honeycomb material was successfully tested in extreme heat under hypersonic flow conditions.

Space Research and Technology

Discipline and systems technologies included in the Space Research and Technology program are propulsion, controls and guidance, automation and robotics, human factors, computer science, sensors, data systems, and communications.

Propulsion—Developments in chemical propulsion included improved cryogenic ball bearings and extended blade life for single-crystal, hollow turbine blades for Earth-to-orbit propulsion systems. Another development was an engine diagnosis tool that uses a spectrometer to view the exhaust plume of an engine and identify bearing materials that are degrading in the plume. For propulsion systems for use in space-based transfer vehicles, testing was begun on reusable, high-performance, variable thrust engines that could be stored and fueled in space. Developments in electric propulsion included advances in magnetoplasmadynamic thrusters, which have the potential advantages over chemical propulsion devices of being simple in concept and compact in size.

Space energy conversion—Research was continued in space energy conversion to improve performance in areas such as solar photovoltaic cells and arrays; power systems for potential future occupied bases; a power module for a space-qualified, free-piston Stirling engine; and a new electrode for a high-efficiency thermoelectric conversion system. In addition to refining and developing current space nuclear power systems, the Department of Energy made considerable progress in designing and developing the next generation of space nuclear power systems for civil and military use.

Aerothermodynamics—Developments in research on the flow phenomena of aerospace vehicles, called aerothermodynamics, included simulation studies for safe separation of the space shuttle orbiter from the booster stack during Solid Rocket Booster burn, and studies of aerobraking of vehicles returning from orbit. Aerobraking is the use of Earth's atmosphere to decelerate the vehicle, thus eliminating the weight of braking rockets and fuel.

Materials and structures—Research on materials and structures included the redesign and concurrent testing of the Solid Rocket Motor field joint and O-ring materials, design of a lightweight material for a multi-wall thermal protection system that could withstand temperatures of 900° F to -423° F, and development and testing of a mast, which is a large structure used in developing dynamic analyses, ground test methods, and control methods for future large space structures.

Controls and guidance—Developments in the area of controls and guidance were focused on demonstrating on the ground advanced control concepts for generic large space structure hardware; developing innovative sensor and actuator concepts suitable for large space systems; and developing modeling, simulation, and control software.

Automation and robotics—Developments in the area of automation and robotics during 1987 featured the use of telerobots to assist an astronaut in the assembly of a Space Station-type truss structure as well as demonstration of the grappling and docking of a telerobot with a satellite in simulated free spin and tumble.

Space human factors—Data were collected on the design and operational qualities for an advanced, high-pressure, hard space-suit that would allow planning of realistic tasks and timeliness in extravehicular activity.

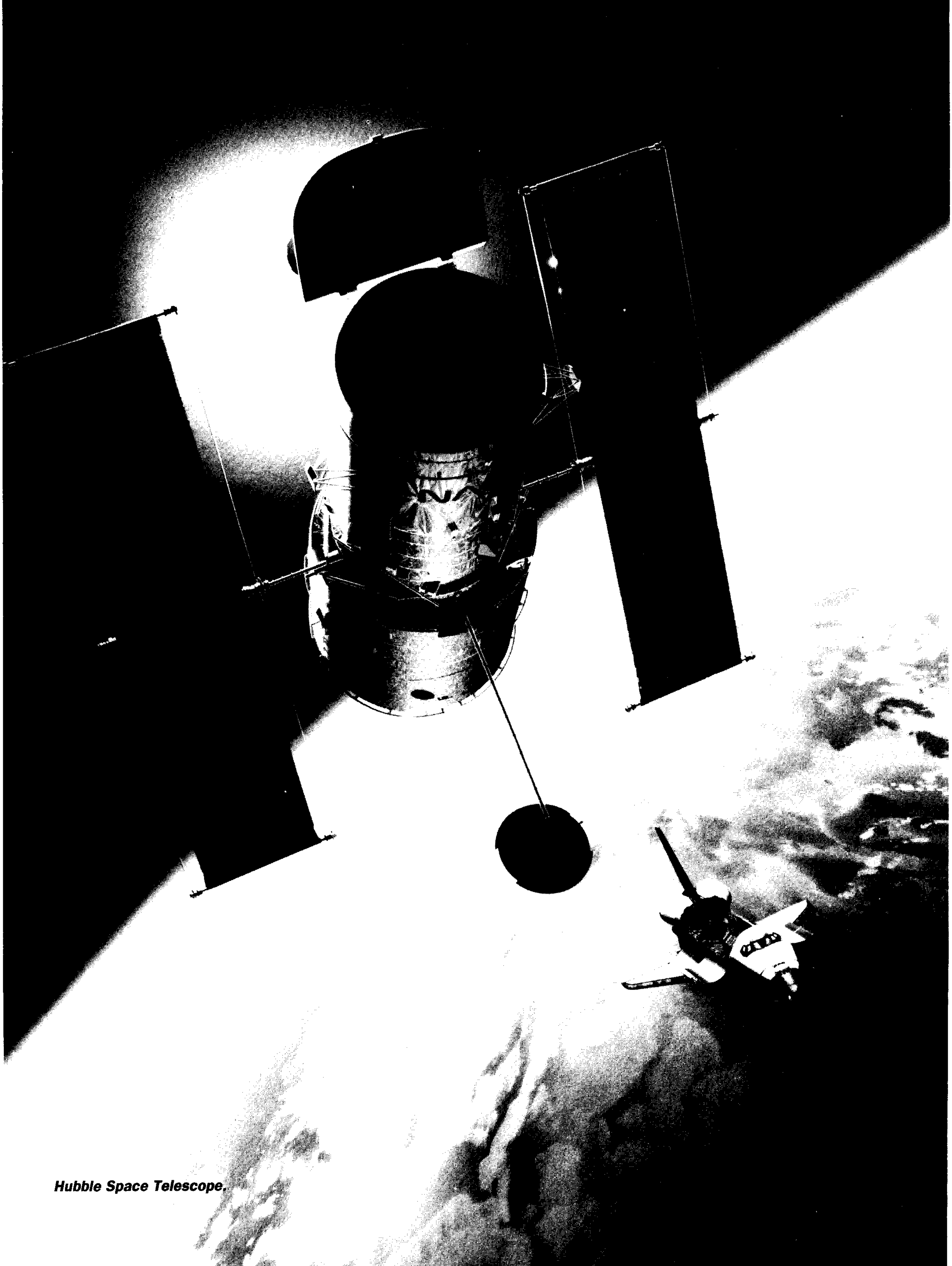
Computer science—This area included the continuing development during the year of a reconfigurable, fault-tolerant architecture for a space-borne symbolic processor.

Sensors—In the area of sensor development, work concentrated on demonstrating and understanding the laser amplification characteristics of the titanium-doped sapphire for use in an Earth-observing laser transmitter. Also development continued of small area devices such as heterodyne receivers based on superconductor-insulator-superconductor mixers, and of the necessary coolers to keep these devices at the required very low temperatures.

Space data systems—Work continued in 1987 on an optical disk recorder having a high-performance mass memory, for use in potential Earth-observing and Space Station missions.

Communications—NASA worked on the development of high-power, diffraction-limited lasers in order to improve laser systems which will transmit data between satellites.

In-space experiments—In the absence of launch activity, NASA initiated Inreach and Outreach Programs to define potential space-flight technology experiments for both the NASA community and the outside aerospace community of industry, universities, and the Department of Defense.



Hubble Space Telescope.

National Aeronautics and Space Administration

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

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

Space Science and Applications

Space Science and Applications programs are directed toward increasing understanding of basic physical, chemical and biological processes, and of the Earth and its space environment, the planets, the Sun, the stars, and the universe. Research activities involve observation of the distant universe, exploration of the near universe, and the characterization of the Earth and its environment. Space Science and Applications science disciplines include astrophysics, solar system exploration, space physics, Earth science and applications, life sciences, microgravity science and applications, and communications and information systems.

Astrophysics

Study of the Distant Universe. The NASA Astrophysics program has as its objectives the study of the origin and evolution of the universe, the fundamental physical laws of nature, and the birth of stars, planets, and ultimately life. Research in these areas requires observations at wave lengths absorbed by the Earth's atmosphere, and therefore must be made from instruments carried into space. The program is centered around a series of space observatories, supported by a research base consisting of instrument developments, sub-orbital research activities, data analysis, and theoretical studies. The four Great Observatories, the Hubble Space Telescope, the Gamma-Ray Observatory, the proposed Advanced X-ray Astronomical Facility, and the proposed Space Infrared Telescope Facility will provide significantly improved sensitivity and resolution over their selected regions of the electromagnetic spectrum. Smaller spacecraft in the Explorer series are used for exploration, all-sky surveys, specific studies, or unique investigations inappropriate for the Great Observatories. As part of the sub-orbital program, rockets, balloons, and aircraft provide the means to make preliminary observations, conduct selected low-cost investigations, test instrumental concepts, and nurture groups capable of developing instruments for future space missions.

Supernova 1987a. On February 24, 1987, Supernova 1987a (SN 1987a) was discovered in the Large Magellanic Cloud by observers at Las Campanus Observatory in Chile. Since this is the nearest observed supernova since 1604, this discovery represents an unprecedented opportunity for astronomers to actively study the death of a star.

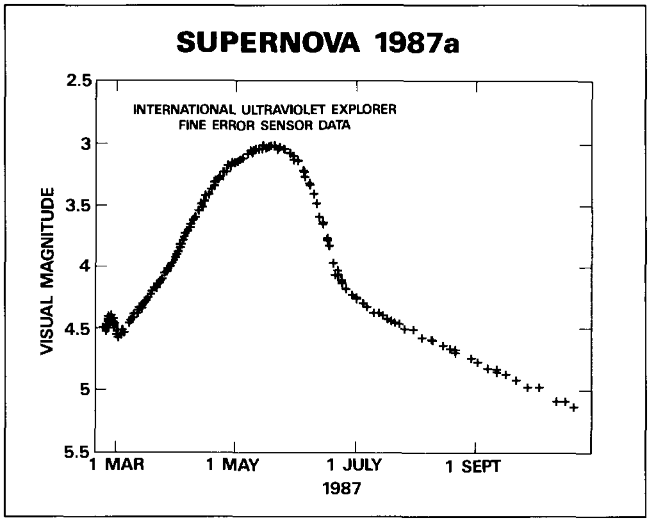
NASA and its international partners used existing spacecraft and radio observatories to study SN 1987a. The International Ultraviolet Explorer (IUE) detected the initial ultraviolet spectrum of the supernova and has since taken spectral data on a regular basis. The IUE also made key observations which confirmed the identification of the progenitor star. NASA's Solar Maximum Mission (SMM) gamma-ray spectrometer monitored the supernova for gamma-ray emissions, and the Japanese spacecraft, Ginga, observed the x-ray's emissions.

NASA is also implementing an extensive rocket, balloon, and airborne campaign from the Southern Hemisphere to make high-sensitivity, high-resolution measurements of various supernova phenomena. This campaign will result in a coordinated study of the gamma-ray, x-ray, ultraviolet and infrared emissions as they evolve. An extensive series of balloon and sounding rocket flights from Australia started in the fall of 1987, and the infrared telescope on the Kuiper Airborne Observatory was flown from New Zealand on several expeditions.

Hubble Space Telescope (HST). Assembly and testing of the first of the four Great Observatories, the HST, has been completed and is expected to be launched into space in 1989. Serviced by the Shuttle and the Space Station, it will be a long-term, major observatory that will extend our vision of the universe by allowing scientists to see clearly 10 to 30 times beyond what can be seen with existing instruments. Observing the solar system, HST will provide the first images of the surfaces of Pluto and its moon, Charon; and by looking back in time and space, will determine how galaxies evolved in the initial period after the Big Bang.

Gamma Ray Observatory (GRO). The GRO will be launched by the Space Shuttle in 1990. GRO will carry four instruments to explore extraterrestrial gamma rays, the highest energy radiation in the electromagnetic spectrum, covering the energy range from 0.1 million electron volts (MeV) to 30,000 MeV. Manufacturing of the mechanical components and electronic systems for GRO neared completion during 1987. The primary structure for the Observatory was fabricated and assembled, and modal survey testing completed. Development of one of the four scientific instruments, the Oriented Scintillation Spectrometer Experiment, was completed, and the instrument has been placed in storage until needed for integration with the Observatory in late 1988. Assembling and testing continued on the remaining three instruments.

Proposed Advanced X-ray Astrophysics Facility (AXAF). This proposed Facility will be a space-based observatory that will be designed to observe celestial sources of x-rays, and will address fundamental questions in astronomy and physics. It will be developed around a large area, high-resolution, grazing-incidence telescope which will focus x-rays onto a complement of high-quality imaging and spectroscopic instruments. Definition phase studies of the observatory were completed by two competing industrial contractors in February 1987. AXAF is planned for launch in the 1990's, and will be a long-lived facility utilizing Shuttle and Space Station servicing.



Spectral data obtained by the International Ultraviolet Explorer of Supernova 1987a.

Proposed Space Infrared Telescope Facility (SIRTF). Expected to be the fourth of the Great Observatories, SIRTF will make the most sensitive observations yet of infrared radiation from stars, planets, quasars, and many other astronomical objects. Detailed studies were made of the spacecraft structure, optical performance of the mirror and mirror mount. Progress was made in understanding the requirements for transferring superfluid helium while in orbit and other in-orbit servicing needs. The principal investigators of the definition phase instruments have demonstrated low-read noise, dark current, and power dissipation in the infrared camera and a simplified optical design for the infrared spectrograph.

High Energy Astronomy Observatories (HEAO's). Application of a new technique for analyzing fields with no detectable point sources observed by HEAO-2 yielded a significant new constraint on the nature and origin of the cosmic diffuse x-ray background. This new result demonstrates that the background cannot be accounted for solely by the integrated emission from distant quasars as suggested earlier. Instead, approximately one-half of this emission must arise from either diffuse hot gas (as indicated by HEAO-1 spectral data) or from a new population of numerous, discrete, low-luminosity x-ray sources. Further analysis of the HEAO-2 data set also uncovered a number of new and peculiar objects. Among these are the discovery of diffuse, soft x-ray emission from the disk of the galaxy M33, perhaps arising from a hot phase of the interstellar medium energized by stellar activity; an extremely unusual x-ray emitting supernova remnant in the Large Magellanic Cloud; and a neutron star with a mass well below the "standard" value set by the Chandrasekhar Limit. Data from the HEAO missions, now part of the Astrophysics Data Program archives, remains in high demand by astronomers investigating phenomena across the broader electromagnetic spectrum.

International Ultraviolet Explorer (IUE). The International Ultraviolet Explorer (IUE) is in its tenth year of operation. More than 1,000 U.S. astronomers have used this orbiting facility to observe objects at distances ranging from inside the solar system to the edge of the universe. In February 1987, the IUE initiated periodic observations of Supernova 1987a. These observations provided the key data required to identify the true progenitor of the Supernova. IUE continues to monitor the condition in the expanding cloud of material in this nearby Supernova.

Cosmic Background Explorer (COBE). The COBE mission will investigate the earliest structure of the universe, as revealed by the cosmic microwave background radiation thought to have originated shortly after the creation of the universe. From polar orbit, COBE's precise and sensitive instruments will measure the spectrum of this radiation, search for evidence of unevenness in energy from the earliest days of the universe, and look for light from the earliest galaxies. Early in 1987, a new design approach for the COBE mission was approved that uses a spacecraft small enough to be launched into polar orbit aboard a Delta launch vehicle instead of the Shuttle, thus avoiding a major program delay. Throughout the rest of the year, development continued on the scientific instruments and on the new spacecraft hardware, and by the end of the year, the instruments were being calibrated and spacecraft hardware was delivered for integration into the new spacecraft structure.

Explorer Platform Missions. The Explorer Platform represents a major step forward in regaining momentum in conducting on-orbit space science research by providing, for the first time, a long-life spacecraft designed to be serviced rather than replaced for each mission. In this new approach, the scientific instruments on the platform will be replaced, and the entire science mission will be reconfigured in orbit by the Shuttle or the Space Station. In early 1987, work on the Explorer Platform concentrated on designing the spacecraft bus based on the Multi-mission Modular Spacecraft, and in the summer, the detailed technical approach was approved. By the end of the summer, all major contracts were let, and a decision was reached to concentrate further design activities on launching the Explorer Platform and its first payload, the Extreme Ultraviolet Explorer (EUVE), on a Delta launch vehicle. Throughout 1987, development of the EUVE payload continued at the University of California at Berkeley in preparation for launch in 1991 to conduct the first highly sensitive, all-sky survey at wavelengths between ultraviolet light and x-rays. Also in 1987, definition continued on the X-ray Timing Explorer (XTE), the mission that will replace EUVE on the Explorer Platform in 1994. XTE will investigate physical processes in black holes, quasars, and x-ray pulsars that are revealed in variations of their x-ray luminosity in time-scales as short as microseconds and as long as years.

Gravity Probe-B (GP-B). This mission will provide a fundamental test of Einstein's theory of relativistic gravitation, known as General Relativity. While all earlier tests of General Relativity looked for relativistic effects due to the motion of objects in fixed gravitational fields, this will be the first experiment to look for relativistic effects due to the motion of the gravitational field itself. In GP-B, four essentially perfect gyroscopes will be orbited over the poles of the Earth to trace not only the curvature of space predicted for ordinary gravitation, but the mix of space and time predicted to originate from the rotation of the Earth and its gravitational field. In 1987, technology developments continued in preparation for a first integrated system test in 1989 and a test flight of GP-B gyroscopes on the Shuttle planned for 1992. The GP-B free-flyer science mission is planned for the late 1990's.

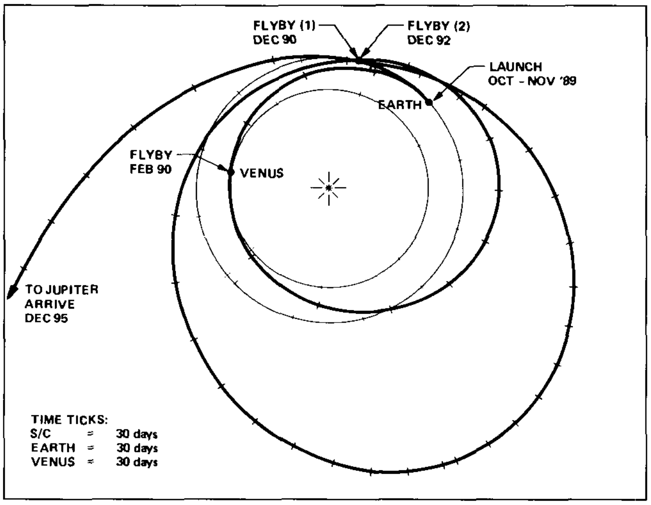
Other Explorer Activities. The San Marco-D program is a cooperative activity in which the United States provides a Scout launch vehicle, technical advice and some instruments to Italy (University of Rome) for integration with its San Marco-D spacecraft. Activities in 1987 concentrated on preparing for launch from the Italian San Marco launch platform located off the coast of Kenya. Launch is expected in late March to mid-April 1988. In a similar cooperative program, a Soft X-ray Telescope (SXT) is in the final definition phase for fabrication in December. The SXT will be delivered to Japan for integration into its Solar-A spacecraft for launch in 1991. Activities in 1988 will be directed toward finalizing design details and fabricating instruments and other components.

Roentgen Satellite (ROSAT). The ROSAT, a cooperative flight project with West Germany, will provide a full-sky, x-ray survey with unprecedented sensitivity. ROSAT was originally manifested on the Space Shuttle, but will now be boosted into orbit in February 1990 by a Delta II launch vehicle supplied by the United States. During 1987, the Germans redesigned the ROSAT spacecraft to be compatible with the Delta II and began manufacturing the ROSAT structural parts necessary for the launch change from the Space Shuttle. One of the x-ray focal plane instruments, the High Resolution Imager, supplied by the United States, was completed and placed in storage, where it will remain until the integration and testing of the ROSAT spacecraft in 1988.

Infrared Astronomical Satellite (IRAS). IRAS was one of the most successful space astronomy missions ever conducted. Discoveries made from the IRAS data have resulted in major advances in astrophysics and astronomy. In the three years since the original IRAS data products were released, there have been more than 300 papers published in refereed journals. Scientists continue to process the IRAS data to produce new archival information and to support an extensive program involving members of the original IRAS science team and a large number of Guest Investigators (approximately 70 groups per year).

Solar System Exploration

Pioneer Venus. The Pioneer Venus spacecraft has been in orbit around the Earth's sister planet since late 1978. Throughout this period, it has made almost daily observations of the planet and its interaction with the solar wind. This span of observation has encompassed nearly a complete solar cycle, with solar activity being maximum in 1980 and minimum in 1986. Data acquisition and analysis during 1987 was directed toward developing an understanding of solar cycle effects on the Venusian atmosphere/ionosphere system, which is quite different from that of Earth because Venus has no planetary magnetic field. Results indicate that



Planned flight path of Galileo spacecraft to Jupiter.

during the 1986-87 solar minimum, the density of the dayside Venus ionosphere was reduced, the usual flow of plasma to the planet's nightside was shut off, and the nightside ionosphere was thus greatly depleted. These fundamental studies of the Venus environment are important because this planet is the first field-free solar system body to be investigated in detail. Venus is expected to have much in common with comets and the planet Mars, whose magnetic field is apparently weak or nonexistent.

The Interplanetary Medium. The Pioneer 10 and 11 spacecraft continue to function well as they move outward from the Sun at a speed of about 2.5 astronomical units (AU) per year (an AU is the distance between the Sun and the Earth). Pioneer 10 is now beyond the orbit of Pluto, and Pioneer 11 is approaching the orbit of Neptune. Power-sharing among instruments, necessary because of declining power levels available from thermoelectric generators aboard the spacecraft, should permit data acquisition well into the 1990's. Voyagers 1 and 2 are also engaged in measuring the properties of the interplanetary medium in the outer solar system; both are now beyond the orbit of Uranus, providing complementary measurements to those of the Pioneers.

While the primary scientific objective of these measurements are to determine how the interplanetary environment changes with increasing solar distance and how this environment ultimately merges with the interstellar medium, other scientific questions are being pursued as well. For example, precise tracking of Pioneer 10 and 11 by the Deep Space Network is being undertaken in the search for a possible tenth major planet and also in an attempt to detect gravity waves generated by Supernova 1987a. Neither of these searches has resulted in a positive detection.

Galileo. The Galileo to Jupiter mission launch date, mission trajectory, and upper stage were re-established in 1987. The Galileo spacecraft, consisting of an orbiter and probe, is now scheduled for launch on the Shuttle Discovery in October or November 1989. The year 1987 was spent primarily reassessing spacecraft environments and system performance requirements. A study of subsystem and component shelf life and aging was conducted to identify critical application of parts with questionable ability to meet requirements for the six-year mission. The new trajectory, which first takes the spacecraft inward toward the Sun, creates a thermal environment substantially hotter than the originally planned 1986 direct trajectory to Jupiter. The increased temperatures necessitated the use of sunshades for several scientific instruments, the high-gain antenna, and the orbiter equipment bus. Most of the thermal designs have been completed and will be ready for the buildup of the orbiter beginning late in 1987. The use of the Inertial Upper Stage instead of the more powerful Centaur booster required that an indirect route to Jupiter using gravity assists from both Venus and Earth be designed. By clever application of orbital mechanic principles, a mission using three gravity assists, one from Venus and two from Earth, was conceived. The trajectory has been termed

"VEEGA" (Venus-Earth-Earth Gravity Assist) in keeping with the order of the assisting fly-bys. The VEEGA trajectory initially places the spacecraft in a direction away from Jupiter and toward the Sun. About 100 days after launch, the spacecraft will encounter Venus, receiving the first of three gravity assists. The first Earth gravity assist (EGA1) occurs about 400 days after launch and the second (EGA2) about two years later in late 1992. EGA2 will place Galileo on a direct path to Jupiter, arriving between October 1995 and August 1996. Enroute to Jupiter and its ultimate mission, Galileo will conduct scientific investigations of Venus and two asteroids, Gaspra and Ida.

Mars Observer. During 1987, the Mars Observer Mission was rescheduled for launch in September 1992. Important design reviews with the spacecraft contractor, RCA, and the upper-stage contractor, Orbital Sciences Corporation, were completed. Experiment implementation plans were developed by each of the eight instrument investigator teams responsible for conducting the geoscience and climatology science experiments. Important design reviews for the instruments also were conducted.

Ulysses. Following extensive negotiations with the European Space Agency (ESA), the launch date for Ulysses was scheduled for October 1990, using the Shuttle/Inertial Upper Stage (IUS) with an energy augmentation derived from a Payload Assist Module. The selected trajectory encounters Jupiter in February 1992, and allows initiation of the primary science mission in August 1994. During 1987, U.S. science instruments were tested periodically in preparation for resumption of activities in March 1988 leading to instruments deliveries to ESA in 1989.

Magellan. In 1987, development of the Magellan mission to Venus continued toward its April 1989 launch by the Shuttle/IUS. The radar-equipped spacecraft will be inserted into a polar orbit around Venus in August 1990. In order to understand how Venus has evolved compared to other bodies of the inner solar system, it will map the cloud-shrouded surface and acquire information on the geology of the planet. During the 243-day mapping mission (one Venus year), high-resolution radar imagery of nearly the entire surface of the planet will be acquired at a resolution 10 times better than that obtained by the Soviet Venera 15 and 16 missions of less than 20 percent of the planet.

In 1987, Magellan subsystem developments were completed and spacecraft assembly and testing activities began. The interfaces between the radar instrument and the spacecraft were verified; the compatibility between the telecommunications system, radar, and spacecraft systems were demonstrated; and a modal survey was conducted of the entire spacecraft system. In 1988, development of the radar sensor will be completed, the radar installed on the spacecraft, and spacecraft environmental testing will begin.

Voyager. Following numerous scientific discoveries resulting from the successful Uranus encounter in early 1986, Voyager 2 continued its epic journey through the solar system. Both Voyager 1 and 2 spacecraft continued to function well and operate much beyond their lifetime expectations. Voyager 1 is leaving the plane of the ecliptic and continues to gather valuable scientific data about the solar system environment.

Preparations were initiated during 1987 for Voyager 2's final planetary encounter with Neptune in August 1989. The Neptune encounter presents even more technical challenges than previous encounters, due to its greater distance from the Sun and increased communication distances to Earth. Significant changes in the operational utilization of the Voyager hardware, necessitated by both these factors, were initiated during 1987. The changes will be accomplished on the spacecraft by reprogramming the computers to permit increased exposure times for the Voyager camera; changes are also being implemented in the operating modes of the spacecraft's control system to improve the stability of the platform to cope with the increased exposure times. The large deep space receiving antennas are being modified to increase their size from 64 to 70 meters. By combining the output of the modified antennas with that of several smaller antennas, the increased communication distances can be tolerated without the loss of scientific data.

Flight Mission Support. In 1987, substantial replanning and work were accomplished at the Jet Propulsion Laboratory to provide planetary flight projects with the support necessary to meet revised launch schedules. New modern computing assets were acquired in the shared computing center. Rapid progress was made in the development of the new multimission Space Flight Operations Center (SFOC), a new generation, real-time, distributed, mission operations support data system. In this regard, all Magellan requirements were identified and incorporated into the SFOC baseline plan. The Magellan's High-Rate Telemetry Processor was replanned and reduced in cost; all baseline and Magellan scheduled deliverables were provided on time and within cost.

Space Physics

Space Physics research programs sponsored by the Office of Space Science and Applications were reorganized in September 1987. A new Space Physics Division was created with responsibility for some of the programs previously administered by the Earth Science and Applications Division and the Astrophysics Division. The Division includes research programs in Ionospheric Physics, Magnetospheric Physics, Solar Physics, and Cosmic and Heliospheric Physics, and thus represents a broad yet cohesive scientific community. The NASA suborbital research program involving rockets and balloons is also included in this new division.

The Space Physics Division supports investigations of the origin, evolution, and interactions of particulate matter and electromagnetic fields in a wide variety of space plasmas. Its studies focus on the upper atmospheres, ionospheres, and magnetospheres of the Earth and other planets; the Sun as a star and as a source of solar system energy, plasma, and energetic particles; and the acceleration, transport, and interactions of energetic particles and plasmas throughout the solar system and the galaxy. Observations, theory, modeling, simulations, laboratory studies, interactive data analysis, instrument development, and active experiments are all important aspects of the program.

Global Geospace Science Program (ISTP/GGS). In 1987, the implementation of a major international program in Solar and Space Physics began with participation by NASA, the Japanese Institute of Space and Astronautical Sciences (ISAS), and the European Space Agency (ESA). The U.S. contribution to this effort is referred to as NASA's International Solar Terrestrial Physics (ISTP) Program. A systematic deployment of a group of satellites is planned for the early-to-mid 1990's by these agencies to provide the measurements and to test models for the study of the interior of the Sun; the origin of the solar wind; the cause-and-effect relations of the flow of energy in the Earth's key magnetospheric source and storage regions; and the microphysics of plasma interactions in the Earth's magnetosphere.

The Collaborative Solar Terrestrial Research (COSTR) program was a new initiative in 1987 to support NASA participation in ISTP. In particular, this initiative enables NASA to support ISAS in providing a GEOTAIL mission to monitor the Earth's magnetic tail region. COSTR also supports collaborations with ESA on the Solar and Heliospheric Observatory (SOHO) which will conduct solar seismology and coronal diagnostics at the Earth-Sun Lagrangian point. Additionally, ESA is planning a CLUSTER mission which is a group of four satellites providing three-dimensional measurements of magnetospheric microphysics processes.

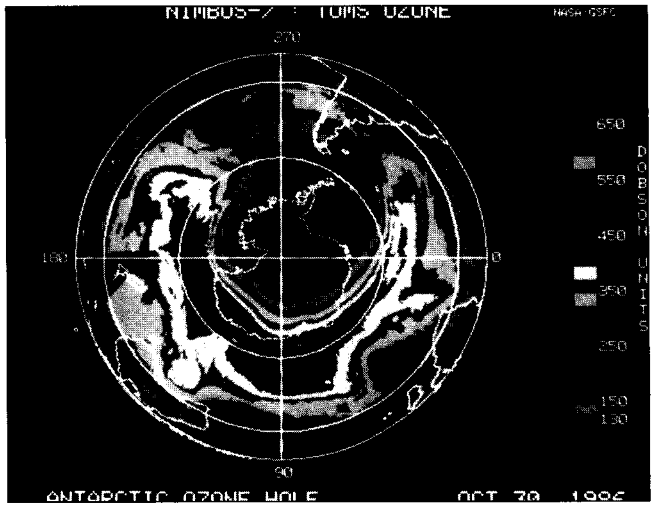
NASA is also planning to provide a WIND mission to monitor the solar wind input, and a POLAR mission to monitor the ionospheric plasma source region. These two missions, in conjunction with the NASA/Department of Defense (DOD) Combined Release and

Radiation Effects Satellite (CRRES) in the equatorial storage region of the magnetosphere, form the Global Geospace Science (GGS) ensemble proposed as a new initiative in the 1988 NASA budget.

NASA plans to launch WIND, POLAR, and GEOTAIL on expendable launch vehicles, and SOHO on the Space Shuttle; CLUSTER will be launched by ESA on an Ariane V development flight. Provision of instruments and tracking support will be shared by NASA, ISAS and ESA. In 1987, NASA and ESA began the process of jointly selecting payloads for the SOHO and CLUSTER missions.

Operational Explorers. Originally launched in 1980, the Solar Maximum Mission (SMM) remains about 75 percent operational. In 1987, SMM continued to provide valuable observations of the solar irradiance and other physical phenomena taking place on the Sun. It also continued to provide measurements of ozone concentration in the atmosphere of the Earth. Such measurements are made in ultraviolet light at spacecraft sunrise and sunset. These unique observations make it possible to map ozone concentration between latitudes of 50°, north and south of the equator, at altitudes of 50 to 75 km. These data will play a very significant role in unravelling the mystery of the "Ozone Hole" in Antarctica. In addition, as the current cycle of solar activity marches toward a maximum in 1991, SMM continues to obtain an unparalleled series of observations of the solar corona and sunspot activity. Such a long sequence of observations has never been possible from space and is certain to become a major resource used to test future models of the sunspot activity cycle. Also, a selection of new SMM Guest Investigators was announced, the fourth in this series. To date, more than 150 scientists from over a dozen countries have participated as Guest Investigators in the analyses of SMM data.

In 1985, Japan invited NASA to provide a U.S. experimental package for flight on its SOLAR-A mission to study solar flares during the solar maximum period in the early 1990's. An Announcement of



Satellite Image of Antarctic Ozone Hole.

Opportunity issued in 1986 led to the selection of a low-energy, x-ray telescope investigation to be conducted by the Lockheed Palo Alto Research Laboratory. The package will be built in cooperation with Japanese solar scientists. The instrument design is nearly complete, and almost all details on its accommodation to the Japanese-built spacecraft have been decided. This mission will be launched in the fall of 1991 by Japan and operations will be directed from there by a joint Japanese/U.S. science team.

Perhaps the most cost-effective spacecraft ever launched by NASA is the 14-year-old Interplanetary Monitoring Platform (IMP-8) satellite, the workhorse of Explorers. It continues to function well as the only existing monitor of solar wind interactions with the Earth's magnetosphere and provides a crucial baseline for missions to other planets. Imaging of the ring current region of the Earth's magnetosphere using energetic neutral atoms was first accomplished using IMP-8 data, thus providing a "picture" of the Van Allen belts.

International Sun-Earth Explorers (ISEE-1 and 2) reentered the Earth's atmosphere on September 26, 1987 as planned, after successfully operating for 10 years. ISEE-1 and 2 were very productive in terms of the large number of scientific papers published. Both spacecraft participated in a multisatellite campaign which provided simultaneous measurements of the dynamics of the Earth's magnetosphere. This campaign was called the Polar Regions and Outer Magnetospheric International Study.

The International Cometary Explorer (ICE) (the retargeted International Sun-Earth Explorer-3, launched in 1978) is still operational. From the large amount of data it generates, over 100 scientific papers a year are published. These papers cover the full range of space plasma phenomena, from studies of collisionless shocks and boundary layers to analyses of wave-particle interactions and currents along auroral field lines. The ICE spacecraft continues to provide unique information on the state of the interplanetary medium, and it complements the interplanetary medium data provided by the Pioneer and Voyager spacecraft (see *Solar System Exploration*). Throughout 1987, numerous scientific results on cometary interactions were generated through analysis of the first spacecraft encounter with a comet when ICE directly passed through the cometary tail of Giacobini-Zinner in September 1985. These results have proved to be an important complement to data sets obtained by the multinational Halley armada in 1986.

The Dynamics Explorer-1 (DE-1) spacecraft continues to provide unique, high-quality data on the interactions between the magnetosphere, ionosphere, and upper atmosphere, as well as on other phenomena. Operations were especially devised to support a variety of collaborative campaigns. Global auroral imaging of the southern polar cap was performed simultaneously with northern polar imaging by the Swedish Viking satellite. The spacecraft played a key role in the extensive Wave Induced Particle Precipitation balloon and rocket campaign from Wallops Island, Virginia, which also involved a ground-based transmitter in Antarctica. Other special operations were performed with a ground-based radar network. Routine data acquisition extends data bases for studies of the solar cycle variation of the ionosphere, which is a major source of plasma for the magnetosphere. The DE-1 satellite also continues to obtain extensive images of south polar ozone density and measurements of cosmic background ultraviolet radiation.

Analysis activities were highlighted by a number of developments. First, there was the continuing controversy over the interpretation of atmospheric holes (dark spots in the atmosphere in UV light), which were suggested to be caused by the influx of snowy comets. Second, the ionosphere is now alleged to be a fully adequate source of plasma for the magnetosphere, although a solar cycle dependence is under study. Third, detailed analysis reveals strong interplanetary control over upper atmosphere neutral winds through momentum coupling with ions convecting in the geoelectric field, for which comprehensive empirical models based on the interplanetary magnetic field direction have been developed. Through the use of simultaneous data sets from DE-1 and DE-2 spacecraft at two altitudes along auroral field lines, extensive analysis was conducted on auroral electrodynamics—the relations between electric fields, field-aligned currents, and auroral particle acceleration.

The Active Magnetospheric Tracer Explorer (AMPTE) program operates two spacecraft: the Charge Composition Explorer (CCE), in a predominantly magnetospheric orbit, and the Ion Release Module (IRM) whose orbit extends out into the solar wind. Charge composition measurements of carbon and oxygen made in 1987 demonstrated that the ionosphere and the solar wind are comparable in importance as sources of plasma for the outer magnetosphere. Moreover, measurements of the Earth's ring current by CCE show correlations of its current intensity with magnetic storm activity. Magnetic field measurements from CCE reveal low-frequency fluctuations which can be understood as global wave resonances of the magnetosphere. Data on the highly charged states of ions obtained by CCE just outside the magnetosphere yielded measurements of the temperature of the solar corona. CCE data also provided the first clear identification of singly charged helium ions picked up from the interstellar medium.

Sounding Rockets. Sounding rockets offer an inexpensive means to perform space-borne experiments. The main advantage of using sounding rockets is that the experiments can be conceived, built, and flown in a one- to two-year timeframe. Thus, the sounding rocket program offers a unique opportunity for universities to train graduate students for advanced experimental research. When Supernova 1987a was reported, the sounding rocket program was able to respond quickly, enabling NASA to carry out meaningful measurements of a new phenomenon in a timely manner. The NASA sounding rocket program at the present time supports about 35 to 40 launches a year. Depending on weight and other requirements of the experiments, these launches include small rockets of the Nike class to large ones of the Aries class.

Balloons. During 1987, there was a total of 41 balloon flights including 29 science flights for astrophysics, space physics, upper atmosphere research, and 12 test flights, six of which carried "piggyback" science payloads. The science flights included two long-duration flights with launches from Australia and recovery in South America; four flights in a quick-response campaign in Australia to study the Supernova 1987a; and four flights to investigate energetic particles during the Solar-Minimum campaign to Canada.

In 1987, the Physical Science Laboratory (PSL), New Mexico State University, was competitively selected to operate the National Scientific Balloon Facility in Palestine, Texas. This facility was previously operated by the University Center for Atmospheric Research (UCAR) in Boulder, Colorado. The 45-day phase-in period for the three-year (plus two years hard options) contract began on August 15, 1987, with full transfer from UCAR to PSL on October 1, 1987.

Earth Science and Applications

Upper Atmosphere. During 1987, NASA completed a major assessment of the state of knowledge regarding atmospheric trends, focusing on possible changes in the abundance and distribution of ozone, but including examination of other parameters and species such as temperature, source gases, and minor constituents. This effort was also conducted under the auspices of the World Meteorological Organization.

NASA continued implementation of the Network for the Detection of Stratospheric Change, which utilizes ground-based, remote sensing instruments in an attempt to provide for the earliest possible identification of small (low percent) changes in the composition of the stratosphere. NASA is being assisted in this effort by the National Oceanic and Atmospheric Administration (NOAA) and the Chemical Manufacturers Association.

NASA, NOAA, National Science Foundation (NSF), and the Chemical Manufacturers Association sponsored two expeditions in 1987 to study the Antarctic Ozone Hole. A second ground-based expedition to McMurdo Station in Antarctica utilized ground and balloon instruments. A major aircraft expedition using the NASA ER-2 and DC-8 aircraft operating out of Punta Arenas, Chile, provided in situ and remote sensing observations of the ozone hole and its chemical composition. Preliminary results of the aircraft campaign have been released, with rigorous analysis to occur in early 1988.

Development work continued on the Upper Atmosphere Research Satellite (UARS) program. The UARS mission will provide the first integrated global measurements of the chemistry, dynamics and energetics of the stratosphere, mesosphere, and lower thermosphere. Remote sensing instruments on the satellite will perform measurements of energy input, chemical composition, and dynamics of the stratosphere and mesosphere. UARS is a critical component of NASA's efforts to understand the upper atmosphere well enough to assess its susceptibility to chemical change.

The UARS observatory design is nearing completion and the manufacturing process is underway. Nine of the ten scientific instruments to be flown aboard the spacecraft have completed Critical Design Review, and several are in final assembly, preparing for environmental tests. Seven remote analysis computers are connected to the UARS initial configuration for the central data handling system and are being used by UARS science investigators to develop mission software. Launch is scheduled for 1991.

In 1987, NASA successfully completed a major tropospheric chemistry experiment in the Amazon rain forest of Brazil in cooperation with the Brazilian Space Agency. This mission, conducted during the wet season, complemented a 1985 mission conducted during the dry season. These two missions provided a large chemical/meteorological data base on the role of the rain forest as a source and sink of important atmospheric gases, and on the mechanism by which gas exchange between the forest's atmospheric boundary layer and the free troposphere occurs. When analyzed during 1988 and 1989, the results are expected to shed new light on the interaction of one of the Earth's most important ecosystems with the atmosphere and on the contribution of that ecosystem to long-term global change.

Operational Meteorological Satellites. NASA continues to support the National Oceanic and Atmospheric Administration's Operational Meteorological Satellite Program by negotiating the procurement and launch of these satellites. On February 26, 1987, the GOES-H weather satellite was successfully launched into a geostationary orbit. Upon arriving on-station at 75° west, the satellite was re-designated GOES-7 and began providing primary weather coverage of the east coast of the United States. The successful launch of GOES-7 restored the Nation's nominal complement of two geostationary weather satellites. (Since the loss of GOES-5 in the summer of 1984, GOES-6 had been providing the only U.S. coverage from mid-country.) GOES-6 is now providing west coast coverage from 135° west. GOES-7 is carrying an experimental search and rescue system to determine if near-instantaneous alert of rescue forces might be achieved.

Morning and afternoon global weather coverage is currently provided by the polar-orbiting NOAA-9 and NOAA-10 satellites. NOAA-9 has now exceeded its design life by approximately one year. NOAA-H is currently being prepared for launch in early 1988 to replace NOAA-9. NOAA-H and the remaining polar satellites in the current series will be launched on Atlas-E expendable vehicles. NASA is currently negotiating for three additional polar-orbiting satellites.

Climate Research. The Climate Research program has focused on the radiation budget of the Earth as a major force in determining the climate. During 1987, the Earth Radiation Budget Experiment (ERBE), which includes a dedicated research satellite in a low-inclination orbit, and space research instruments aboard two polar-orbiting NOAA operational meteorological satellites (NOAA-9 and NOAA-10), continue to collect radiation balance measurements. Analysis of the first several months of data indicates that the Earth's clouds have a net cooling effect on the Earth. This is an important finding in view of the continuing accumulation of the so-called greenhouse gases in the atmosphere.

The International Satellite Cloud Climatology Project (ISCCP) established by the World Climate Research Programme in 1983, continues to acquire global observations of the cloud distribution statistics. The data are being acquired from an array of operational polar and geosynchronous orbiting meteorology satellites. These data are intended to collect a comprehensive long-term cloud census for use in research on the role of clouds in the Earth's energy balance and how cloudiness varies interseasonally and interannually. NASA plays a central role in the ISCCP through its support of the Global Processing Center, which serves as the focus of international climatology operations.

The first ISCCP regional experiment was successfully conducted over Wisconsin in late 1986; its objective was to provide information on the role of cirrus clouds in the radiation budget. In 1987, the second ISCCP regional experiment was conducted off the coast of southern California to study marine stratocumulus clouds. These regional experiments successfully acquired the measurements needed to understand the relationships among cloud microphysics and macrophysics and the radiative transfer properties of the clouds.

Global-Scale Atmospheric Processes. Research on remote sensing techniques, both active and passive, continues to develop satellite capabilities for observing the Earth's atmosphere. Active techniques include both lasers and radars. Lasers are being developed to measure such parameters as aerosols, water vapor, temperature, and wind profiles. Several of these techniques were tested aboard NASA research aircraft during 1987; others (for temperature and wind) are undergoing continued development. A dual frequency radar and passive microwave radiometers were flown aboard an aircraft platform to measure precipitation in a program designed to develop a technique for eventual use in space. Under a bilateral agreement, this was a joint research effort with scientists from Japan's Radio Research Laboratory. The ability to measure both wind and precipitation from space is essential to understanding the Earth's hydrological cycle, a primary objective of Earth system science.

Plans are being completed for a large-scale aircraft and ground-based measurement program to refine our knowledge of the distribution of aerosols in the lower atmosphere. These measurements will provide the criteria to design a spaceborne laser system, which will use Doppler shifts of the backscattered laser energy from aerosols moving with the wind, to observe those winds.

Mesoscale Atmospheric Processes. During 1987, a joint NASA/NOAA panel was established to study the feasibility of developing a spaceborne lightning sensor. This study has evolved from NASA's research on an airborne version of the sensor, which has measured lightning from research aircraft flying high above active thunderstorms during daylight hours and at night. Ground-based lightning detectors have a limited range; even in a network they can only measure ground-to-ground strokes. The proposed instrument would be capable of detecting both cloud-to-cloud and cloud-to-ground lightning strokes from a geosynchronous satellite. It would locate lightning strokes that occur at about 10 km from the ground or higher, measuring the intensity and frequency. Research has shown a strong correlation between lightning intensity and storm intensity, and the information thus provided would yield new insights into the role of atmospheric electricity and cloud growth, storm development, intensity and precipitation processes, and the Earth's global electrodynamic circuit.

Oceanic Processes. NASA's oceanography program is focused on obtaining and analyzing remotely sensed satellite data for studying ocean circulation, atmospheric forcing of the ocean surface, biological productivity, and sea ice. NASA expects a system of satellite sensors to be ready by the early 1990's to support several global experiments. These large international experiments include studies of the tropical oceans; determining world ocean circulation; investigating the fluxes of carbon and associated biogenic elements in the ocean; and polar ocean research. Under the auspices of the World Climate Research Program, the results of these experiments will help to explain the role of the global oceans in the Earth's climate. In focusing on these experiments, NASA is working closely with the National Science Foundation, the National Oceanic and Atmospheric Administration, the Navy, and a number of international partners.

To study the tropical ocean and world ocean circulation, NASA is pursuing two space flight activities. The NASA Scatterometer is an active microwave radar designed to measure near-surface ocean winds, the primary ocean forcing mechanism. TOPEX/POSEIDON is a combination of NASA's Ocean Topography Experiment and the French Space Agency's POSEIDON Project. It is a satellite radar altimetry system which measures the sea surface height and allows scientists to deduce the ocean response to wind forcing and ocean circulation.

The NASA Scatterometer is scheduled for launch aboard the Navy Remote Ocean Sensing System Satellite in mid-1992. Construction of the Scatterometer started with the six flight antennas already manufactured; and a science team completed a preliminary science plan for use of scatterometry wind observations.

For TOPEX/POSEIDON, NASA will provide the satellite, an altimeter and several supporting sensors. The French Space Agency is also providing several sensors and will launch the satellite on an Ariane IV rocket in late 1991. The combined American and French-sponsored science teams met for the first time in November 1987 and began developing a science plan for the mission.

Ocean color information can be used to determine the phytoplankton distribution in the ocean. As an initial measure of change and variability, NASA is also reprocessing the data collected by the Coastal Zone Color Scanner aboard the Nimbus-7 Satellite into global maps of phytoplankton distribution.

To support Arctic research, NASA is establishing a processing and archive center which will give the scientific community access to global sea ice products derived from the Special Sensor Microwave Imaging Radiometer that was launched in June 1987. Looking to the future, NASA's Jet Propulsion Laboratory and the University of Alaska are developing the Alaska Synthetic Aperture Radar Facility in Fairbanks. Synthetic aperture radar data will provide detailed observations of pack ice. Once constructed, scientists can receive, process, and archive synthetic aperture radar data from the European Space Agency's First European Remote Sensing Satellite, the Japanese First Earth Remote Sensing Satellite and the Canadian Radarsat.

Geodynamics. Geodynamics involves the study of the solid Earth, its global gravity and magnetic fields, the movement and deformation of its crust, and its rotational dynamics. This research contributes to our understanding of earthquakes, the evolution of the Earth, and the interaction between the solid Earth, the oceans, and the atmosphere. Over 30 countries participate in NASA's geodynamics research, and there is inter-governmental cooperation between NSF, U.S. Geological Survey (USGS), NOAA, and DOD. The Crustal Dynamics project involved 20 investigators from Australia, Brazil, Canada, Chile, China, the Federal Republic of Germany, France, Italy, Mexico, the Netherlands, New Zealand, Peru, Spain, Sweden, Switzerland, the United Kingdom, and Venezuela. In 1987, joint projects and programs included measuring tectonic plate motion and Earth rotation, using fixed and mobile laser ranging systems, with Italy, France, Israel, and Mexico; using techniques of Very Long Baseline Interferometry, with Japan and Italy; lunar and satellite laser ranging operations, with Australia; data exchanges, with China; and a study of earthquake hazards in the Caribbean Basin, with several nations.

Land Processes. The Land Processes program consists of four interrelated elements: studies of terrestrial ecosystems, the hydrologic cycle, geology, and remote sensing science. The first three represent the space-based components of classical science disciplines. The last element is the study of the physics and biology of the land surface as it relates to its interaction with electromagnetic radiation. The major focus is to conduct research in the Earth sciences that concentrates on developing methodologies, rather than on instruments and techniques for scientific or applied use.

Extensive use is made of data from operating satellite sensors, such as the Landsat Multispectral Scanner System (MSS) and Thematic Mapper (TM), the Advanced Very High Resolution Radiometer (AVHRR) on NOAA polar-orbiting satellites, and sensors aboard the French SPOT Satellite. In 1987, through a cooperative agreement with the French Centre Nationale d'Etudes Spatiales, a limited number of SPOT images were made available to NASA investigators at a reduced cost. Shuttle flights, such as the Shuttle Imaging Radar (SIR) series, also are important data sources. In addition, Land Processes program investigators make extensive use of airborne sensors that are developed as prototypes for satellite sensors. These include the Airborne Imaging Spectrometer (AIS), the Airborne Visible and Infrared Imaging Spectrometer (AVIRIS), the Thermal Infrared Multispectral Scanner (TIMS), and the L-band Pushbroom Microwave Radiometer. New L- and C-band Synthetic Aperture Radars (SAR) are under construction to replace the previously used L- and C-band SAR, which were destroyed with the NASA CV-990 airborne laboratory during an accident in 1985.

A major new research effort within the Land Processes program supports the initial elements of the International Satellite Land Surface Climatology Project (ISLSCP); specifically, the First ISLSCP Field Experiment (FIFE). The goal of FIFE is to develop and validate algorithms that convert satellite-observed radiances to climatological variables at a variety of spatial scales. In 1987, FIFE was conducted on the Konza Prairie near Manhattan, Kansas primarily in four intensive field campaigns during which ground-based and airborne measurements were made simultaneously with the acquisition of satellite data over the site. Analysis and synthesis of the data will proceed through 1989.

Studies of global ecosystem productivity using AVHRR data continued in 1987 and an internally consistent, global vegetation index data set spanning the years 1979 through 1987 is being prepared. These data will be used in future years to document, for the first time, global patterns of interannual variations in phenology and productivity.

A significant portion of atmospheric precipitation results from evapotranspiration. Recent work on developing an algorithm for estimating surface wetness from Scanning Multichannel Microwave Radiometer (SMMR) and AVHRR data includes analyzing of brightness (temperature) over the U.S. southern Great Plains from 1979 to 1983 and developing an empirical equation to relate surface wetness and the normalized difference vegetation index from AVHRR data. Analysis of global data from 1979 to 1985 demonstrates the feasibility of quantifying vegetation dynamics by correlation with the normalized difference vegetation index, rainfall, and seasonal variation of atmospheric carbon dioxide.

High spectral resolution reflectance data acquired by NASA's Airborne Imaging Spectrometer (AIS) have been used to estimate forest canopy lignin concentrations and forest ecosystem nitrogen mineralization. Laboratory results on techniques for prediction of lignin concentrations in plant materials were extended to the field successfully. Future research will test the robustness of this statistical technique and attempt to understand the biophysical basis for the relationship.

The community dynamics of a boreal forest ecosystem were investigated using the Landsat MSS record from 1973 to 1983 to generate stochastic descriptions of the key life cycle states of community landscape elements. Such descriptions can provide input and verification for models of community development, landscape dynamics, and ecosystem stability. The 10-year observations of this boreal forest region in northern Minnesota indicated that there are considerable successional changes at the landscape element level in an ecosystem that has been relatively stable over several centuries. Managed areas within the region were much more dynamic and heterogeneous than the wilderness areas. Large volumes of volcanogenic sulfur dioxide can be detected through analysis of data from the Total Ozone Mapping Spectrometer

(TOMS) aboard the Nimbus 7 spacecraft. Analyzing TOMS data and monitoring volcanic activity continued. In addition, work was initiated to develop algorithms to make TOMS more sensitive to sulfur so that volcanic eruptions of less sulfuric content can also be detected. Also, in collaboration with USGS geologists, analysis of AIS and the Thermal Infrared Imaging Spectrometer (TIMS) data obtained from Hawaiian volcanoes continued.

Construction of the Airborne Visible and Infrared Imaging Spectrometer (AVIRIS) was completed in early 1987, and flown during the summer and fall. This sensor can cover the entire wavelength region from 0.4 to 2.5 micrometers with a 10-nanometer sampling interval; its swath width is 11 kilometers. Preliminary AVIRIS images show the data to be of high quality. The first results of the performance and data evaluations should be available in mid-1988.

Reconstruction of the L- and C-band SAR sensors for use on the DC-8 aircraft acquired by NASA after the loss of the CV990 aircraft remained on schedule. In the last months of 1987, integration of the completed sensors onto the DC-8 began.

NASA's Research Announcement for SIR-C, issued during the summer of 1987, elicited over 400 Letters of Intent to propose from 27 countries. SIR-C represents an enhancement in capability beyond that available in previous SIR flights. It will be capable of acquiring C-band and L-band radar images of the Earth's surface at selectable incidence angles ranging from 15 to 60 degrees simultaneously at four polarizations. NASA, the Bundesministerium fur Forschung and Technologie (BMFT, the West German Federal Ministry for Research and Technology), and the Consiglio Nationale delle Ricerche (CNR, the Italian National Research Council) are currently planning to fly an X-band system (X-SAR) in conjunction with the SIR-C mission.

Interdisciplinary Research. NASA continued its Interdisciplinary Research program in Earth science to investigate and understand long-term physical, chemical, and biological changes in the Earth's environment. Based on their importance to science, areas that have been selected for new investigation include research to understand the origins and consequences of increases in atmospheric concentrations of methane, to understand the extent to which changes are taking place in climatologically important properties of land surfaces, and to develop a better understanding of the magnitude and variability of oceanic carbon fluxes on a basin-to-global scale. Under existing programs, complementary investigations are being conducted in the areas of atmospheric dynamics and radiation, oceanic processes, global biology, tropospheric chemistry, climate and land processes.

Life Sciences

The Life Sciences program is involved in all aspects of NASA's activities in space exploration. The program has two major goals, derived from NASA's charter: to promote health and productivity in human space flight and to study biological processes and life in the universe. The Life Sciences program extends from basic research to applied clinical practice. Major areas of research include Space Medicine, Gravitational Biology, Global Biology (Biospherics), Exobiology, and Controlled Ecological Life Support Systems. The long-range benefits include the gradual expansion of knowledge of the origin, evolution, and distribution of life and life processes in the universe, and development of measures that will allow human exploration of space without substantial penalties to health.

Space Medicine. Through basic and applied research, clinical studies, and flight programs, NASA is investigating the nature and mechanisms of adaptation, deconditioning, and inherent risks resulting from exposure to space flight. In turn, this knowledge helps scientists to develop protective measures and safety procedures needed to ensure the health and productivity of crews during long-term missions. The program will develop protective measures for repeated exposure to space.

The space environment affects the human body in several ways: the heart becomes deconditioned, muscles weaken, bones lose strength, various neurosensory changes occur, and radiation exposure is substantially higher than on Earth. Within the biomedical research program there are efforts aimed at each of these critical areas.

In the current Shuttle era, program emphasis is on cardiovascular and neurosensory issues. The cardiovascular research program investigates how the circulatory system adjusts to weightlessness and readapts to gravity after spaceflight. Postflight adaptation is particularly important because of the tendency towards fainting upon return to the Earth's gravity field. Basic and applied studies on the neurovestibular system are directed at understanding the causes of space motion sickness which affects about 50 percent of the people who fly in space, and ways to prevent or treat symptoms.

As NASA moves into the era of the Space Station, other biomedical areas will assume greater importance. While changes in bones and muscles are minimal during 7-day flights of the Shuttle, the projected 180-day tour of duty on the Space Station will result in significant changes. Development of effective countermeasures to maintain health will require understanding the basic physiological mechanisms responsible for spaceflight deconditioning. For long-duration flights, radiation exposure may be the ultimate limiting factor. Current research in this area includes risk assessment, dosimetry, shielding studies, and development of drugs that may protect the body from the harmful effects of space radiation. Other areas where requirements for spacecraft environmental health are also being developed include air quality, water purity, and exposure limits to various chemical agents that will be present in the Space Station.

Substantial planning has begun for the future Space Station era. The two main program areas emphasized are countermeasures to maintain health and performance during long-term exposure to weightlessness, and basic scientific studies in space physiology and medicine. In addition, research is directed toward increasing the crew tour of duty from four to six months and thereby reducing the number of Space Shuttle flights required to support the Space Station.

A Health Maintenance Facility (HMF) is being developed for the Space Station that will incorporate state-of-the-art technology and inflight medical care. It will also allow adequate exercise and health monitoring for space crews. Tests of physical exercise protocols for the HMF are underway. In the area of human factors and man-machine interface, a computer modeling system is under development that is based on anthropometric measurements made in space flight and on the ground. This system will accelerate the design of workstations, assess work conditions, and determine appropriate work loads for space crews.

Gravitational Biology. The goals of the Gravitational Biology program are to understand the effects of gravity and weightlessness on the biological processes of plants and animals, and to use the space environment to advance knowledge in the biological sciences. The program focuses on cell biology, gravity perception, biological development, and biological adaptation. Both flight- and ground-based research are needed to determine the biological significance of gravity.

The focus of ground-based animal research is on developing working models of functioning gravity-sensing neural (information) networks to understand neurosensory processing in microgravity.

Ultimately, scientists should be able to use biological neural network connectivity in the design of decision-making computers. Understanding mechanisms that control bone and muscle formation and loss, and delineating regulatory mechanisms of physiological control systems that are influenced by gravity continue to be important parts of the program. Ground-based research on gravitropism has clarified some of the mechanisms that control differential growth and plant orientation. This research contributes directly to the Controlled Ecological Life Support System (CELSS) program. Additional space research is needed to confirm and complement current developmental and metabolic studies. Studies of a reusable vehicle with which this research could be accomplished began in 1987.

Exobiology. The Exobiology program goal is to understand the origin, evolution, and distribution of life in the universe. Attainment of this goal is sought by concentrating on specific research objectives that trace the pathways taken by the biogenic elements, leading from the origin of the universe through the major epochs in the evolution of living systems and their precursors. The epochs are the cosmic evolution of biogenic compounds, prebiotic evolution, early evolution of life, and the evolution of advanced life. Research and analysis conducted within the program focus on the specific objectives, and provide the framework for compelling questions that require spaceflight missions to answer. To pursue its goal, the Exobiology program relies on three aspects of these missions: enhanced observational capabilities, as represented by the Hubble Space Telescope and follow-on Great Observatories, and by enhanced radioastronomy capabilities; comparative planetary studies, as represented by solar system exploration missions, such as the Mars Observer and the proposed Comet Rendezvous Asteroid Flyby Mission; and emerging capabilities for experimental exobiology that may be accommodated on the Space Station and future Spacelab flights.

Recent discoveries have extended the known range of biologically related molecules found in the interstellar medium, and support the evidence that the materials essential to life are inextricably linked to the processes that result in the formation of planetary systems around stars. Such a link expands the likelihood that life could be found elsewhere, and provides a new understanding of the conditions required for the origin and evolution of life on Earth. Additional studies have provided an awareness of the conditions on the early Earth as life evolved, and of the geological and biological processes that led to evolution of the present biosphere.

Recent technology development related to the Search for Extraterrestrial Intelligence (SETI) has combined sensitive receivers with fast, efficient computer circuits and programs. The specially designed Very Large Scale Integrated (VLSI) chip performs signal processing tasks several times faster than its nearest competitor. This will allow a search to be undertaken that can exceed all previous searches combined by a factor of 10 billion. Studies also have been undertaken to determine the spinoff potential of SETI technology and several promising applications have been identified in diagnostic medicine, computer and engineering development, geology, and radio astronomy.

Biospherics. The goal of the Biospherics program is to understand how contemporary biological and planetary processes interact. These processes now include a significant input from human activity, and combine to affect the long-term habitability of the Earth. Efforts in the program are concentrated in research projects that involve wetlands in the eastern United States, temperate forests in the western United States, tropical forests in the Amazon Basin in South America, and biogeochemical modeling of the interactions of ecosystems on a global scale. Another area of growing interest is the application of remote sensing techniques, in conjunction with field research and mathematical modeling studies, to combat vector-borne diseases, like malaria, that may affect underdeveloped nations. Recent results using remote sensing techniques have been encouraging, and may prove to be of use in the amelioration of global health problems.

Controlled Ecological Life Support Systems (CELSS). The CELSS is proposed as a system that will recycle the food, air, and water needed to support long-term missions with humans in space. Bioregenerative systems have the potential to provide long-term human life support needs. They can provide food by photosynthesis of plant products in a controlled environment, thereby allowing continuous production of fresh edibles; they can provide breathable air through photosynthetic release of oxygen and fixation of carbon dioxide; and they can provide clean water because higher plants take up nutrient solution through their roots, and transpire through their leaves nearly pure water which can then be condensed for drinking. In all likelihood, all of this can be accomplished with significant economic and safety benefits over currently envisioned physical-chemical systems, which will require food resupply and waste disposal. A CELSS also has other advantages in terms of overall human health and mission objectives, including psychological benefits from aesthetics and resupply independence. As noted by the National Commission on Space, a CELSS will allow space settlements to "live off the land" by converting available materials into life-support consumables. Recent study results are consistent with this vision, showing world-record crop productivity that minimizes the volume and weight penalties of such a system, and demonstrating that natural light available in low-Earth orbit may reduce the energy needs of a CELSS.

Flight Programs. The Flight programs activities in Life Sciences support the conduct of experiments critical to fulfilling medical responsibilities for space crews and for obtaining fundamental knowledge about life in the universe. These experiments have been conducted on the Shuttle, and will be conducted on the Space Station, spacecraft exploring the solar system, and expendable launch vehicles. In addition, Life Sciences research is being conducted on ground-based projects.

One of the highlights during the year was the biomedical data received from 26 experiments conducted on COSMOS 1987 in a highly successful collaboration between NASA and the Soviet Union. COSMOS 1987 was launched September 29 and landed October 12, 1987. The biomaterials returned from this mission are currently being analyzed in the United States by the principal investigators. The relationship between U.S. and Soviet space life scientists has continued for 17 years from the first joint collaboration on COSMOS 782, and the United States plans to participate in the 1989 COSMOS biosatellite flight.

The existence of a permanent research facility in Earth orbit will allow significant advances in understanding the relationship of gravity and life. It also will allow collection of the first intact interplanetary and interstellar particle fragments; and will permit high fidelity theoretical studies to be performed that are impossible to achieve on Earth. The reference set of science objectives, experiments, and hardware requirements have been developed and design work on long-lead items, such as a variable gravity research centrifuge, is underway. A mockup was developed and subsystem tests were initiated on the Space Station Health Maintenance Facility, which will provide preventative medical, diagnostic, and therapeutic capabilities for space crews.

Studies also were initiated for the future conduct of small autonomous but important life sciences investigations on expendable spacecraft, thus maintaining the vitality of the space life sciences community and relieving some of the burden on manned space experimentation.

Microgravity Science and Applications

The mission of the Microgravity Science and Applications program is to foster the development of near-Earth space as a national resource. This will be accomplished by providing the infrastructure to facilitate research and development activities by the academic community and industry.

The goal remains to promote high-quality science and applications research which uses the microgravity environment with reduced buoyancy forces, hydrostatic pressure, sedimentation, thermal convection flows, and surface contamination. This environment will allow the fundamental science that governs processes on Earth and in the universe to advance; the increased understanding of the role of gravity in various industrial processes used on Earth; and the production of limited quantities of certain exotic or high-value materials with enhanced properties for specialized applications.

Over 100 principal investigators and five Centers of Excellence pursue microgravity research in the following areas:

Fundamental Sciences—This includes the behavior of fluids and the study of transport phenomena in microgravity, and experiments that use enhanced measurement precision in microgravity to analyze physical properties and to challenge contemporary theories of relativity and condensed matter physics.

Materials Science—This includes the processing of electronic and photonic materials, metals, alloys, and composites; and glasses and ceramics, and polymers. The primary objective is to obtain a better understanding of the role of gravity-driven convection in the processing of such materials to achieve better control strategies on Earth. Also, new processing technologies are being developed that take full advantage of the microgravity environment. Production of limited quantities of exotic new materials with superior properties should be possible that can serve as bench marks for certain strategic applications. Eventually, such efforts will lead to commercially viable enterprises.

Biotechnology—The focus of the microgravity program in biotechnology is the growth of protein crystals and other process-oriented experiments. Superior ordering of the protein crystalline lattice can be achieved in microgravity and the molecular structure of complex proteins can be derived from x-ray diffraction data obtained from these crystals. This could have enormous implications for understanding the biological function of important proteins at the molecular level. In addition to this fundamental knowledge, such information provides the basis for rational drug design, the development of new vaccines, and protein engineering. Also, researchers are continuing to explore the possible advantages of cell culturing, cell separation, and cell fusion in microgravity.

The delay in the flight program due to the Challenger accident reduced momentum in the microgravity science program, but there were some benefits. There was an emphasis on replacing several pieces of outdated research hardware with redesigned, programmable systems with greatly expanded capabilities; specifically, the Advanced Automated Directional Solidification Furnace, Protein Crystal Growth, and the Electromagnetic Levitator apparatus. During the same period, over 200 journal articles were published and nine committees were convened to analyze the key elements of the microgravity science program. The most notable committee was that headed by the Nobel Laureate, Dr. Robert Schrieffer, which prioritized the flight opportunities for the highest quality science programs.

The interruption in the flight schedule increased the utilization of the ground-based microgravity facilities at several NASA centers. The drop tower at the Marshall Space Flight Center had nearly a fourfold increase in drop testing over the previous year, and the drop tube at the Lewis Research Center may go to a second shift to accommodate researchers. The increased use of aircraft testing contributed to significant hardware improvements in the protein crystal growth and phase partitioning experiments. Sub-orbital, low-gravity testing also allowed a clearer definition of experiment parameters for both solid-surface and droplet combustion experiments.

During 1987, a four-step planning process began. First, scientists from each of six Discipline Working Groups (DWG) (Biotechnology, Combustion, Electronic Materials, Fluid Dynamics and Transport Phenomena, Glass and Ceramics, and Metals and Alloys) specified the areas of science and technology in their disciplines which could benefit from study in microgravity. Each DWG also assigned priorities to the areas in its discipline. Second, the Microgravity

Science and Applications Science Panel considered ground-based experiments to conduct. The third step, to define, prioritize, and develop hardware necessary to accomplish the experiments, was begun in 1987. In the fourth step, priorities for placement of the hardware and experiments on Shuttle and Space Station will be made based on requirements for volume, power consumed and dissipated, weight, crew time, and other pertinent factors.

The centerpiece of this endeavor is the Space Station which will serve as a National Microgravity Laboratory. For the first time, scientists will be able to conduct experiments in an interactive mode and feed the results of one set of experiments into the next set in a timely manner. Also, for the first time, there will be adequate power to support materials science experiments involving high temperature and the growth of large-diameter crystals.

Improvements in both hardware and the design of microgravity experiments will yield a high return in the amount and the quality of future research in space.

Six generic Space Station facilities have been identified: Advance Protein Crystal Growth Facility; Modular Containerless Processing Facility; Space Station Furnace Facility; Biotechnology Facility; Modular Combustion Facility; and Fluid Physics/Dynamics Facility. These facilities will be highly modular and designed to share host systems. Nine Advanced Technology Development (ATD) areas have been identified with the objective of enhancing the scientific quality and integrity of flight experiments. They include noncontact temperature measurements; interface measurements; laser light scattering; combustion/fluid diagnostics; high resolution/high rate video; high temperature materials technology; high temperature furnace technology; vibration isolations; and biosensors. All NASA centers and the Jet Propulsion Laboratory participate in these activities by leading and supporting the development of one or more of the Space Station generic facilities and ATDs. After review by a NASA task force, planning was initiated for a series of Spacelab flights to regain the U.S. competitive advantage in microgravity science and to evaluate Space Station hardware concepts. In addition, the plan is flexible enough to make use of any commercially developed space facility, that may become available.

The quality, complexity, relevance, and competitiveness of the Microgravity Science and Applications program will establish U.S. leadership in microgravity science in the 1990's and beyond.

Communications and Information Systems

NASA's programs in satellite communications and information systems are committed to the advancement of the state of the art in commercial satellite communications and the implementation of information systems for the efficient performance of scientific research in today's data-intensive environment. Key elements of the communications program are the Advanced Communications Technology Satellite (ACTS) program, a collaborative endeavor with an industry consortium to deploy a satellite that will provide mobile communications services, and studies leading to design improvements of the operational Search and Rescue system flown on the NOAA polar-orbiting satellite system. The information systems program is responsible for NASA's long-term data archives, institutional computer operations in support of ongoing research programs, and advanced planning and architecture definition for scientific data systems of the future.

Advanced Communications Technology Satellite (ACTS). In 1987, the ACTS project moved closer toward its goal of a spacecraft launch from the Space Shuttle in the early 1990's. The design, implementation and testing of the communication engineering models (transponders and antennas) are essentially complete. These systems are the "heart" of the spacecraft and the key technical challenge. The current ACTS technology items, including the spaceborne-based processor, steerable antenna and the high-powered fast hopping spot beam antenna system, will make ACTS as significant in the 1990's as the original SYNCOM was in the 1960's. These advancements will contribute to U.S. prominence in the world telecommunications marketplace of the future.

Mobile Satellite. The joint mobile satellite program with U.S. industry and other Government agencies will provide two-way, satellite-assisted communication with cars, trucks, trains, boats, and aircraft within the next four or five years. Such a system, offering nationwide voice and data communications, is especially important for mobile users in rural and remote areas of the United States. Recently, a significant milestone was reached with the allocation of international frequencies for this application. Most importantly, a single consortium has emerged to own and operate a mobile satellite service in the United States. Licensing approval by the FCC is expected within several months.

NASA has completed the development of a number of power, spectrum, and orbit-efficient technologies designed to greatly increase system capacity and ensure the growth of future mobile satellite systems. In direct response to the President's policy on the commercial use of space, the system will create new hardware markets, business and service industries in the United States, and counter growing foreign competition, such as the Japanese launch of an experimental mobile satellite in August 1987, and planned European and Australian systems.

Search and Rescue. The COSPAS/SARSAT system (COSPAS, translated literally from Russian meaning Space System for Search of Distressed Vessels, and SARSAT, the acronym for Search and Rescue Satellite-Aided Tracking, the U.S. contribution to the system) completed its fifth year of operation in 1987. Over 950 lives have been saved as a result of the use of this system. Development of U.S. capability to compete in the manufacture of 406 MHz beacons has been enhanced by the development of equipment specifications.

NASA has provided technical advice to support rulemaking by the regulatory agencies for increasing carriage of the beacons by new classes of ships and aircraft. Cooperation with foreign partners is continuing and has resulted in the installation of terminal equipment in several nations. Technical effort continues to reduce the false alarm rate of the older 121.5 MHz system.

Advanced Planning. In close coordination with its advisory groups, NASA is developing plans to address future space communications needs, and the increasing demand for communication bandwidths. The agency has begun defining the technologies that will build on ACTS, support the future data distribution requirements of Space Station, and the science community, and contribute to the continued competitiveness of the satellite communications industry. Technologies under study for possible development and application include optical communications for high-resolution transmission in space sensing, robotics and planetary missions; communication links to support lunar and planetary exploration bases; and large, space-based antennas for Earth sensing and communication applications. The latter could be tested and calibrated at the Space Station in a near zero-gravity environment and subsequently transported to their final positions in space.

ATS-3. In 1987, the Advanced Technology Satellite (ATS-3) celebrated its 20th anniversary and continues to support the National Science Foundation, National Oceanic and Atmospheric Administration, Department of Defense, Department of the Interior, Drug Enforcement Administration, several universities, state and local governments, and a number of domestic and international disaster relief organizations. Through satellite voice and data links in science and communications application experiments, support is provided to North and South America, most of the Atlantic Ocean, and a large part of the eastern Pacific, including Hawaii and Antarctica.

Information Systems

The Information Systems program supports Space Science and Applications flight projects and science programs by operating large-scale computational resources used for data analysis; working with discipline programs to establish data centers for managing and distributing data; and developing computer networks and exploiting advanced technologies to access and process massive amounts of data acquired from successful space missions.

Several major data processing systems used by researchers to make large-scale computations and to test complex scientific models are located at the Goddard Space Flight Center. In addition, the program is responsible for the National Space Science Data Center (NSSDC), which archives data from science missions, and coordinates management of NASA data at distributed data centers. The Science Internet program at the Ames Research Center develops computer networks and explores new technologies to improve access to computers, data bases, and collaborators.

In 1987, an electronic master directory for all NASA-acquired data at the NSSDC was completed, and development of compatible online catalogs for all science data centers began. International electronic access to NASA's distributed discipline data centers was established; this capability was fully exploited during NASA's Supernova 1987a campaigns by researchers worldwide.

Throughout the data systems technology program, new capabilities to access and manage data for the astrophysics, planetary, and land processes disciplines was also developed. The successful demonstration of networks, optical disks, workstations, and other technologies integrated for one science discipline facilitates their adaptation by other disciplines and flight missions.

Flight Systems

Spacelab Flight Program. Reorganization of the Office of Space Science and Applications (OSSA) reflects significant progress toward utilization of the Space Station. To this end, the focus is on both the Space Station and Spacelab. The Spacelab will support the Space Station through systematic and methodical development of experiments, science, and operational procedures associated with flight systems.

Since the Space Shuttle is scheduled to resume flight in August 1988, renewed efforts have begun to prepare high-priority scientific missions for manifest opportunities in 1988 and 1989. Due to a more limited number of flight opportunities, missions have been modified to maximize the scientific return. In addition, mandatory new testing and analysis are underway to meet the new standards of safety, reliability, and quality.

The astronomical payload (ASTRO), which was ready for a 1986 flight, is presently scheduled for a 1989 launch. ASTRO's three independent ultraviolet telescopes that operate on the Instrument Pointing System will conduct independent but complementary measurements of ultraviolet spectra from a variety of astronomical sources, including stars and galaxies. Materials Science Laboratory missions are being prepared for flight starting in 1989. These missions are intermediate class payloads intended to develop new capabilities and facilities in the area of microgravity sciences. The Spacelab Life Science Module Mission has been reconfigured and is available for flight in 1990, and the Atmospheric Laboratory for Application and Science is being prepared for a flight opportunity in early 1991.

Space Station Activities. OSSA plans to be a major user of the resources offered by the Space Station program. OSSA expects that the Space Station will be a research laboratory in space for microgravity experiments in the pressurized modules, payloads on the core station, and Earth-observing experiments on the polar orbiting platform. Planning for the science utilization of the Space Station was intensified during

1987. An outgrowth of the Science Operations Task Team that was started in 1986 was the Space Station Science Operations Management Working Group, which completed a study defining alternate approaches to the management of science operations for the Space Station. OSSA is proceeding with the detailed evaluation of management alternatives leading to an approach which will maximize the scientific utility of the Space Station.

During 1987, OSSA progressed into the preliminary definition of a Science and Applications Information System (SAIS), which will allow long-term evolution of OSSA data networks and involve the user community in systems development. A key element of the science operations concept, which is embedded in the SAIS, is "telescience"—the capability to conduct experiments in space from the researcher's own laboratory. The OSSA Telescience Testbed Pilot Program began in 1987 with an initial complement of 14 universities. The first phase will test the applicability of emerging technologies and methodologies to the implementation of telescience, validate system requirements, and investigate implementation options.

As part of the increased focus on improving OSSA's ability to use the Space Station early in its operational phase, a plan was developed to augment definition work on candidate payloads on the core station. Experiment definition funding was set aside for definition and accommodation assessments of high priority payloads that show particular promise for flight on the Space Station, and for the study of technologies that will increase the efficiency and economy with which OSSA can use the facility. A committee representing the space and Earth sciences community was convened to review and implement this plan.

A coordinating subcommittee of OSSA science advisory committees is being formed as a successor to the Task Force on the Scientific Uses of the Space Station. Its purpose will be to provide advice and recommendations on OSSA's plans for use of the Space Station.

Space Transportation

Transportation Services

During 1987, most activity in Transportation Services centered on a concentrated effort to develop a combined Shuttle and Expendable Launch Vehicle (ELV) manifest. This mixed fleet manifest resulted from an assessment of NASA's launch requirements and capabilities in the wake of the Challenger accident and the subsequent reevaluation of the Shuttle program. The manifest incorporated major elements that include the President's policy on the commercialization of space, which provides that NASA will no longer launch commercial satellites except for those that are Shuttle-unique or have foreign policy implications; revised Department of Defense requirements; and new definitions of secondary payloads. The definition of secondary payloads was broadened to include larger payloads up to approximately 8,000 pounds. Secondaries now include large materials processing and technology development payloads and early design-related Space Station experiments.

Launch and Landing Operations

Throughout 1987, the focus of Shuttle processing activities at the Kennedy Space Center was on reevaluating, improving, and recertifying procedures, associated facilities, and ground support equipment. Permanent weather protection modifications were completed on launch Pad B, and similar modifications to launch Pad A are scheduled for completion next year. Several additional modifications to launch facilities were identified as mandatory for completion prior to the next launch. They include redesign of the External Tank vent umbilical system, upgrade of the emergency egress system, and upgrade of the Payload Changeout Room. The Orbiter Modification and Refurbishment Facility and Thermal Protection System Facility were completed on schedule in 1987.

The Shuttle Processing Contractor and the Base Operations Contractor are conducting extensive operational training. Also, support is being provided to conduct vehicle testing and develop improved procedures and processes.

Processing the Shuttle Orbiter Discovery for the flight of STS-26 began in September in the Orbiter Processing Facility. Design and construction efforts commenced during 1987 for Space Shuttle support facilities at Ben Guerir Airfield, Morocco and the Yundum International Airport in Gambia. Runway modifications were initiated at the White Sands Space Harbor, New Mexico to satisfy required contingency landing capabilities.

Flight Operations

As related to the Space Transportation System, flight operations encompass all resources and functions necessary to plan, train, and conduct a mission. They include ground facilities, crew training, and mission support personnel.

Operations personnel participated in large-scale reviews of Shuttle systems, mission rules, failure mode and effects analyses, and launch commit criteria. Training and certification of flight controllers and crew personnel continued. A long mission simulation (3 days), and an average of 8 hours per week of general simulations, have allowed proficiency to be maintained for the return to flight. Also, selection was made of 15 new astronaut candidates to support future missions of the Space Shuttle program.

Several replacements and enhancements of operational ground support facilities were started or completed. The Mission Operations Computers in the Mission Control Center at Johnson Space Center were replaced and tested. The Shuttle Mission Trading Facility upgrade program will include the Fixed Base, Motion Base, and Guidance, Navigation, and Control Simulators.

Under the STS Operations Contract (STSOC), contractor personnel were able to complete a backlog of software discrepancy reports and document critical processes. Also, STSOC contract renegotiations were completed that will allow a closer alignment of the operational tasks and environmental needs of Shuttle operations.

Orbiter

During 1987, major efforts continued to focus on returning the Orbiter to flight status. Safety changes identified in the System Design Reviews and the Critical Items List Reviews are being incorporated into the Orbiter. Crew escape and landing system changes recommended by the Presidential Commission on the Space Shuttle Challenger Accident are also being incorporated. Other safety-related areas under review include the critical items list, launch commit criteria, hazard analyses, design requirements and design certification.

A major structural loads analysis, which includes updated wind tunnel and flight data, is nearing completion. Changes required as a result of this analysis will be incorporated into the Orbiter.

Previous initiatives to improve the general purpose computer, inertial measuring unit, auxiliary power unit, and brakes continued. The improved fuel cell was completed and will be flown on the first return-to-flight vehicle. The production of the replacement Orbiter (OV-105) was initiated in August 1987 when a contract was signed with Rockwell International. The foundation for this vehicle will be the structural spares that have been under construction for the past four years and represent about one-quarter of a completed Orbiter. With the use of these structural spares, the new Orbiter will be delivered in approximately 45 months. The assembly and testing of the vehicle is taking place at Palmdale, California where all of the previous vehicles were built. OV-105 will incorporate all of the latest redesigns for return to flight.

External Tank

During the year, four external tanks were delivered. The External Tank recertification process is well under way and no problems are expected.

Solid Rocket Booster (SRB)

All areas of the SRB's were assessed for minimum impact on the return-to-flight schedule. Primary design changes were to the Solid Rocket Motor (SRM) field joints, nozzle-to-case joints, case insulation and seals. The established SRM redesign team evaluated design alternatives which would minimize the redesign time but ensure adequate margins of safety. Analyses and tests of the redesign baseline were conducted. Several tests of case and nozzle-to-case joints with intentionally flawed insulation and O-rings were completed. Also, two of the four static motor test firings required prior to reflight were successful. A second horizontal static test stand that will be used in simulating environmental stresses, loads, and temperatures experienced during launches was constructed. The first static test using this facility will be conducted in April 1988.

The filament wound case (FWC) development program was completed, but FWC production was postponed. A minimum of two years will be required for requalification and production of flight sets.

Subsequent to the Challenger accident, the five major solid propulsion contractors were funded to study innovative changes to the existing SRM joint design and to design new concepts for improved SRM performance. The results of these studies were reported to Congress in January, as required by Public Law 99-349. In response to direction in the NASA Authorization Act, an SRM Acquisition Strategy and Plan, which indicated that NASA proposed to initiate Phase B studies for an Advanced Solid Rocket Motor, was submitted to Congress in March. The five solid propulsion contractors were awarded contracts in August for nine-month preliminary design studies of both a monolithic and segmented Advanced Solid Rocket Motor.

Space Shuttle Main Engine (SSME)

A program was initiated to address key problems areas of the SSME that were identified following Challenger's accident. This consisted of 23 mandatory changes required prior to the first return-to-flight mission. The test rate to accomplish all of the required certification tests was increased from 8 to 12 per month. The engine certification test program achieved a major milestone when engine 2105 reached 30,000 seconds of testing. The third test stand (B-1) was completed at the National Space Technology Laboratories and should be activated early in 1988.

The Technology Test Bed program is underway at the Marshall Space Flight Center. It provides an independent means to evaluate technology programs and technical advances arising from the development program, and to test the alternate pumps. Testing should start mid-1988. The alternate high pressure pump program has been underway for over a year. Component testing is scheduled to start in early 1989. Also, a SSME Health Monitoring Diagnostics program was initiated to provide greater reliability, safety margin, and lower operational costs.

Upper Stages

Production continued on Inertial Upper Stage (IUS) vehicles for three additional Tracking and Data Relay Satellite missions, and for the Galileo, Ulysses, and Magellan planetary missions. In addition, work continued on the modified Payload Assist Module (PAM), which will be used with an IUS for the Ulysses mission.

Production continued on two Transfer Orbit Stage (TOS) vehicles for the Mars Observer planetary mission and the Advanced Communications Technology Satellite mission. The upper stage is being built by Orbital Sciences Corporation. As exemplified by the TOS and PAM vehicles, commercially developed upper stages are playing a more significant role in the Nation's space activities.

The Solid Propulsion Integrity program (formerly Solid Rocket Motor Integrity program) continued to improve understanding of solid rocket motor designs and manufacturing processes that affect reliability. This program is providing a data base against which designs of solid rockets can be substantiated. The Space Shuttle Solid Rocket Booster organizations have used this data base to verify some of their redesigns.

Termination of the STS/Centaur upper stage contracts continued. The design of the STS/Centaur G prime vehicle is being used by the Department of Defense as one of the upper stages for the Titan IV launch vehicle.

Orbital Maneuvering Vehicle

Design and development of the Orbital Maneuvering Vehicle (OMV) continued. The Program Requirements Review was held in late summer 1987; work is progressing towards the Preliminary Design Review in July 1988; and the Critical Design Review is scheduled for September 1989. The OMV is expected to be available for its first mission in June 1993.

Tethered Satellite System

The Tethered Satellite System is a cooperative development between NASA and Italy to provide a capability for conducting experiments in the upper atmosphere and ionosphere. It will be capable of deploying and retrieving a tethered satellite up to 100 kilometers below or above the Space Shuttle which will serve as the orbiting base. The first mission will be an outward deployed electro-dynamic mission with a 20-kilometer conductive tether.

During 1987, the Tethered Satellite System was in a phased-down mode consistent with a two-year delay in the first mission and compatible with the Italian development effort. The manufacture and qualification of the 20-kilometer conductive tether was completed and the flight unit was delivered. Work on other major subsystems continued with qualifications and deliveries continued with qualifications and deliveries for 1988 and 1989. The first mission is scheduled for January 1991.

Spacelab

Action was taken in 1987 to recertify the Spacelab hardware for safe return to flight. This activity identified the critical categorization of the Spacelab components, and documented the recertification of critical hardware and associated processing activities.

Marshall Space Flight Center completed development of the second hitchhiker. This hitchhiker is a Shuttle Payload of Opportunity carrier that fits into the Shuttle payload bay. The Spacelab Enhanced Pallet development progressed through a successful critical design review. The enhanced pallet system will be used for the Tethered Satellite System and the Space Technology Experiment platform.

Expendable Launch Vehicles (ELV)

In 1987, NASA launched four spacecraft missions using expendable launch vehicles. Three of these missions were successful: a Scout launch of a Navy Transit satellite in September 1987; a Delta launch of GOES-H for the National Oceanic and Atmospheric Administration in February 1987, and a Delta launch of PALAPA B-2, a communications satellite for the Indonesian Government in March 1987. In March 1987, an Atlas/Centaur launch attempt of FLTASAT-COM 6, a Navy Communications satellite, resulted in a failure when lightning in the vicinity of the vehicle caused the engines to malfunction. The vehicle was destroyed by the range safety officer.

As a result of the Challenger accident, NASA conducted a series of space transportation requirements and capability studies that concluded that a Mixed Fleet, consisting of the Space Shuttle and expendable launch vehicles, is necessary to help ensure continued U.S. operations and access to space. A two-phased plan to implement the Mixed Fleet program is under way. In the first phase, launch vehicles for five, high priority missions requiring launch before 1992 will be acquired non-competitively, either directly from commercial operators or through Department of Defense contracts. In the second phase, for missions after 1992, NASA will acquire expendable launch vehicle services in support of approved missions on a competitive basis from private sector operators whenever the opportunity exists.

Space Flight/Space Station Integration

During 1987, a new organization was created within the Office of Space Flight to facilitate the integration of the Space Station program, and its unique requirements, into Space Transportation support systems. It coordinates the exchange of information between the two programs and serves as a forum for presenting and resolving issues related to technical and programmatic interfaces. In 1987, a major transportation study was conducted with the Space Station program. The study examined transportation capabilities, including expendable launch vehicles, proposed heavy lift launch vehicles, Space Shuttle enhancements, extra vehicular activity, and on-orbit crew time. It identified areas that will help reduce Shuttle flight rate requirements and increase the support margins for Space Station. An increase in Shuttle down weight capability identified by the study will have benefits across the entire Shuttle manifest.

Continuing Space Flight/Space Station integration activities include reviewing and implementing Space Station operations concepts, preparing a congressional report on cost-effective transportation for the Space Station program, and initiating specific technical and programmatic areas to enhance support of the Space Station.

Advanced Planning

In a joint effort, NASA and DOD continued the Space Transportation Architecture Studies (STAS) to define future space transportation requirements. Guided by recommendations of STAS, NASA and DOD coordinated studies to define concepts for unmanned heavy lift launch vehicles that will satisfy both near- and long-term mission requirements. The Air Force-led Advanced Launch System studies concentrate on a heavy lift launch system which incorporates advanced technologies to achieve longer term objectives (1998 and beyond) for significantly reduced transportation costs. The NASA-led Shuttle-C (Cargo) studies concentrate on a capability compatible with the existing Shuttle fleet that can deliver a minimum of 100,000 lbs. of useable cargo to low-Earth orbit.

For manned flight, NASA continued efforts for near-term Shuttle performance enhancement, initiated studies for Shuttle evolution, and continued studies of a next-generation Shuttle II vehicle. The Advanced Solid Rocket Motor (ASRM) program, currently in the definition phase, offers a potential increase of payload mass to orbit from 12,000 lbs. to 20,000 lbs for the Space Shuttle. New technologies are being explored for the ASRM to enhance quality and improve performance. A new study on Liquid Rocket Boosters (LRB) examines the feasibility of replacing the Solid Rocket Motors with liquid engines. Potentially, the LRB's offer advantages in performance and thrust.

Concurrent with efforts to enhance the Space Shuttle performance, studies are underway to evaluate its evolution, while achieving cost and efficiency objectives. Changes to current systems in the areas of operations and avionics have potential for follow-on orbiters while other options, ranging from two to single stage-to-orbit configurations, are being examined for a post year 2000 next-generation Shuttle II vehicle.

In support of potential lunar and Mars missions, studies focused on large, on-orbit cargo storage techniques and space transfer vehicles that could be required at the turn of the century and beyond.

Satellite Servicing

In 1987, NASA continued to focus its Satellite Servicing program on the development of systems, tools, and procedures that will use Shuttle capabilities and be compatible with the Space Station and the OMV. The program addressed requirements for refueling, repairing, retrieving, and retrofitting associated with Shuttle operations and remote servicing, using the OMV or a dedicated service device.

The definition of tankers, couplings, and techniques to support refueling satellites on-orbit is well underway and will be applicable to both Shuttle-related manned

EVA and remote OMV resupply requirements. Tools and special fixtures for EVA applications are also under development, including a remote blind mate and EVA scoop proof connectors, an umbilical carrier mechanism, improved EVA suit glove, and a voice control system and force torque sensor for unmanned telerobotic applications.

Satellite retrieval capability studies are focused on soft docking using laser sensor technology, a potential OMV front end kit with the capability to retrieve tumbling satellites, and a light-weight satellite holding and positioning device. Procedures and techniques for retrofitting or upgrading equipment on polar platforms are also under study.

A study and laboratory program to define and evaluate several highly promising applications of tethers in space continued. The focus of these efforts has been on defining and implementing flight experiments and demonstrations. Applications being investigated include power generation, orbital altitude changes without the use of propellants, artificial gravity and tethered space platforms for science and application uses.

Advanced Operations

A new program initiative addresses advanced operations effectiveness as key to improving safety and efficiency and reducing life-cycle costs for space transportation and orbital systems. New and innovative ground, flight, and on-orbit operations techniques are being assessed for use with existing and future space systems.

In 1987, efforts concentrated on expert and autonomous systems applied to key operational functions, such as thermal protection system measurement, weather forecasting, paperless management tracking systems, and on-orbit rendezvous and docking operations. Current plans emphasize the application of expert systems for labor-intensive operations such as flight and launch planning. Robotic applications will reduce hazardous operations and improve safety. Advanced software engineering tools, new instrumentation techniques, and other key technologies also will be the subject of operations-oriented advanced development efforts.

Safety, Reliability, Maintainability and Quality Assurance

As part of a NASA-wide effort to improve the communication of safety problems to upper management, the Office of Safety, Reliability, Maintainability and Quality Assurance established the NASA Safety Reporting System (NSRS). The NSRS is a confidential, voluntary, and independent reporting system through which NASA employees and contractors working on the National Space Transportation System may directly and anonymously inform the NASA Headquarters Safety Division of their concerns about the safety of the Shuttle program. To assure that the confidentiality of individuals using the NSRS is maintained, NASA has contracted with an independent agent, the Battelle Memorial Institute of Columbus, Ohio, to administer the program. Individuals who have knowledge of a risk to the NSTS may document this on a NSRS Reporting Form which is postage-paid and pre-addressed to Battelle in Columbus.

The NSRS is not intended to replace any existing methods of communicating safety problems to management and is not intended to bypass supervisors. Instead, it is a supplementary reporting system which allows individuals to contact the upper levels of NASA management with their concerns when the standard reporting methods have failed to provide a timely or satisfactory resolution. Offering anonymity to the reporter removes the obstacle of fear of reprisal often associated with making supervisors aware of problems or hazards.

A Technical Advisory Group (TAG), comprised of representatives from the Space Transportation System (STS) Centers, the Office of Space Flight, and chaired by the Manager of the STS Safety Program, has been formed to investigate the hazards or concerns reported to the NSRS. Each TAG member at the STS Centers has formed an action team to assess the NSRS concerns assigned to the Center and develop a plan for corrective action. The plan and accompanying schedule for implementation must be approved by the Director of the Safety Division at NASA Headquarters before the matter is considered resolved. The Director also reserves the option to request an independent evaluation of the proposed hazard resolution.

During 1987, Battelle received reports addressing a variety of concerns related to safety procedures and to the design and maintenance of the Shuttle. To date, only two of all the reports received dealt with issues outside the scope of STS safety. One of them is being studied as a legitimate safety concern in spite of its "out-of-scope" designation. Currently, the NSRS is handling only STS-related safety issues. However, the system will be expanded in the future to include safety issues in all NASA programs and projects.

In October 1987, the first NASA Excellence Award for Quality and Productivity was presented to IBM Federal Systems Division in Houston, Texas and Martin Marietta Manned Space Systems in New Orleans, Louisiana. The two companies were selected from among seven finalists. The purpose of the Award is to recognize the highest standards of performance among NASA contractors, subcontractors, and suppliers in the aerospace industry, to transfer their superior ideas to others, and to create public awareness of the importance of quality and productivity to the United States.

The Nondestructive Evaluation (NDE) Laboratory at Langley Research Center has a new computational model of the physical structure of the Shuttle Solid Rocket Motor (SRM) to select the best NDE technique for evaluating bondline defects between the steel case, the insulation, and the fuel. The physical model disclosed that frequency windows exist through which the bondlines can be inspected with ultrasonics. The model was verified with experimental tests on SRM samples with defects, and an instrument is being built for testing at Morton Thiokol on one of the test motors. In addition, ground was broken in 1987 for the NDE Center which will house a major research team to advance the NDE sciences and technologies needed for aerospace. Also, a contract was let for the construction of a novel X-Ray tomography system that will permit the first observation of microdetail (50 microns resolution, 2 micron detectability) in solids while the solid is undergoing loading and fatigue. This system will permit the observation of failure mechanism in three dimensions inside materials, providing a NDE science base for understanding such mechanisms.

Commercial Use of Space

The Office of Commercial Programs (OCP) was established by NASA to encourage private sector investment in commercial space activities. Fostering industry involvement in space is vital to the Nation's economic development and competitiveness in the world market. OCP's progress toward achieving its objectives is exemplified in its accomplishments for 1987.

Centers for the Commercial Development of Space (CCDS) are nonprofit consortia of universities, industry, and government working closely to conduct space-based high technology research with commercial potential. OCP established and funded 7 additional Centers in 1987, bringing the total number to 16. Over 100 organizations are currently affiliated with these Centers.

A recent and major contribution by two researchers supported by the CCDS Program was the high-temperature superconductivity breakthrough, with the highly publicized fabriçation of material superconducting above the temperature of liquid nitrogen. For three quarters of a century, scientists have sought to produce materials which would remain superconducting above liquid nitrogen. This increase in temperature could make possible commercial applications of resistance-free electricity, long contemplated but impractical in light of the cooling requirement. The range of potential applications is too broad to catalog, but there is general agreement that the ability to transport electrical current with no resistance on a practical basis will engender profound technological and sociological changes throughout the world.

A NASA Shuttle Manifest through FY 1992 has been developed that projects tentative space flight activities, including more than 30 payloads associated with OCP. Specifically, the first flight of renewed Shuttle operations will carry a payload, developed by the 3M Corporation of St. Paul, Minnesota, to study the properties of highly ordered organic materials produced in orbit. This flight also will carry equipment to grow protein crystals of a size and quality to facilitate detailed analysis of their characteristics, with significant implications for the future manufacture and use of pharmaceuticals. The protein crystal work emanates from the CCDS/Center for Macromolecular Crystallography, located at the University of Alabama at Birmingham, Alabama.

In March 1987, NASA and General Dynamics (GD) Corporation signed the first U.S. Government agreement transferring operation of a Government-developed expendable launch vehicle (ELV) to the private sector. The transfer is in line with a Government policy supporting efforts by U.S. companies to develop commercial launch capabilities competitive with those of Europe, Japan, China, and the Soviet Union. The agreement transfers to GD authority to use NASA-controlled facilities and capabilities for commercial manufacture and launch of the Atlas/Centaur vehicle. GD announced plans to start construction of 18 commercial Atlas G/Centaurs in 1987, and to introduce the vehicle to flight service in 1989.

The Technology Utilization (TU) Program has evolved into a broad array of transfer mechanisms designed to encourage and facilitate the use of aeronautics and space technology in the public and private sectors of the economy.

Currently, over 30,000 spinoffs from NASA technology touch our lives. Of particular note are two spinoffs resulting from application engineering projects. A Programmable Implantable Medication System was implanted in 18 diabetics, to date, eliminating the need for intravenous insulin. An Automatic Implantable Defibrillator, being implanted at a rate of approximately 20 a month, sends an automatic electric pulse during a heart attack, thus saving lives.

The NASA Industrial Applications Centers (IAC) are a major component of the TU Program. The IAC network consists of 10 Centers throughout the United States which stimulate corporate interest in NASA technology. The university-based IACs cultivate strong ties with industry, identify industrial client problems and technological interests, and assist their clients through the exchange of technological information.

Recently, the IACs expanded their outreach activities through a new initiative called the Industrial Applications Affiliates Program. A number of the Centers have developed cooperative working relationships with State-sponsored business assistance institutions, making NASA's valuable technologies available to a wider range of U.S. industry. To date, 30 State institutions have been established, and 12 more are in process. This cooperative effort is being accomplished with very little cost to NASA or to the State-sponsored affiliates. NASA expects to broaden these cooperative linkages with States where business assistance organizations exist.

In March 1987, NASA entered into an interagency agreement with the Federal Laboratory Consortium (FLC) to provide linkages between more than 400 Federal laboratories and NASA's nationwide transfer network. Access to unique technological resources and capabilities of the Federal laboratories will be facilitated by this agreement. Such Federal resources may provide useful answers to the needs of industry as well as State and local governments. This arrangement provides the FLC, formally established with the passage of Public Law 99-502, with an established technology transfer network serving the requirements of industry on a nationwide basis.

Another major program element designed to transfer NASA technology is through publications, the principal one being the NASA Tech Briefs journals. This journal, which is published 10 times each year, announces as many as 60 to 70 new NASA technologies an issue. Since NASA privatized NASA Tech Briefs journals 2 years ago, circulation among engineers and scientists in U.S. industry has doubled to over 155,000. This clearly indicates the important role that this publication plays in making new advances in science and engineering available for industrial and commercial use.

An important responsibility of OCP is the administration of the agency's Small Business Innovation Research (SBIR) Program. The basic objective of the SBIR Program is to achieve greater participation of small, innovative businesses in Federal R&D activities with resultant benefits to the Government, the small businesses involved, and to the economy as a whole. As specified by law, NASA's SBIR Program funding this year was 1.25 percent of the agency R&D budget.

The 1987 SBIR Program Solicitation invited proposals from qualified high-technology business in any of 122 technical subtopic areas. A total of 1,825 proposals was received (in contrast to the 1,628 received in 1986), and, from these, 206 were selected for award of Phase I contracts.

Phase I SBIR contracts are intended to explore the feasibility of research innovations. Their duration is 6 months and they are funded as firm fixed-price contracts for up to $50,000 each. Phase II SBIR contracts continue the development of the promising Phase I projects, with durations of up to 2 years and funding up to $500,000 each.

During 1987, contracts were let for Phase II continuations of research initiated in 84 of the Phase I projects completed in 1986. By the end of 1987, an additional 60 Phase II projects were selected to continue the most promising Phase I activities completed in 1987. It is anticipated that shortly after the end of the year, an additional 25 proposals from that same group also will be selected for Phase II awards.

As in previous years, the 1987 SBIR Program encompassed every area of research and technology in which NASA is engaged. Interest in the program is increasing, and the number of Phase I proposals submitted in areas of high technical interest continues to grow. Examples of high-interest areas are telerobotics, advanced materials and structures, and instrumentation for both space and aeronautical applications. Among the many Phase I proposals submitted this year, 61 were related to materials processing in microgravity and in commercial applications in space. Seven of these were included in the group of proposals selected for contract awards.

In 1987, most of the Phase II projects emanating from research initiated in the first year of the program were completed. Several project results are slated for immediate NASA applications, including an advanced fire detection system for large facilities, an improved spectro-radiometer instrument for oceanographic measurements, and several advanced structures and materials-processing techniques. Other research products, such as analytical methods, design concepts, instrumentation, and data processing techniques, are viewed as important contributions to both aeronautics and space technology, adding to the overall state of knowledge in these fields and increasing the agency's ability to conduct its R&D activities.

In 1987, NASA began a critical assessment of the SBIR Program. As required by the legislation reauthorizing the program last year, the initial assessment concentrates on the quality of SBIR research projects, to date, and the impact of the program on overall R&D activity. NASA's assessment will be included in a report prepared by the General Accounting Office about the SBIR Program which will be submitted to Congress at the end of 1988.

Space Station

During 1987, NASA made considerable progress toward developing the permanently manned Space Station mandated by President Reagan in his 1984 State of the Union address. In January, NASA through contracted study efforts completed a 22-month comprehensive preliminary design study. During the spring, following a major cost review, the baseline configuration underwent significant changes. After extensive analysis, a revised baseline configuration was endorsed by a special design review group within NASA and by the National Research Council. By December, major support contracts were in place, and the agency had selected the principal contractors for hardware development. Negotiations with the Space Station's international partners, Europe, Canada, and Japan, establishing cooperative arrangements for Station development and operation, neared completion. At the end of 1987, NASA had established a strong foundation for the program, and was ready to proceed with Space Station detailed design and development.

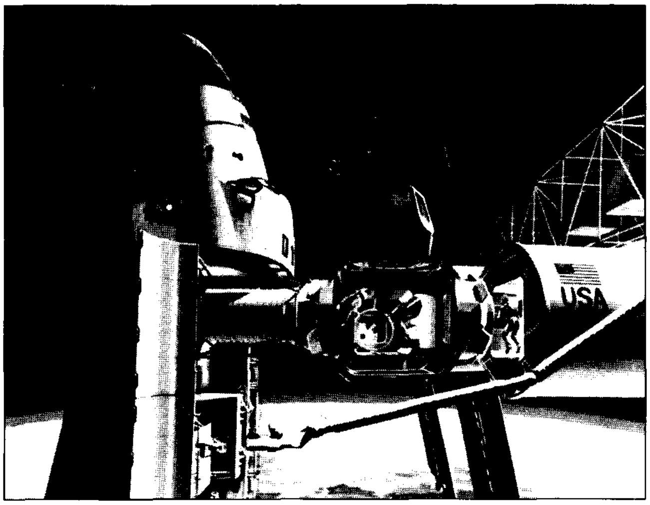
Program Description and Goals. The Space Station will be used as a research laboratory in space and could serve as a stepping stone in support of the long-term goal of expanding human presence and activity into the solar system. The Station will serve as an observatory and a microgravity laboratory. As it evolves, it may become a servicing center, transportation node, assembly facility for spacecraft, manufacturing facility, storage depot, and staging base for potential future exploration.

Basic goals were set for the Space Station at the outset of the program, and have remained unchanged. They are as follows:

- To help assure leadership in space during the 1990's and beyond;
- To stimulate advanced technology;
- To promote international cooperation;
- To enhance capability for space science and applications;
- To develop the commercial potential of space;
- To contribute to American pride and prestige; and
- To stimulate interest in science and engineering education.

Artist's conception of the Space Station configuration.

Configuration Description. The Space Station configuration was established in the summer of 1987, after considerable analysis which took into account both scientific, technological, and commercial user requirements. After a substantial increase in the cost of the program, NASA and the Administration decided to take a phased approach toward Space Station development. The revised Baseline Configuration will include four pressurized modules accommodating a crew of eight. The habitation module and one of the laboratory modules will be developed by NASA. Japan and the European Space Agency will each be responsible for developing a laboratory. These modules will be attached to a 120.3 yard (110 meters) boom. The Station will be powered by four photovoltaic arrays, supplying an average of 75 kilowatts of power. Other features of the Station will be a Mobile Servicing



Artist's depiction of space shuttle rendezvous with Space Station.

System, supplied by Canada, accommodations on the boom for attached scientific payloads, a flight telerobotic servicer, two unmanned free-flying polar platforms (one provided by European partners), and servicing for European man-tended free-flyer.

The Space Station configuration is being designed to accommodate future changes. The system will include "hooks" and "scars." Hooks are accommodations to facilitate the addition or update of computer software after Space Station operations begin; and scars are physical provisions in the baseline hardware that exceed initial requirements or that allow future growth. A future phase might utilize the dual keel design of an enhanced configuration. This enhanced configuration could include the addition of more truss to increase attached payload accommodations, an additional 50 kilowatts of power produced by two solar dynamic generators, a servicing bay, and a co-orbiting platform. The path of future evolution, however, has not yet been determined. It will be based on future national goals, mission requirements, and budgetary resources.

Program Status. The Space Station program made considerable technical and managerial progress in 1987. Important events occurred in contract activities, program cost reviews, program organization and management, and congressional oversight.

In January, NASA through contracted studies successfully concluded Phase B of the Space Station program, a 22-month preliminary design study. The Space Station program is divided into four work packages, each managed by one of NASA's field centers. NASA announced selection of the prime contractors for Phase C/D—advanced design and hardware development—in December. The Boeing Company will develop Work Package 1, McDonnell Douglas will develop Work Package 2, General Electric will develop Work Package 3, and Rocketdyne will develop the elements in Work Package 4. In fulfillment of a congressional requirement to pursue the development of automation and robotics technology, NASA released the Phase B Request for Proposals for the Flight Telerobotic Servicer (FTS) in May. Grumman Aerospace and Martin Marietta were selected to conduct FTS definition studies. The FTS is part of Work Package 4.

Other contract activity in 1987 focused on procurement of support services for Space Station systems engineering and integration (SE&I). The Technical and Management Information System (TMIS) contract, awarded to Boeing Computer Services in April, is providing a compatible, integrated computer system for engineering and management users. A Software Support Environment (SSE) contract was awarded to Lockheed in July. Lockheed will develop a common foundation for all program software development, integration, and maintenance. Finally, NASA awarded the Program Support Contract (PSC) to Grumman Aerospace in July. Grumman is providing a variety of support in SE&I, utilization and operations, information systems, program control, safety, reliability and quality assurance (SR&QA), and coordination of international activities.

Space Station costs were reviewed several times during the year. In January, a top-to-bottom review of development costs was completed by NASA. Significant increases in program cost in the spring led to a phased approach to Space Station development. In addition, NASA conducted cost studies to support the National Research Council's review of the Space Station. Finally, in accordance with a requirement in NASA's Authorization Act for FY 1988, the agency began preparation of a total cost plan spanning three years. Entitled the Capital Development Plan, it will be prepared annually through 1996. The plan will include the estimated cost of all direct research and development, space flight, control and data communications, construction of facilities, and resource and program management. This plan will complement the Space Station Development Plan submitted to Congress in November 1987.

Other important events included the implementation of many of General Samuel Phillips' recommendations for stronger Space Station program management. In the spring, the Program Office was relocated to the Washington, D.C. area from Johnson Space Center, moving to its permanent facility in Reston, Virginia in September. A new management structure is now in place, providing a stronger, centralized approach to overall control of the program. Overall policy decisions are made at Level I, the Office of Space Station at NASA Headquarters. Level II, the Program Office, is in charge of systems integration and program management. Level III, the four NASA field centers assigned work packages, will be responsible for the actual hardware development of the Space Station.

Operations and Utilization Planning. Operations and utilization are two areas which require extensive advance planning if the Space Station is to realize its potential and if costs are to be controlled. Therefore, the Space Station program has placed strong emphasis on the design of a system of operation that provides affordability over time. Such planning is key to the development of a cost-effective Space Station,

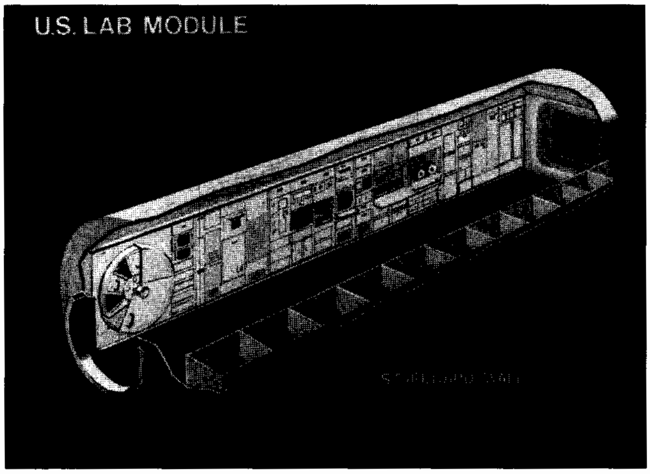
Possible configurations for Space Station laboratory and habitation modules.

just as incorporation of user requirements in the design of the Space Station is key to its usefulness.

Four important accomplishments that occurred this year in operations planning were the development of an operations concept by a NASA Space Station Operations Task Force; implementation of an operations plan; further study of operations cost management; and a preliminary study on science operations management.

The Space Station Operations Task Force, established in 1986, examined space operations and support systems, ground operations and support, user development and integration, and management integration, completing its formal report in April. Other operations events included the submission to Congress of reports on science operations and operations cost management. The latter report summarized the definition of an approach to operations management, identified key factors driving operations costs, and developed a management process to control operations costs. It also examined the potential uses of automation and robotics technology to control operations costs.

The study on science operations management,



Proposed U.S. Laboratory Module on Space Station.

completed in August, examined alternative approaches to the management of Space Station scientific operations. The science operations considered included science planning and payload selection, payload development and integration, science tactical and increment planning, and science operations and data management. The study concluded with a number of recommendations concerning science operations management and identified necessary follow-on activities.

In the area of utilization, significant progress was made. A preliminary draft of a Space Station Users Handbook was completed that will be a guide to the Space Station for commercial and Government users; and a number of pricing policy studies were initiated that will lead to an economic basis for the allocation of resources in the Station. Following new inputs from potential users, revisions were made to the Mission Requirements Data Base. In addition, efforts were initiated to develop a Space Station operations management concept for users; and international utilization panels, established by the Phase B Memoranda of Understanding, were activated to discuss issues confronting international users of the Space Station.

Commercial Utilization and Development. Commercial participation in the Space Station program was a particularly visible issue in 1987. The encouragement of commercial activity in space is a stated national goal. Commercial activities include participation in the development and use of the Station, and NASA is searching for ways to foster both kinds of commercial involvement in the program. Such involvement will do much to promote the development of commercial activities in space.

NASA and interested industry members have engaged in several activities to establish the role of industry in Space Station development and utilization. In late December 1986, guidelines were finalized to encourage U.S. commercial participation in Space Station development and operation. These guidelines welcomed commercial initiatives, discussed issues such as proprietary rights, and delineated the responsibilities of both NASA and Space Station commercial users and developers.

In November, NASA sponsored a Space Station workshop on commercial missions and user requirements. The workshop provided NASA with a commercial perspective on how to make the Space Station a valuable tool for industry. Progress was made toward identifying potential commercial research, development, services and other opportunities; providing updated information for the Mission Requirements Data Base to ensure that commercial interests are properly represented; and identifying other issues of commercial concern.

Finally, NASA's Office of Space Station, and Space Industries, Inc. (SII) held discussions in 1987 on cooperation during Phase C/D. SII is a U.S. company defining and developing with private funds a man-tended Industrial Space Facility and an associated docking system designed to be compatible with Space Station hardware.

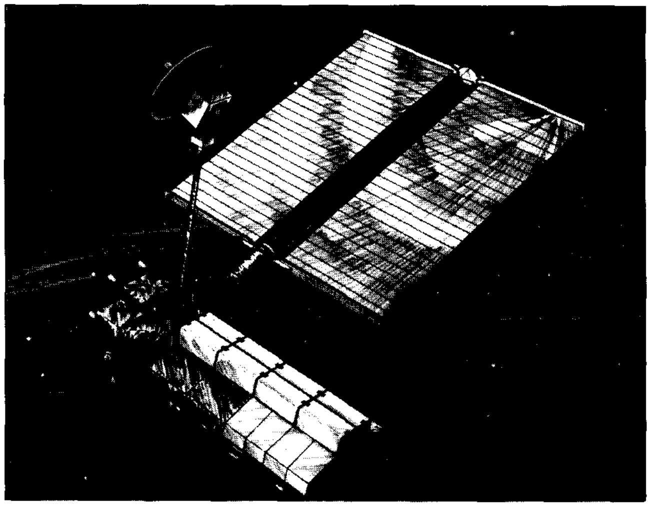
Evolution Planning. Accomplishments this year include the establishment of an Evolution Management

Council and a NASA-wide evolution working group established at the Langley Research Center. The working group is responsible for recommending policy and technology planning approaches, for preparing and maintaining a Space Station evolution plan, and for monitoring the status and implementation of hooks and scars in the Space Station design. NASA also began planning for advanced technology development—technology that will improve the productivity and efficiency of the Space Station.

A number of evolutionary paths also were identified. The dual keel enhanced capabilities configuration is considered the primary reference evolution option, but other options are being examined. These include the four leadership initiatives considered by the Ride Commission—Humans to Mars, Outpost on the Moon, exploration of the Solar System, and Mission to Planet Earth.

International Cooperation. Negotiations with NASA's international partners neared conclusion at the end of 1987. In December, informal agreement was reached with Canada on its development of the Space Station's Mobile Servicing System. Negotiations with the European Space Agency on its development of a laboratory module and a polar orbiting platform remained open at the end of the year. Agreement with Japan, which will be developing a laboratory module and two logistics carriers, was close to completion.

National Research Council Assessment. Following an Administration request in the spring, the National Research Council (NRC) conducted a six-month study of the Space Station program. The NRC was asked to assess the program's costs; review the mission priorities and user requirements affecting the Station configuration; identify and assess alternatives to the configuration chosen by NASA; examine the arrangements projected for international participation; and report on any other matters that would contribute to the development of the Space Station.



Artist's rendition of the U.S. polar platform.

Recognizing that the Space Station is a formidable challenge that will require a national commitment, the NRC issued several findings and recommendations. The Council also endorsed the revised baseline configuration, deeming it the most practical first step in Space Station development. In addition, it stressed that the Nation's long-term goals in space should be clarified before committing to an enhanced configuration. In looking at alternatives to the configuration, it concluded that a man-tended facility would not be an adequate substitute for a permanently manned facility. It also emphasized the need for an extensive test bed and backup hardware provision for the program. The NRC expressed concern about the potential for Space Station cost growth arising from as yet unidentified difficulties. While NASA planners acknowledge the concern, they believe that the cost estimates include a reasonable amount for contingencies. NASA found the NRC overview to be very helpful. Current Space Station planning takes into consideration all of the NRC's relevant findings and recommendations.

Site of Second TDRS Ground Terminal (STGT), White Sands, New Mexico.

Space Operations

In a reorganization designed to increase management emphasis on space operations, NASA established an Office of Space Operations in January 1987. This office is responsible for developing a plan to manage NASA's increasingly complex space operations, with initial priority given to man-tended and man-related space operations. The functions of the Office of Space Tracking and Data Systems became an integral part of the Office of Space Operations.

A Space Operations Task Force, established in March 1987, developed options for a plan of operations within NASA that could be implemented after Shuttle recovery. The Task Force findings are under study by NASA management.

During 1987 the Space Tracking and Data Systems program continued to provide vital tracking, command, telemetry, communications, data relay, and data processing support to meet NASA's flight program requirements.

Space Network

The transition which began with the first Tracking and Data Relay Satellite (TDRS) from a ground-based tracking network to a space-based tracking capability for low-Earth orbital missions continued in 1987. Final assembly, test, and launch preparations were conducted during the year for the two additional TDRS spacecraft that will be launched when Shuttle operations resume in 1988. The present ground-based tracking network has been retained to support low-Earth orbital missions until the TDRS system becomes operational. The TDRS system will be operational when three fully functioning spacecraft are in geosynchronous orbit, and the spacecraft and the ground systems have completed their separate and integrated acceptance tests.

During 1987, the Tracking and Data Relay Satellite in space continued to support the Landsat, Solar Mesospheric Explorer, and Earth Radiation Budget Satellite missions. This aging spacecraft has experienced major system failures and anomalies since its launch in April 1983. However, without further degradation, it can continue to provide mission support. Should the satellite fail, contingency plans have been developed to provide limited support through the Ground Network.

To ensure continuity of service in the early 1990's, a TDRS Replacement Spacecraft Program to replace the satellite lost in the 1986 Challenger accident was initiated in 1987. A ground-breaking ceremony to initiate the construction of the Second TDRS Ground Terminal (STGT) was held in New Mexico in August. Operational readiness of this facility is planned for 1992.

Ground Networks

The three ground-based tracking and data networks, the Space flight Tracking and Data Network, the Deep Space Network, and the Aeronautics, Balloon, and Sounding Rocket programs continued to support NASA's in-flight missions.

The Deep Space Network is preparing for its next major challenge when the Voyager spacecraft encounters the planet Neptune in 1989. During 1987, major modifications were underway at all Deep Space Network facilities in preparation for this encounter and future missions. The 64-meter antennas at each of the Deep Space Network sites are being increased to 70 meters, with work completed at two of the three sites. During the encounter with Neptune, signals will be combined with those from antennas at non-NASA facilities.

Also underway in the Deep Space Network were modifications to support the Galileo, Magellan, and other planetary missions scheduled for the 1989-1991 timeframe.

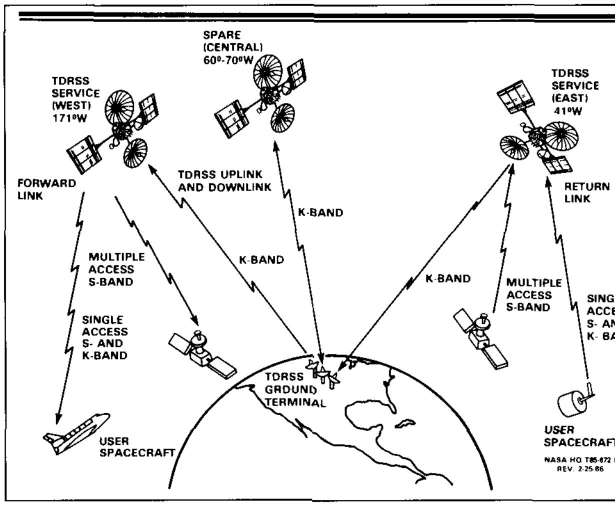
Communications and Data Systems

The basic elements of the Communications and Data Systems Program form the vital link between data acquisition stations and users and include communications, mission control, and data-capture and processing. During 1987, the data systems and communications programs continued to support low-Earth orbiting spacecraft for both scientific and applications missions.

Under the Numerical Aerodynamic Simulator program, the Program Support Communications Network successfully supported the interconnection of NASA's supercomputers for use by the aerospace industry.

Aeronautics Research and Technology

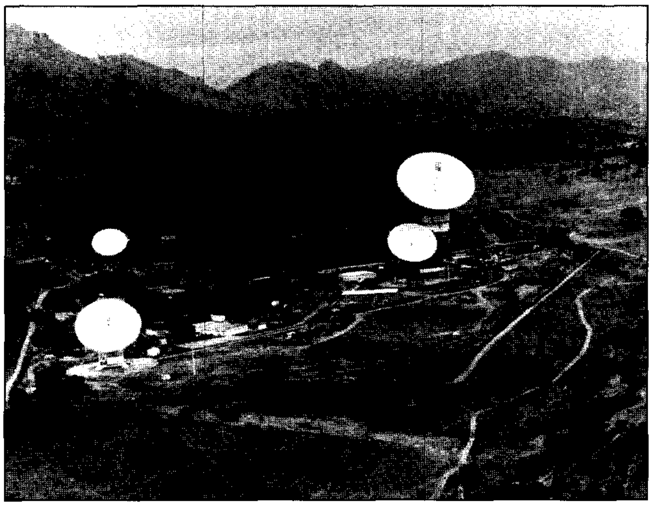
The goal of the NASA aeronautics program is to conduct effective and productive aeronautics research and technology development which contribute materially to the enduring preeminence of U.S. civil and military aviation. In 1987, NASA's aeronautical research and technology efforts continued to expand U.S. capabilities in civil and military aviation, contributing significantly to U.S. world aviation leadership and national security. These efforts covered the spectrum from fundamental disciplinary research to flight testing.



Tracking and Data Relay Satellite System (TDRSS).

The U.S. aviation industry is unique because of its contribution to the balance of trade, its role in national security, and as a symbol of American technological strength and national pride. Since the late 1940's, the United States has been the world leader in the development and application of aviation technology. This world leadership is the result of a solid national technology base and rapid progress in aeronautics research. Today, however, U.S. technology is being challenged by friendly foreign competitors—the European Fighter Aircraft; Rafale; and A320 Airbus—as well as adversaries—the Soviet Su-27 and MiG-29 aircraft.

In 1985, the White House Office of Science and Technology Policy (OSTP) published a report entitled "National Aeronautics R&D Goals: Technology for America's Future" which outlined opportunities for significant advances in aeronautics that could reshape civil and military aviation by the turn of the century. In February 1987, the OSTP published a sequel entitled



Deep Space Network station, Madrid, Spain, using 70 meter antennas.

"National Aeronautical R&D Goals: Agenda for Achievement" which presented a cohesive strategy and an eight-point action plan to achieve the national goals and retain U.S. leadership in the world aviation marketplace. Building on its historically innovative and productive research and technology capabilities, NASA has redirected its aeronautics program to focus on the technologies mentioned in the first report. In addition, it has followed the action plan outlined in the second report by conducting research on emerging technologies which offer the potential for order-of-magnitude advances in aircraft capabilities. Major objectives include providing technology results well in advance of specific application needs and conducting long-term, independent research.

Within NASA, the Office of Aeronautics and Space Technology (OAST) conducts the overall aeronautics research and technology program. The research is conducted at three facilities: Ames Research Center (ARC) at Moffett Field and the Ames-Dryden Flight Research Facility (DFRF) at Edwards AFB, California; Langley Research Center (LaRC) in Hampton, Virginia; and Lewis Research Center (LeRC) in Cleveland, Ohio. These Centers comprise the most comprehensive and unique set of aeronautical research and test facilities in the world and remain an essential resource for aeronautics research and development in the United States.

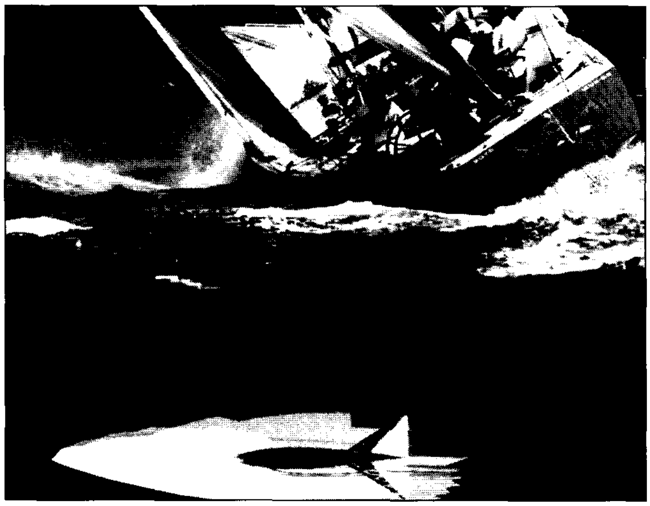
There has been an increasing concern about the condition of the older major NASA wind tunnels and their ability to meet a growing demand. During 1987, an extensive, independent study was conducted to assess the condition of these facilities and the project demand. The conclusion was that NASA must revitalize these critical wind tunnels. As a result, NASA is developing a multi-year program to address this need.

NASA's research program includes both fundamental disciplinary research and vehicle-specific research. Disciplinary research may be generically applied to all classes of vehicles, whereas vehicle-specific research is focused primarily on technology which has the potential for increasing the capabilities of specific classes of vehicles—subsonic transports, rotorcraft, high-performance military aircraft, supersonic cruise aircraft, or hypersonic vehicles. The NASA program has long provided a foundation in the traditional aeronautical disciplines, but NASA also is making significant progress in the application of new disciplines such as artificial intelligence and advanced computational simulation. In addition to the research and technology (R&T) base efforts, NASA has placed additional emphasis on the following specific areas: transatmospheric R&T, numerical aerodynamic simulation (NAS), low noise/vibration rotorcraft, composite materials and structures, high angle-of-attack and supermaneuverability research, aircraft automation, computational fluid dynamics (CFD) code verification, advanced short-takeoff and vertical landing (STOVL) aircraft studies, supersonic fan research, high-speed transport studies, small engine technology, and advanced high-temperature engine materials.

Disciplinary Research and Technology

NASA's disciplinary aeronautical research activities seek to improve the understanding of basic physical phenomena and provide the technological base for new concepts and ideas necessary for future advances. Research activities are in aerodynamics, propulsion, materials and structures, information sciences and human factors, and flight systems.

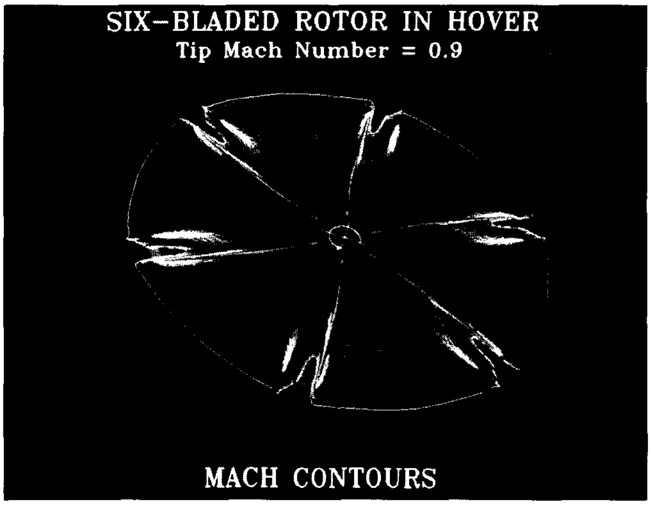
Aerodynamics. With the increasing availability of supercomputers, the discipline of computational fluid dynamics is now providing powerful analytical, simulation, and predictive tools to address the basic physics of aerodynamic flow fields. New CFD tools are being used to advance the understanding of the complex flow environment of advanced aircraft configurations and to permit aerodynamic optimization of new aircraft designs and propulsion systems. During 1987, NASA-developed CFD techniques were applied to the design of the America's Cup yacht "Stars and Stripes." In addition to the use of NASA's CFD codes for hull/keel design, the winning "Stars and Stripes" used two other NASA-developed drag reducing concepts, "riblets," to reduce skin friction drag and swept wingtips (on the keel's winglets) to reduce induced drag.



America's Cup winning yacht "Stars and Stripes" and NASA computational fluid dynamics illustration of hull/keel design.

During 1987, new CFD techniques were applied at Ames Research Center to perform the first numerical simulation of vortex bursting over a double-delta wing configuration, as well as the first computation of three-dimensional (3-D) unsteady viscous flow within a single stage of an engine. At Langley and Ames Research Centers, CFD codes were applied to the simulation of hypersonic vehicle aerodynamics for generic configurations and for the evaluation of designs for the National Aero-Space Plane (NASP) program. Substantial progress was made in developing and testing new solution algorithms for the efficient computation of complex viscous flows. These new algorithms were tested on a variety of applications, including airfoil stall and hysteresis, engine exhaust jets interacting with ground crossflows, and separated flows over wings. As these new algorithms are further developed and validated, they will be applied to realistic vehicle configurations to analyze new design concepts and aircraft performance.

In light of the important long-term payoffs, NASA and Stanford University jointly created the Center for Turbulence Research (CTR) in 1987 to capitalize on the recent advances in supercomputers, instrumentation, and theoretical concepts. This Center provides a synergistic environment for coordinated computational, experimental and theoretical research on the onset, structure, mechanisms and modeling of turbulence. Visiting participants include outstanding senior and junior researchers from universities, government laboratories and industry. Through T1 (1.54 megabits per second) data communication links between Stanford and NASA Ames Research Center, CTR participants have access to the Ames CDC 205, Cray X-MP/48, Cray-2, and prototype NAS computers. Additional support of full turbulent simulations includes funding (jointly with DARPA) and software develop-



Computational fluid dynamics illustration of six-bladed rotor in a hover.

ment for the prototype Princeton Navier-Stokes computer. Delivery of the first prototype is expected in early 1988.

In a related activity, the Computer Networking Subsystem, a high-speed mainframe computer network, which was implemented in 1986 and designed to exchange large bulk files between large mainframe computer facilities located at the NASA Research Centers, was used extensively to support NASP CFD development and application. The ability to validate the new CFD computer codes was advanced through the application of advanced nonintrusive laser-based instrumentation in focused validation wind tunnel experiments. In addition, flight tests, such as the successful F-14 laminar flow glove experiment, were conducted under actual conditions to provide validation data that is not obtainable in ground-based experiments.

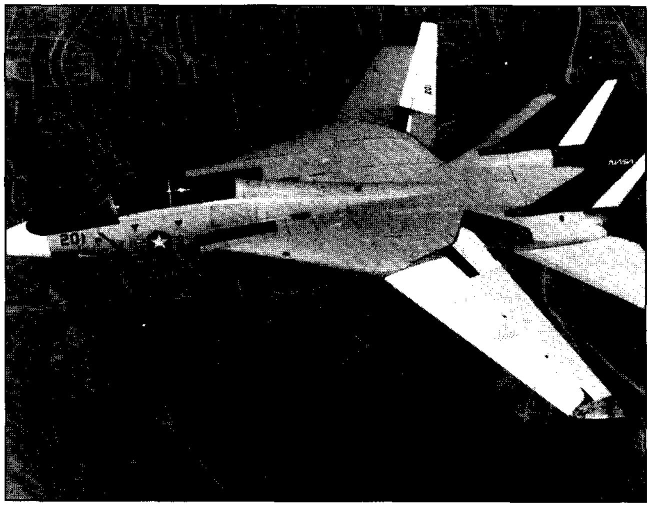
Propulsion. Advances in propulsion technology historically have provided a major share of aircraft system performance improvements and allowed development of new generations of flight vehicles. NASA's current propulsion research is focused on understanding the physical phenomena occurring at the disciplinary, component, and subsystem levels that will lead to future high-payoff improvements in propulsion system capability, efficiency, reliability and durability. The development, experimental validation, and application of internal computational fluid mechanics analysis codes continue to be increasingly important tools in achieving these improvements.

In 1987, an advanced 3-D viscous turbomachinery code was completed at the Lewis Research Center and applied in the aerodynamic design and analysis of a supersonic throughflow fan stage. The predicted ability to achieve such a stage would provide a major breakthrough in high-speed flight by allowing the elimination of inlet length, weight and drag penalties now imposed by current turbomachinery's subsonic throughflow limitation. Advanced computational analysis also is playing a major role in general aviation engine research. During 1987, a single-rotor, stratified charge rotary engine demonstrated significant improvements in both fuel consumption and power density. Additional benefits are projected by enhancing the burn rate through improved internal flow field and combustion process computational analyses. Similarly focused research on small gas turbine engines continued. In 1987, the major accomplishment was the operations startup of three new component research facilities to expand the experimental validation data base.

In the area of improved reliability, an engine control sensor failure detection, isolation, and accommodation system demonstrated successfully analytical redundancy. During full-scale testing in 1987, the system showed that the engine could be operated safely with a faulty and/or inoperative sensor signal through comparison with, and replacement by, analytically derived values. Additional accomplishments in the sensor and control area include the development of a prototype fiber-optic-based sensor, which promises reduced electromagnetic interference sensitivity, laser anemometry and high-temperature electronics for nonintrusive flow field measurements to support the experimental validation of analysis codes.

Materials and Structures. Composite materials are finding increased use in current and future airframe designs because they are lighter and stiffer than conventional metallic aircraft structural materials. A new thermoplastic composite material developed by NASA's Langley Research Center, LaRC-TPI, is being evaluated currently by the aircraft industry for design of high-temperature composite structures. Low-cost fabrication by thermoforming of this material offers the potential for improved aircraft performance. Future plans include a major new initiative in advanced composite materials and structures technology for aircraft systems.

NASA is a leader in the development of analytical methods for transonic aeroelastic analysis of advanced aircraft configurations, including the phenomena of divergence and flutter. These analysis codes are used by the aircraft industry to predict unsteady airloads and flutter phenomena which are critical to the successful design of advanced aircraft. In 1987, a new analytical approach to predict the unsteady aeroelastic response of complete aircraft configuration was developed by the Langley Research Center. This new analysis code, termed Computational Aeroelasticity Program-Transonic Small Disturbance (CAP-TSD), is capable of treating complete aircraft geometries with multiple lifting surfaces. The CAP-TSD method is very efficient when compared with previously used analysis and has received broad interest from the aircraft industry. A complete F-16C aircraft modeled using the new CAP-TSD code correlated closely with experimental wind tunnel data and demonstrated the program's complete aircraft modeling capability. Future plans include performing additional analysis on various aircraft configurations to demonstrate the advantages of this new analytical method.



NASA F-14 research aircraft testing natural laminar flow (NLF) glove.

NASA has made significant progress in determining the fabrication feasibility of silicon carbide reinforced titanium aluminide composites. These materials are being considered for hypersonic vehicle applications, such as the NASP, because of their high strength/density at elevated temperatures. One of the drawbacks of titanium aluminides, however, is their brittle nature. In 1987, Lewis Research Center found that additions of niobium improved the ductility and allowed forming processes to be carried out. These composites were fabricated utilizing a powder-cloth technique. Progress also was made on the development of other aluminides such as iron aluminide and niobium aluminide. During the past year the potential hydrogen compatibility problem of the titanium aluminides under the projected service conditions was identified by Ames Research Center. Further efforts to determine the effects of hydrogen on material performance are underway.

Information Sciences and Human Factors. NASA is conducting research in cooperation with the

FAA to provide a means for increasing the efficiency of the Air Traffic Control (ATC) system in the United States. During 1987, a time-based terminal area flow control concept was evaluated in the Ames Research Center ATC simulation system. This concept is designed to allow new techniques for fully utilizing runway capacity and improving fleet operational efficiency while enhancing operational safety within the National Airspace System. Flight evaluation of this concept is planned for the Denver terminal area in 1988-1989.

Research in human factors and automation is exploring the potential for artificial intelligence (AI) computer systems and improved methods of control to enable humans and automated machines to work together more successfully. A primary example of progress in the area of man-machine integration is the work underway at the Ames Research Center examining error tolerant cockpit systems. This exploratory program is focused on the development of methodology leading to safer transport cockpit system designs. In 1987, field studies were conducted to examine crew operations in highly automated cockpits.

Flight Systems. Improving flight safety through research into the operating environment is viewed by NASA as vital and is being addressed with research related to natural phenomena and to operational flight systems. Storm hazards research concentrates on lightning and rain effects while NASA's Aircraft Icing Program is focused on the problems caused by aircraft icing. Heavy rain can change airfoil effectiveness and the airflow, and cause a loss of airplane performance, possibly severe enough to reduce safety margins. Tests conducted last year in the Langley Research Center's 14- by 22-foot wind tunnel, using a wing section model, revealed that the maximum lift was reduced by 20 percent during periods of very heavy simulated rainfall. In 1987, the installation of a water spray system was initiated over a span of track at the Aircraft Landing Dynamics Facility in order to conduct tests on a section of a full-scale wing. The wing section will be mounted on a moving carriage which will be propelled along the track and through the simulated heavy rain of the spray system. Performance degradation of the wing's lift and drag will be determined.

NASA icing research develops analytical and experimental methods to determine the changes in aircraft performance and handling qualities due to ice accumulation on aerodynamic surfaces. Little or no quantitative icing data has previously existed that is useful for the complex engineering analyses which are required to determine these icing effects. In 1987, initial evaluation of computer simulation codes for iced airfoil performance were completed and the results were found to compare closely with experimental data from wind tunnel and flight tests. Calibration efforts for the Icing Research Tunnel were begun following the complete rehabilitation of the tunnel, a facility that is unique in the free world.

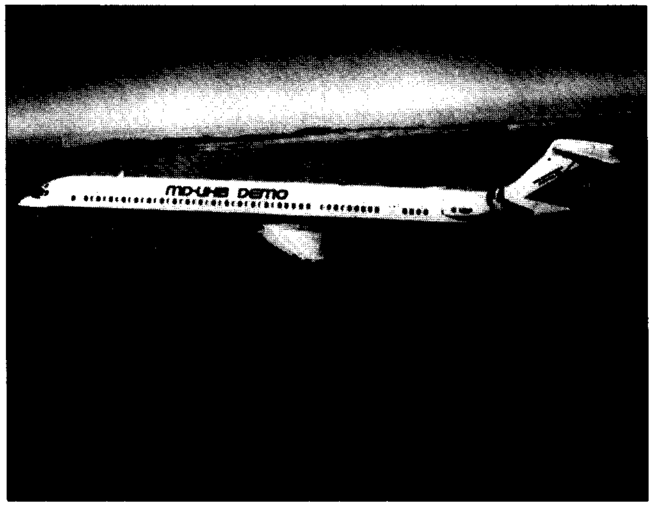
Progress was made this year in utilizing both the power of new aerodynamic computational methods and parameter identification techniques to model low altitude wind shear characteristics. This atmospheric phenomenon, characterized by large, rapid changes in wind magnitude and direction over small changes in altitude, is a potential hazard to all aircraft, especially during takeoff and landing. During 1987, these wind shear computer models were used to develop and evaluate a wind shear hazard warning index to provide aircrews advance warning of hazardous wind shear conditions. Also during 1987, studies of two candidate airborne sensor concepts were initiated. These concepts are airborne doppler radar and airborne light detection and ranging (LIDAR). Flight evaluation of one or both concepts will be conducted over the next several years.

Systems Research and Technology

Transports. NASA works closely with aircraft manufacturers, the airlines, the Department of Defense (DOD), and the Federal Aviation Administration (FAA) to advance the technology for subsonic transport aircraft. This close relationship is essential to the timely introduction of new technology that assures the United States preeminence in this important world market. The long-range goal of subsonic transport research is to establish the technology readiness that will permit future aircraft designs with twice the fuel efficiency of today's best transport aircraft while substantially increasing their productivity and affordability.

In 1987, large-scale propfan propulsion system flight evaluation activities were continued by NASA and industry as part of the Advanced Turboprop Program (ATP). A large-scale (9-foot diameter) propfan was installed and flight tested on a Gulfstream II twinjet. Speeds up to Mach numbers of 0.85 and altitudes of 5,000 to 40,000 feet were flown as power loading on the propfan was varied. All blade stresses were consistently below unlimited life levels and noise levels agreed closely with model test data and analytical predictions. Preparation for low-altitude community noise testing at NASA Wallops Flight Facility was also initiated during 1987.

Significant progress was achieved in the joint NASA/General Electric Unducted Fan (UDF) program. This ungeared concept incorporates two unducted, counter-rotating fans with eight highly swept blades on each fan. This configuration has promise because it reduces the wake swirl common to single rotation designs and further increases the propulsive efficiency. The UDF system successfully completed flight testing on a modified Boeing 727 in February 1987. Flight condition ranges up to Mach numbers of 0.84 and altitudes of 35,000 feet were attained. Blade stresses were well within limits and acoustic data agreed closely with predictions. General Electric, in conjunction with McDonnell-Douglas, also began conducting flight tests on a modified McDonnell-Douglas MD-80 aircraft.

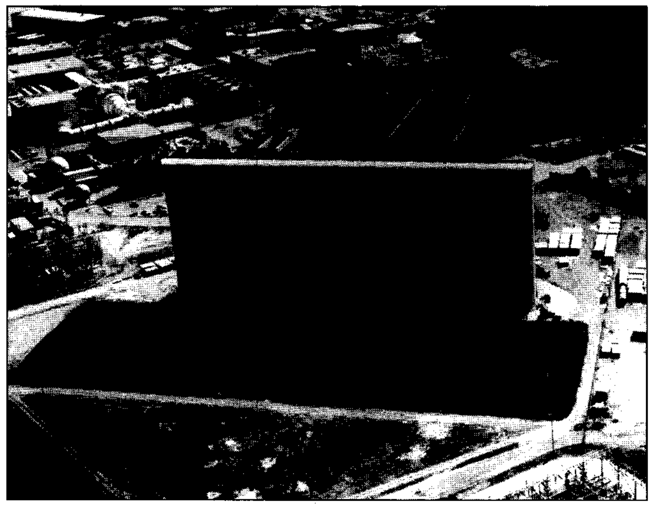


MD-80 aircraft flight testing the NASA/General Electric Unducted Fan (UDF) engine.

During subsonic flight, approximately one-half of the aircraft's total drag is caused by skin friction which is strongly a function of whether the airflow over the aircraft's surface is laminar (smooth) or turbulent. It has long been known that laminar flow reduces skin friction. NASA is investigating three concepts for maintaining laminar flow over aircraft surfaces: passive natural laminar flow (NLF) which is achieved with careful airfoil design and is applicable to small airplanes; active laminar flow control (LFC) which is achieved by suction through tiny slots or perforations in the surface and is applicable to transport aircraft; and hybrid laminar flow (HLF) which uses both active and passive techniques and also is applicable to transports.

Previously conducted wind tunnel and flight tests of a full-sized proof-of-concept NLF wing on a Cessna 210 aircraft demonstrated that the new airfoil achieved natural laminar flow over 70 percent of the upper and lower surfaces over a broad range of operating condi-

Artist's concept of a High-Speed Civil Transport.



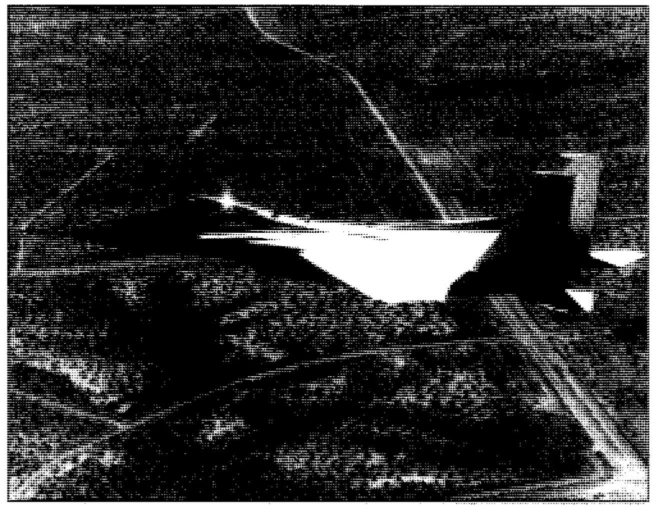
Upgraded National Full-Scale Aerodynamics Complex, featuring the inlet to the new 80-by-120-foot test section.

tions. A contoured NLF "glove" was installed on the wing of a Boeing 757 aircraft in the region of intense acoustic radiation from the turbofan engine and flight tested. It demonstrated that laminar flow could be maintained in close proximity to engine noise and on the moderately swept wings of commercial transports. An important milestone in active laminar flow control technology was achieved when flight evaluations on a Jet Star verified the effectiveness and practicality of two different system concepts for maintaining laminar flow over the leading edge of the wing while operating under representative commercial airline operations. In 1987, a NLF glove was flight tested on a variable-sweep wing F-14 aircraft and provided fundamental data on the stability of laminar flow at various sweep angles. Also in 1987, a contract was awarded to the Boeing Company to conduct the next phase of laminar flow research which will concentrate on hybrid laminar flow control (HLFC), a combination of the best features of both active and natural laminar flow. HLFC is expected to achieve a substantial reduction in aircraft drag. Under this NASA/DOD/Boeing jointly funded program, a gloved HLFC wing section will be flight tested on a Boeing 757 beginning in 1988.

Achieving the promise of economic, high-speed air transportation has eluded the technical community for some time. However, the market for an economically viable and environmentally compatible long-range, high-speed civil transport appears to be substantial. NASA, in close cooperation with industry, is currently conducting High-Speed Civil Transport studies to assess the market and economic factors and to define the most promising vehicle and propulsion system concepts for future long-range, high-speed (Mach 2.0 to hypersonic) civil transports necessary to guide U.S. technology development efforts.

Rotorcraft. The Nation's continued leadership in military and civil rotary wing technology depends on a strong and broad-based research program. In cooperation with other Government agencies and industry, NASA conducts rotorcraft research that addresses the fundamental areas of aerodynamics, structural dynam-

High-speed rotor on Boeing Model 360 helicopter.



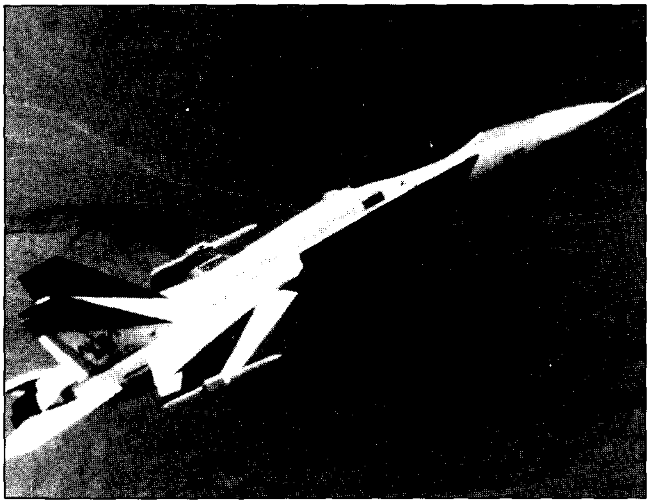
NASA F-15 research aircraft flight testing the Highly Integrated Digital Electronic Control (HIDEC) system.

ics, acoustics, guidance, stability and control, propulsion and drive systems, and human factors to exploit the full potential of this unique vehicle class. In 1987, there were a number of significant accomplishments in the key areas of noise reduction, improved rotor performance, and high-speed performance.

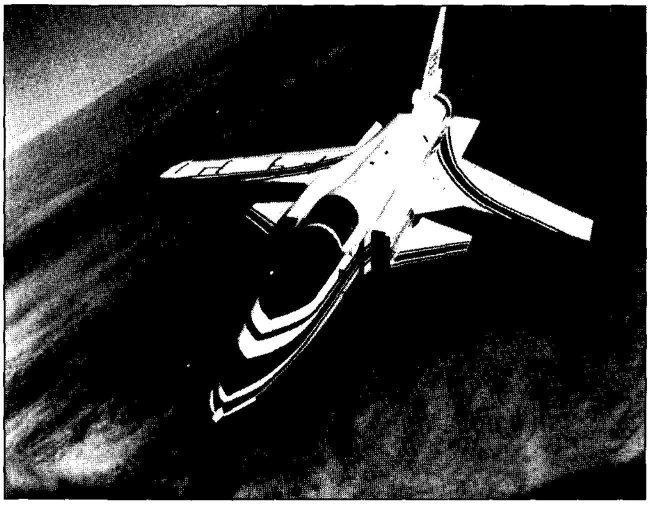
Reducing rotorcraft noise is essential for community acceptance and to reduce detectability. A new helicopter total system noise prediction code, called ROTONET, has been developed and a second generation code was made available to industry in 1987. Additional aeroacoustic experiments were conducted in a large German-Dutch wind tunnel which measured rotor blade pressures, airloads, and acoustics systematically in a controlled environment for the first time. The results of this test are being included in ROTONET. In addition, a comprehensive main rotor/tail rotor interaction test was conducted that will enable the development of a semi-empirical noise methodology for ROTONET.

Also in the area of noise reduction, a wind tunnel test was conducted to evaluate the feasibility of active control to reduce blade-vortex interaction noise. Computation prediction methods were used to select the specific test conditions which demonstrated an 80-percent (3 to 4 db) reduction in this impulsive noise source.

At Ames Research Center, the upgraded 40- by 80-foot wind tunnel of the National Full-Scale Aerodynamics Complex (NFAC) became operational in May and a new 80- by 120-foot tunnel was dedicated on December 11, 1987. The major upgrade was the installation of four 130,000 horsepower motors to drive the common fans. Speeds up to 345 mph (up from 230 mph previously) are now attainable in the 40- by 80-foot tunnel and up to 115 mph in the new 80- by 120-foot tunnel, which has a test section three times larger in cross-section area. Both test sections also have been acoustically treated to minimize noise levels. The first major test conducted in the 40- by 80-foot tunnel was a large-scale model V-22 tiltrotor wing/nacelle/



NASA F/A-18 High Angle-of-Attack Research Aircraft during flight test. Angles-of-attack up to 70 degrees are anticipated.



X-29 Forward Swept Wing aircraft during follow-on agility and maneuverability testing.

rotor, conducted at the request of the Navy, and will be followed by a series of high-priority tests including a model for the Army's LHX (Light Helicopter Family) program.

Also in support of the LHX program, Phase I flight testing of a highly instrumented UH-60 was completed and reported to industry. This test was significant since it obtained detailed blade loads data of a rotor in high-speed maneuvering flight for the first time.

The first flight of the NASA/Boeing/Army advanced High-Speed Rotor on the new Boeing Model 360 helicopter occurred in June 1987. NASA and the Army are cooperating with Boeing Helicopter for special instrumentation to gather research data for analysis and correlation on the advanced rotor. Flight at more than 200 knots is expected in 1988, and a new helicopter speed record is possible.

Lewis Research Center provided key support to a major new Army program in advanced rotorcraft transmissions. This effort will provide the technology base to reduce helicopter drive train weight by 25 percent, reduce the source of noise of the transmission by 10 db, and increase the mean time between removal to 5,000 hours.

A comprehensive tilt rotor technology report was issued that detailed the promise of civil tiltrotor applications and outlined an integrated technology plan. The study reported that a $3 to $4 billion a year market existed, primarily for city-pair commuter service that would save trip time and relieve airport congestion.

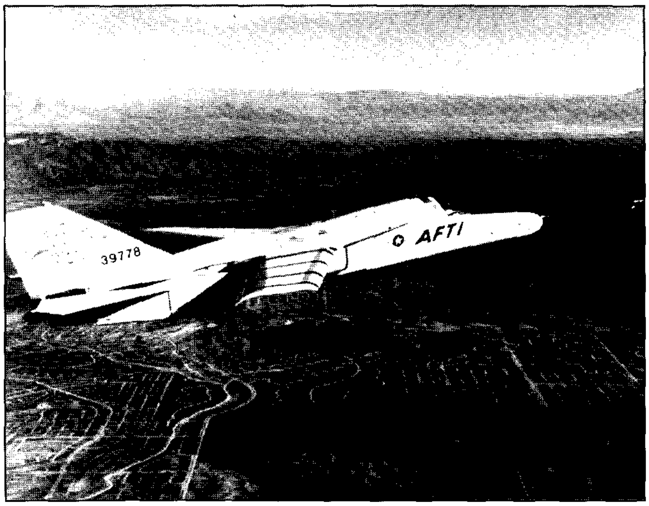
The Rotor Systems Research Aircraft (RSRA)/X-Wing research vehicle was cleared to begin flight testing in September 1987. The X-Wing rotor is a four-bladed, extremely stiff rotor system that utilizes circulation control aerodynamics for lift and control. In hover and low-speed flight, the rotor system rotates as a conventional helicopter rotor, but in high-speed forward flight, the rotor is stopped in a fixed X-Wing configuration. This joint NASA/DARPA/Sikorsky program continues the effort to advance the state of technology in high-speed rotorcraft flight. First flight of the RSRA/

X-Wing vehicle with the rotor hub, but without the rotor itself, was made at the Ames-Dryden Flight Research Facility in December 1987.

High Performance Aircraft. NASA's high performance aircraft research provides long-range, high-risk technologies applicable to future military aircraft and is planned and conducted in close coordination with the DOD. Much of this research, however, is equally applicable to civil aviation.

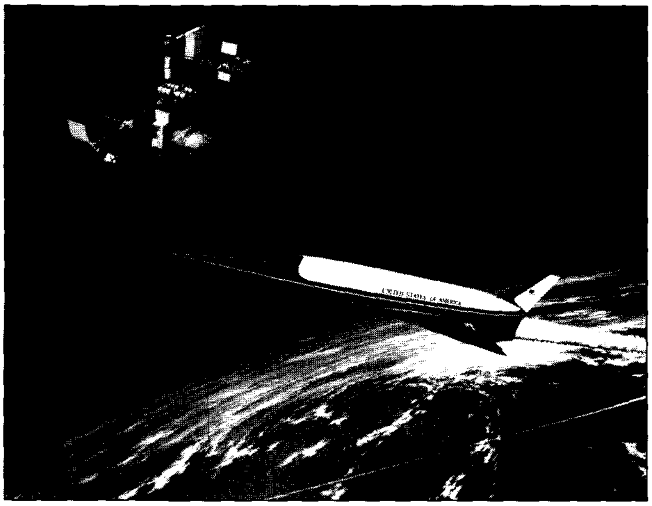
Flight tests have been completed in an F-15 at Dryden on the Highly Integrated Digital Electronic Control (HIDEC) system, the first system to integrate an aircraft's propulsion and flight control systems. It featured an Adaptive Engine Control System (ADECS) which increased the engine's efficiency by reducing the operating stall margin when conditions permitted. The initial results were reported to industry via a symposium held at Dryden in March, and the final results will be reported in 1988. Flight testing with two modified engines demonstrated performance improvements of up to 25 percent in certain portions of the flight envelope.

In 1987, both ground and flight research activities were accomplished to assess high angle-of-attack flight technologies for high performance aircraft. A modified and highly instrumented F/A-18 High Angle-of-attack Research Vehicle (HARV) was flown on its first research flight in April. The objective of the first phase is to obtain and assess the aerodynamic characteristics of vortex flows at high aircraft angles-of-attack and correlate them with the results of computations, wind tunnel experiments, and simulations. The vortex flow around the aircraft forebody and wing leading edge extension was visualized on-surface by colored dye and off-surface by natural moisture and smoke. Angles-of-attack up to 40 degrees have been explored to date, and it appears that angles-of-attack in excess of 70 degrees are possible. The results of these flight tests will be applicable to the designs of future high performance aircraft. In July, a contract was awarded to install thrust vectoring devices on the HARV in order to further explore the high alpha and supermaneuverability flight regimes in the next phase of flight testing. The final design is expected to be completed by April 1988.



AFTI/F-111 Mission Adaptive Wing (MAW) aircraft in flight. The wing has a variable camber that can be changed during flight.

Advances in propulsion system thrust-to-weight ratios, propulsive lift control, and the understanding of low-speed aerodynamics combine to open new opportunities for significant advances in vertical/short takeoff and landing (V/STOL) aircraft technology, as well as for new short takeoff and vertical landing (STOVL) aircraft concepts. In 1987, the United States and the United Kingdom continued the joint research program begun the previous year to reduce the technological risk associated with development of advanced STOVL aircraft. In an ongoing joint effort with Canada, Ames Research Center will begin testing a large-scale STOVL model in the new NFAC in 1988. The model is of a transonic fighter aircraft configuration, designated the "E-7," which utilizes vectored thrust and thrust augmentation systems for low-speed operations. As part of this program, a full-scale ejector



Artist's concept of the National Aerospace Plane.

was tested in 1987 at the Lewis Research Center's new Powered Lift Facility, and the thrust augmentation ratio was determined to be greater than predicted for the system.

The first envelope expansion phase of X-29 Forward Swept Wing research aircraft flight testing was successfully completed in 1987. The flight envelope was expanded to a Mach number of 1.4 at 40,000 feet and the aircraft drag polar was determined to be better than predicted. The results demonstrated the successful integration of several advanced technologies including a composite, thin, supercritical, variable camber, aeroelastically tailored forward-swept wing; close-coupled canard; straked flaps; relaxed static margin (up to 35-percent negative); and an advanced fly-by-wire digital control system. A follow-on NASA/Air Force flight research program has been initiated using the first X-29 aircraft. The areas of research include agility and maneuverability, high angle-of-attack stability and control, low-speed control, and transonic aerodynamic efficiency. A second X-29 is being modified and instrumented to conduct a high angle-of-attack research program and investigate other areas of interest. The first flight of the second aircraft is expected in 1988.

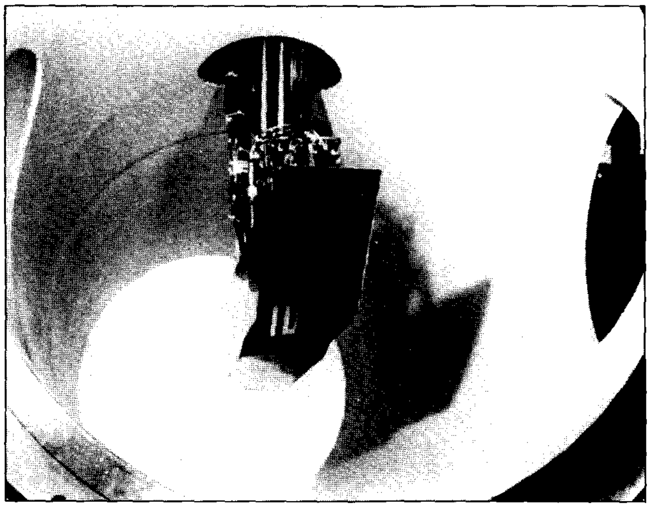
The Advanced Fighter Technology Integration (AFTI)/F-111 Mission Adaptive Wing (MAW) is a testbed aircraft with a wing modified so that its camber can be changed in flight. The manual mode phase of the program was completed in June 1987 (26 flights/58 hours total). The flight envelope was cleared to a Mach number of 1.3, and the performance results were better than predicted for the smooth, variable-camber wing. Drag reductions of 8 percent at the design point, and up to 20 percent at off-design points, were realized during flight testing. After the aircraft was modified, the automatic variable-camber portion of the flight test program began in September and is scheduled to be completed in July 1988.

Hypersonics. One of the key technology thrusts of the aeronautics program being pursued by NASA is the technology foundation for hypersonic vehicles. The program focuses on vehicle configuration studies, propulsion, and materials and structures. Recent NASA accomplishments in these areas, combined with earlier progress in hypersonic research, have contributed to the state of readiness for the NASP program being funded jointly by the DOD and NASA. The NASP program may result in a hypersonic flight research vehicle (X-30) which would be used to validate and demonstrate the successful merging of aeronautics and space technologies into a flightworthy vehicle. NASA maintains a strong research and technology base effort within its aeronautics program in support of the NASP and for future advances in hypersonic flight vehicles.

During 1987, continued testing in the Langley hypersonic propulsion wind tunnels demonstrated that measured thrust levels agreed with theoretical predictions for airframe integrated supersonic combustion ramjet (scramjet) engines. Significant progress on variable geometry scramjet configurations was achieved with the successful testing of the variable geometry inlet configuration at a Mach number of 4.0 and with the accomplishment of a Navier-Stokes flow analysis for the transition area of the engine combustion section. These 1987 accomplishments are significant steps toward achieving a hypersonic propulsion system that can be operated over broad ranges of speeds and altitudes.

In related structures research, an advanced technology fuel injection side strut for the scramjet engine was fabricated using a complex brazing process. Two shortened versions of a full-size, flight-weight article were assembled successfully. This effort demonstrated the feasibility of this design approach and preparations are now underway to test the strut assembly with burning fuel in Langley test facilities. Accomplishments in hypersonic structures also included progress with the fabrication of load-carrying, honeycomb panels of high-temperature superalloys. A panel array of superalloy honeycomb material was successfully tested at extremely hot temperatures under hypersonic flow conditions.

NASA's numerical aerodynamic simulation capability, now in operation, provided vital support to the technology development program by enabling the calculation of pressure contours on a baseline NASP configuration. The capability to provide an analytical solution for the NASP configuration at high Mach numbers allows analysis and prediction of vehicle aerodynamic loadings and aerothermodynamic interactions at Mach numbers beyond the capability of existing ground test facilities.



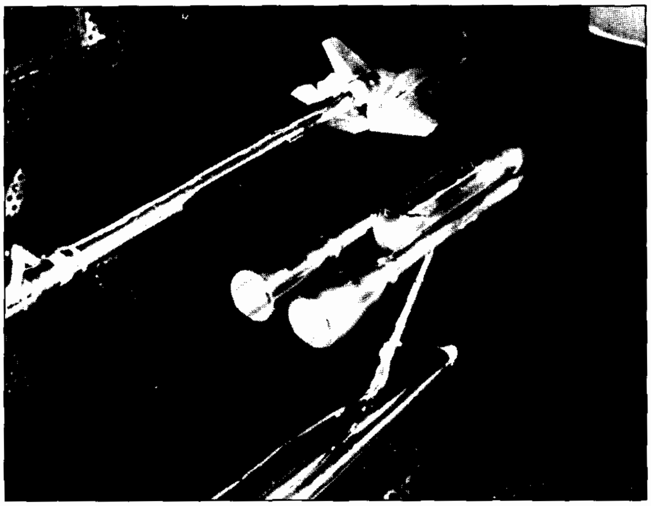
Variable geometry scramjet during testing in hypersonic wind tunnel.

National Aero-Space Plane (NASP) Program

In February 1986, President Reagan announced the National Aero-Space Plane program to Congress and the Nation during his State of the Union Address, directing NASA and DOD to proceed with plans for the program. The goal of the joint DOD/NASA program is to develop and demonstrate hypersonic and transatmospheric technology for a new class of aerospace vehicles powered by airbreathing, rather than rocket, propulsion.

The NASA OAST centers are heavily involved in the extremely complex technical challenges of the NASP program. In 1987, the program completed the conceptual design phase and is now into the preliminary design and component development phase. The competition has been reduced to three airframe and two engine contractors. This phase will lead to a decision in early 1990 on whether or not to build and test the X-30 research vehicle. This program presents challenges in all technologies in which OAST engineers and scientists have expertise. The success of the program depends heavily on their technical guidance.

One of the technical areas in which NASA is making major contributions is the application of computational fluid dynamics (CFD) analysis methods. Since the X-30 will fly in a hypersonic regime which cannot be adequately simulated in ground facilities, CFD will have to be used to extrapolate beyond these facility limits and describe the aerothermodynamic environ-



Wind tunnel testing to determine the feasibility of separating the space shuttle orbiter from the boost stack during Solid Rocket Motor burn.

ment in which the vehicle must operate. In order to accomplish this formidable task, CFD codes must be developed to the point of providing three-dimensional (3-D), real gas, viscous flow capability with finite rate chemistry where needed. The needs of NASP, and the funding support provided by it, have propelled CFD development forward significantly during 1987. Three-dimensional CFD codes, developed by NASA, are now being applied by Government and contractors for vehicle aerodynamics and internal propulsion flows. Real gas effects and finite rate chemistry are now being added to these capabilities. Codes for combustors and nozzles are being developed and methods for reducing costly computer time are being implemented. Experimental tests are being planned for validation of these codes and some progress already has been made. During 1988, significant progress is expected to be made in these areas.

Another area in which major work was initiated is in boundary layer transition. There is a critical need for analytical means of predicting the length and stability of laminar flow and the onset of transition to turbulent flow in the boundary layer at hypersonic speeds. The validation of the analysis with very specific experimental tests is also critical. Both have been addressed in a NASP-sponsored program at Langley. Early results indicate that analysis methods which are successful at transonic speeds also may be successful at hypersonic speeds.

Considerable progress has been made defining local thermal loads in areas of complex shock interactions. Both analytical and experimental results have now been published and are being used in the design of the X-30.

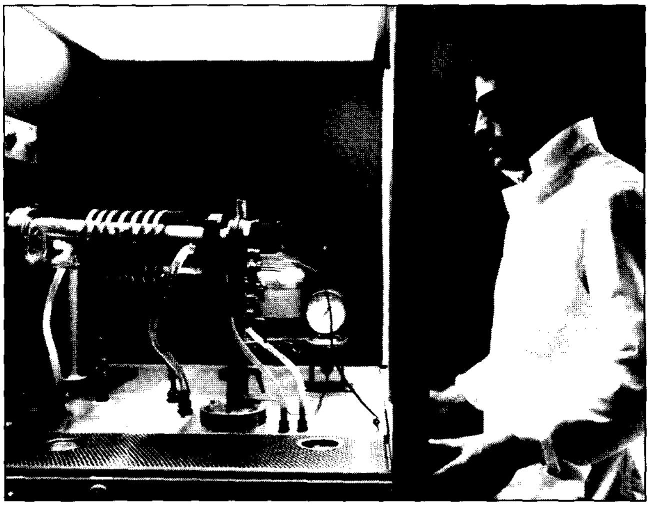
Space Research and Technology

The goal of the Space Research and Technology (R&T) program is to establish a recognized leadership role for space research and technology by providing capabilities and talent for all national space sectors as well as civil mission opportunities. This goal requires a national commitment to research in the scientific and engineering disciplines required for future national programs for the exploration and exploitation of space. Advancements in the technology base are essential for the conceptualization and design of advanced space vehicles that provide low-cost access to space, permanent human presence in space, advanced study of the Earth, and potential future manned space missions. Discipline and systems technologies included in the program are propulsion, space energy conversion, aerothermodynamics, materials and structures, controls and guidance, automation and robotics, human factors, computer science, sensors, data systems, and communications. All NASA centers are involved in the Space Research and Technology program, along with significant participation by industry and universities.

The technology program also serves the long-term needs of civil, commercial, and military uses of space. An important part of this support is space-based experimentation to conduct research and to validate technology in that unique environment. The goal is to provide NASA and the aerospace engineering community with on-orbit laboratory capability, primarily using the Shuttle and later the Space Station when it becomes operational.

Propulsion. This area of research continues to develop the technology base for all types of chemical and electrical propulsion systems. The chemical propulsion technology program focuses on key life-extension and performance issues associated with Earth-to-orbit (ETO) and space-based orbit transfer vehicle (OTV) propulsion systems. Significant progress is being made to develop advanced component designs for future ETO propulsion systems. To enable longer life cryogenic bearings, a thermal environment model has been developed and validated by data obtained in a bearing test rig. A new powder metallurgy technique for fabricating bearings has been developed and will be used to make new ball bearings for evaluation in the bearing test rig. Advanced single-crystal hollow turbine blades have been evaluated in a burner test rig and show promise of extending blade life up to 30 times that expected with currently used directionally solidified materials. A method of detecting engine anomalies by viewing the exhaust plume with a spectrometer has been developed and has been used to detect degrading bearing materials in the plume. With further development, the instrument will be reliable enough for active engine shutdown in real time. This and other diagnostic sensors have been developed for installation on a Space Shuttle main engine testbed, which is scheduled for initial operation in June 1988, to verify the performance of advanced technology components in a system-level environment.

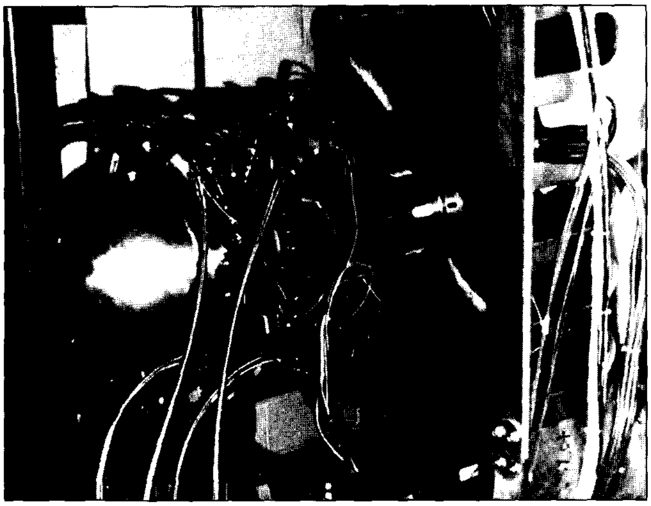
For OTV propulsion, testing was begun on an advanced liquid oxygen/hydrogen testbed engine designed to explore technologies for a reusable, space-based vehicle. This vehicle will require small, high-performance, variable thrust engines that can be stored and fueled in space. Test results comparing two engine options indicate that the necessary high operating pressures are achievable with the simpler option.



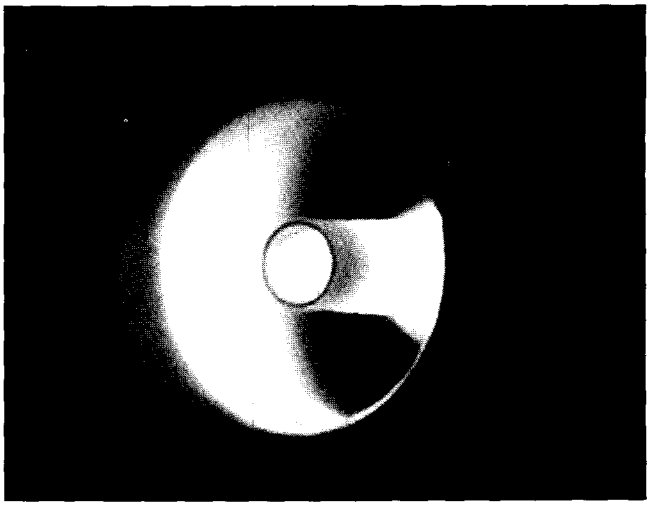
Equipment used at the Lewis Research Center to make indium phosphide (InP) solar cells that will have good performance and resistance to natural space radiation.

High-pressure operation ensures high-engine performance over a wide throttle range, with smaller engine size for a given thrust level. The simpler engine cycle promotes longer service life and easier in-space maintenance and reduces the number of diagnostic sensors needed for engine health monitoring. This is essential for automated between-flight inspection and checkout and for fault-tolerant engine operations.

In electric propulsion, advances were made from research on magnetoplasmadynamic (MPD) thrusters. Electric propulsion will provide significant advantages for planetary missions, as well as for satellite altitude control and orbit changing. Compared to chemical systems, the MPD thruster proposed for advanced propulsion systems has the potential to provide a twofold to fourfold reduction in propellant mass. An MPD thruster was tested that would have many advantages as a space propulsion system. It is both simple in concept and compact in size. Basically, it consists of a central cathode rod within a cylindrical



The Space Power Demonstrator Engine, developed to demonstrate the technology required to convert the heat output of a space nuclear reactor into electrical energy.



Testing of the magnetoplasmadynamic (MPD) thruster at the Jet Propulsion Laboratory.

anode. Thousands of amperes are passed between the two, ionizing and accelerating a propellant gas. During partial-power tests to date, erosion of the components has been negligible, indicating progress in solving this critical technical problem.

Space Energy Conversion. This area of research develops the technology base for high-performance, long-life power systems for space applications. Progress in improving the performance of solar photovoltaic (PV) cells and arrays continued. Indium Phosphide (InP) solar cells, a type that combines good performance and efficiency with improved tolerance to natural radiation, have been fabricated. Using a chemical vapor deposition process reactor, a carefully controlled layer of InP has been formed on a cell, leading to higher efficiency. Cell energy output has been raised from 13 percent to 18.8 percent, and recent efforts indicate that 20 percent is achievable. In geosynchronous orbit, conventional silicon solar cells can lose up to 25 percent of their output during a 7-year life; and in the low-Earth orbit radiation belts, the loss can be as high as 80 percent. Measurements to date have shown InP cell efficiency to be essentially unaffected by natural radiation. This means future solar arrays can be smaller and lighter by eliminating the need for systems oversizing to accommodate efficiency losses due to radiation damage.

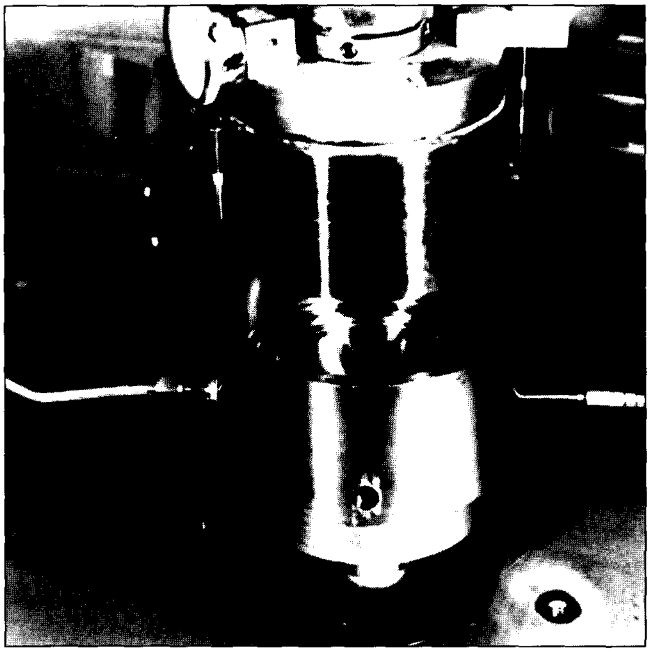
Potential future manned outposts will require power systems that can provide hundreds of kilowatts of power for 7 to 10 years. Dynamic conversion systems in conjunction with the joint DOD/DOE/NASA Space Nuclear Reactor Power System (SP-100) Program are being developed to meet this need. The Space Power Demonstrator Engine (SPDE) was fabricated to demonstrate technology necessary to proceed into the final design of space-qualified free-piston Stirling engines. The SPDE Power module was tested over a wide temperature range achieving a 25-kilowatt power level at 22-percent efficiency. Alternator bench tests and analyses indicate that by substitution of nonmagnetic material into the alternator the 25-percent efficiency goal will be achieved. The SPDE will be used to test, develop, and validate design codes and components for the next generation Stirling engine.

Progress was made in another approach for high-efficiency conversion of thermal energy to electricity. The alkali metal thermoelectric conversion system can generate electricity from a radioisotope or reactor heat source with essentially no moving parts. A new electrode material was discovered and demonstrated which shows promise of meeting the initial goal of 15-percent system efficiency.

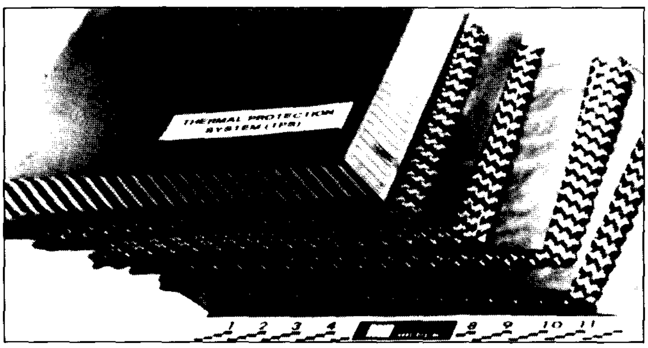
Aerothermodynamics. This area of research advances understanding of the flow phenomena of aerospace vehicles, both for the development of advanced vehicles and to predict and understand the performance of existing vehicles in unusual flight regimes. The development of advanced aerospace vehicle systems requires well-chosen, ground-based experiments and use of the most advanced computational codes.

To improve the safety of the Space Shuttle, the feasibility of separating the Shuttle orbiter from the booster stack during Solid Rocket Booster burn was studied. Wind tunnel tests were conducted from Mach 0.6 to 4.5 to establish the data base required to perform separation simulation studies. This aerodynamic data was used in computer simulations which calculated precise separation trajectories and determined angle-of-attack/wing loading limits and potential plume impingement problems. The studies show that it is aerodynamically feasible to separate the orbiter from the lower stack from Mach 0.9 to Solid Rocket Booster separation at Mach 4.0.

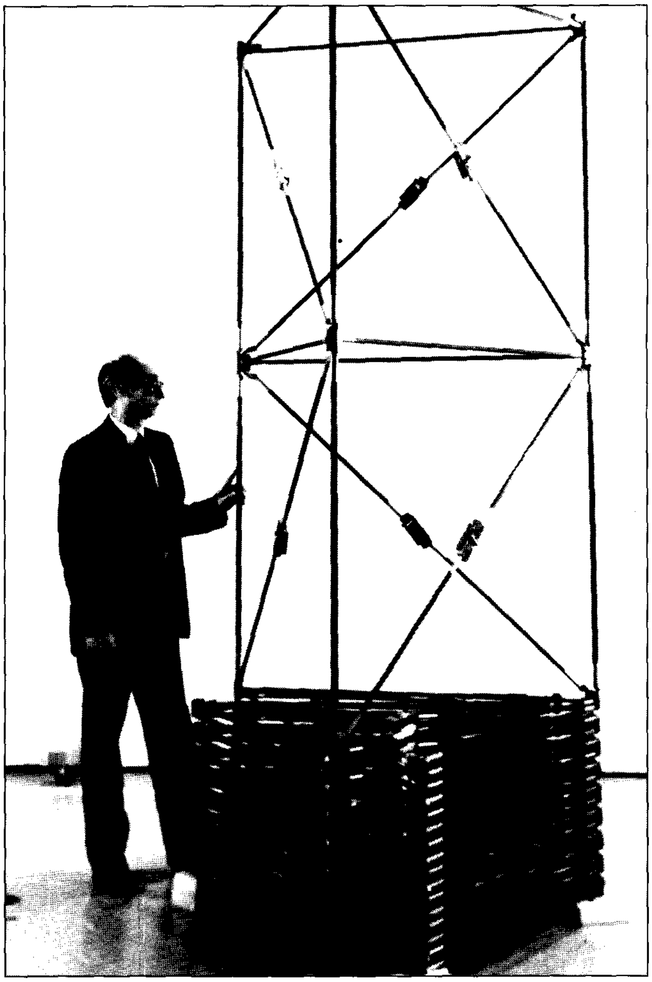
The ability to return vehicles from high-Earth orbit, geostationary orbits, and the Moon, would be greatly enhanced by using the Earth's atmosphere as an aerobrake instead of using rockets. This would reduce fuel and mass requirements and could allow servicing missions to geostationary satellites. The ability to design and use aerobraking technology depends on



Special test fixture developed at the Langley Research Center to qualify O-ring materials for the space shuttle Solid Rocket Motors.



An expanded view of a titanium multiwall tile for cryotank (liquid oxygen and liquid hydrogen tank) construction that will provide strength and insulation at substantially reduced weight.



Deployable, 20-meter mast that will be used to develop dynamic analysis and ground test methods to suppress the vibrations of large, flexible structures in space.

the ability to model the aerodynamic heating and flow using computational fluid dynamics. In order to develop this capability, an Aeroassist Flight Experiment (AFE) is planned to be launched and retrieved from the Space Shuttle. Mach 20 flow tests of the AFE forebody have been completed in a NASA hypersonic helium wind tunnel. Aerodynamic performance characteristics (force and moment data) have been defined for this vehicle concept as a function of angle-of-attack. Flow visualization techniques clearly indicate shock shape and shock standoff distances which are critical in determining the aerodynamic loads and aeroheating data base and for calibrating with computational fluid dynamics codes.

Materials and Structures. This area of research will improve the safety of existing vehicles, as well as advance the technology for future spacecraft, large area space structures, and advanced space transportation systems.

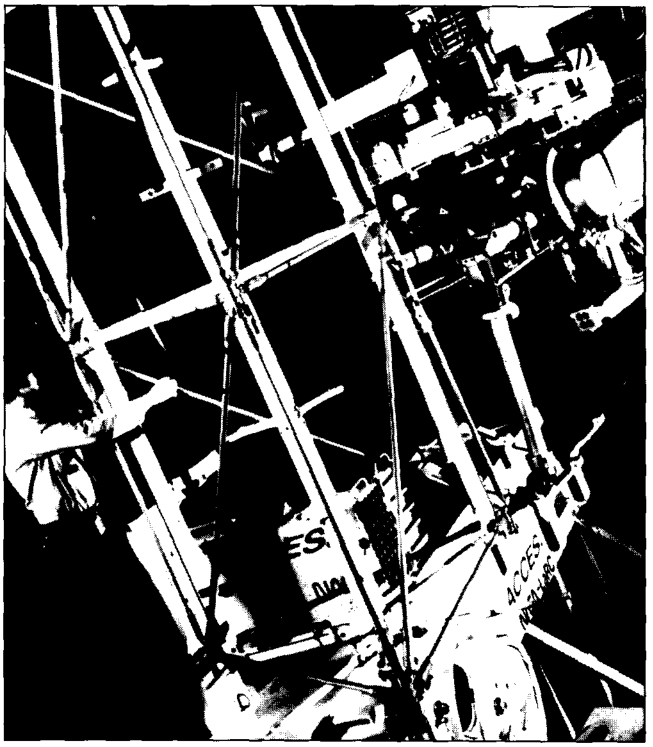
To improve the safety of the Space Shuttle and to support NASA's recovery from the Challenger tragedy, OAST was actively involved in the redesign of the Space Shuttle solid rocket motor field joint under the materials and structures program. A significant part of this effort was directed toward developing a test procedure for qualifying candidate O-ring materials. A test method has been established as the standard for O-ring materials. Three tests are involved in the procedure: a resiliency test; a vibrational damage resistance test; and a test simulating in-situ conditions, including temperature, gas pressure and controlled gap closure. Special fixtures were developed for these tests.

To improve the performance of vehicles which require cryogenic fuels, current research is focused on design fabrication of evacuated multilayer concepts for lightweight cryotank insulation. The goal is to reduce structural weight from 1.5 lbs per square foot to 0.3 lbs per square foot over the temperature ranging from 900°F on the exterior to -423°F on the interior. A multiwall thermal protection system has been fabricated from titanium foil formed into a dimpled pattern and bonded to titanium separation sheets. The entire multilayer assembly has been enclosed with a titanium cover sheet with scarfed edges. Plates measuring 12-inches by 12-inches have been fabricated and tested to evaluate their potential for advanced thermal protection applications.

In the area of large structures and control, a mast having 18 bays, 162 structural members and 111 folding joints has been developed and tested. It weighs about 70 kilograms and measures about 1.2 meters on each side. This mast will serve to develop dynamic analyses, ground test methods and control methods to suppress motion for future large space structures. Initial predictions of bending modes have correlated well with test data. Very detailed analyses of the joints have been conducted to predict their contribution to overall stiffness. Vibration damping measurements indicate a somewhat smaller contribution from the joints than expected.

Controls and Guidance. This area of research is focused on control of large, flexible space systems; large antennas; and large, segmented astrophysics telescopes. Developments in this area are focused on demonstrating advanced control concepts on generic large space structure hardware; developing innovative sensor and actuator concepts suitable for large space systems; and developing modeling, simulation, and control software. The integration of controls and structures disciplines is the key for the successful implementation of future large, lightweight flexible spacecraft.

An experiment on a large, lightweight offset antenna configuration has tested disturbance motion suppression using advanced sensors, actuators and control algorithms. This experiment has demonstrated successfully the implementation of a distributed control algorithm to provide the precise figure control that must be maintained between the reflector surface and the communication antenna feed that would be located



Space truss assembly using teleoperated manipulators, duplicating the assembly performed by two astronauts in 1985.

at the top of the boom. Algorithms of this type will be extremely valuable for a large number of spacecraft including the Space Station, large instrument platforms, large Earth and deep space radiometers, and space-based radars.

Automation and Robotics. This area of research is developing the technology base for telerobotic and robotic systems. These systems will reduce costs; improve performance of future missions; and provide safer, more efficient methods of accomplishing mission objectives. The program is developing and demonstrating technology applicable to the Space Station, the

Orbital Maneuvering Vehicle, orbital transfer vehicles, mobile remote manipulator systems, geostationary satellite systems, and planetary rovers. It also will address the automation needs of ancillary systems such as prelaunch and mission operations and related ground systems.

The program's two foci are telerobotics, which will develop and demonstrate technology to evolve teleoperation through supervisory control of in-orbit robots, and systems autonomy, which will develop technology to reduce the need for ground control crews and to automate onboard subsystems through the use of artificial intelligence and expert systems. Both the telerobotics and systems autonomy parts of the program are involved in a series of demonstrations to validate evolving technological capabilities. They also share a core technology research program that is divided into the areas of sensing and perception, planning and reasoning, control execution, operator interface, and system architecture and integration.

During the Access I experiment on STS Flight 61B, two astronauts assembled a truss structure in the bay of the spacecraft. To demonstrate the current capability for space assembly, the Access experiment was repeated in a ground-based laboratory using a teleoperated manipulator. In the ground-based demonstration the manipulator system was substituted for one of the astronauts, while a person assumed the role of the other astronaut. The demonstration proved that current manipulators have sufficient dexterity to assist the flight assembly of Space Station structures.

Vision-based tracking of spinning and tumbling satellites will allow free-flying telerobots to grapple and dock as the first step in maintenance, repair, or assembly operations. In recent tests, a satellite mockup was suspended from a counterweight and a universal joint, allowing smooth simulation of zero-g dynamics. A five-camera array viewed the satellite, and an image processing system extracted features from the images, such as edges and corners. These features were matched to a computer model of the satellite, which allowed the computer to determine the position and orientation of the satellite. This tracking data was used to guide the manipulator and effectors to the grapple fixtures. At the instant of physical contact, control of the arms was switched from vision-based position control to hybrid position-force control, with the wrist force-torque sensors providing the information needed to gently decelerate the satellite within the force capabilities of the arms.

Space Human Factors. This area of research focuses on improving the productivity, efficiency, and safety between humans and machines during space missions. The Space Station represents a challenge for this research area, providing significant opportunities to verify human performance models in long-term weightless conditions. Complex man-machine operations involving highly automated onboard systems, telerobotic systems, and extravehicular activity (EVA) are the key areas for space human factors research.

EVA will be an intricate part of Space Station operations. The type of space suit used for EVA will significantly affect human capabilities and productivity. Quantitative data on these effects are needed to design suits and to plan for EVA. Building on recent progress made in the design and operational evaluation of an advanced high pressure (eight pounds per square inch) hard space suit, several studies have been conducted to evaluate astronaut performance using this type of suit. Data on the reach envelopes of people in shirt sleeves and in pressurized suits have been collected for several different size men and women. Further, it was found that a subject had a greater reach envelope in the prototype hard suit than in the current soft suit. Strength studies have shown that a pressurized glove cuts the hand grip strength of an astronaut to about 47 percent of the bare hand grip strength. Data are being collected during the brief periods of zero-gravity induced by parabolic aircraft flights to validate relationships between suit types and astronaut maneuvers and this data is being compared to data obtained on the ground in neutral buoyancy facilities. If the capabilities of EVA astronauts can be predicted from simulated zero-gravity data, realistic tasks and timeliness can be planned more easily.

Computer Science. This area of research is intended to enable and enhance the development and use of advanced data processing systems both in space and for related ground operations. A reconfigurable, fault-tolerant architecture is being developed for a space-borne symbolic processor. This includes addressing the issues of software development environment versus run-time environment, dynamic data base maintainability, and an operating system for efficient use of the multiprocessor architecture.

Sensors. This area of research is directed toward developing new materials, devices, components, and systems that will enable active and passive detection and imaging of electromagnetic radiation for future space missions. A major goal of the active sensing research program is to develop an all solid-state tunable laser transmitter in the near-infrared. Such a system would fulfill many of the scientific needs of Earth-observing missions. A system tunable in the near-infrared could be used to observe the atmosphere water vapor bands from which pressure and temperature profiles could be derived. Work has concentrated this year on the demonstration and understanding of the titanium-doped sapphire for laser amplification.

The submillimeter spectral region includes the spectral lines of large numbers of atomic and molecular species of importance to astrophysics, planetary science, and Earth atmosphere research. Currently, detector technology in this region is underdeveloped. The most promising candidate detectors are what are called "heterodyne" receivers based on superconductor-insulator-superconductor (SIS) mixers. Small area SIS devices have been fabricated and tested by measuring their current-voltage characteristics. The nonlinear nature of these devices is the key feature

Automatic grappling of a spinning and tumbling satellite using robot vision and robot force-torque sensing.

necessary for their use as mixer elements in heterodyne receivers. Future plans include fabrication of smaller area devices while retaining the properties necessary for operation at submillimeter wave frequencies. SIS devices, as well as many other sensing devices, need to be cooled to very low temperatures in order to operate. Orifice pulse tube refrigerators are a new type of cooler that have important advantages over existing coolers in terms of potential reliability. The only moving part is a room temperature compressor which has a low pressure ratio. The orifice in this type of cooler is relatively large, in the warm part of the system, and is not subject to blockage by contamination. A single-stage cooler has been built in collaboration with the National Bureau of Standards, Boulder, Colorado, and has been used to explore the characteristics of this type of cooler. Results show that the efficiency of the orifice pulse tube is very competitive.

Space Data Systems. This area of research advances the processing, storage, and use of space-derived information. Work is continuing on a space flight optical disk recorder. The objective is to enable a high-capacity (greater than one terabit), high-rate (greater than 300 megabits per second) data storage system for future NASA spaceflight data systems such as Earth-observing missions and Space Station. Commercially available erasable optical disk systems demonstrate the feasibility of the technology, but these systems fall far short of meeting the needs of future missions in both capacity and data rate. The need for a high-performance mass memory system is recognized by many Government agencies and a technology demonstration is being conducted under a multiagency contract effort. In 1987, an expandable optical disk recorder concept was developed. The concept is extremely flexible and compatible with a wide range of space flight requirements.

Communications. This area of research seeks to develop microwave and optical communications devices. Future communications satellites are likely to use gallium arsenide (GaAs) monolithic microwave integrated circuit (MMIC) technology in most, if not all, communications payload subsystems. Multiple-scanning-beam antenna systems are expected to use GaAs MMIC's to increase functional capability, to reduce volume, weight, and cost, and to greatly improve system reliability. Matrix switch technology based on GaAs MMIC's also is being developed for these reasons. MMIC technology offers substantial advantages in power consumption and weight over silicon technologies for high-throughput processor systems. For the more distant future, pseudomorphic indium gallium arsenide (InGaAs) and other advanced materials offer the possibility of MMIC communication subsystems at shorter wavelengths. The use of ultra-fast (1 pico second) laser pulses for electro-optical testing of MMIC modules has the potential of providing a completely no-touch, noninvasive, nondestructive test capability. Such testing techniques avoid problems of mounting and wire-bonding and eliminate the wasteful handling of nonfunctional chips. The method is adaptable to fully automated, high-volume testing with the potential for significantly reducing MMIC costs.

Laser systems are attractive for free-space satellite communications systems because they are small, all solid-state, and are capable of carrying data rates in excess of 200 Mbits per second. NASA is developing laser systems which transmit data between satellites by directly modulating the output powers of semiconductor lasers with injected current. Although powers in excess of 100 milliwatt (mW) are required to carry NASA data rates, the best commercially available semiconductor lasers are limited to powers less than 40 mW. NASA has undertaken the development of high-power, diffraction-limited lasers in order to improve laser performance. Recent work on the laser structure has improved its electrical efficiency and other performance parameters. The development of arrays of these lasers should allow the transmitter subsystems to be reduced in size and weight.

In-Space Experiments. Due to the Challenger tragedy and other launch vehicle failures, no in-space experiments were conducted under the Space Research and Technology program in 1987. During this gap in activity, studies were undertaken to understand and define potential in-space technology experiments, both internal to NASA (inreach) and from university and industry proposals (outreach). These inreach and outreach experiments will be developed and flown in future years.

The Outreach Program was initiated to enable the aerospace community (industry, universities, and DOD) to have access to space for the verification and

A 20 gigahertz monolithic microwave integrated circuit (MMIC) built in a single crystal of gallium arsenide. The circuit includes five phase shifting circuits, a phase shift amplifier, and a power amplifier.

validation of unique technologies required to maintain U.S. leadership in space. Thirty-six proposals were selected for definition of space flight experiments and five proposals were selected for the development (design, fabrication, and testing) of experiments to be flown on the Space Shuttle. Many of the definition proposals may provide technology development experiments for validation on Space Station.

The Inreach Program was initiated to provide space flight validation of technologies defined and developed within the R&T base programs at the NASA field centers. Seven proposals were selected for the definition of flight experiments and one proposal was selected for the development of flight experiment hardware. Operating plans were assessed for each of these experiments and definition and development efforts are underway.

Department of Defense

The loss of the Space Shuttle Challenger on January 28, 1986, resulted in an unprecedented setback for the U.S. space program. All of the existing heavy-lift launch capability was lost, leaving only eight Titan 34D medium-payload vehicles to fulfill the Nation's launch requirements. This situation was further complicated by the failure of the first two Titan 34D launches in 1986, leading to the development of a new space launch strategy that could put U.S. launch requirements back on schedule and reduce the Nation's dependency on a single launch system.

During 1987, the Department of Defense (DOD), NASA, the Department of Transportation (DOT), and the commercial as well as scientific communities developed a Space Launch Recovery Plan that was intended to balance the use of the Shuttle and expendable launch vehicles (ELV's). Shuttle launches were planned to exploit the flexibility of having a man-in-the-loop, while ELV's were allocated for more routine as well as very high risk missions.

While the recovery plan has made progress toward satisfying national military, scientific, and commercial launch requirements, it got off to a slow start in 1986, resulting in the formation of a new strategy for 1987. The Challenger accident not only caused a 30-month delay in Shuttle use, but raised additional safety concerns which slowed flight rates, created performance losses, and necessitated payload repackaging with attendant design delays. To overcome these shortcomings, the new strategy proposes to use the Shuttle only when necessary, reinstate the ELV production base, build facility infrastructure, and pursue critical technology issues. It is aimed at improving launch reliability, capability, and capacity at reduced costs. This is being accomplished through the procurement of more boosters (Titan IV's and Delta II's) to improve production costs and launch rates with a sustained production into the outyears. The new strategy created a 13-percent increase in spending in 1987, and doubles the funding over the 8-year period of the recovery.

Although the Space Launch Recovery Plan endeavors to meet national requirements for access to space and capability for launch, this will not be accomplished solely through the acquisition of additional vehicles. A plan for a fleet of evolutionary new vehicles to meet future needs with reduced costs per payload-pound must be developed. This plan must allow for a long-range technology program, the results of which can be used to develop new launch vehicles and upgrade existing systems where appropriate. The recently completed DOD/NASA Space Transportation Architecture Study (STAS) provides the first assessment of far-term national space launch requirements. The key findings of this study were as follows:

- Existing Shuttle and current ELV operating costs are significantly higher than more modern system designs.
- Current funding, scientific base, and facilities are inadequate for future space transportation systems.
- Future systems must be driven by operational requirements.
- Architecture preferred includes both manned and unmanned vehicles, with reuseable systems for maximum reduction in launch costs.
- A new space launch capability and a long-term coordinated space program will be required to retain world leadership in space. The United States may be past the point of "retaining" world leadership in several aspects of space systems and technology.

The study supports an aggressive space launch recovery plan that continues far into the future in order to meet the growing needs of U.S. military, scientific, and commercial communities in space.

Space Activities

Military Satellite Communications

MILSATCOM. Military communications satellite capabilities are provided by several satellite systems, each tailored to the specific set of requirements that the system is meant to fulfill. The Fleet Satellite Communications (FLTSATCOM) system consists of Government-owned FLTSATCOM satellites, augmented by dedicated, leased, contractor-owned satellites (LEASAT). Using small, mobile terminals, it provides low-capacity, worldwide command and control in the Ultra High Frequency (UHF) band to a large community of customers. Also in the UHF band, the Air Force Satellite Communications (AFSATCOM) system provides specialized command and control capabilities required by U.S. nuclear forces that use communications packages placed on the FLTSATCOM satellites and other host satellites. In the Super High Frequency (SHF) band, the Defense Satellite Communications System (DSCS) provides the backbone of high-capacity, command, multi-channel communication service for control and intelligence purposes to a diverse group of strategic, tactical, and non-DOD customers.

In 1987, planning the future deployment of the Milstar satellite communications system continued. This system will employ the Extremely High Frequency (EHF) band to provide highly survivable and essential communications for critical users. Work also progressed on defining an upgraded capability for the DSCS system. Using portions of the EHF technology developed under Milstar, the upgrade will greatly increase the communications capacity and survivability for these users.

Fleet Satellite Communications System. The satellite constellation consists of five FLTSAT satellites and three leased satellites (LEASATS) in synchronous equatorial orbits providing worldwide coverage between 70° north latitude and 70° south latitude.

The Request for Proposal (RFP) for the UHF Follow-On (UFO) was issued in 1987 to ensure availability of replacement as current satellites reach their end of life points in the early 1990's. This will be the first military system considering use of purely commercial expendable launch systems.

Launch vehicle difficulties, adversely affecting U.S. progress in space, hit the FLTSAT program especially hard in 1987. FLTSAT 6 had to be destroyed shortly after liftoff due to a lightning strike, and a critical part of the Atlas-Centaur rocket earmarked for the FLTSAT 8 launch was inadvertently destroyed in a ground accident at the Kennedy launch site. The launch of the last satellite in the current FLTSAT series is not scheduled until 1989.

Air Force Satellite Communications (AFSATCOM)/Single Channel Transponder (SCT). The AFSATCOM is a satellite communications capability that provides reliable global communications between and among the National Command Authorities and the nuclear capable forces. The primary missions supported are the dissemination of emergency information and force-directing messages to deployed forces. The system terminal segment consists of fixed and transportable ground terminals and airborne terminals, and a transponder control system. The Single Channel Transponder Injection System is a new improvement which is providing highly survivable communications. Single Channel Transponders on DSCS III satellites are located over the East Pacific, the East Atlantic, and West Atlantic.

Defense Satellite Communications System (DSCS). The primary mission of the DSCS is to provide worldwide coverage between 75° north and 75° south latitude. It is employed within the Defense Communications System (DCS) primarily to provide long-haul service between the continental United States and overseas locations. The DSCS is divided into three major segments: space, control, and ground.

The operational space segment currently consists of two DSCS II and three DSCS III satellites with two DSCS II's as reserves. It was expanded to this five-operational satellite constellation in May 1987 with the activation of a DSCS III in the West Atlantic. Two active satellites are needed to support requirements in the Atlantic basin. The DSCS III models provide increased performance in a jammed environment and protection against the electromagnetic pulse effects of a nuclear detonation. Delays in the transition to a complete DSCS III constellation continue due to the lack of launch capabilities. The DSCS II models are currently providing service beyond their projected lives, and are degrading slowly.

The control segment provides for near real-time monitoring and control to ensure optimum use of resources, thereby maximizing user support. This control segment was expanded in 1987 with activation of the fifth DSCS Operations Center (DSCSOC) at Ft. Meade, Maryland. Also, the initial deliveries of DSCS Frequency Division Multiple Access Control System (DFCS) equipment were accepted from the contractor in 1987. This equipment, installed at each DSCSOC, will provide control of the Frequency Division Multiple Access networks in each satellite area. A DFCS follow-on evaluation is scheduled for 1988. Finally, a contract was awarded in 1987 to produce a system to control the Spread Spectrum Multiple Access anti-jam networks.

The ground segment consists of a family of large, medium, and small Earth terminals and associated communications equipment that support both strategic and tactical user communities. In 1987, 10 new AN/GSC-52, fixed terminals were activated. With these activations, the total terminal population using the DSCS exceeds 500. In addition, actions were initiated to define the next generation Earth terminal to support the expanded requirements of the 1990's, and to plan for replacing or upgrading the aging terminals currently within the networks.

Milstar. Milstar is a multi-channel, Extremely High Frequency/Ultra High Frequency (EHF/UHF) satellite communications system that will provide survivable, enduring, jam-resistant, and secure voice/data communications for the President, the Joint Chiefs-of-Staff, and the Commanders-in-Chief of the Unified and Specified commands. It will be used for the worldwide command and control of U.S. strategic and tactical forces in all levels of conflict. Milstar satellites, which contain special survivability features, will be launched into high-and low-inclination orbits to provide full Earth coverage. Full-scale development of the space and mission control segments continued in 1987, when Critical Design Reviews were conducted. Detailed planning for payloads and their integration into the satellite bus received major emphasis. Nuclear hardened Milstar terminals will be provided to command facilities, to surveillance outposts, and to strategic and tactical forces during the 1990's. When completed, Milstar will provide the United States with its most survivable wartime communications capability. The Air Force is the lead service for the procurement of Milstar satellites, the dispersed mission control network, and most of its own terminals. The Army and Navy also have terminal development and procurement programs. The terminal programs of all three Services are coordinated through the Navy's Joint Terminal Program Office, which has the responsibility to ensure interoperability and common specifications among the three designs.

Satellite Laser Communications. The Satellite Laser Communications (SLC) system is a joint technology demonstration effort between the Navy and the Defense Advanced Research Projects Agency (DARPA) to provide the capability to communicate from space with a submerged submarine using a laser beam as the transmitting medium. To date, the basic capability has been proven by sending messages to a submarine from an aircraft using green laser light. An operational system will use blue laser light, which provides greater transmission efficiency. An aircraft-to-submarine test using blue laser, scheduled for the spring 1988, will complete the joint technology demonstration.

Navigation and Geodesy

Global Positioning System (GPS). No additional GPS satellites were launched during 1987. The last developmental GPS satellite, Navstar 11, was launched in October 1985. Currently, seven GPS developmental satellites are operating; five are performing well. The remaining two, operating substantially beyond their design lifetimes, are showing the effects of age and are performing marginally. In late 1987, DOD passed a cumulative 50 years of successful GPS on-orbit operations. Procurement of operational satellites was in its sixth year under a multiyear, 28 spacecraft contract. The first operational launch is scheduled for 1988, with full operational capability planned for late 1990 or early 1991. These dates reflect an approximate 2-year delay due to the lack of Space Shuttle launches. The launch capability provided by the new Air Force Delta II launch vehicle will allow full GPS operational capability to be achieved.

Low Rate Initial Production (LRIP) of GPS user equipment continued in 1987, after being approved by the Defense Department in 1986. LRIP will continue through 1989, pending verification of correction of reliability and maintainability problems encountered during 1985 field testing. Platform integration activities by all Services have started. Two second-source contracts were awarded in late 1987. These contracts are for building several sets for inspection and testing. Once the sets are validated, the contractors will compete with the incumbent for full-rate production sets. In late 1989, DOD plans another review of user equipment performance before approving full-rate production. The Control Segment, which is responsible for daily management of the on-orbit satellites, continues to perform well. Preparations to support the launch of the first operational satellite are on schedule. Full operational capability of the control station is planned to be concurrent with full GPS capability.

Meteorology and Oceanography

Navy Remote Ocean Sensing System (N-ROSS). At the request of the Secretary of the Navy, the N-ROSS program was restarted in April 1987. The plan was to complete documentation requirements and present the program to the Defense Acquisition Board and the Defense Resources Board in the fall of 1987. However, due to severe budgetary constraints, the N-ROSS program was canceled once again. Alternative approaches are being considered, with the primary emphasis placed on seeking opportunities to fly N-ROSS sensors, especially the NASA-funded scatterometer and the Special Sensor Microwave Imager, on other space platforms.

Defense Meteorological Satellite Program (DMSP). DMSP is the DOD's most important source of weather data. In June 1987, DMSP's satellite, F-8, was launched with a new sensor, the Special Sensor Microwave/Imager (SSM/I). Upon completion of calibration and validation of the sensor and associated software algorithms in late 1988, the SSM/I will provide DOD, for the first time, twice-daily global views of rainfall rate, sea ice, ocean wind speed, and atmospheric water vapor content measurements. SSM/I sensors are planned to be on board all DMSP satellites starting 1990. A feasibility study was initiated in 1987 to investigate flying the NASA-developed scatterometer on board a DMSP 5D-3 spacecraft in the mid-1990's. Another feasibility study of importance to naval units involved the conceptual design of a low-data-rate, real-time direct readout capability. Such a capability would allow fleet units with simple, omni-directional antennas to receive low-resolution DMSP data. Finally, the Remote Atmospheric and Ionospheric Detection System (RAIDS), which is envisioned to enhance measurement of naturally occurring airglow emissions from the upper atmosphere and ionosphere, was begun in 1987.

Surveillance and Warning

Surveillance and warning systems provide warning of attack on the United States by ballistic missile or threats by air-breathing vehicles. Early-warning satellites, complemented by ground-based radars and sensors, warn of potential intercontinental missile and submarine-launched ballistic missile attacks. In May and June 1987, two phased array warning system (PAVE PAWS) radars, located at Eldorado AFB, Texas, and Robins AFB, Georgia, respectively, reached their initial operational capability (IOC). They joined the operational PAVE PAWS sites at Cape Cod AFS, Massachusetts, and Beale AFB, California, which had reached IOC in 1980.

Surveillance and warning functions for continental air defense are currently provided by the Distant Early Warning radar line (DEW Line), and by a system of radar sites and Sector/Regional Operations Control Centers in the United States and Canada, called the Joint Surveillance System. Near-term upgrades to these systems include the planned joint Federal Aviation Administration/Air Force Radar Replacement Program to modernize the Joint Surveillance System radar. The North Warning System (NWS) program will modernize the DEW Line radar systems.

The Over-The-Horizon Backscatter (OTH-B) radar systems, already under development, will extend warning times around the United States. The east coast OTH-B radar achieved limited operational status in December 1987. In 1987, the Air Defense Initiative program began to define and develop advanced technologies to detect, identify, track and engage future air-breathing threats to North America, particularly those incorporating advanced penetration technologies.

Strategic Defense Initiative

Since the inception of the Strategic Defense Initiative (SDI), a series of technology developments and experiments have underscored the potential for using advanced technology to construct an effective strategic defense. During 1987, the SDI program successfully demonstrated the ability to intercept targets within the atmosphere and in space. In mid-September, Secretary of Defense Caspar Weinberger approved the Defense Acquisition Board's recommendation that certain SDI technologies enter the demonstration and validation phase of the defense acquisition process. The purpose of this phase is to evaluate—through data analysis, experimentation, and simulation—the feasibility of the critical elements of a potential Strategic Defense System (SDS). Listed below are the six technologies and concepts approved by Secretary Weinberger.

- *Battle Management/Command, Control, and Communication (BM/C3).* This element will monitor and control the activities of the other elements of a Strategic Defense System. Information from all elements will be relayed to the battle managers and processed; target assignments will then be communicated to space- and ground-based weapons. This complex communications system must assess rapidly the characteristics of ballistic missile attack and provide timely, reliable information to the SDS commander, who will direct the battle. Once a defense response has been determined, the BM/C3 system must execute the response, assess its effectiveness, and revise its action if necessary. The BM/C3 must be able to withstand enemy jamming and the effects of nuclear radiation.

- *Boost Surveillance and Tracking System (BSTS).* BSTS will detect and track attacking ICBM's and SLBM's during their boost—or powered—phase of flight. Once the BSTS senses a launch and tracks the attacking missiles, the information will be relayed to the BM/C3 system and other SDS elements. If an attacking MIRVed missile can be destroyed early in its boost phase, the shortest phase of its flight, the number of nuclear warheads destroyed will be maximized.

• *Space-based Interceptor System (SBI).* The SBI will consist of a number of space platforms housing multiple rocket-propelled interceptors. Upon receiving the appropriate command, these nonnuclear interceptors will seek out and destroy the attacking missiles during the boost and post-boost phases, and also the Reentry Vehicles (RV's) in the mid-course phase of their flight. They will destroy their targets by direct collision at extremely high speeds.

• *Space-based Surveillance and Tracking System (SSTS).* The SSTS will detect and track RV-dispensing post-boost vehicles and the RV's themselves in the post-boost and mid-course phases of flight. The system will use a series of satellites to acquire and track objects and discriminate between reentry vehicles, decoys, and space debris. This tracking and discrimination information will be relayed to the BM/C3 system and other SDS elements. The BM/C3 system will then assign targets to the SBI to intercept the incoming warheads.

• *Ground-based Surveillance and Tracking System (GSTS).* The GSTS, also known as the Probe, has three basic functions: search/acquisition, track, and discrimination. Launched into space upon warning of an ICBM launch, the GSTS would track attacking RV's in the missile's mid-course and early terminal trajectory phases; this information will be used to assign both ground- and space-based interceptors to destroy the RV's. GSTS will possess the capability to discriminate between RV's, decoys and space debris.

• *The Exoatmospheric Reentry Vehicle Interceptor Subsystem (ERIS).* The ERIS is a ground-launched, nonnuclear missile interceptor system that will destroy attacking warheads during the mid-course phase of their flight. Space and ground surveillance systems must first discern between warheads, decoys, and space debris. This information will be relayed to the BM/C3 systems, which will process it and communicate target assignments to interceptors, such as the ERIS. The small ERIS vehicle will destroy the attacking warhead by colliding with it at an extremely high speed.

These six technologies will represent the first phase of a multi-phased strategic defense system. The phased deployment approach takes four key factors into consideration: time, technology, defensive missions, and responsive threats. With this approach, some efforts and technologies will mature faster than others. Deployment of a defense, regardless of the first deployment date of its elements, must take place over time. As other technologies mature and are deployed, they also will provide additional capability to perform new and more demanding missions, including overcoming potential Soviet attempts to evade, deceive, or defeat U.S. defensive systems.

Aeronautical Activities

Fixed-Wing Programs

Bomber Development (B-1B). In June 1985, the first B-1B was delivered to the Strategic Air Command. By the summer of 1988, all 100 B-1B's will have been delivered to the Air Force with operational basing at Dyess Air Force Base, Texas; Ellsworth Air Force Base, South Dakota; Grand Forks Air Force Base, North Dakota; and McConnell Air Force Base, Kansas. The B-1B has been on alert as part of the Strategic Air Command's defense force since October 1, 1986. Testing of the B-1B continues at Dyess AFB and Edwards AFB, California.

B-2 Advanced Technology Bomber. Work has been ongoing on the Advanced Technology Bomber (known as the B-2) with Northrop as the prime contractor, and Boeing, LTV, and General Electric

Aircraft Engine Group as subcontractor to Northrop. The B-2 employs low-observable, or stealth, technology, and is based on a flying wing concept which exhibits high aerodynamic efficiency giving high payload, long-range capability.

Work in 1987 will lead to a follow-on contract award to Northrop in 1988, and a first flight scheduled for the fall of 1988. The current schedule is leading to an IOC (Initial Operational Capability) in the early 1990's with the first operational base at Whiteman AFB, Missouri. The B-2 depot facility will be at the Air Logistics Center, Tinker AFB, Oklahoma.

Advanced Tactical Fighter (ATF). The ATF program is developing the next generation Air Force fighter to counter the Soviet threat projected for the late 1990's and beyond. As a follow-on to the F-15, the ATF is being designed to penetrate high-threat enemy airspace and support the air-land battle forces with "first-look, first-kill" capability against a technologically advanced, numerically superior enemy. The ATF's improved capabilities will be made possible by significant technological advances in the areas of signature reduction, aerodynamic design, flight controls, materials, propulsion, sensors, and integrated avionics. It will reach an initial operational capability in the mid-1990's.

In April 1986, the ATF program was restructured to include flying prototypes and ground-based avionics prototypes in the Demonstration/Validation (Dem/Val) phase of the program. The restructured program implements Packard Commission recommendations, emphasizes fly-before-buy and competitive contracting, and provides the means to reduce technical and cost risks before proceeding with full-scale development in 1991.

In October 1986, the ATF program completed a Joint Requirements Management Board Milestone I and received Office of Secretary of Defense approval to award the Dem/Val contracts. Contracts were awarded to Lockheed and Northrop, and flight demonstrations of their prototype aircraft, designated YF-22A and YF-23A respectively, will begin in 1990. General Electric and Pratt and Whitney are providing the prototype engines for the AFT aircraft.

C-17. The C-17 aircraft completed its second year of full-scale development in December 1987. Preliminary design reviews and more than 5,000 hours of wind tunnel tests of scale models have been completed. Recent wind tunnel tests have discovered a "deep stall" characteristic in which the aircraft can be inadvertently flown into an unrecoverable condition using manual (hydro-mechanical) flight controls. To resolve this problem, a decision has been made to redesign the flight control system to a "fly-by-wire" system incorporating quadruply redundant electronic flight controls. More than 45 percent of the engineering drawings for manufacture of the C-17 airframe components have been completed. The engines for the C-17 are modern, efficient, commercially developed, turbofan designs that will be equipped with unique thrust reversers specifically developed for the aircraft. The maximum thrust rating for the engines, originally 37,000 pounds, has been increased to 40,700 pounds to provide increased takeoff performance. After a December 1987 review of the proposal, the Defense Acquisition Board approved procurement of the first two production aircraft that will be used initially in the test program. By December 1987, more than 70 subcontracts for the C-17 aircraft were awarded.

Remotely Piloted Vehicle. The Navy and Air Force are jointly developing a medium-range, unmanned reconnaissance vehicle. The Navy is developing the unmanned vehicle, and the Air Force is developing an electro-optical sensor suite to be carried by Air Force and Navy manned and unmanned tactical reconnaissance vehicles. In 1987, two contractors will be selected to participate in a competitive fly-off of their unmanned vehicles that will occur during 1988.

Helicopter Programs

AH-64H (Apache) Advanced Attack Helicopter. In December 1987, the 308th AH-64 Apache helicopter was delivered to the Army. The FY 1988 procurement is for 77 more aircraft and constitutes the seventh production lot for the aircraft. With this procurement, the Army will have contracted for 603 Apaches.

CH-47 Modernization. In April 1985, a 5-year multiyear procurement (MYP) contract was awarded to modernize 240 CH-47A-, B-, and C- model cargo helicopters to the D-model configuration. The CH-47D provides substantial improvements in reliability, availability, maintainability, flight safety and survivability. By December 1987, as the program moved through the third year of the 5-year MYP, 190 CH-47D aircraft had been delivered to the Army. A proposed second MYP contract from 1990 to 1992 would complete a procurement objective of 472 CH-47D's, which is the total of all CH-47A/B/C aircraft available for modernization.

UH-60A Blackhawk. By December 1987, a total of 861 UH-60A's had been accepted by the Army. These aircraft were distributed to priority units in the United States, Europe, Japan, Korea, Panama, the Army National Guard, the Army Reserve, and to the Training and Doctrine Command.

Light Helicopter Family (LHX). In 1985, the Army initiated a technology development program called the Advanced Rotorcraft Technology Integration (ARTI) to reduce the technical risk of LHX development. The ARTI program, and other programs like it, have provided sufficient advances in technologies such as forward-looking infrared (FLIR), very high-speed integrated circuit (VHSIC), target recognition, and composite construction to enable the LHX program to start development with an acceptable level of risk. Risk-reduction efforts have continued to this date, in anticipation of a 1988 start of the LHX demonstration and validation phase. It is expected that the initial demonstration work will be conducted in the area of the mission equipment package, applicable to the LHX, as well as to other aircraft. In a parallel effort, the Army has awarded contracts to two industry teams for the development of the 1200-shaft horsepower T-800 engine. The T-800 is an advanced technology turboshaft engine characterized by high-power-to-weight ratio and low-specific fuel consumption.

Advanced Technology Demonstrators

V-22 Osprey (formerly JVX). The Osprey is designed to provide the Marine Corps, Navy, and Air Force with a multimission Vertical/Short Takeoff and Landing (V/STOL) capability for the 1990's and beyond. It will satisfy operational requirements such as Marine Corps assault vertical lift, Navy combat search and rescue, and Air Force special operations. In April 1983, the Preliminary Design Phase began; in 1986, a decision leading to full-scale development was made. Powered model, aero-elasticity, and large-scale rotor performance tests were completed. Results of these tests will lead to detail design of the Ground Test Vehicle.

Aeronautics Technology

Microwave Landing System (MLS). MLS is the precision approach landing system of the future. It will replace the existing instrument landing system (ILS) and precision approach radar by the year 2000. Both fixed and mobile MLS ground equipment will be acquired, as well as MLS avionics for DOD aircraft. The Federal Aviation Administration has overall responsibility for the national MLS program, and the Air Force was designated the lead Service for the DOD. In 1987, the Air Force continued with programs to acquire modified commercial MLS avionics and mobile MLS capabilities. The modified commercial MLS avionics will be used in cargo, tanker, trainer, and support aircraft. The mobile MLS will replace existing mobile precision approach radars. The modified commercial avionics contract was awarded in October 1987. The mobile MLS Request for Proposal was released in 1987, and contract award is planned for March/April 1988. The FAA Fixed Based MLS Request for Proposal will be released in 1988, and will include equipment for the DOD. Contract award is planned for 1989. An MLS avionics architecture study, completed in 1986, considered MLS avionics alternatives that could accommodate the environmental and space constraints that exist in high-performance aircraft. As a result of this study, the Air Force awarded contracts in 1987 to conduct a concept definition effort for a high reliability (20,000 hour mean-time-between-failure) MLS/ILS receiver. Full-scale development is planned for fiscal year 1989. The ILS capability will be retained until the transition to MLS is completed in the year 2000.

Advanced Fighter Technology Integration (AFTI). In 1986, the AFTI/F-16 completed its last full year of testing at Edwards Air Force Base. Its automated maneuvering attack system provides highly accurate maneuvering against ground targets from very low altitudes and improved air-to-air effectiveness. Technologies in the AFTI program will be used to improve the performance of future aircraft, such as the Advanced Tactical Fighter.

X-29 Advanced Technology Demonstrator. The forward-swept-wing X-29 aircraft has completed its second year of flight testing. This innovative program demonstrates advanced high-risk, high-payoff technologies for future consideration. Exploitation of these technologies will improve future fighter aircraft performance and will reduce the time, risk, and cost of future development. It is a joint DARPA/NASA/Air Force program that expands significantly the existing data bases for advanced composite research, aerodynamic and structural analytic design methods, design techniques of digital flight control systems, systems integration, and test and evaluation capabilities. The flight testing is being conducted by a joint Government/industry team at NASA's Dryden Flight Research Facility at Edwards Air Force Base, California.

During 1986, the X-29A completed more than 85 test flights to expand fully its flight envelope to a maximum altitude of 40,000 feet and a maximum Mach number of 1.45. Considerable testing was conducted at high dynamic pressures, a combination of low-altitude, high-speed, and high-G load factors that stressed the capability of the aircraft structure, flight control system, and aerodynamic stability. Test results indicate that vehicle drag levels are significantly lower than predicted, and that vehicle stability throughout the flight envelope is better than analysis had predicted. A follow-on program has been defined and approved to flight test the second X-29 aircraft at high angle of attack.

National Aerospace Plane (NASP). This joint program, including DARPA, Air Force, Navy, Strategic Defense Initiative Organization, and NASA, is developing advanced technologies for a new generation of aerospace vehicles. After a horizontal takeoff, these liquid-hydrogen-fueled, air-breathing, ramjet/scramjet-powered vehicles will be capable of operating at hypersonic speeds (Mach 6 to 12) in the atmosphere or in space as a single-stage-to-orbit launch vehicle.

Between 1986 and 1989, the main goal of the technology development phase (Phase II) is to demonstrate the technologies required for single-stage-to-orbit. New technologies needed to usher in this new generation of air-breathing aerospace vehicles will be developed, such as advanced propulsion engines, advanced low-drag airframe configurations, advanced high-temperature materials, actively cooled structures, lightweight cryogenic tankage, and high-speed computer analysis of non-linear fluid dynamics. These technologies being developed offer the potential of a future space launch vehicle having substantially reduced cost-per-pound delivered to orbit, and a future hypersonic cruise aircraft having 2-hour flight time (or less) from the United States to any point on the globe.

The next phase (Phase III), the detail design, construction, and flight test of an experimental aircraft, is currently scheduled to begin in 1991. First flight of this experimental vehicle, designated the X-30, is planned for 1996. The goal of Phase III is to accomplish sufficient flight demonstration to provide a verified technological basis for future operational vehicles.

The many spinoffs from NASP technologies will enhance U.S. leadership in aeronautics and in the commercial use of space during the early decades of the next century. Reduced space launch costs and dramatically reduced transit times on long-haul airline routes will result in significant economic benefits.

X-Wing. The X-Wing Rotor System will be flight tested on the NASA/Army Rotor Systems Research Aircraft (RSRA). Successful testing of the X-Wing/RSRA will provide the basis for a whole new generation of air vehicles that combine the best features of both helicopter and fixed-wing aircraft. In the helicopter mode, the X-Wing rotates like conventional helicopter blades. While airborne, the blades stop rotating and the aircraft flies in a fixed-wing mode. In order to accomplish this feat, four emerging technologies will be refined and integrated: digital flight controls that can maneuver an airframe with both helicopter and fixed-wing features; composite materials that are both lightweight and extremely rigid; air that circulates around the rotor blades to increase lift; and propulsion techniques that provide both shaft horse power and thrust from a single engine.

Test and Experimental Research Capabilities. DOD and NASA have conducted several studies and reviews of the Nation's experimental capabilities and facilities. A concern about adequacy continues to grow relative to these assets that are so vital to continued growth in technology and systems development in aeronautical and space systems. The Defense Acquisition Board's Test and Evaluation Committee (TEC) is taking action toward planning and budgeting for a national investment program to ensure that investments are adequate to preclude a major long-term shortfall of capabilities to achieve national objectives in aeronautics and space. The TEC will integrate, at the Office of the Secretary of Defense level, service requirements and plans to provide a better national investment approach with NASA. The specifics of approach and investment objectives are expected to mature in 1988. The primary areas of concern clearly center on highly integrated electronic systems for advanced weapons, hypersonic research, and space systems.

Army Aeronautical Technology Research and Advanced Technology. The purpose of this program is to increase operational effectiveness of rotorcraft, reduce life-cycle costs, and improve systems integration and flight simulation capabilities. The program includes research in the areas of aerodynamics, structures, propulsion, reliability, maintainability, safety and survivability, subsystems, mission support, flight simulation, and man-machine integration. In 1987, work on the development of a Crew Station Research and Development Facility was completed, with all hardware and software fully integrated. As the Free World's most versatile rotorcraft research and development simulator, this facility is now operational with research under-way. It will provide a means of evaluating advanced cockpit concepts and designs for future rotorcraft systems and man-machine-mission capabilities. Additionally, it will provide the tools for supporting the selection of future Army rotorcraft procurements, resulting in more cost-effective fielded systems. The development and operation of the facility was a joint Army/NASA effort, and it is housed at the NASA Ames Research Center, Moffett Field, California.

Rotorcraft flying close to trees and terrain require almost continuous pilot attention to be directed outside the cockpit, as well as constant "hands-on-the-controls." This, in addition to the growing complexity of state-of-the-art systems/cockpit equipment, results in a very high pilot workload. A JOH-58 helicopter was modified to incorporate the electronics required to evaluate pilot performance using voice commands to initiate the pilot inputs to the system, versus the same inputs done manually. Comparisons between voice commands and manual inputs were made during both day and night flights. Results indicate that under conditions of high workload, voice input is the medium of choice. Voice technology has a great potential for reducing workload to a manageable level, and for improving mission effectiveness and flight safety for aircraft pilots and their passengers.

Quick, accurate diagnosis of system failure is the answer to many of the Army's aircraft readiness goals. A program of aircraft system fault isolation using artificial intelligence technology has provided Army aviation the means to reduce maintenance costs by avoiding time-consuming trouble-shooting. A diagnostic system has been developed for aircraft flight controls, auxiliary power units, fuel systems and selected avionics for the AH-64 Apache and UH-60 Blackhawk helicopters. The system correctly diagnosed 12 system faults during tests at Fort Rucker, Alabama, and Fort Hood, Texas. A similar system was developed to monitor the flight controls of a CH-47D Chinook helicopter tested at Fort Eustis, Virginia, and Fort Campbell, Kentucky. A field demonstration applying the technique to the TOW missile system of the AH-1S Cobra was conducted at Fort Lewis, Washington, and correctly diagnosed almost all potential system problems. Reductions in maintenance manhours, aircraft downtime, component false removals, and maintenance test flight requirements have been shown.

A technique was developed to repair battle-damaged aircraft fuel cells that minimizes both aircraft downtime and manpower resources. The major breakthrough was the development of a new chemical compound that reduces epoxy cure time and is easy to apply. A fuel cell repair kit was developed and fielded that reduces repair time from the current 8 to 30 hours to less than 2 hours.

In 1987, a 4-year program to develop and demonstrate a 5,000-horsepower Modern Technology Demonstration Engine was completed. This engine represents the latest turbine engine technology and provides a lightweight engine with lower fuel consumption than other turbine engines in its class. The program has met or exceeded all design goals, which include more than 6-horsepower-per-pound of engine and 20 percent lower fuel consumption, leading to greater range and payload capability. The engine design life is 5,000 hours, which will greatly extend service life compared to current engines. The demonstrated mean-time-to-repair of less than 1 hour will reduce aircraft downtime.

An investigation to evaluate the feasibility of using an advanced compound cycle engine (a combination of gas turbine and diesel technology) for future Army aircraft applications has been completed. Results indicate potential engine efficiency values as high as 45 percent over the current engine technology without resorting to extremely high-temperature design technology. Resulting aircraft range or payload capability could improve by more than 50 percent.

Working with the NASA computational based Numerical Aerodynamic Simulation Facility, Army researchers have developed computational fluid dynamic computer codes that model the air flow near and over helicopter rotor blades. This analytical approach reduces the high risk, time and cost of "guess and check" experimental model testing usually required to test and evaluate new concepts for helicopter rotors.

Advanced Digital Optical Control System (ADOCS). The task of the Advanced Digital Optical Control System is to advance technology to provide a battlefield-compatible flight control system for new Army aircraft. The ADOCS will allow survivability of the control system in the natural and man-made electromagnetic environment of the future battlefield. The ADOCS also will provide improved capability, reliability, maintainability, and reduced ballistic vulnerability. Mission-tailored handling qualities combined with improved soldier-machine interfaces will significantly improve rotorcraft mission performance. A ground test of the ADOCS, using a UH-60 flight demonstrator, was completed and flight tests were initiated. The development of an Optohydraulic

Servovalve was completed and work on a number of additional improved optical components was initiated. These components will be designed to upgrade and replace large, heavy, inefficient prototype components in the original flight demonstrator. The testing of the ADOCS Flight Demonstrator configuration was completed in 1986. Development of Advanced Optical Components will continue in 1987, along with a Tri-Service program to develop approaches to Atmospheric Electrical Hazard Protection for the Digital Optical Control System.

Advanced Composite Aircraft Program (ACAP). ACAP was formulated to demonstrate the benefits of applying composite materials to a primary helicopter airframe structure. The program goals of achieving a 17-percent reduction in airframe cost and a 22-percent reduction in airframe weight were met or exceeded by the two helicopter manufacturers conducting this demonstration. In 1986, Sikorsky and Bell completed their ACAP flight test programs. In 1987, the program then proceeded to the initiation of the militarization phase in which avionics/lightning compatibility issues will be addressed; landing gear and crashworthy characteristics will be demonstrated; and acoustics, and maintainability improvements will be developed to ensure battlefield sustainability of composite materials used as a primary airframe structure. Due to the inherent high stiffness of composite materials, acoustic energy (noise) may be more readily transmitted than it is in metal structures. Acoustic isolation modifications for the ACAP aircraft will be fabricated and installed in the flight test vehicle; tests of the avionics, electromagetic interference, and lightning characteristics of the airframe will be completed; and a concept for enhancing maintainability will be developed.

Department of Commerce

Agencies of the Department of Commerce involved in the Nation's aeronautics and space programs during 1987 were the National Oceanic and Atmospheric Administration (NOAA), National Bureau of Standards (NBS), and National Telecommunications and Information Administration (NTIA).

The National Oceanic and Atmospheric Administration (NOAA) conducts research, gathers, stores, and analyzes data about the oceans, atmosphere, space, and Sun, and applies this knowledge to limit the potential impact of severe weather conditions, manage the Earth's natural resources, and plan and conduct many other activities of national and international importance. NOAA satellite data and products are received around the globe, and are utilized by industries such as shipping, aeronautics, agriculture, and the military. The National Environmental Satellite, Data, and Information Service (NESDIS) manages satellite activities under NOAA.

The National Bureau of Standards (NBS) is responsible for establishing and maintaining national standards of measurement, and provides Government, industry, and academia with the measurement services and fundamental physical, chemical, and engineering data to serve national goals. NBS supports space systems, atmospheric and space research, and aeronautical programs.

The National Telecommunications and Information Administration (NTIA), the principal communications adviser to the President, develops and coordinates Executive branch policy in telecommunications and information. NTIA also is responsible for managing the radio spectrum assigned for Federal use and provides technical assistance to other Federal agencies. An important NTIA role is to help develop and coordinate U.S. policy in space communications.

Space Systems

Satellite Operations

The satellites operated by NOAA include both geostationary and polar-orbiting spacecraft. The Geostationary Operational Environmental Satellites (GOES) orbit the Earth in synchrony with the rotation of the Earth so that each appears to be fixed in space directly above one place. This gives each spacecraft a continuous, 24-hour view of one entire hemisphere of the planet. Each of the two polar-orbiting satellites, interchangeably called TIROS and NOAA, move in circular, sun-synchronous orbits from pole to pole. Since the orbital rotation rate of each polar-orbiting satellite around the Earth is adjusted to be half the rotation rate of the Earth around its own axis, each spacecraft views successive overlapping swaths of the Earth's surface. This orbital geometry allows each satellite to view each place on the planet twice every day (once during the morning and once during the evening).

GOES spacecraft are in orbit approximately 22,300 statute miles (35,800 km) above the equator. Since the orbital path tracks directly above a single point on the Earth's surface, it is capable of imaging the entire hemisphere once every half hour and can view smaller areas as often as once every 15 minutes. The complement of instruments on this spacecraft include a Visible and Infrared Spin-scan Radiometer Atmospheric Sounder (VAS) which provides 24-hour images of the Earth's temperatures, cloud cover and atmospheric water vapor. Additionally, each GOES carries a Space Environment Monitor (SEM) that measures the conditions of the Earth's magnetic field and the energetic particle flux in space near the Earth; and the Data Collection System (DCS) that receives and retransmits data collected by remote data collection platforms. Unlike polar-orbiting spacecraft, the GOES has no platform-locating capability. The GOES also has the capability to broadcast processed environmental data, such as imagery, charts, and alphanumeric messages through a product distribution system called Weather Facsimile (WEFAX).

The normal operational configuration for the GOES system includes one spacecraft placed at 75° west longitude and one at 135° west. From these locations they can observe the eastern and western parts of the United States and their adjacent ocean areas. Other partially operational GOES satellites, used for data relay communications, DCS and a dedicated central WEFAX broadcast, are positioned elsewhere.

Polar-Orbiting Satellites. NOAA 9 and NOAA 10 satellites provided the polar-orbiting service during the year. They are in orbit 450 miles (853 km) above the Earth's surface. With the on-board data recorders, the satellites provide total global imaging coverage. The complement of instruments on the polar-orbiting spacecraft include an Advanced Very High Resolution Radiometer (AVHRR) which provides global visible and infrared imagery; a Space Environment Monitor (SEM) to measure near-earth charged particle spectra; a TIROS Operational Vertical Sounder (TOVS) system, consisting of a Microwave Sounding Unit (MSU), a High-Resolution Infrared Radiation Sounder (HIRS) and a Stratospheric Sounding Unit (SSU) which combine to provide atmospheric temperature profiles from the surface of the Earth to the upper stratosphere; a Search and Rescue (SAR) package to locate emergency transmitters anywhere in the world, an Earth Radiation Budget Experiment (ERBE), and an ARGOS Data Collection System to track and report data from remote data collection platforms, such as drifting buoys, free-floating balloons and remote weather stations.

The normal operational configuration for the TIROS/NOAA system includes two 3-axis stabilized spacecraft in near-polar orbit (inclined 98.7°) with an orbital precession of 0.986° per day (in the same direction and rate as the Earth's average daily rotation about the Sun).

Geostationary Satellites. In February 1987, GOES-H, the last of the current series of GOES spacecraft, was successfully launched. After an initial check-out period, the satellite became operational in March 1987, as GOES-7 on station at 75° west longitude. GOES-6 was then re-positioned from its 108° west location to its new operational station of 135° west. The year 1987 also marked the inauguration of a new data rate and transmission format (Mode AAA). This new format takes full advantage of the capabilities of the VAS instrument and provides operational dwell soundings and multispectral images.

GOES-Next. During 1987, the Ford Aerospace and Communications Corporation continued the design and development of the next generation GOES spacecraft, GOES I-M, and associated ground equipment. Launch of the first in the new series of spacecraft is expected in mid 1990.

LANDSAT Commercialized Operations. Pursuant to the Land Remote Sensing Commercialization Act of 1984, the Earth Observation Satellite Company (EOSAT) operated the Landsat 4 and 5 remote sensing satellite systems for NOAA in 1987. In October of 1987, the U.S. Congress approved a revised Landsat program commercialization plan releasing additional funds for continued development of follow-on Landsat 6 space and ground systems. In addition, the Department of Commerce will direct a study to plan the development of an advanced commercial system beyond Landsat 6. New Landsat sensing instruments are under development for Landsat 6 that will advance the position of the United States in the international market for remote sensing satellite data.

They include the Enhanced Thematic Mapper—featuring a 15-meter resolution panchromatic band, and other spectral bands, including thermal infrared—and a Compact Wide-Field Sensor that will provide low resolution, wide area coverage suitable for land and ocean studies.

Satellite Data Services

During 1987, NOAA provided several satellite data services made possible by the observing and communicating capabilities of TIROS/NOAA and GOES spacecraft.

GOES Data Collection System (DCS). In 1987, the DCS had a significant increase in the number of environmental data collection platforms able to use the system. This increase caused the ground system computers to become saturated. Through some innovative software development, NESDIS was able to increase system capacity by 25 percent. This increase will allow NESDIS to add users at a carefully managed rate until the new system is installed in mid-1989. During 1987, a new system was specified which will allow significant growth and enable users to expand or add programs to the DCS.

GOES-Tap. GOES-Tap, a program enabling other Government and commercial users to acquire high-quality meteorological satellite data on a near-real-time basis continued to expand with approximately 25 new users added in 1987. There are currently close to 200 GOES-Tap primary connections. The users of this program are the National Weather Service, the Air Force, the Navy, the FAA, airline companies, television stations, universities, and private companies. GOES-Tap satellite data consists primarily of sectorized visible and infrared GOES imagery. GMS, METEOSAT, and NOAA satellite data are also distributed.

WEFAX. The Weather Facsimile system (WEFAX) continued to broadcast processed satellite imagery, meteorological analyses and prognoses via three GOES spacecraft to the national and international community. In 1987, there were 204 known active WEFAX sites, 122 in the United States and 82 outside the United States.

NOAA/Navy Joint Ice Center (JIC). Executing the plans of the 1986 Letter of Agreement between the Navy and NOAA to improve the data processing capabilities at the NOAA/Navy Joint Ice Center (JIC) in Suitland, Maryland, a renovation of the methods by which the JIC processes satellite data was begun. A major software development project was undertaken by NESDIS to preprocess the raw satellite image data for use by the Digital Ice Forecast Analysis System (DIFAS).

The NOAA facility in Boulder, Colorado, began adapting its regional atmospherically oriented image processing system into one to meet the needs of the JIC. The image processing and computing hardware was procured through the National Ocean Service.

GOES-VISSR Atmospheric Sounder (VAS) Data. In September, NESDIS began operational processing of VAS data to support the National Weather Service (NWS). The system was developed at the Cooperative Institute for Meteorological Satellite Studies at the University of Wisconsin and delivered to the World Weather Building. In addition to providing high-frequency profiles of atmospheric temperature and humidity (every 90 minutes), the system can also derive wind estimates, automatically, from time-sequenced images of visible and infrared radiation viewed by the satellite. These winds, in particular, have been shown to improve simple model hurricane track forecasting by the National Hurricane Center. Forecast model impact studies using the VAS data are currently being pursued by the NWS and the European Center for Midrange Weather Forecasting.

Atmospheric Temperature and Moisture Soundings. The year 1987 marks the eighth year of operational atmospheric soundings production from NOAA's polar-orbiting satellite system. The NOAA-10 satellite was successfully implemented for soundings in February 1987, replacing the NOAA-6 satellite which no longer had a functioning High Resolution Infrared Sounder. The enhanced soundings (17 km resolution) implemented in April 1986 are of great interest to meteorological experimenters and researchers. Numerous requests for these data were honored during 1987. A completely new sounding system was implemented in June 1987 using data from the Special Sensor Microwave/Temperature on board the Defense Meteorological Satellite Program polar satellites. These new soundings supplement the morning polar satellite sounding coverage with all-weather microwave measurements. This new product is the first product to be operationally produced under the Shared Processing agreement between NOAA, the Navy, and the Air Force.

Sea Surface Temperature. Observations of sea surface temperature at 8 kilometer resolution were produced from NOAA-9 infrared data during 1987 and transmitted to the National Meteorological Center of the National Weather Service, the Navy Fleet Numerical Oceanography Center, and the World Meteorological Organization for use in oceanographic and meteorological models and products.

The National Oceanographic Data Center and the Scripps Institute of Oceanography combined their resources to form a Joint Environmental Data Analysis Center for surface and subsurface temperatures. Among the products being produced monthly are graphic displays of sea surface temperature anomalies and dynamic heights for the mid-latitude Pacific Ocean.

In November 1986, an enhanced SST observation archive was implemented in support of the Tropical Ocean and Global Atmosphere project of the World Climate Research Program. This archive will permit the efficient reprocessing of satellite sea surface temperatures if improved algorithms are developed. New products being tested this year include a global sea surface temperature analysis at a 50-km resolution, and a global aerosol optical thickness product at a 100-km resolution. The latter product will be used to correct sea surface temperature measured in the presence of stratospheric aerosols from large volcanic eruptions. Support was provided to NASA and the Navy in the migration of the operational production of global satellite sea surface temperature observations under the Shared Processing agreement.

Ozone. Operational total, level, and layer ozone observations continue to be generated from the Solar Backscatter Ultraviolet Radiometer (SBUV/2) on the NOAA-9 (afternoon) polar-orbiting satellite. These products are provided to NASA Goddard Space Flight Center, NOAA Environmental Research Labs, and the Atmospheric Environmental Service of Canada. Preparations are being made for reprocessing all of the SBUB/2 data acquired since March 1985. This reprocessing, using the latest ozone algorithm and calibration techniques, will provide the "best" ozone data set currently possible. This improved data set will be used along with other ozone data sources to determine trends in world ozone amounts.

Three types of special support were provided for the flight operations of the NASA Antarctic Ozone Field Experiment. Infrared data from the High Resolution Infrared Sounder (HIRS/2) on NOAA-10 were supplied in near-real time to the European Centre for Medium-Range Weather Forecasts and used to generate Southern Hemisphere maps of total ozone during the polar night; Microwave Sounder Unit and HIRS/2 data from NOAA-10 were sent to NASA Goddard Space Flight Center to provide temperature sounding support to Antarctic meteorological forecasts; and SBUV/2 ozone observations were provided to NOAA's Climate Analysis Centers for generation of daytime ozone analyses over Antarctica. These data allowed NASA to locate the "Ozone Hole" which forms over Antarctica during the polar night in August and guide instrumented aircraft flights to sample atmospheric constituents in the Ozone Hole. These samples should allow researchers to determine the mechanism leading to the dramatic decrease in ozone over Antarctica in late winter.

IFFA. In 1987, the Interactive Flash Flood Analyzer (IFFA) continued producing satellite estimates of precipitation in near-real time. This operation began in 1983 in support of the National Flash Flood Program. IFFA consists of an interactive computer processing system which allows the meteorologist to display, enhance, and animate digital satellite imagery. The meteorologist then generates graphical (contoured) estimates of precipitation for specific areas (counties). These estimates are communicated to the affected NWS Forecast Office using AFOS.

Winds. The cloud motion winds operation continued during 1987, generating wind vectors at several levels for inclusion into the NWS National Forecast Models. These data are also transmitted to worldwide users on the WMO GTS system. Development of automatic wind tracking routines continued at the University of Wisconsin with encouraging results. An operational demonstration on the VDUC was successful in late 1987, and the integration of winds capability on the VDUC was accomplished.

NOAA Ocean Products Center. Near-real-time altimetric data were received at the NOAA Ocean Products Center from the Navy's GEOSAT. Algorithms were developed to generate wave height averages for the one-second altimetric data. Methods were developed and tested to assimilate these observations into numerical ocean wave models.

Satellite Cloud Climatology. The Satellite Research Laboratory of NOAA's National Environmental Satellite, Data, and Information Service continued to compile a data set of calibrated visible and infrared radiances from U.S. geostationary and polar-orbiting meteorological satellites. These data are part of a global set collected by an international array of satellites from which the cloud amount, height, optical thickness and cloud-top temperature are inferred on a scale 250 km by 250 km globally. Copies of the first cloud product tape for July, 1983, were distributed worldwide to over 50 scientists for their comments and early study. These data will be extremely useful in analyzing the effects of "cloud forcing" on the Earth's radiation budget, in understanding the role of clouds in the hydrodynamical cycle, and in parameterizing clouds in climate models.

Direct Readout Program. The Direct Readout Program provides over 4,000 stations in more than 120 countries with technical guidance and informational support to enable them to copy and use data from TIROS and GOES environmental satellites. To date the support provided by this program pertaining to station planning, data reception and analysis has facilitated an international investment in receiving stations that exceeds $500 million. This technology transfer effort has greatly contributed to the public health and welfare both nationally and internationally, by making local access to Automatic Picture Transmission, Direct Sounder Broadcast, High Resolution Picture Transmission, Visible and Infrared Spin Scan Radiometer, and Weather Facsimile services possible. A new brochure has recently been reproduced by NOAA/NESDIS describing these services and applications by Government, commercial, academic and amateur users.

NOAA/NESDIS' Special Programs Office manages the Direct Readout Program. This Office is the focal point for providing technical guidance to, and informational exchange among, the direct readout user community. It also collects information for feedback to NOAA satellite operators and spacecraft design engineers.

Training. During 1987, NOAA's satellite training commitment continued to grow. A major effort was expended to ensure coordinated interagency satellite training with laboratory exercises, audio and video cassettes, script-slide programs, and interactive video disk systems. The Satellite Applications Laboratory of NESDIS conducted two training courses for U.S. Navy officers. In addition training was provided to National Weather Service and Air Force forecasters, Navy reservists, television weathercasters and others. In 1987, almost 850 persons received satellite applications training from 36 NOAA workshops.

The joint NWS and NESDIS training program on satellite imagery interpretation continued. Following the creation of a handbook on imagery interpretation and collection of a series of videotapes depicting various aspects of imagery analysis, NWS and NESDIS prepared a correspondence course tied to these training materials. The course will be distributed throughout NWS (and probably the Air Force and

Navy) during 1988.

A script-slide program on polar orbiter interpretation was completed during 1987. Additional programs and laboratory exercises on tropical cyclones, downbursts, local wind regimes, ocean cyclogenesis, and satellite applications for assessing numerical model initial analysis were began. Working with the National Weather Association, NESDIS ensured widespread availability of Forecasting Handbook #6 entitled "Satellite Imagery Interpretation for Forecasters" to universities, television weathercasters, and other satellite data users.

National Geophysical Data Center

Geophysical Data Bases. The National Geophysical Data Center (NGDC) archives, publishes, and analyzes various geophysical data bases that include space, environment and cryospheric data recorded by NOAA satellites and some NASA, DOD and other country satellites. Satellite data archives expanded during 1987 include those from the GOES Space Environment Monitor, GEOSAT, the Defense Meteorological Satellite Program (DMSP) electron and ion detector, the DMSP nighttime auroral imager, and DMSP visible and infrared images up to four times daily at resolutions of 2.7 km and 5.4 km global (0.6 km for the USA, Central America, the Western Arctic, Europe, and Far East) since 1973.

Arctic Snow Melt Mapping Project. The National Snow and Ice Data Center, in conjunction with Columbia University's Lamont-Doherty Geophysical Observatory, has mapped brightness changes associated with the progression of summer snow melt on the Arctic pack from 0.6 km and 2.7 km DMSP visible-band images for the years 1977, 1979, 1984 and 1985. Manual analysis of brightness and texture patterns are used to construct 3-day melt charts consecutively from May through August of each year. The charts are digitized and values converted to approximate albedoes, resulting in the first basin-wide data base of temporal and spatial changes in the ice surface and its albedo. NSF has funded the continuation of the project for FY 1988. Six additional years will be analyzed. The combined 10 years of melt data will be available as a data set.

Cryospheric Data Management System (CDMS). The National Snow and Ice Data Center completed the development stage of the CDMS in preparation for receipt of the Special Sensor Microwave Imager (SSM/I) passive microwave data from the DMSP satellite. The CDMS is a computer-based data management and online data delivery system for primarily scientific users. Passive microwave data are specially useful for detection and mapping of sea ice type and concentration on a year-round basis. No other satellite sensor system is able to accomplish this task on a routine operational basis. It is expected that the brightness temperature data and gridded polar products will be available to the user community by February 1988.

POES Users. The North American NOAA Polar Orbiter Users Group (NANPOUG) was founded by NGDC in 1986 to help users assist each other in sophisticated applications and the development of new uses for POES. Now exceeding 130 members, the group held a well-received first meeting in Boulder in July 1987. This meeting included a tutorial on POES design, operations, and applications. One surprise was that over half the participants emphasized land applications of a system nominally thought of as a meteorological satellite. POES users are invited to join the Users Group by writing the Secretariat at NOAA's National Geophysical Data Center, in Boulder, Colorado.

POES Stereo Data for Land Applications. One new use for POES is the application of AVHRR stereo imagery for regional analysis of the Earth's physiographic setting for environmental applications. These applications are being investigated by NOAA/NESDIS' National Geophysical Data Center. The stereo imagery recently caused a stir at a United Nations meeting on sand dune movements, as it helped illustrate the environment of dune movement. The stereo imagery also permits the production of digital elevation data for very large (eventually global) areas to assist environmental modeling.

Assistance to the Egyptian Government. NOAA's National Geophysical Data Center provided remote sensing technical assistance to the Minerals, Petroleum and Groundwater Assessment Program of the Egyptian Government, and effort sponsored by the U.S. Agency for International Development. NGDC is helping set the specifications for implementing a data processing system designed for image processing and geographic information systems. This system will help Egypt to assess its environment, as well as to provide information to guide investment in Egypt's natural resources.

Assistance to the Food and Agricultural Organization of the United Nations. NOAA's National Geophysical Data Center provided technical assistance to the UN-FAO during 1987. FAO is organizing a program to document a methodology for cartography, stabilization, and afforestation of sand dunes. NGDC is providing assistance in remote sensing and cartography, as well as in getting the desired work done within a very limited budget.

Satellite Altimetry. NOAA's National Oceanographic Data Center and National Geophysical Data Center have become the repositories for the public domain version of data from the Navy's GEOSAT satellite altimeter. These Centers are helping the public utilize these important data for oceanographic, solid Earth and cryosphere applications.

Solar Geophysical Data. Often geophysical data are collected by satellites at great expense to serve an immediate, primary operational need for monitoring and alerts. However, these data provide an important long-term resource when processed into archival formats and retained for later scientific analysis. Data describing solar activity that affects Earth are published in "Solar-Geophysical Data" (SGD) reports. In July 1987, NGDC/ World Data Center A for Solar-Terrestrial Physics published in the 400-page report UAG-96 "Solar-Geophysical Activity Reports for STIP Interval XV (12-21 February 1984 Ground Level Event) and STIP Interval XVI (20 April - 4 May 1984) Forbush Decrease." It combined ground-based and satellite data reports from 68 worldwide sources to describe two intense periods of energetic solar particle deposition in near-Earth space that interfered with satellite operations, hf-radio telecommunications, and other technological systems.

GOES Data. Each month NGDC receives magnetic tapes containing GOES space environment monitoring data, including solar X-rays, energetic particles, and magnetic field variations from geostationary altitude. Plots of each data set on 35 mm microfilm provide a convenient and inexpensive medium for scientists to use in reviewing these large data sets. Energetic particle measurements from lower-altitude polar orbits are received from NOAA/TIROS and DMSP satellites. The Air Force Air Weather Service sends film images in visible and infrared wavelengths that show polar region aurora, the extent of snow and ice coverage and other features of interest for retrospective studies.

Satellite Anomalies. The detailed data base of satellite anomalies maintained at NGDC doubled in number of listed events during 1987 and the Spacecraft Anomaly Manager (SAM) software used to access the data was developed into an internationally accepted format used to exchange this type of information between the NGDC, Japan, Australia, Canada, England, India, and the European Space Agency and NASA. NOAA's Space Environment Services Center implemented a Space Weather warning service and collects quick-time reports of satellite anomalies in the SAM format and forwards these monthly to NGDC. The Space Environment Support Services of the Air Force in Omaha, Nebraska uses a modified SAM system to maintain a classified data base of anomalies of DOD satellites.

In 1987, NGDC staff provided invited briefings of Solar-Terrestrial activity as a cause of satellite anomalies at the Reno meeting of the AIAA, a Workshop on

Spacecraft Charging in Paris, a NATO Advanced Studies Institute, and in seminars at NOAA and NASA Headquarters. Results from the anomaly data base and SAM include changed operating procedures for currently orbiting satellites, tighter specifications for environmental hardening for future spacecraft, and the realization that improved environmental observations are needed to fill gaps in the current data collection during all levels of solar activity.

The Satellite Data Services Division (SDSD) of the National Climatic Data Center manages data collected by environmental satellites and the products that NOAA prepares from the data. The environmental satellite data base includes complete digital data from the present generation of NOAA's operational polar-orbiting and geostationary satellites, selected sensors aboard NASA's Seasat and Nimbus 7 satellites, and DMSP satellites, as well as limited amounts of digital data from earlier NOAA and NASA satellites. The volume of digital data consists of 110,000 digital tapes and an additional 19,000 videocassettes of geostationary satellite data. The data base includes 10 million film images from 369 satellites, dating back to the first TIROS satellite launched in 1960. Each month in 1987, 1,000 computer tapes, 150 videocassettes, and 7,000 images were added.

Polar Orbiter Electronic Catalog Service. In 1987, SDSD implemented an Electronic Catalog Services system, which gives users on-line access to its digital holdings of Polar Orbiter data from 1987 to the present. At present, the system is being used by eight test users, including two foreign users. Next year the system will be opened to all interested users.

The SDSD participated in the International Satellite Cloud Climatology Project (ISCCP), continuing its role as the Sector Processing Center for Global AVHRR data, and as the ISCCP Central Archive. In 1987, over 5,000 data sets were processed for the project, and 200 data tapes from various project processing centers were logged into the Central Archive.

Weekly Global Vegetation Index. The weekly Global Vegetation Index, which depicts the extent and "greenness" of vegetation on a global scale, was produced again in 1987. The product, which is computed from Global AVHRR data, is mapped to Plate Carree, polar stereographic, and mercator projections. The time series of this product is continuous from April 1982 to the present. The product will be produced and archived in 1988.

Experimental Aerosol Chart. Continued use of a NOAA-9 AVHRR aerosol algorithm detected smoke from slash burning in Central America, smoke from forest fires in China, Saharan dust in the tropical Atlantic Ocean, monsoon-borne dust over the Arabian Sea, smoke from the September 1987 California and Oregon forest fires, and air pollution off the East Coast of the United States. These weekly composite analyses of aerosol optical thickness are derived from reflected solar radiation measured by the AVHRR. Surface meteorological observations of sky conditions and winds support the satellite determination of dust, smoke, or haze in these regions.

Surface Heating and Precipitation. A 6-year 1980-85 set of GOES data for selected sites in the State of Kansas provides an interesting study of the relation of surface heating to climatological precipitation. Average surface heating is high during the winter season, but declines to a lower value during the summer. The decline is probably caused by increased evapotranspiration associated with active vegetation and the warm season precipitation maximum that occurs in Kansas. There is also a climatic factor in the surface heating. The amount of 30-day average heating is largest for the most arid site and decreases according to increasing annual precipitation.

Monitoring Global Climate. The capabilities of the NOAA polar orbiters to monitor long-term global climate change is demonstrated by the El Nino phenomenon. Color coded sea surface temperature maps for the El Nino years of 1982 and 1986 clearly show the disappearance of the cold tongues of water along the equator that are present during non-El Nino years (e.g., 1983).

The satellite-derived time series, 1982 to 1985, for a particular spot in this region sharply delineates the difference in the annual temperature cycle during El Nino and non-El Nino years. During the El Nino years of 1982 and 1986, the annual warming trend starts at mid-year. During non-El Nino years, the annual warming begins at the end of the year.

Upper atmosphere ozone amounts form Dobson/Umkehr measurements show decreases in ozone over the past decade. Satellite measurements(NIMBUS 7, SBUV) also show decreases at 42 km since 1979. Comparison of instruments, TOVS and NIMBUS 7, SBUV, with Dobson over a 7-year period show good agreement until mid-1984. Ozone amount trends from the satellite data sets also show differences from the Dobson data.

A major expedition was mounted in 1987 to better observe the Antarctic ozone "hole" phenomenon. NOAA/NESDIS is supplying satellite data from TOVS and SBUV observations on a near-real-time basis for additional observations scheduling. The October ozone "hole" can be depicted by observation for a single day from the NOAA-9 SBUV/2 instrument. A color image can be generated which shows the different amounts of total ozone over the region.

Search and Rescue

In 1987, the international satellite search and rescue service provided by Canada, France, the United States, and the Soviet Union was responsible for the rescue of 265 people, for a total, since the service began in 1982, of over 1,000 people. During 1987, a final draft of an intergovernmental agreement to extend this valuable service beyond the 1990's was completed.

Although the current service has proven to be extremely successful, some emergency alerts are being missed due to an insufficient number of ground stations to receive and process distress messages. For example, service in and around Hawaii, Puerto Rico, and the U.S. Virgin Islands is marginal since these areas are at the extreme limits of the currently installed ground stations. In addition, there is no service at all in and around Guam.

When using the present service, survivors may have to wait several hours before a satellite passes their position. To augment this global polar orbiting satellite search and rescue service, an experiment using a NOAA geostationary satellite is in progress. Preliminary test results during 1987 indicated that the use of properly instrumented geostationary spacecraft can provide instantaneous alerting of people in distress in most areas within the satellite's field of view.

Since a geostationary spacecraft's field of view would not cover the polar regions or provide full Earth coverage, it would not replace the current polar-orbiting service. It would only improve it. Preparations for an operational test and evaluation of this combined service began in 1987.

International Activities

CGMS. In September, the United States hosted the sixteenth meeting of the Coordination on Geostationary Meteorological Satellites (CGMS) group. Participants included the European Space Agency, the European Organization for the Exploitation of Meteorological Satellites, Japan, and the World Meteorological Organization. CGMS discussions this year included coordination of plans for launch of future satellites, use of international data collection frequencies, and contingency planning where one satellite replaces another. It was learned that the USSR has delayed launch of its geostationary meteorological satellite until 1990.

ERS-1. Negotiation of the MOU with the European Space Agency for exchanging ERS-1 ocean satellite data has resumed. The ERS-1 ocean satellite is planned for launch in early 1990.

IPOMS. The International Polar-Orbiting Meteorological Satellite (IPOMS) group made progress during its November 1986 meeting in Tokyo. Originally organized under the Economic Summit, IPOMS has brought Summit Members and other nations together to contribute to the next generation of polar-orbiting meteorological satellites. Currently, the United States operates both polar-orbiters. In the next decade, through the efforts of this group, one will be provided by international contribution.

ARGOS. In 1986, the Centre National d'Etudes Spatiales (CNES) created a subsidiary organization responsible for all promotional and operational activities of the Argos environmental data collection and processing system. In April 1987, Service Argos, Inc., an Argos data processing center in the United States, became operational in the Washington, D.C. area.

International Training. The National Environmental Satellite, Data, and Information Service (NESDIS) conducts in-house training and participates in training seminars and workshops to improve the quality and exchange of satellite data and to contribute to cooperative research activities. The in-house training is done in the context of formal agreements such as the United States and People's Republic of China protocols on Atmospheric Science and Technology and Marine and Fishery Science Technology. Training topics during 1987 included applications of meteorological satellite data, research in marine geology and geophysics, oceanographic data management procedures, crop yield assessment, and Climate Computing Systems (CLICOM) and operation. Also during 1987, NESDIS developed plans for conducting international training courses/workshops by coordinating with relevant international organizations, such as the World Meteorological Organization (WMO).

RADARSAT. In June 1987, the Canadian Government approved the RADARSAT project, a 5-year, nonreserviceable mission, with a June 1994 launch date. The major instrument will be a Synthetic Aperture Radar (SAR) related to ice operations and ice and land research. The United Kingdom will provide the platform and an Advanced Along Track Scanning Radiometer. NASA will provide the launch. NOAA's major responsibility is "to facilitate the national distribution of RADARSAT data." In particular, NOAA is being asked to assist Candada in identifying an American private sector entity to market RADARSAT SAR data in the United States as part of an international consortium composed of Canadian, U.S. and U.K. partners. SAR and other data will be available to the U.S. Government for experimental and pre-operational purposes. Multilateral negotiations between the Canadian Space Agency, NASA, NOAA, and the British National Space Centre are expected to conclude with a signed Memorandum of Understanding by the end of 1987.

CEOS. In November 1986, the Committee on Earth Observation Satellites (CEOS) met in Frascati, Italy. CEOS members are Brazil, Canada, the Federal Republic of Germany, France, India, Italy, Japan, the European Space Agency, the United Kingdom, and the United States (NOAA/NASA). At this meeting the members endorsed the continuation of the two working groups in Data Management and Sensor Calibration and Validation. The Terms of Reference were expanded to include the Space Station era. The next meeting, hosted by Canada, is scheduled for Fall 1988. The CEOS Working Group on Data, chaired by NESDIS, met in March 1987 in Washington, D.C. This group continued the work of the two previous meetings, moving toward compatibility and complementarity in space-borne Earth observation data. Agreements and planning were conducted for coordinated action in user access, archives, storage media, and synthetic aperture radar formats. The next meeting to be hosted by the British is tentatively scheduled for February 1988.

IFEOS. In November 1987, the International Forum on Earth Observations Using Space Station Elements (IFEOS) held its second meeting. Members included representatives from Australia, Brazil, Canada, the Federal Republic of Germany, France, India, Italy, Japan, New Zealand, the United Kingdom, the United States and European Communities. The group has been instrumental in aggregating the interests of the international remote sensing community for both experimental and operational use of the Space Station. At its second meeting, the group reviewed national plans for use of the Space Station for Earth observations and was briefed on the status of development of the Space Station.

Cooperation with the People's Republic of China. NESDIS conferred with the Satellite Meteorology Center of the People's Republic of China to discuss the details of a 3-year joint study to determine the impact of satellite soundings and cloud motion wind vectors on the numerical analyses and forecasts produced by the People's Republic of China. NESDIS is supplying data tapes to China for use in their experiments.

International Training. In 1987, visiting foreign scientists were trained by NOAA in applications of remote sensing data obtained by environmental satellites that included estimating precipitation from satellite imagery, assessing climate, forecasting weather and crops, and managing satellite data. NESDIS continued to discuss with WMO needed training courses for foreign meteorologists and oceanographers. Aviation weather, tropical meteorology and oceanography applications were among the courses being considered.

Research

Turbulence. A study of infrared and 6.7 micron water vapor imagery from the GOES satellite has revealed a signature which is related to the occurrence of severe high-altitude mountain wave turbulence. In cases where cirrus clouds show a pronounced, narrow, stationary clearing or dark zone parallel to the downwind edge of large mountain ranges, the likelihood of turbulence is high. This signature may provide advance notice of this dangerous type of turbulence for commercial and military jets.

Precipitation. The operational convective satellite rainfall estimation technique has been modified to include three new factors: a rain burst factor, a low-level inflow factor, and a speed of storm factor. The ingredients of 3-12 hour heavy convective precipitation forecast index has been developed. The ingredients include an instability burst factor (the local change of stability with respect to time), moisture, storm propagation or regeneration and upward vertical motion. An evaluation of the index and the three new factors is planned for the spring and summer of 1988. A methodology for using the VAS Data Utilization Center in the analysis and forecast of heavy precipitation has been developed. An objective automatic precipitation estimation technique is being developed as a first-guess estimate for every thunderstorm occurring anywhere in the United States. The automated estimates will help meteorologists "zero in" on potential flash flood-producing thunderstorms. During the past year, encouraging progress has been made with the applications of passive microwave rainfall monitoring techniques to events both within and outside the United States. The findings are of direct relevance to a number of NOAA programs.

Planning continues for experiments that NTIA will conduct utilizing the Advanced Communications Technology Satellite (ACTS) under development by NASA. NTIA experiments will center on communication systems performance with measurements being undertaken to evaluate network and switching performance. These will be accomplished utilizing NTIA-developed, user-oriented performance parameters and measures recommended in American National Standards (ANS) X3.102 and X3.141. NTIA also will be evaluating beam pointing and timing accuracy issues directly related to the equipment capabilities. Results of these and related experiments are expected to provide valuable insights as to the performance of advanced satellite communication systems to meet U.S. objectives.

World Administrative Radio Conference. World Administrative Radio Conferences (WARCs) are conducted under the aegis of the International Telecommunication Union (ITU), and the National Telecommunications and Information Administration (NTIA) of the Department of Commerce actively participating in them. In its role as organizing agency and focal point for executive branch preparations for future ITU WARCs, the NTIA-led preparation for the 1987 Mobile WARC and the 1988 ORB (2) WARC, both of which are of major importance to U.S. space interests.

At the Mobile WARC, with strong NTIA participation as part of the U.S. delegation, an important frequency allocation was won for the Radiodetermination Satellite Service (RDSS). The RDSS will use satellites to provide users with specific information on their location for management, inventory and safety. Additionally, some radio spectrum was allocated to the Land Mobile Satellite Service (Land MSS) with provision for aeronautical and maritime mobile satellite operations. This essentially generic MSS is new to the ITU Radio Regulations and allows more economical satellite systems to be implemented. The WARC on the Use of the Geostationary Satellite Orbit and the Planning of Space Services Utilizing It, known as the ORB (2) WARC, is expected to develop planning methods, and improve and simplify regulatory procedures for gaining access to the geostationary orbit for all countries. As a key participant in the development of U.S. positions, proposals and strategy, NTIA is working to ensure the protection of present and future U.S. satellite systems.

Tropical Cyclone Research. A comprehensive project to improve our understanding of hurricanes and typhoons using extensive satellite and aircraft data sets is underway at the Regional and Mesoscale Meteorology Branch of NOAA/NESDIS at Colorado State University. Three-hourly digital satellite data from the Geostationary Meteorological Satellite (GMS), located at 140° east longitude, are being processed with respect to nearly 100 tropical cyclones in the West Pacific. One of the drawbacks of past tropical studies based on satellite observations has been the lack of "ground truth" data to verify the satellite diagnosis. Air Force research is being used for this purpose. The aircraft data provide wind and pressure observations which measure the tropical cyclone's intensity and wind pattern. The intensity and extent of the deep convective clouds, which provide the energy to drive the tropical storm circulation, are calculated using the infrared data from GMS. Results suggest important new findings concerning tropical storm development and diurnal variation of rainfall. Improvement in satellite estimates of intensity and size of the tropical cyclone circulation are anticipated after additional analyses.

Fisheries Satellite Oceanic Remote Sensing. Satellite oceanic remote sensing is beginning to play an important role in fishery research and management by providing synoptic oceanic measurements for evaluating environmental effects on abundance and availability of fish populations. Variations in ocean conditions play key roles in causing fluctuations in stocks of fishes and in their vulnerability to harvesting. Information on the changing ocean, rather than on average ocean conditions, is necessary to understand and eventually predict the effects of the ocean environment on fish stocks. This knowledge is required to provide the best possible advice for making fishery management decisions and for developing efficient harvesting strategies for fishery resources.

The recent developments in satellite remote sensing techniques for fisheries applications have concentrated on measurements of sea surface temperature, ocean color, and ocean transport derived from satellite-measured wind stress. Synoptic coverage of ocean temperature, color, and information is applicable to fisheries problems. However, knowledge of key oceanographic conditions and processes affecting the recruitment, distribution, abundance, and harvest of fishery resources may often be gained using these data.

Recent satellite research at the Southeast Fisheries Center of the National Marine Fisheries has focused on using satellite data to aid in locating adult and juvenile forms of commercially important fish species in the Gulf of Mexico and Caribbean. Some of these species include bluefin tuna, yellowfin tuna, butterfish, king mackerel, menhaden, and shrimp. A pilot study was conducted in the Gulf of Mexico using thermal data acquired from NOAA satellites to assist fishermen in locating commercial concentrations of butterfish. The data were processed at the satellite data processing facility that was recently established at the Mississippi Laboratories of the Southeast Fisheries Center.

Fisheries scientists from the Southwest Fisheries Center and the University of Oregon are currently evaluating the feasibility of using satellite measurements of ocean temperature and color to determine the best time to release salmon smolts from Columbia River salmon hatcheries. The objective is to time the release of smolts during ocean environmental conditions which would be favorable for their survival and, thereby, improve their chances for subsequent recruitment into the salmon fisheries. Southwest Fisheries Center scientists are also completing a case study using SEASAT Scatterometer wind stress measurements to define locations of oceanic convergence and divergence which are believed to be important in determining the availability of albacore tuna to the U.S. fishery off the coast of North America.

At the Northeast Fisheries Center the Northeast Area Remote Sensing System (NEARSS), an association of government, academic and private non-profit institutions, has guided the development of a communication network between users of remote sensing data and data/information sources. The NEARSS continues to provide a forum for the exchange of information and a support base for meeting regional satellite data and information needs.

Detection of Gravitational Waves. Scientists at NBS are continuing to explore and assess the practicality of using lasers to detect gravitational waves in space with periods of about 0.1 seconds or longer. The detection of such waves (pulses) would provide an entirely new way of studying events in the Universe involving very large masses. These events include collisions of massive black holes, which are thought to exist at the centers of many galaxies and probably provide the energy source for quasars.

Earth's Atmospheric Chemistry. Through a cooperative agreement with NASA, NBS scientists are engaged in experimental studies of the chemical dynamics of gas phase processes (reaction rates and mechanisms) selected for their importance in atmospheric chemistry. Results of these NBS studies are useful in modeling of various atmospheric phenomena including the effects of natural and atmospheric emissions on the stratospheric ozone layer, the atmospheric radiation budget (greenhouse effect), and tropospheric acid precipitation. Although homogeneous atmospheric chemistry involves the interactions of dozens of free radical and stable species, its study has been facilitated by its subdivision into reaction cycles whose elementary steps can be elucidated through laboratory study.

The principal focus of NBS activity during 1987 was chemical kinetics of the hydroperoxy free radical, HO2. The experiments focused on the reaction of HO2 radicals and their combination with CH3O2. This reaction is important in the atmospheric oxidation of methane and other hydrocarbons as well as in low temperature combustion systems. In other NBS studies, flash photolysis-kinetic spectroscopy is being used to study the kinetics and chemistry of the vinylidene unsaturated biradical (H2CC). The photolysis of hydrocarbons control the atmospheres of the outer planets. Understanding the chemistry of the vinylidene radical will help in modeling outer planet atmospheres.

Far Infrared Absorption Spectra. In a program sponsored by NASA in collaboration with several universities, NBS is investigating experimentally and theoretically, far infrared absorption spectra that are produced by collisions of the nonpolar molecules found in the atmospheres of the outer planets. Such results are needed to interpret the thermal emission from these atmospheres and to determine, for example, temperature profiles and the concentrations of such gases as H2, He, CH4, and N2.

The principal focus during 1987 was the study of the gaseous mixtures H2 and He and H2 and CH4. Accurate laboratory spectra of H2-CH4 and those for H2-He and H2-H2 were obtained earlier. These spectra were analyzed to determine the various mechanisms responsibile for the absorption, in order to represent the spectra by simple analytical models. In this way, laboratory measurements taken at only several temperatures and concentrations could be readily extrapolated to the various temperatures and concentrations required in applications to studies of planetary atmospheres.

Solar Activity Affecting Communication Systems. Geophysical responses to solar activity are dominated by enhanced electromagnetic and particle fluxes associated with solar flares. The highly energetic radiation can cause irregular, impulsive ionospheric disturbances that affect the intensity, frequency and phase of radio signals. Thus, an ability to understand and predict flare events is crucial for maintaining and improving our communication systems.

In collaboration with NASA and National Solar Observatory scientists, NBS scientists are focusing their efforts on the structure and evolution of flares in the solar transition region (104 < Te < 105), because this region is much less well understood than in either the lower chromosphere or the corona. It is in this region that the intense EUV resonance lines of neutral and ionized helium have a crucial role not only in determining the physical conditions during many phases of the flare, but also as a diagnostic tool for studying these conditions.

Measuring Surface Magnetic Fields on Cool Stars. NBS scientists are pursuing a major program to measure surface magnetic fields on stars cooler than the Sun. They have already succeeded in making magnetic field measurements on stars much cooler than was heretofore possible. They have also developed an analysis technique to take into account for the first time the saturation of optically thick absorption lines. These measurements confirm the hypothesis that magnetic fields are at the heart of solar-like phenomena by showing that stars with the most energetic phenomena, for example, flares and enormous starspots, also have the strongest measured field strengths and spatial coverage. Three additional conclusions may be drawn from these measurements and the field parameters in somewhat warmer stars. First, the field strength is determined by hydrodynamic processes in the photosphere and not by dynamo field creation processes in the stellar interior. Second, stars with energetic or widespread magnetic-related phenomena have fields that cover nearly the whole star, indicating a high rate of field production in the stellar interior. Third, the fraction of the stellar surface covered by magnetic fields depends on the stellar rotation, as would be expected if fields were amplified by the dynamo process. These findings should aid in understanding stellar activity, such as flares, spots, and hot coronae on some stars.

An NBS scientist is a major participant on several key science working groups doing the detailed planning for astronomical missions as well as planning for future space observatories to obtain ultraviolet and X-ray astrophysical data. For example, the NBS scientist is a co-investigator on the Space Telescope Imaging Spectrograph (STIS), now being designed to replace the HRS 5 years after launch. This instrument will have high-spatial imaging capability as well as high-spectral resolution over the extended spectral range 110-1100 nm.

Artificial Satellite Orbit Analysis. The non-uniformity of the Earth's gravitational field imparts stability properties to certain sets of satellite orbits that can be exploited by mission planners. Orbits inclined at 63.435° called the critical inclination, comprise one such set. Solutions to the equations of motion for satellites at this inclination possess a first order stationary point; that is, based on a first order analysis, the orbital ellipse of satellites placed at this inclination will maintain their initial orientation and shape in space. Satellite missions involving navigation, data collection, and Earth resource analysis place stringent requirements on a satellite's orbit and lead to a need for stationkeeping maneuvers to correct for drift of the satellite's orbit not predicted by the first order analysis. Stationkeeping maneuvers need to be minimized to extend the lifetime of a satellite with limited fuel capacity. Many proposed satellite missions place such strict specifications on the orbits that designers cannot depend on first order orbital analysis to adequately describe the long-term stability of the orbit. Until now, the body of knowledge about the stability of the second order equations for this problem has been quite incomplete. Previous research efforts have attempted to characterize the phase space of the critically inclined satellite problem as that of a simple pendulum. Work of Deprit at NBS shows that this problem is much more complex. The phase space for the satellite problem depends on several components of the angular momentum in such a way that at certain parametric values, bifurcations in the phase space occur. For some values there are four stationary points in the phase space, but for others there are no stationary points and the semi-major axis of the orbital ellipse will circulate continuously. An important aspect of this research is the discovery of a set of coordinates that allow the phase space to be mapped onto a sphere. Using these coordinates the analysis of the critical inclination problem has, for the first time, been extended to include a neighborhood of the circular orbits.

This research activity is based upon the use of advanced automated mathematical analysis techniques on specialized symbolic computers. Current effort is directed towards improved analytic and graphical techniques for the analysis of complex nonlinear dynamics problems.

Diamonds in the Sky. Diamonds have been discovered in interstellar dust in meteorites. NBS scientists have shown that meteoritic samples contain extremely fine-grained diamond crystals. Other scientists have used mass spectrometry on the same material to show that it contained isotopically anomalous krypton, xenon, and nitrogen, which suggests that the sample origin is probably outside of this solar system. High-resolution imaging and electron diffraction with the transmission electron microscope were used to identify the diamond grains, which had dimensions less than 0.005 m, found in the meteorites Allende, Murchison, and Indarch. The researchers believe that the diamonds are most likely formed as a metastable phase from a hot gas at low pressure, shown recently in laboratory experiments. One possible scenario is that the diamonds were implanted with the isotopically anomalous gases from a supernova.

Work is now in progress to see if the size distributions of the diamonds agree with observations currently being made on the new supernova occurring in the Large Magellanic Cloud. This would compare or contrast two radically different optical techniques: the telescopic analysis of a supernova 170,000 light years away and the laboratory electron microscopic analysis measured at approximately 1,000,000X magnification.

Measuring Microwave Emission From Stars. Scientists from NBS and Goddard Space Flight Center have several projects underway to study microwave emission for stars. They have now completed a survey of microwave emission from 39 of the closest stars that are more luminous and cooler than the Sun. This survey at 5 and 15 GHz was made using the National Radio Astronomy Observatory's Very Large Array (VLA). The purpose was to measure mass loss rates for a class of stars (giants and supergiants of spectral types G, K, and early M) for which there was little data heretofore. Microwave emission from these stars is thermal bremsstrahlung from the ionized component of the circumstellar gas leaving the star. The scientists have now extended the program to study mass loss from the coolest M giant stars, many of which are SiO maser emitters. In addition, an extensive survey of microwave emission from close binary stars and from binary systems containing white dwarf companions and strongly enhanced heavy metal abundances has been completed.

Models for the Outer Atmosphere Layers of Stars. NBS scientists and a colleague from Oxford University have completed work on a set of detailed models for the outer atmosphere of solar type stars. These models describe the amount of emitting material in the chromosphere, transition region and corona. The models were constructed to match ultraviolet emission line fluxes observed by the International Ultraviolet Explorer satellite and X-ray fluxes observed by the Einstein X-Ray Observatory.

Atmospheric Parameters of Hot Stars. In a continuing project to determine accurate values for the atmospheric parameters of hot stars, NBS scientists are carrying out a detailed analysis of the line spectra of 16 hot stars they observed at Kitt Peak National Observatory to high photometric precision (S/N of order 300). The analysis is based on non-LTE stellar models that account for radiation scattered back into the star by its stellar wind, an effect already shown to be important for hot luminous stars. This so-called "wind blanketing" causes the value of the effective temperature inferred from stellar spectra to be significantly lower than would be found if the effect were ignored. Seven stars have now been analyzed, and work on the remaining nine is now well underway. The results for Zeta Puppis appear to settle a longstanding uncertainty of about 40 percent. Also, the method of determining temperatures of hot stars from measurement energy distributions has been shown to be utterly unreliable; many temperatures in the literature could be in error by 25 percent or more.

An analysis of this kind gives accurate values of the effective temperature and surface gravity, and can be extended to yield the chemical composition. A program has been set up, in collaboration with a group from the Institute for Astronomy and Astrophysics of the University of Munich, to determine as accurately as possible the stellar parameters of 20 to 30 stars in our galaxy and in each of the Magellanic Clouds. In view of the widely different elemental abundances of these three galaxies, these data will provide the first observational tests of stellar evolution theory that can discriminate among alternative theories of mass loss and convective overshooting. The scientists have shown that by using the terminal velocity of a star's stellar wind, which can be measured from line profiles, in addition to the effective temperature and surface gravity, it is possible to infer the absolute luminosity, and hence the distance to the star. The method uses purely spectroscopic data and contains no calibration or empirical correlations. It can be tested definitively in the next few years when distances to some "nearby" hot stars will be measured accurately by satellite observations using trigonometrical methods. Meanwhile, scientists are testing the method by analyzing spectra of stars for which distances are known independently.

Other Uses of Satellites

Geodynamical Measurement Methods. The accuracy of a number of geophysical and astronomical studies based on microwave distance measurements is limited mainly by the uncertainty in the correction for water vapor in the atmosphere. NBS scientists are developing a microwave-optical system to improve the accuracy in the correction to the microwave distance measurements due to the atmospheric water vapor. This system will enable scientists to measure the integrated water vapor content between a transmitter on the ground and a receiving package in an aircraft. Since optical distance measurements are much less sensitive to water vapor, the difference between the measured optical and microwave distances can be used to determine the correction. The basic transmitter and receiver for the system have been constructed and tested in the laboratory. Construction refinements to the system are continuing. NASA and other researchers are expected to use the NBS instrument to test the accuracy of water vapor radiometers and radiosonde data.

New Format for First Space-Made Product. The NBS Office of Standard Reference Materials made available the first product manufactured in space in 1986. Billions of tiny polystyrene spheres made aboard a NASA space Shuttle flight were offered as an NBS standard reference material (SRM 1960). This SRM is being used to improve microscopic measurements made throughout the economy in electronics, medicine, and other high-technology areas. This year, NBS has made available SRM 1965, Microsphere Slide, a new format for the original SRM 1960, 10-m polystyrene spheres. In this new SRM, a few thousand microspheres are deposited on a glass microscope slide and permanently sealed in an air chamber produced by a cover glass and a support glass with aperture. In one grouping, the spheres are in an unordered arrangement, resembling strings of beads. This grouping is primarily for exercises in micrometeorology that include measuring microsphere diameter and shape, as well as other experiments in optical measurements. The other grouping of microspheres is an ordered two-dimensional hexagonal array, like a single layer of marbles packed together. Because all the microspheres on the slide are of almost equal size, the array can be used by those who work with microscopes as a two-dimensional microlength standard to replace calibrated stage micrometers. These are precision scales that are placed under the object lens of optical microscopes to calibrate the instruments and are used as rulers to measure small objects. The hexagonal structure also can be used for array sizing, for diffraction experiments in crystallography, and for calibrating microscope image distortion and magnification. One of the reasons SRM 1965 was prepared with these sphere arrangements is to provide an educational tool for teachers and students interested in microscopy. Approximately 200 units of SRM 1965 have been purchased during this year.

Effects of Gravitational Fields on Properties of Interfaces. NBS is conducting a systematic theoretical and experimental investigation of liquid-liquid, liquid-solid, and liquid-vapor interfaces. The studies include investigation of the phenomenon of wetting as well as the effects of gravitational fields on wetting, wetting transitions, and interfacial tension. Of particular interest is the effect of various parameters such as gravity on the thickness of wetting layers and their ability to intrude between layers of other liquid layers. Interfacial properties are very important to the understanding and predictability of many technological processes ranging from enhanced oil recovery to biotechnology. NBS experiments have shown that current theories are inadequate in explaining the measured results, including the fact that wetting persists over large temperature ranges. Measurements in microgravity are needed to provide data for systems which will allow the development of adequate theories for explaining the results of current normal gravity results in the NBS experiments. These theories will then, in turn, provide for the development of predictive models for a large range of industrial and aerospace applications.

Low Gravity Alloy Processing. The coarsening of solid alloy particles in liquid-solid mixtures was investigated by both theory and experiment to evaluate the advantages of space flight experiments for accurately measuring this effect. Virtually all two-phase mixtures coarsen, such that the average sizes of the dispersed phase regions increase while their numbers decrease. This coarsening is responsible for the aging process that is critical in determining the properties of precipitation-hardened alloys. Detailed ground-based measurements of coarsening in liquid-solid Pb-Sn mixtures have been completed. Similar experiments in low gravity which will allow suppression of perturbing effects from sedimentation and buoyancy driven fluid flow are planned.

Properties of Electronic Materials. Theoretical studies of the fluid flow, solute segregation, and interface morphology which occur during directional solidification are performed to develop information needed in planning and designing space flight experiments on solidification processes in low gravity environments. These space flight experiments will be designed to determine cellular wavelengths as a function of growth conditions. Interface stability during solidification is important in controlling properties of electronic materials. The effect of an electric current on morphological stability of a planar interface has been investigated in a binary alloy. Electromigration of solute and perturbation of the electric field by the perturbed crystal-melt interface modify the conditions for morphological stability.

High-Temperature Thermophysical Properties. NBS is developing and utilizing techniques which are capable of highly accurate measurements of thermal, optical, and electrical properties of technically important materials at high temperatures using very high heating rates in the range of 104 - 108 K/s. The current techniques perform measurements at millisecond and microsecond intervals as samples are rapidly heated through the melting temperature. It is highly desirable to obtain experimental data through the melting temperature and into the liquid region; however, gravity causes the liquid sample column to collapse before results can be obtained. NBS has developed a millisecond apparatus for use in microgravity; in fact, some results have been obtained from KC-135 aircraft in simulated zero-gravity flights. Plans are underway for NBS to develop apparatus which can be flown on spacecraft and which can yield accurate data for liquid metals at temperatures up to 10,000 K. To date, results have been obtained on conducting materials such as niobium, graphite, and other refractories. NBS is developing similar techniques to perform measurements on nonconductors.

Network Protocols. The National Bureau of Standards is working with COMSAT in a joint research project to test and evaluate the performance of computer network protocols over satellite networks. Results of this collaborative research are helping to advance the development of network products that implement Open Systems Interconnection (OSI) standards. Being developed by national and international standards groups, the OSI standards will enable different manufacturers' products to be interconnected through networks using a variety of communications methods. However, because of the complexity of the standards and the different interpretations that implementors may have for the specifications, tests are needed to assure correct implementation of standards and efficient operation of networks when different communications methods are used and different applications are processed.

An NBS/COMSAT research team has been developing test methods for and measuring the performance of network systems when data is transmitted by satellite. The experiments started with one data communications protocol (the transport protocol) in the OSI family of standards. As a result of the investigations, modifications of the protocol standard were developed to enable data to be transmitted more efficiently. More recent experiments have added more protocols to the group being tested. This work, along with experimental work with other organizations, is directed toward verifying a simulation model developed by NBS for a complete set of protocols for computer-to-computer communications. The model is also being evaluated by the European Space Agency.

Transport Property Measurements in Microgravity. It is not possible to experimentally study dynamic critical phenomena and measure the transport properties of fluids close to the critical point under conditions of normal gravity. Gravity-induced fluctuations mask the fluid behavior and properties so that definitive results are not possible. NBS has developed a torsionally oscillating viscometer to measure the viscosity of fluids at very low frequencies and shear rates. Extensive baseline measurements are underway and will be used, in conjunction with microgravity results, to better predict behavior and properties very close to the critical point. Results have been obtained on a series of pure fluids, fluid mixtures, microemulsions, and liquid metals. A prototype version of the viscometer will be developed by NBS which can be used on spacecraft under conditions of microgravity.

Department of Energy

For many years, the U.S. Department of Energy (DOE) and its predecessor agencies, the Atomic Energy Commission (AEC) and the Energy Research and Development Administration (ERDA), have supported the design, development, production, and delivery of nuclear power sources for highly specialized space and terrestrial applications. Since the beginning of the program in 1956, the various nuclear electric power systems, originally known as Systems for Nuclear Auxiliary Power (SNAP), delivered by DOE to the National Aeronautics and Space Administration (NASA) and to the Department of Defense (DOD), have provided safe and highly reliable electrical power that contributed to the success of some of the most ambitious and spectacular astronautical events undertaken by the United States.

Space Nuclear Power Systems

Space nuclear power systems are of two basic types, reactors and isotopic. The SNAP-10A reactor was tested in space in 1965, and many Radioisotope Thermoelectric Generators (RTG's) have been used since 1961. In 1987, responsibility for the development of these space nuclear power systems within the Department of Energy was placed in the new Office of Space and Defense Power Systems, under the Assistant Secretary for Nuclear Energy. Considerable progress was made in 1987 in designing and developing the next generation of these uniquely enabling power units for the challenging space missions of the future.

Radioisotope Thermoelectric Generators

The purpose of the space Radioisotope Thermoelectric Generator (RTG) program is to provide flight-qualified RTG's and maintain a technology base necessary to meet present and future NASA and military requirements. The RTG is a static isotopic power system with no moving parts that uses a radioisotope heat source coupled thermally to a converter segment. Thermoelectric elements in this converter segment convert heat, generated by decay of the radioisotope fuel, to electricity using a basic material property known as the Seebeck effect. Due to its high power output and long-term power production (87.6-year half-life), plutonium 238 has been the fuel used to power all U.S. space RTG's launched to date. The United States has successfully used 34 RTG's on 19 space systems, such as navigation and communication satellites launched by DOD and scientific spacecraft launched by NASA, to provide electric power for Earth orbital, lunar, and deep space systems. RTG's have proved to be rugged, dependable power supplies, regardless of the operating environment. Unique characteristics of these radioisotope power units, such as acceptably low-level radiation and no moving parts, contribute significantly toward meeting stringent space system requirements. All RTG's, from the SNAP-3A to the Multi-Hundred Watt (MHW) unit, exceeded their design requirements by providing greater power than required or for lasting longer than the planned lifetimes. This was dramatically shown by the Voyager 2 flyby of Uranus in January 1986; MHW-RTG's have operated for 5 years beyond the originally specified lifetime. The same Voyager spacecraft is now heading toward Neptune with a flyby scheduled for 1989. All indications are that the RTG's will continue to provide adequate power for the Neptune flyby and beyond.

The state of the art in RTG technology is the General Purpose Heat Source (GPHS) RTG. Two of these units will power NASA's Galileo mission to Jupiter, scheduled for launch in 1989, and one GPHS-RTG will be launched in 1990 to power NASA's Ulysses mission to observe the Sun out of the plane of the solar system. Each unit has a mass of 55.5 kilograms and produces 4,410 thermal watts which is converted to at least 285 watts of electricity at the beginning of the mission. Silicon-germanium thermocouples are used to convert heat to electricity.

During 1987, DOE continued to support studies of RTG design, heat source materials, and thermoelectric materials. Some of this work will support designs for the future NASA Mariner Mark II class of spacecraft. Principal activities in 1987 were in support of the

NASA Galileo and Ulysses missions. The four GPHS-RTG's assembled and tested for those missions by DOE, through its contractors and laboratories, were returned from Kennedy Space Center to Mound Plant, Ohio, following the Challenger accident. These RTG's continue to be monitored and serviced as required to ensure their integrity in the interim period until the new NASA launch dates. Revision of the Final Safety Analysis Reports (FSAR), which contain risk analyses of postulated accidents, continued for both the Galileo and Ulysses missions. Additional safety tests and analyses were conducted to consider changes in the NASA mission profiles and launch vehicles. The new FSAR's for the GPHS-RTG's and Light-Weight Radioisotope Heater Units (LWRHU) are expected to be completed in late 1988, approximately one year prior to the launch date of Galileo.

Life testing of the GPHS qualification RTG unit continued successfully for a period of over 25,000 hours; life testing of the engineering unit was discontinued at approximately 23,000 hours to conduct post-test analysis and to use components in further safety testing of the GPHS-RTG. The qualification unit was built as a test generator to qualify the GPHS-RTG design for mission-related environments. The engineering unit was constructed before the qualification unit as a nonnuclear test article to check the engineering design. Life testing has provided valuable data in support of the long-term performance and reliability predictions of the flight RTG's, and the power output matches the engineering predictions very well. The qualification life test is expected to continue through FY 1990.

In 1987, additional development of advanced technology RTG's for future space missions continued. The modular radioisotope thermoelectric generator program (MOD-RTG) focused on the design, development, manufacture, and test of an electrically heated engineering test unit. It will demonstrate two new advanced components, a lightweight insulation system and a new compact thermoelectric conversion device, the multicouple. Current efforts are directed toward qualification of the multicouple at the component level. The MOD-RTG design will provide a significant advance in RTG specific power (watts/kilograms) and improved efficiency for use in NASA's Mariner Mark II and DOD missions during the next decade. Details of the current and improved RTG's are provided in Table 1.

Dynamic Isotope Power System

No single nuclear power source can span the wide range of power requirements for the variety of space applications now contemplated. The best progression of space nuclear power systems from lowest power to higher power has been exhaustively studied and is currently judged to be isotope-static, isotope-dynamic, reactor-static, and reactor-dynamic. Current DOE space nuclear power system programs are using and developing each of these combinations of heat-source and energy-conversion methods. To bridge the gap between isotope-static and reactor systems, DOE and DOD have been developing the Dynamic Isotope Power System (DIPS), targeted for the range of 1-10 kW_e, which can be certified for first flight in the mid-1990's.

These units, for example at 6 kW_e, would contain up to 53 kg of plutonium 238 each, and have a mass of up to 800 kg and a volume of about 0.8 cubic meters. A prime contractor was selected in 1987, and a choice of the closed Brayton cycle as the energy conversion system was made in early 1988. The final design is now under way. The heat source is the well characterized and developed GPHS. Materials being considered for dynamic systems already meet 10-year life requirements. If even greater efficiency is sought through higher temperature, more material development and testing will be needed. For the Brayton cycle, studies of bearings and possibly of special turbine materials will be necessary. Heat rejection will be by means of heat pipes to a flat radiator, although a

Table 1: RTG Performance Data

Type RTG	Power Output			System		Energy Density T.E.	
	kW_t	BOM(kW_e)	EOM(kW_e)	Mass(kg)&Vol(m^3)		(kg/kW_e)	Effic(%)
GPHS-RTG	4500	300	285	56	0.19	187	6.5
MOD-RTG	3600	300	285	39	0.14	130	8.0

NOTE: RTG = Radioisotope Thermoelectric Generator
BOM = Beginning of Mission
EOM = End of Mission, assumes 7 years.
T.E. = Thermoelectric power conversion
kW_e = Kilowatts electric
kW_t = Kilowatts thermal

cylindrical radiator remains an option which would provide more hardness to the spacecraft. There appear to be no significant technological problems which would prevent the development and demonstration of the high reliability (98 percent) components essential for the DIPS.

SP-100 Space Reactor Program

The SP-100 Program was initiated in 1983 as a cooperative effort among the Department of Energy, the Department of Defense, and NASA. The purpose of the program is to develop and demonstrate technology for space reactor power systems that will enhance a wide variety of emerging civilian and military missions whose requirements cannot be met by current space power sources.

The first phase of the program focused on assessing and advancing technology for space nuclear reactors in the power range of tens of kilowatts to 1,000 kW_e (1MW_e) and was completed in 1985. A liquid-metal-cooled, fast-neutron reactor, using a thermoelectric power-conversion concept, was selected for further engineering development and ground demonstration testing during the second phase of the program. Also in 1985, the decommissioned Plutonium Recycle Test Reactor containment facility on the Hanford Reservation in Washington was selected as the preferred test site for the reactor ground tests. In 1986, conceptual designs for the required test site modifications were undertaken. Also, in 1986, a competitive selection was made for a contractor to design a reference flight system and to validate this design by building and ground testing various subsystems and components both separately and in integrated tests. Concurrent with these 1985 and 1986 activities, supporting technologies, such as fuel, materials, thermoelectrics and heat pipes, were developed and tested at DOE and NASA laboratories and centers.

In 1987, phase II of the SP-100 Program proceeded vigorously. The project management team was led by the Jet Propulsion Laboratory and supported by the Los Alamos National Laboratory. General Electric was the lead contractor for the system contract and the thermoelectric cell technology development. Los Alamos was assigned the fuels development tasks. Westinghouse Hanford Corporation conducted the fuel pin testing and evaluation and continued to work on the reactor test site. Materials testing and evaluation were conducted at the Oak Ridge National Laboratory, and support test facility work will be done at the Energy Technology Engineering Center in Los Angeles. Substantial progress was made in 1987 by the system contractor, on the Hanford ground test site, and in a variety of technology development areas.

The system contractor team led by General Electric established a reference design configuration, that included innovative mass reduction and safety design features. The thermoelectric multicouples form the basic building block of the Thermoelectric Converter Assemblies. There also has been substantial definition of requirements for the Nuclear Assembly Test (NAT) facilities and equipment, establishment of clearly defined interfaces with the test site, and continuing development of data bases in important technical performance areas such as fuel, bonded fuel cladding, heat pipes, refractory materials, and thermoelectric materials, insulators, and compliant pads.

A very important aspect of the ground testing effort is the planning and conduct of the nuclear assembly performance test. This will involve a ground demonstration test of a prototypical space reactor, shield, and primary heat transport loop in a temperature controlled vacuum chamber to simulate the space environment to the maximum degree practicable.

General Electric will conduct the system-level Integrated Assembly Test of the space power system using an electric heat source to simulate an operational reactor. A major goal of this test is to demonstrate that the solid lithium within the power system heat transport piping can be thawed in a consistent, predictable, and reliable manner. This nonnuclear integrated assembly test also will demonstrate performance of the thermoelectric power conversion subsystem, thermal integration of the entire power system, and mechanical and electrical integration of the whole system except the nuclear reactor. This test will simulate thermal and vacuum aspects of the space environment to the maximum degree practical. Environmental and safety compliance is of major importance to this testing effort. An Environmental Assessment was prepared in compliance with the National Environmental Policy Act.

Technology development continued to be a high priority in 1987, in order to meet the challenging technical requirements of the SP-100 Program schedule. The focus was on long lead items and that technology which is key to the program. Progress was made in all areas during the year, resulting in the following significant accomplishments:

- Mockup of the initial reactor core for zero power criticality tests at the Argonne National Laboratory-West Zero Power Plutonium Reactor criticality facility in Idaho. This facility approximates the reactor core by the loading of fuel and material coupons in a honeycomb structure mounted on a split table. When the two halves of the core on the split table are brought together, measurements of the core's ability to sustain or avoid a chain reaction in normal operational or accident situations are made. Completion of these initial tests provided excellent benchmarks for validating nuclear design computer codes, which are used to analyze normal and water-immersion conditions.

- Characterization testing of the mechanical properties of in-reactor and out-of-reactor refractory alloys. This data base is essential to the design process, particularly for the reactor core and for validating the reactor operating lifetime.

- Improved performance of thermoelectric materials was confirmed and further development effort was underway. A contract was initiated to pursue an alternative concept to accommodate thermal stress in the thermoelectric panels. This alternate approach is considered a backup to the reference GE concept.

• Two nuclear fuel irradiation tests were conducted in DOE's Experimental Breeder Reactor II (EBR-II). Maximum burnup achieved to date was approximately 5 atom percent, which represents more than half of the 7-year full power lifetime planned for SP-100. Previously, irradiated fuel pins were reinserted in the reactor to achieve burnups of up to 9 atom percent, which is well beyond the design burnup of SP-100. Examination of the latest set of fuel pins tested in EBR-II indicated problems with free-standing liners. However, since the reference design has changed to bonded rhenium liners, this result has no effect on the current SP-100 reactor design.

• Hyperstoichiometric uranium nitride fuel pellets with the required specifications were successfully fabricated and analyzed at the Los Alamos National Laboratory.

• The processes and equipment necessary to produce the fuel for the ground reactor test were almost in place, and pre-production quality assurance reviews were conducted.

By the end of 1987, the SP-100 Space Reactor Program was well underway and already yielding exciting results. Continuing at this pace, the goal of producing a flight-ready system to meet NASA requirements by the mid-1990's is definitely within reach. Concurrently, DOE will apply much of the technology developed under this program to the next higher space power reactor also in development, the Multimegawatt reactor.

Multimegawatt Space Reactor Program

In 1985, the Multimegawatt (MMW) Space Nuclear Power Program was established as a joint DOD-DOE program. The primary goal of this program is to identify at least one space nuclear power system concept by 1992 that meets the high performance, multimegawatt power requirements of advanced Strategic Defense Initiative (SDI) applications, and to resolve all feasibility issues by that time. There also is great potential for follow-on civil applications for nuclear MMW power systems. Examples are nuclear electric propulsion to cut interplanetary transport times substantially, power for manned bases on the Moon or on Mars, and power for the many large-scale industrial processing schemes in space that are being contemplated.

The necessity for developing MMW space nuclear power systems is driven by both civilian and defense applications and needs, but the predominant factors are the stringent requirements imposed by space-based defense weapons and power users. Depending on the specific MMW application, power requirements range from a few MWe to hundreds of MWe for continuous or burst power applications. Multimegawatt space reactor systems could offer several desirable features, such as low weight, compactness, long life, power growth and potential for continuous use, direct power conversion with few or no moving parts, benign or no effluents, high reliability, and inherent radiation hardness and survivability.

The MMW Space Reactor Program is a multiple-phase program. After some preliminary concept and requirement studies, Phase I will evaluate and conceptually design a specified number of candidate concepts and identify key technology issues for each concept. Phase II will include analyzing, designing, and configuring in detail the best concepts from Phase I, and resolving all corresponding technology feasibility issues. In Phase III, a ground-engineering system will be built and tested, with the flight demonstration work being conducted during Phase IV.

In March 1987, DOE completed work on the definition of the MMW reactor systems concepts and requirements. The results were incorporated into a

Phase I Request For Proposal (RFP) for MMW space reactor power supplies. On July 1, 1987, an RFP was issued to solicit the best concepts from industry. On September 30, 1987, numerous MMW proposals were received, the evaluation and selection process began, and final contract awards to six of the best concepts were made in early 1988. During Phase I, the selected contractors will pursue preliminary system concept evaluations, analyses, tradeoff studies, identification of technology feasibility issues, conceptual design configurations, and Phase II development plans.

At the end of Phase I, in early 1989, two or three system concepts will be selected from the Phase I candidates to implement their approved Phase II development plans. Other Phase II activities for the selected concepts will be the completion of a preliminary safety assessment, resolution of feasibility items identified in Phase I, detailed system concept evaluations, analyses and tradeoff studies, detailed design configuration and specific component selections, and a Phase III development plan and ground-engineering system test configuration. During both Phases I and II, a parallel technology development program, which focuses on and directly supports the selected concepts, will be pursued by the national laboratories. Upon the completion of Phase II in 1992, at least one concept which meets the MMW program goals will be identified for possible selection by the Strategic Defense Initiative Program to proceed with Phase III and possibly Phase IV development and testing. Phases III and IV are expected to be completed during the mid-to-late 1990's and early 2000's, respectively.

In 1987, there were several important MMW technology accomplishments. Contracts were issued to fabricate both depleted and enriched Uranium-Carbide Zirconium-Carbide-coated fuel particles and corresponding particle bed fuel elements for use in tests in gas-cooled, electrically or fission-heated environments scheduled for mid-1988. Processes for fabricating MMW cermet fuels were developed and demonstrated using both surrogate and Uranium Nitride fuel particles. Testing was conducted, with encouraging results, on fabrication, welding, compatibility, creep rate, and irradiation of high-temperature refractory alloys. The capability to reverse the fuel cycle process and convert steam into hydrogen and oxygen was demonstrated for the monolithic solid oxide fuel cells. Also, several contracts and Program Research and Development Announcements (PRDA's) were issued to explore and develop advanced MMW concepts and technologies.

By the end of 1987, the MMW Space Reactor Program was progressing steadily toward providing high power for civil and defense space missions of the 21st Century.

Thermionic Fuel Element Verification Program

The Thermionic Fuel Element (TFE) Verification Program began in 1986 as an outgrowth of the SP-100 program and is currently sponsored under the Multimegawatt Space Power Program. Thermionic technology offers higher conversion efficiency and growth potential than thermoelectric converters, but it presently has lifetime limitations. Therefore, to meet far-term, high-power needs, the TFE program was established as an aggressive hardware testing program to solve these technology issues and to verify the technology.

The TFE program is an extension of work conducted during the 1960's and early 1970's which was sponsored by the AEC (currently DOE) and NASA. Using the technology developed during that period, work was in progress to further define and improve upon the basic building blocks of the thermionic system. The primary goal of the TFE program is to demonstrate a 7-year lifetime for TFE components operating in a 2 to 5 MWe in-core thermionic space reactor. The TFE program will resolve feasibility and readiness issues associated with components integral to the TFE design. It will accomplish this through an iterative approach using accelerated irradiation testing and analytical modeling to verify the technology.

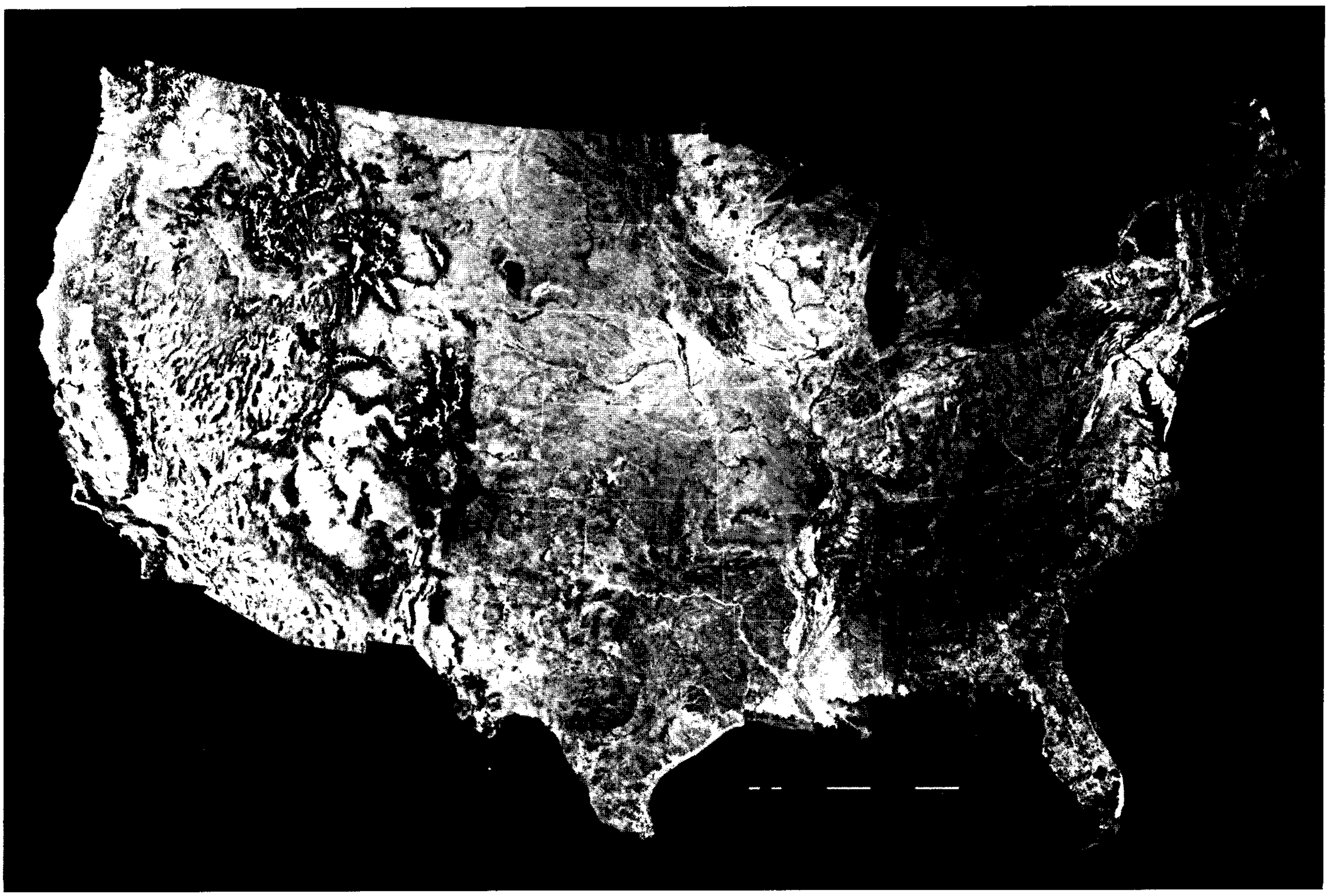
During 1987, work in the following areas was pursued: fabrication and testing of the converter; in-core testing at the Fast Flux Test Facility (FFTF) of sheath insulators and cesium reservoirs; and fabrication of intercell insulations, end restraints, seal insulators, cesium reservoirs, and sheath insulators. The latter items will be tested in the FFTF. Late in 1987, ongoing in-core testing of fueled emitters was conducted in the Experimental Breeder Reactor II (EBR-II), and in-core testing of fueled emitters continued on three test capsules in General Atomic's TRIGA reactor. One of the TRIGA capsules was removed for post-irradiation examination. Design, computer modeling, fabrication, and fabrication techniques are ongoing to support the test program. This will provide sufficient information from which a final and fully prototypic pair of TFE's can be designed and tested in a fast spectrum reactor. The program will provide a well-characterized set of performance parameters for the design of a power system.

The TFE program is well focused and is aimed at providing design solutions and verifying the results to prolong operating lifetime. The final results of the program will be a high performance technology that may meet space power needs in the late 1990's and beyond.

Nuclear Test Detection

The DOE continues to meet its responsibilities in support of national requirements to verify compliance with the Limited Test Ban Treaty and the Nonproliferation Treaty by producing nuclear detonation detection systems deployed as secondary payloads aboard DOD satellites. These systems, consisting of optical and direct radiation sensors, are the primary means for monitoring nuclear testing in the atmosphere and are the only systems capable of detecting nuclear detonations in space.

The DOE laboratories, which produce these detection systems, maintain continuous programs for improving the related technology. The goal of these programs is better energy resolution, faster sensor response times, wide spectra coverage, compression of data processing, greater survivability, and the development of new applications and sensors. In 1987, the emphasis was placed on improving radiation hardening for spaceborne detector systems. Considerable research also is devoted to the study of satellite operating environments in order to enhance event discrimination and prevent false alarms. Many such developmental experiments are flown aboard NASA satellites, and are conducted in cooperation with the space programs of other countries.



Black-and-white reproduction of NOAA-AVHRR image mosaic of the United States that was produced by mosaicking 15 separate AVHRR false-color images.

Department of the Interior

As caretaker for more than 2 million square kilometers of public lands, the U.S. Department of the Interior is responsible for managing, conserving, and developing natural resources on this element of the national domain. The Department frequently relies on data acquired by remote sensing devices for inventorying, managing, and monitoring these vast, often inaccessible lands. Research in the analysis and application of remotely sensed data is also an important component of the Department's activity. Bureaus of the Department participating in remote sensing studies during 1987 included the Bureau of Indian Affairs (BIA), Bureau of Land Management (BLM), Bureau of Mines (BOM), Bureau of Reclamation (BOR), Minerals Management Service (MMS), National Park Service (NPS), U.S. Fish and Wildlife Service (USFWS), and U.S. Geological Survey (USGS).

Remotely Sensed Data Acquisition and Processing

Satellite Data

Landsat. The USGS continued to use the EROS Data Center (EDC) as the principal facility for archiving, processing, and distributing Landsat data under agreement with and funding from the National Oceanic and Atmospheric Administration (NOAA), in support of the Earth Observation Satellite (EOSAT) Company, the commercial Landsat operator. During 1987, EDC received, processed, and archived approximately 44,000 Landsat Multispectral Scanner (MSS) and Thematic Mapper (TM) scenes. Currently, over 834,000 scenes of Landsat data are archived and geographically referenced in the Main Image File. This computerized cataloging system also references over 1,500,000 scenes that were received and archived at foreign Landsat stations. In 1987, over 20,000 film and digital products with a sales value of over $7.6 million were produced and distributed to users around the world. To assist Federal agencies in obtaining Landsat satellite products and services, USGS has established a basic ordering agreement with EOSAT. Landsat purchases under this agreement in 1987 were $4.5 million, or more than half of total Landsat sales.

Between 1972 and the commercialization of the Landsat program on September 27, 1985, many Federal agencies purchased Landsat data that can be used, without restriction, by any Federal Government agency. Landsat data purchased after the date of commercialization are subject to restrictions on their use and cannot be freely shared among Federal users. Because considerable cost savings can be realized by Federal agencies through data sharing, the USGS has compiled a catalog providing information on Landsat digital data purchased by Federal agencies before commercialization. Any Landsat data purchased prior to September 27, 1985, may be listed in the catalog and may be shared. To date, the BLM, BOR, BOM, USGS, and National Aeronautics and Space Administration (NASA) have contributed information on over 6,000 scenes.

Systeme Probatoire d'Observation de la Terre. On April 20, 1987, the USGS and the SPOT Image Corporation signed a procurement contract to facilitate the purchase of French Systeme Probatoire d'Observation de la Terre (SPOT) satellite products and services on behalf of Federal agencies. This contract will eliminate the need for individual agency contracts for data purchase with SPOT Image Corporation. In addition, the USGS has obtained access to the SPOT Image worldwide satellite catalog through a direct dial-up capability from the EDC to Toulouse, France.

Advanced Very High Resolution Radiometer. In 1987, the USGS completed development of an operational system at EDC to receive, process, archive, and distribute Advanced Very High Resolution Radiometer (AVHRR) data from NOAA polar-orbiting satellites for land science applications in Department of the Interior and other Federal research projects. The AVHRR Data Acquisition and Processing System (ADAPS) is used to receive AVHRR data of the entire conterminous United States; screen the data for image quality and cloud cover; and produce radiometrically corrected and geographically registered data on computer tape, floppy disk, or film within 48 hours after acquisition.

The ADAPS can acquire daily coverage of the conterminous United States (between 6 to 10 scenes daily) from the NOAA-9 and NOAA-10 satellites. All data are kept for 90 days, at which time approximately 20 to 25 percent of the best data are selected for the long-term archive. An AVHRR microfiche reference system has been developed to aid in the selection and ordering of scenes in the permanent archive.

During 1987, over 1,400 AVHRR scenes of the United States were acquired, of which approximately 20 percent have been selected for the permanent archive. EDC generated over 750 AVHRR products for users during 1987, including 30 to 35 products a week to support NASA's First International Satellite Land Surface Climatology Project Field Experiment. The workload for 1988 will increase to 12 to 14 products a day (3,000 to 3,500 products for the year) in response to agreements that were recently negotiated with the Central Intelligence Agency, the Agency for International Development (AID), and the National Weather Service.

Aerial Photographs

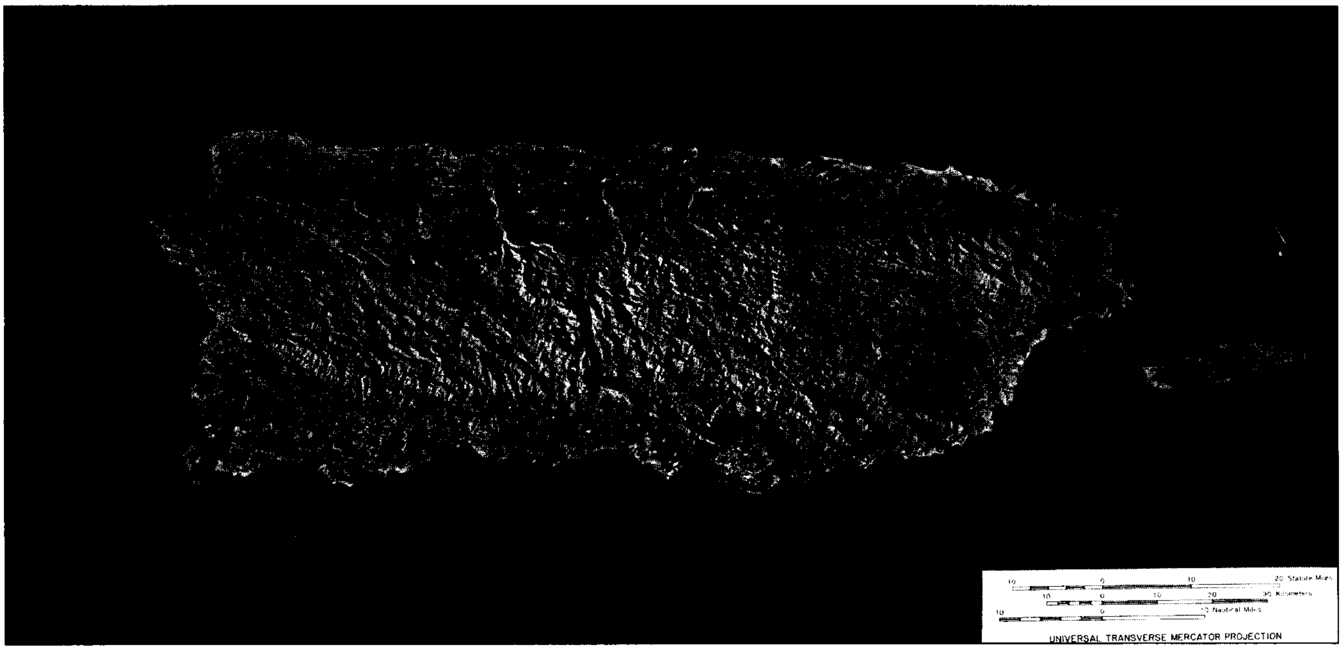
The National High Altitude Photography (NHAP) Program began in 1980 to acquire 1:80,000-scale black-and-white and 1:58,000-scale color-infrared aerial photographs of the conterminous United States. Through 1987, photographs covering over 7,800,000 square kilometers, or about 98 percent of the conterminous United States, have been acquired under NHAP and are available to the public from both the USGS and the U.S. Department of Agriculture.

Federal agencies cooperating in the NHAP Program have reassessed their needs and redesigned the NHAP Program to meet current requirements for higher resolution, larger scale photographs. As a result, the National Aerial Photography Program (NAPP) was begun in 1987 to provide complete coverage for the 48 conterminous United States on a 5-year cycle. NAPP is a cooperative program guided by a multiagency steering committee and administered by the USGS on behalf of the State and Federal cooperators. Color-infrared aerial photographs will be acquired at a scale of 1:40,000, centered on quarter sections of standard USGS 7.5-minute quadrangles. By the end of 1987, coverage was nearly complete for Indiana, northern Utah, southern Idaho, and central California.

Side-Looking Airborne Radar Data

The USGS Side-Looking Airborne Radar (SLAR) program began in 1980. Since that time, coverage for more than 20 percent of the United States has been acquired and made available to the public. The USGS selects approximately 30 sites for SLAR coverage each year based on a technical review of proposals submitted by State geological surveys, Federal scientists and managers, the academic community, and the private sector. Because SLAR is an active sensor (illuminating the surface features with microwave energy), the mission design parameters such as look direction, depression angle, and range are chosen to produce images that are optimized for the studies proposed for each site.

The USGS has supported more than 100 research studies addressing the use of SLAR data for geologic, hydrologic, engineering, and cartographic applications. Some examples of the research and application studies supported by the USGS showing the scope of this program include using SLAR data for fold and fault frequency analysis to help develop a model of the Appalachian Mountains addressing seismic risk and natural gas production; using SLAR data to aid in evaluating the hydrologic characteristics of proposed high-level nuclear waste repositories; preparing SLAR image maps of the Aleutian Islands of Alaska; and using SLAR to aid in permafrost and glacier studies.



U.S. Geological Survey Side-Looking Airborne Radar (SLAR) image of Puerto Rico. SLAR data of Puerto Rico are being used for geologic mapping, regional aquifer system analysis, and sedimentation and landslide susceptibility assessment.

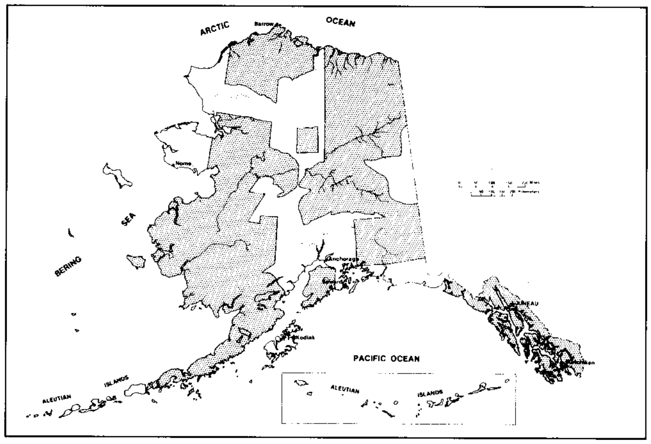
Remote Sensing Applications

Renewable Resources

During the past 7 years, the USGS has worked cooperatively with Federal and State resource management agencies to produce land cover and terrain maps throughout Alaska. During 1987, USGS and USFWS personnel analyzed digital Landsat MSS data and terrain data to produce land cover and terrain maps for comprehensive management planning in the 28,000 square kilometer Innoko and Selawik National Wildlife Refuges in Alaska. Land cover mapping was also completed for the Izembek Lagoon in the Izembek National Wildlife Refuge. The emphasis in the Izembek Lagoon was on mapping eel-grass beds, which are critical staging areas for black brant waterfowl before their seasonal migration into and out of Alaska.

The USGS and the U.S. Forest Service (USFS) cooperated to classify land cover for 120,000 square kilometers in southeastern Alaska during 1987. Land cover classifications were completed and estimates of land cover types and timber production are being integrated into a four-phase sampling scheme to provide statistical data for the National Resource Inventory in Alaska.

With the completion of these USFWS and USFS projects in 1987, USGS and cooperating government agencies have now completed land cover and terrain maps using Landsat and digital terrain data for almost 1 million square kilometers of Alaska, or over 60 percent of the State.



Current status of land cover classification in Alaska using digital analysis of Landsat satellite data.

The BLM uses a variety of remote sensing tools to assist in gathering data and monitoring activities on public lands. Aerial photographs, including NHAP, NAPP, and BLM-acquired aerial photographs, continue to be heavily utilized in operational activities involving rangeland, forest land, and wildlife management. A new application of aerial photographs involves the use of low-altitude photographs to evaluate and monitor critical riparian vegetation conditions. During 1987, BLM acquired coverage of over 640 linear kilometers of streams for riparian analysis. BLM also utilizes digital NOAA-AVHRR satellite data operationally to map fire fuel types in 10 western States. These data are merged with digital terrain data and provide a major component of BLM's Initial Attack Management System.

During 1987, the BIA conducted operational and experimental projects using both Landsat and SPOT satellite data and aerial photographs. These projects include both visual interpretation and digital analysis to determine information content, interpretation efficiencies, and accuracies for natural resource management applications. Projects are in progress on the following reservations: San Carlos Agency, Arizona—a land cover and land use map of the reservation for use in range survey; Warm Springs Agency, Oregon—evaluation of Landsat TM images for land cover mapping; Crow Agency, Montana—farmland mapping using Landsat TM images; Pine Ridge Agency, South Dakota—identification and mapping of prairie-dog towns and prairie-dog activity using aerial photographs, and rangeland assessments using Landsat TM data and aerial photographs. All thematic interpretations are converted to appropriate digital formats and incorporated into BIA geographic information systems.

The BOR uses a variety of remotely sensed data for environmental inventory and assessment of major water development projects. An intensive environmental inventory involving 4,700 square kilometers of land that may be affected by the Garrison Diversion Unit of the Pick-Sloan Missouri Basin Project of North Dakota was completed in 1987. Information was extracted from large-scale color-infrared aerial photographs and entered into a digital data base, which is currently being used in a field-office geographic information system for statistical analysis and display. A study of the Grand Canyon was completed using large-scale aerial photographs from four dates spanning a 20-year period. Selected river reaches along the Colorado River were inventoried for riparian vegetation to detect changes in the development of native and exotic plants since the construction of Glen Canyon Dam.

BOR scientists are mapping backwater habitat on the Green River below Flaming Gorge Dam in Utah and Colorado from large-scale aerial photographs that were acquired on five dates coincident with several river-flow scenarios since construction of the Dam. This work is designed to result in recommendations for water flow rates that maximize backwater habitat, which is a critical variable needed to preserve the Colorado River squawfish, an endangered species.

Head of Surveys of the Senegal Crop Protection Service using vegetation greenness maps derived from satellite data to direct personnel for field surveys of grasshopper infestations.

The BOR Calamus (Nebraska) Dam Post-Construction Analysis Study was also completed during 1987. A data base of natural resources information was developed from interpretation of aerial photographs taken before the Dam was built, and project boundaries were overlaid to determine construction impacts.

The BOR has used digital Landsat MSS data to monitor the effects of the Central Arizona Project on the area's native vegetation. Data acquired before and after construction of the Granite Reef and Salt-Gila aqueducts were processed to quantify the amount of natural vegetation change due to alteration of surface hydrology by the aqueducts.

The BOR is participating in PEPS (Preliminary Evaluation Program for SPOT) to evaluate the utility of digital SPOT data for monitoring irrigated lands. Results indicate that the spatial resolution and spectral characteristics of these data are well suited to this application.

The USFWS places a high priority on wetlands mapping and the gathering of wetlands trends information in support of the North American Waterfowl Management Plan which was signed by both the U.S. Department of the Interior and Canada. To accomplish these mapping objectives, the USFWS continues to acquire and use high-altitude aerial photographs to conduct the National Wetlands Inventory. Due to the variability in land use and habitat cover types in wetlands, and the degree of accuracy required for detailed resource mapping, the National Wetlands Inventory has used high-altitude aerial photographs exclusively, while keeping abreast of developments in the acquisition and application of satellite images.

The USGS has been assisting in the U.S. AID-sponsored grasshopper control programs in the Sahel region of Africa. During 1987, a pilot study was conducted to develop, test, and evaluate procedures for real-time mapping and monitoring of grasshopper habitat using remote sensing and geographic information system technologies. AVHRR images were collected daily for several months, geographically referenced, and used to produce thematic maps displaying 14-day vegetation conditions and changes in conditions in Senegal, The Gambia, Mauritania, Chad, and Niger. The maps are sent by air-express to Africa for use by grasshopper control teams to identify potential infestation areas and to plan reconnaissance and spraying missions for grasshopper control.

Hydrology

The National Wildlife Refuge Monitoring Program was initiated by the BOR in 1983 as part of the Garrison Diversion Project. It has continued each year using remote sensing and geographic information systems technologies to map submerged vegetation in the refuges and to quantify the natural peak-water-flow conditions before the Garrison Project is complete and the return water flows are redirected into the James River Basin.

BOR scientists have developed empirical models that predict several parameters of fresh-water lakes and other water bodies from Landsat TM data. These models are being applied to a series of TM images of Lake Mead between Arizona and Nevada to determine the spatial and temporal variation of temperature, turbidity, and chlorophyll-a concentration. In conjunction with the Center of Hydrographic Studies of the Spanish Ministry of Public Works, the BOR is conducting complementary studies of reservoirs in Spain using TM data.

The BOR has cooperated with Arizona State University to process 84 Landsat images of Pyramid Lake, Nevada, acquired between 1972 and 1986 to document the occurrence of blue-green algae blooms. The purpose of the work was to better understand the potential impacts of a proposed wastewater treatment facility for the city of Reno, Nevada.

Oceanography

Under the Alaska Region Studies Program, the MMS funds a remote sensing project that acquires, analyzes, and archives satellite images and other remotely sensed data of the U.S. Arctic Region. During 1987, MMS scientists continued to correlate ice-motion events, such as ice-ridge building and polynya formation (permanent or semipermanent open-water areas within an ice-covered sea), with meteorological conditions in the Chukchi Sea and Hope Basin areas. Studies focused on the characteristics and dynamics of lead systems (open-water or thin ice channels within ice-covered areas) in the Chukchi Sea during the spring migration of bowhead whales and other marine mammals. MMS scientists continue to study polynyas in the Chukchi Sea and Hope Basin areas to determine their importance to regional biota and their role in the generation of sea ice.

Geology

Mineral Resource Development Activities. BLM is using both SPOT and Landsat TM data to assess and monitor mineral development activities on public lands. During 1987, applications that were identified included mapping of activities related to oil and gas development; mapping of areas where minerals materials extraction is occurring; and monitoring of compliance with surface management regulations associated with mining claims.

The USGS is using Landsat TM data on a routine basis in its programs for Conterminous U.S. Mineral Assessments of 1°x 2° quadrangles, in BLM Wilderness Studies, and BIA Mineral Assessment Studies of Reservations. Cooperative experiments with agencies of the Spanish government have demonstrated that TM data can be used to identify halos of contact-metamorphosed rocks caused by both presently exposed and buried igneous plutons. Some of the exposed plutons have contained tungsten and tin deposits; similar minerals may occur within the shallowly buried plutons, which previously had not been recognized.

Additional research and applications have been made with aircraft sensor platforms that cover the visible and reflective infrared part of the spectrum. A non-imaging 512-channel Airborne Spectroradiometer was used to identify and map rocks containing rare earth deposits. Also, data from 64- and 128-channel Airborne Imaging Spectrometers were utilized to identify and map hydrothermally altered rocks that potentially could contain precious and base metals. Airborne data from a Thermal Infrared Multispectral Scanner aided in the identification of jasperoids, a form of hydrothermal quartz, which are associated with carbonate-hosted disseminated gold deposits found in the western United States. These technological advances could be applied to other areas of the world that have similar rock occurrences.

In the laboratory, efforts are underway to spectrally characterize the visible and reflective-infrared, as well as the emitted-infrared characteristics of rock-forming minerals. Spectra of these well-characterized minerals form a comprehensive digital data base and reference source for the spectral behavior of minerals on a worldwide basis. Data in these spectral libraries will be of direct application to ongoing NASA and USGS studies that utilize the Airborne Imaging Spectrometers.

Mine Development and Safety Monitoring. In 1987, the BOM was in the process of concluding remote sensing investigations of predicting coal mine ground hazards at a western U.S. study site in Utah, and began new investigations at the eastern U.S. study site in Alabama. These investigations will lead to development of a methodology to define potential ground hazards to mining activities in underground coal mines and to define how remotely sensed data can be applied to this methodology. At the western test site, positive correlations of about 80 percent have been achieved when comparing zones of potential geologic hazard predicted from remotely sensed data with actual ground-control problem areas that were encountered during underground mining operations.

Landsat MSS and TM data have been the primary remotely sensed data used in these investigations. However, SLAR data, Skylab and Space Shuttle Large-Format Camera photographs, SPOT satellite images, and aerial photographs are also being evaluated for their utility in the ground-hazard prediction process. Preliminary results indicate that Skylab and Large Format Camera photographs are of limited use because of restricted areal and temporal coverage. SLAR images have proven to be quite useful in defining the geologic structure in areas such as Alabama that have relatively subtle topography. Ancillary data are also being used to better interpret the surface expression of certain subsurface geologic structures, and to make more accurate determinations of potential ground hazards in minus. Digital topographic data are used in conjunction with Landsat data as an input to computer programs that calculate vertical pressure at the mine level for structural stability analysis.

Planetary Studies. A new geologic mapping program has been initiated by NASA in conjunction with USGS and map users to study Mars using high-resolution Viking images. Areas of high scientific interest will be mapped on photomosaic bases at 1:500,000 scale. The resulting geologic maps will show in detail the structure, stratigraphy, and morphologic aspects of the Martian surface. These maps will be invaluable in planning future missions and determining possible landing sites for sample return missions. An example of significant advances made by this type of mapping is the 1:500,000-scale geologic map of the Central Valles Marineris, which shows previously unrecognized volcanic structures. The volcanic units appear very fresh; some have frontal lobes that bury landslides, and others are composed of dark material that apparently erupted explosively along faults. Because these units are very young, their presence suggests that Mars has been geologically active in relatively recent times.

Jupiter's volcanically active moon, Io, has been the subject of much interest. Studies of Voyager spacecraft data and Earth-based infrared observations of Io's hot spots are continuing. A correlation between low-albedo calderas and thermal emission was described and used to identify potential hot spots in areas not directly observed by infrared detectors. From this work, Io's global heat flow was estimated to be about 1.8 watts per square meter, more than 20 times greater than the average heat flow of the Earth.

Prelaunch planning for the U.S. Magellan mission to Venus in 1990 is partly based on the analysis of high-resolution radar images of Venus acquired by the Soviet Venera 15 and 16 spacecraft. USGS scientists are using these images to provide mission planners with the most up-to-date, detailed geologic information of Venus. Mapping already completed indicates that volcanic and tectonic processes dominate the Venusian landscape. In the absence of datable samples, the age of these surfaces has been estimated by comparing the density of observed impact craters on Venus with the calculated impact density (based on actual density of astronomically observed Venus-crossing asteroids and comets) and with the known density of impact craters on Earth. The average age of Venus' surface appears to be no more than a few hundred million years, indicating a level of tectonic activity similar to that of Earth.

USGS personnel are involved in much of the preliminary work of naming newly discovered extraterrestrial features, although the International Astronomical Union is the final arbiter of planetary nomenclature. When a body is first imaged by a sensor, the most conspicuous features are given names. In the last 14 years, 24 descriptive terms have been chosen and nearly 4,000 features have been named on the 23 extraterrestrial solid bodies imaged by space missions.

Cartography

Satellite Image Mapping. During 1987, the USGS continued its image mapping research by applying techniques originally developed for Landsat MSS and TM data to data from other satellite sensors. For example, restoration (deconvolution) software can now be applied to both NOAA AVHRR data and SPOT data. Techniques have been developed for combining image data sets possessing different spatial and spectral characteristics. The majority of this work has centered on combining 30-meter resolution multispectral Landsat TM data and 10-meter resolution single-channel SPOT panchromatic data. This process creates an image that has the spectral quality of the TM multispectral data and the 10-meter spatial resolution of the SPOT data. Techniques were developed in 1987 for digital generation of latitude/longitude grid and annotation information that can be registered and embedded into a digital image for reference.

The USGS continued its satellite image mapping program in 1987. Landsat MSS image maps (1:250,000 scale) were printed for the Goldfield, Needles, and Tonopah, Nevada; Anchorage, Alaska; and Roanoke, Virginia, quadrangles. Landsat TM image maps (1:100,000 scale) were printed for the Cactus Flat and Pahute Mesa, Nevada, and Kansas City and Olathe, Missouri/Kansas, quadrangles.

A special image product of the Phoenix, Arizona area was produced to show Landsat MSS and TM data, SPOT panchromatic and multispectral data, and Landsat TM and SPOT panchromatic data merged and displayed at various scales. This lithographed product also shows portions of an orthophotoquad and a standard topographic quadrangle for comparison with SPOT panchromatic data.

Geologic Mapping. In early 1987, the USGS published an experimental 1:100,000-scale, color "Geologic Map of Cape Cod and the Islands, Massachusetts," in which four Landsat 3 return beam vidicon (RBV) images were mosaicked to form an image base for the geologic map. Landsat image-mosaicking technology developed by the USGS can now be used to prepare cartographically accurate image base maps at scales of 1:100,000 or smaller for any part of the land and shallow-sea areas of our planet covered by Landsat 3 RBV or Landsat 4 and 5 thematic mapper (TM) images.

Digital Orthophotoquads. The USGS presently uses a variety of orthophoto instruments to produce orthophotographs in quadrangle format. While these techniques produce orthophotoquads of high quality, they remain in photographic form, which limits their applications. The USGS can now produce digital orthophotoquads from raster-scanned aerial photographs and digital elevation model data. Research is underway to combine these digital rectification techniques with digital mosaicking and image enhancement techniques to develop a digital orthophotoquad production system. To date, two digital orthophotoquads have been produced for a two-scene mosaic of NHAP photographs covering the Fontana, California, 1:24,000 quadrangle.

Global Positioning System. Following applications testing in 1986, the Global Positioning System (GPS) was used for production work in 1987. Although the full satellite constellation will not be fully operational for several years and system coverage is limited, it has already proven to be cost effective for many of the USGS mapping survey requirements. Three new receivers were purchased during the year for use in the National Mapping Program. A new generation of GPS receivers for scientific applications emerged with the implementation of new software that enabled simultaneous determination of ground station coordinates and orbital parameters. Relative accuracies of 0.5 parts per million have been achieved with this software. New developments in GPS-based dynamic positioning systems were closely monitored with a view to procuring a system for airborne geophysical surveys. The GPS was used to complement conventional techniques in monitoring the San Andreas fault in California, and a major volcano deformation survey was completed in Hawaii. USGS also cooperated with NOAA and NASA on several GPS experiments designed to measure crustal motion across the United States.

International Activities

Antarctic Activities

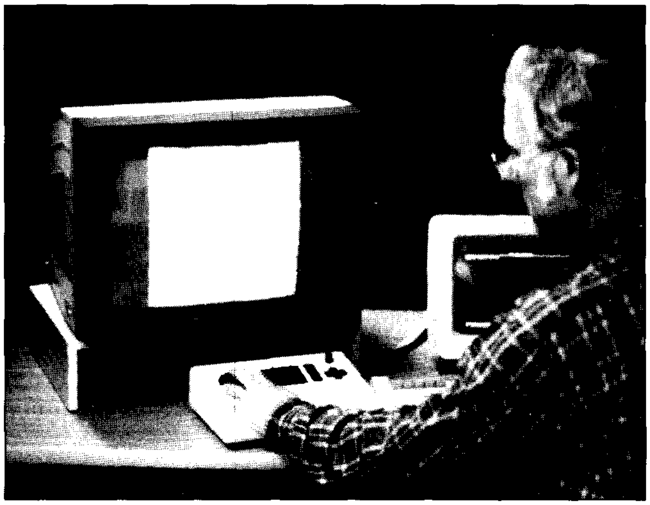
The USGS continues to maintain year-round personnel at the South Pole Station, Antarctica to collect satellite data to support geodetic programs and glaciological studies such as ice sheet movement at the South Pole. During 1987, the USGS cooperated with the Norwegian Polar Research Institute to analyze Landsat TM images of an area in Queen Maud Land, Antarctica for surface temperature mapping. Landsat TM thermal band images permit the mapping of brightness temperatures with a spatial resolution of 120 meters. The resulting temperature map with contour intervals of 2°C was compared with ground measurements obtained concurrently with the TM image acquisitions. Results show that surface temperature decreases with increasing elevation on the ice plateau. With a modification in the nominal calibration coefficients, also consistent with nonpolar observations, the TM-derived temperatures are in good agreement with the surface observations.

Global Monitoring of Glaciers. The USGS continued work on the preparation of a Satellite Image Atlas of Glaciers, a long-term project involving more than 55 U.S. and foreign scientists from 30 countries to document the areal extent of glacier ice on Earth from Landsat 1-3 multispectral scanner (MSS) images and ancillary data. Eleven volumes will be published under USGS Professional Paper 1386 (A-K). Chapter B, Antarctica, is being prepared in cooperation with the British Antarctic Survey and the Ministry of Works and Development (New Zealand).

Department of Agriculture

In 1987, the principal aeronautics and space activities of the U.S. Department of Agriculture (USDA) were those related to remote sensing. For many decades, aerial photographs have been a key source of information about land use, agriculture, rangeland, and forestry. Extensive research is now in progress to determine the utility of data from satellites and other space platforms as a source of information for USDA programs and policy decisions. The establishment of the Remote Sensing Research Laboratory in the Department's Agricultural Research Service (ARS), aided by continuing remote sensing applications research at ARS field centers, constitute a major step toward realizing the full potential of Earth observations from space.

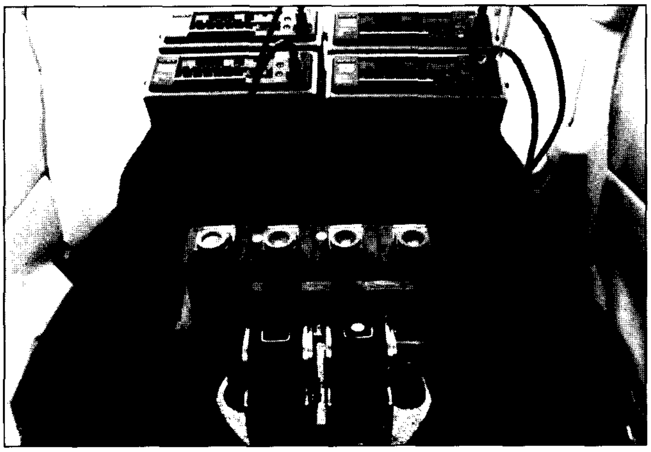
In 1987, staffing and installation of equipment at the ARS Remote Sensing Research Laboratory were completed. Located at the Beltsville Agricultural Research Center near Washington, D.C., the Laboratory serves as the hub of a national network of scientists and users concerned with the application of remote sensing techniques to solve high priority national agricultural problems. The Laboratory works closely with staff personnel of USDA agencies, the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), and universities and private institutions to develop specific procedures and technology to solve agricultural problems.



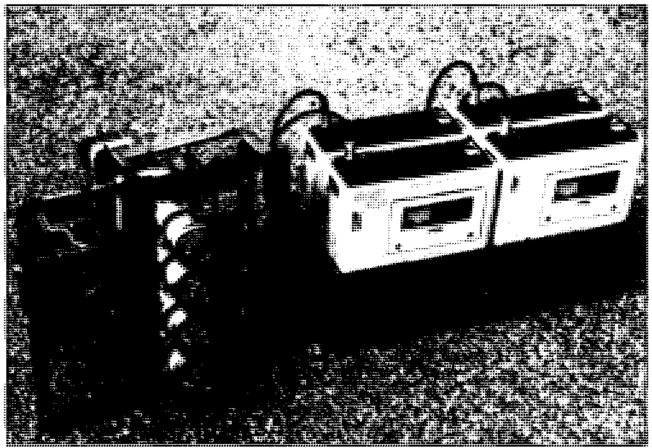
Interior view of ARS Remote Sensing Research Laboratory where digital data for crop monitoring and resource management are displayed and analyzed.

The remote sensing research conducted by the Laboratory and at associated ARS field centers is both basic and applied and uses aeronautical and aerospace data systems. Plans for research include combining digital remotely sensed data with other digital data through data base and modeling systems to enhance the value of the information received. A feature of the research is the development of methods for combining data from sensors carried by different satellites.

Combining data from different Earth-viewing satellites has necessitated an extensive effort to calibrate the visible and near-infrared channels of the sensors. For example, quantitative use of satellite data and comparison of numerical values from year to year, and from satellite to satellite, cannot be accomplished with precision unless differences in data values are recognized. A portion of this work is being conducted cooperatively with NOAA. Some of the testing for this activity has been completed to relate data received from NOAA's Advanced Very High Resolution Radiometer (AVHRR), carried on polar-orbiting environmental satellites. The calibration effort also includes conducting research on data from the thematic mapper and multispectral scanner sensors carried aboard Landsats 4 and 5. Other cooperative research with NOAA includes using data from Geostationary Operational Environmental Satellites (GOES) to assess soil moisture in the U.S. Great Plains.



View of remote sensing equipment in light aircraft.



View of the multispectral video system being tested at the ARS Center in Weslaco, Texas.

In 1987, research was completed that assesses the utility of data from the French SPOT satellite for the National Resources Inventory program of the Soil Conservation Service. In this activity, the Laboratory was assisted by cooperating ARS scientists at Durant and Chickasha, Oklahoma. The SPOT satellite data were treated through an image processing system and interpreted for potential detection of land use changes. Independent verification of changes supports evidence that the higher resolution data are a potential substitute for "standard" photographic products.

During 1987, ARS remote sensing researchers at Weslaco, Texas continued developmental work on applications of infrared photography, and made considerable progress in evaluating color-infrared video imagery. In one example, a study was conducted to evaluate the potential of color-infrared video imagery for the remote sensing of rangelands. Color-infrared video imagery and color-infrared photography of three different rangeland scenes were obtained simultaneously. The color response of the video images of the rangeland scenes were similar to those of the color-infrared photographic images. These results show that color-infrared video imagery has considerable application as a tool for rangeland assessment. Moreover, because access to many rangeland areas is often difficult, the ability to view video imagery immediately can be cost-effective.

Federal Communications Commission

Communications Satellites

International Commercial Communications Satellites

At the beginning of 1987, the International Telecommunications Satellite Organization (INTELSAT) global communications system consisted of 15 satellites in orbit: 1 INTELSAT IV, 3 INTELSAT IV-A's, 8 INTELSAT V's and 3 INTELSAT V-A's. Due to the unavailability of launch vehicles, no international INTELSAT satellites were launched. During the year, one IV and one IV-A were ejected into higher orbits. At the end of 1987, INTELSAT maintained 13 satellites in geosynchronous orbit: 1 IV-A, 4 V's, and 2 V-A's in the Atlantic Ocean Region; 2 V's and 1 V-A in the Indian Ocean Region; and 1 IV-A and 2 V's in the Pacific Ocean Region. The IV-A satellites have exceeded estimated maneuver life.

In 1987, the Commission approved the construction and operation of 19 new Earth station facilities to access the INTELSAT system in the Atlantic and Pacific Ocean Regions for the provision of INTELSAT business service and television transmission, and 5 for multipurpose service stations.

In 1985, the Commission released its policy statement in CC Docket No. 84-1299 establishing the regulatory policies that will be used to consider applications for satellite systems providing international communication services independent of INTELSAT. The Commission found that separate international systems proposed by the Executive Branch would provide substantial benefits to international telecommunications users without causing significant economic harm to INTELSAT. Finding that their applications met its legal, technical, and initial financial qualifications and public interest considerations, the Commission granted conditional authority to establish separate satellite systems to Orion Satellite Corporation, International Satellite, Inc., RCA American Communications, Inc., Pan American Satellite Corporation (PanAmSat), and Cygnus Satellite Corporation. In 1986, the Commission granted conditional authorization to two additional applicants, McCaw Space Technologies, Inc., and Columbia Communications Corporation.

Only PanAmSat has reached agreement with a foreign correspondent and initiated the INTELSAT consultation process. In April 1987, PanAmSat's use of five 4/6-GHz transponders for service between the United States and Peru was successfully consulted with INTELSAT. On September 30, 1987, the Commission issued a final construction permit and launch authority for its "Simon Bolivar" satellite scheduled to be launched in January 1988. Currently before the Commission is a proposal by PanAmSat to use six 11/14-GHz transponders on its "Simon Bolivar" satellite for service to Europe.

Domestic Commercial Communications Satellites

In 1987, no new domestic satellites were authorized for construction and launch. At year's end, 27 domestic satellites were in orbit at locations between 69° and 143° west longitude on the orbital arc. Of these 27 satellites, 16 operate in the 4/6-GHz band, 8 operate in the 12/14-GHz band, and 3 operate in both bands. In September 1987, 20 applications for new or replacement satellites were filed as part of the next domestic satellite processing group.

In 1985, the Commission authorized the construction and launch of 20 additional domestic fixed satellites to provide communications services through the end of the century. Some of these satellites were scheduled for launch in 1987. However, due to the launch crisis, only one new domestic satellite is expected to be placed in orbit in 1987.

The Commission's Advisory Committee on 2° Spacing was established in 1985 to elicit suggestions by industry representatives on the most efficient and economical methods to accommodate satellite operations under reduced spacing conditions. The Committee issued its recommendations in 1986. With respect to Earth stations, the Committee recommended mandatory manufacturer product qualification testing and mandatory on-sight verification tests by operators of all Earth station systems, including transportables. The Committee also recommended that the Commission revise Section 25.209 of the Rules and Regulations concerning antenna performance standards to be more definitive regarding side-lobe requirements.

On the subject of space stations, the Committee recommended the adoption of certain technical parameters for C and Ku-band satellites, including opposite polarization for adjacent satellites and ground control of polarization switches. The Committee also proposed the creation of a satellite spacing coordination data book to be used by the Commission, satellite users and operators to aid in the implementation of 2° spacing. The data book would contain data on interference, satellite characteristics, key transmission parameters and satellite system operation/coordination procedures.

In the area of coordination, the Committee recommended standard video masks for computation of video interference between adjacent satellites; mandatory uplink identification signals for all video transmission; and adoption of power flux density limits for C-Band Earth stations and antennas less than nine meters in diameter.

The Commission released a Notice of Proposed Rulemaking in February 1987 that incorporated many of Committee's recommendations and made several additional proposals. Comments were filed by a wide range of entities in June and July 1987.

Maritime Satellite Service

National and international efforts to establish a future global maritime distress and safety system are continuing. The International Maritime Organization (IMO) is developing the system which will use Standard A and Standard C ship-Earth stations through INMARSAT as well as satellite emergency position indicating radio beacons (satellite EPIRB's) to provide initial distress alerting information from ships to rescue coordination centers. While present plans include satellite EPIRB's through polar orbiting SARSAT, a NOAA Weather Service satellite for search and rescue satellite data tracking, and the Russian equivalent, called COSPAS, the IMO Maritime Safety Committee is also considering use of L-Band EPIRB's through INMARSAT (geostationary orbit). In addition, trials of distress and safety services started in the summer of 1987 on the U.S. GOES satellites and will continue through 1988. The global maritime and safety systems are expected to be phased in between 1991 and 1997.

Currently, INMARSAT is leasing two in-orbit satellites from the European Space Agency, a spare MARECS A in the Pacific Ocean Region (POR) and an operational MARECS B-2 in the Atlantic Ocean Region (AOR); four in-orbit INTELSAT piggy-back Maritime Communications Subsystem (MCS) satellite packages, the spare MCS B (F-6) in the AOR, the operational MCS A (F-8) in the POR, and the operational MCS A (F-5) and spare MCS C (F-4) in the Indian Ocean Region (IOR); and three MARISAT backup spare satellites leased from Comsat General, the MARISAT F-1 in the AOR, the MARISAT F-3 in the POR, and the MARISAT F-2 in the IOR which are also for special purpose use.

Second-generation satellites, the first of which is expected to become operational in 1989, are being built under INMARSAT specifications, and will have a capacity about triple that of the present leased satellites. INMARSAT serves over 6,500 vessels through its 53 member-country organization. Twenty coast stations in thirteen countries are in operation, with two more expected in 1988 or before.

In 1986, the Commission issued three decisions bearing on the INMARSAT's second-generation satellites. First, the FCC authorized COMSAT to participate in INMARSAT's program to procure three second-generation satellites to serve the Atlantic Ocean Region beginning in 1988. Then COMSAT was authorized to participate in an INMARSAT contract with Arianespace for an additional launch of its second-generation maritime satellite communications system. COMSAT's request for this additional launch was based on the uncertainty of the planned June 1988 Shuttle launch. Finally, COMSAT was authorized to participate in an INMARSAT program to lease capacity of the MARISAT system to provide additional backup facilities and to provide currently authorized INMARSAT services via INMARSAT satellites. This authority was deemed necessary due to the serious deficiency in performance of two of INMARSAT's first-generation satellites and other service irregularities. In 1987, INMARSAT was also authorized to contract for a Delta launch which is scheduled for late 1989.

Aeronautical Satellite Service

In October 1985, the Assembly of Parties of the International Maritime Satellite Organization (INMARSAT) adopted amendments to the INMARSAT convention and operating agreement which will allow it to offer aeronautical services. The amendments will take effect 120 days after two-thirds of member countries representing two-thirds of the total INMARSAT investment shares have filed notices of acceptance. INMARSAT's first three second-generation spacecraft are being constructed with three megahertz of bi-directional bandwidth in the Aeronautical Mobile Satellite Service (R) band. Through its Subcommittee on Future Air Navigation Systems, the International Civil Aviation Organization has been discussing standards for aeronautical satellites and other issues involving the use of satellites in a coordinated program for civil aviation. The aviation community is actively developing, through the Airlines Electronic Engineering Committee, an aeronautical satellite system which will provide voice and data services. Under contracts awarded at the end of 1986, INMARSAT is developing aircraft antennas and avionics needed for this service. Aeronautical Radio, Inc. is still pursuing an international aeronautical system by interconnecting its terrestrial VHF network with satellite facilities for oceanic coverage. In addition, land mobile satellite applicants are proposing to provide aeronautical service on their systems.

Direct Broadcast Satellite Service

Of the eight "first-round" DBS companies previously granted permits in 1983 to construct Direct Broadcast Satellites, three are actively progressing in the construction of their authorized satellites. These three permittees will utilize 200 to 230-watt traveling wave tube amplifiers (TWTA's) in conjunction with various half-CONUS or full-CONUS beam configurations to provide service across the continental United States. Modifications granted in September 1985 allow two of these companies to increase transponder capacity from six channels to eight channels per satellite. Projected completion of satellite construction varies for each company from mid-1987 through 1988. These permittees are required to have their satellite systems in operation by the last quarter of 1988.

Additionally, of the six "second-round" applicants granted conditional permits in late 1984 and early 1985, one has demonstrated "due diligence" in construction of its satellite system and has been awarded channels, orbital position, and launch authority. In contrast to the three "first-round" companies, this system will utilize two 16-channel satellites equipped with 100-watt TWTA's to provide DBS service. Advances in antenna and receiver technology are cited in support of mid-power transponder selection. Commencement of DBS operations for this company is scheduled for mid-1989.

Of the conditional construction permits for new satellite systems granted in September of 1985, none were able to demonstrate "due diligence" in satellite construction within the required timeframe. Accordingly, these permits have been cancelled.

Of the three companies awarded conditional construction permits for new satellite systems in September of 1986, one has demonstrated "due diligence" and has requested channel and orbital position assignments. The system will utilize two 16-channel satellites equipped with 125-watt TWTA's to provide DBS service. The projected estimate for commencement of operation of this system is 1991.

One new DBS system application was filed in May of 1987. Another applicant has requested that its previously granted application be returned to pending status. Consequently, both applications currently remain pending.

In a related matter, on November 25, 1986, the Commission issued a ruling in which it expanded on its earlier statements regarding the acceptable uses of the Direct Broadcast Satellite service allocation. Nonconforming uses of DBS transponders which do not detract from the goal of introducing DBS service, and which may help advance it, will be permitted provided that certain restrictions are met.

New Satellite Services

New technology is developing to provide additional uses for satellite-delivered communications. Increased capacity in the 11/12/14-GHz band allows the development of services using much smaller antennas than feasible in the 4/6-GHz band. This has prompted several applications for large private networks of small Earth stations to provide communications services between various business locations. These applications request streamlined licensing procedures which will enable such networks to be constructed more expeditiously and economically. In April 1986, the Commission issued a declaratory ruling which adopted streamlined processing procedures to apply to pending and future applications. Several small Earth station antenna networks were authorized in 1987.

In addition, the radio determination satellite system continued to develop. In 1986, the Commission authorized four companies to construct and launch satellites to provide this service which allows subscribers to determine latitude, longitude, and altitude, and to exchange brief coded messages using inexpensive, hand-held transceivers. Although two of the authorized companies turned in their licenses in 1987, one, Geostar Corporation, has begun to provide this service by placing packages on domestic fixed-satellites. Geostar has also begun construction of its own dedicated satellite.

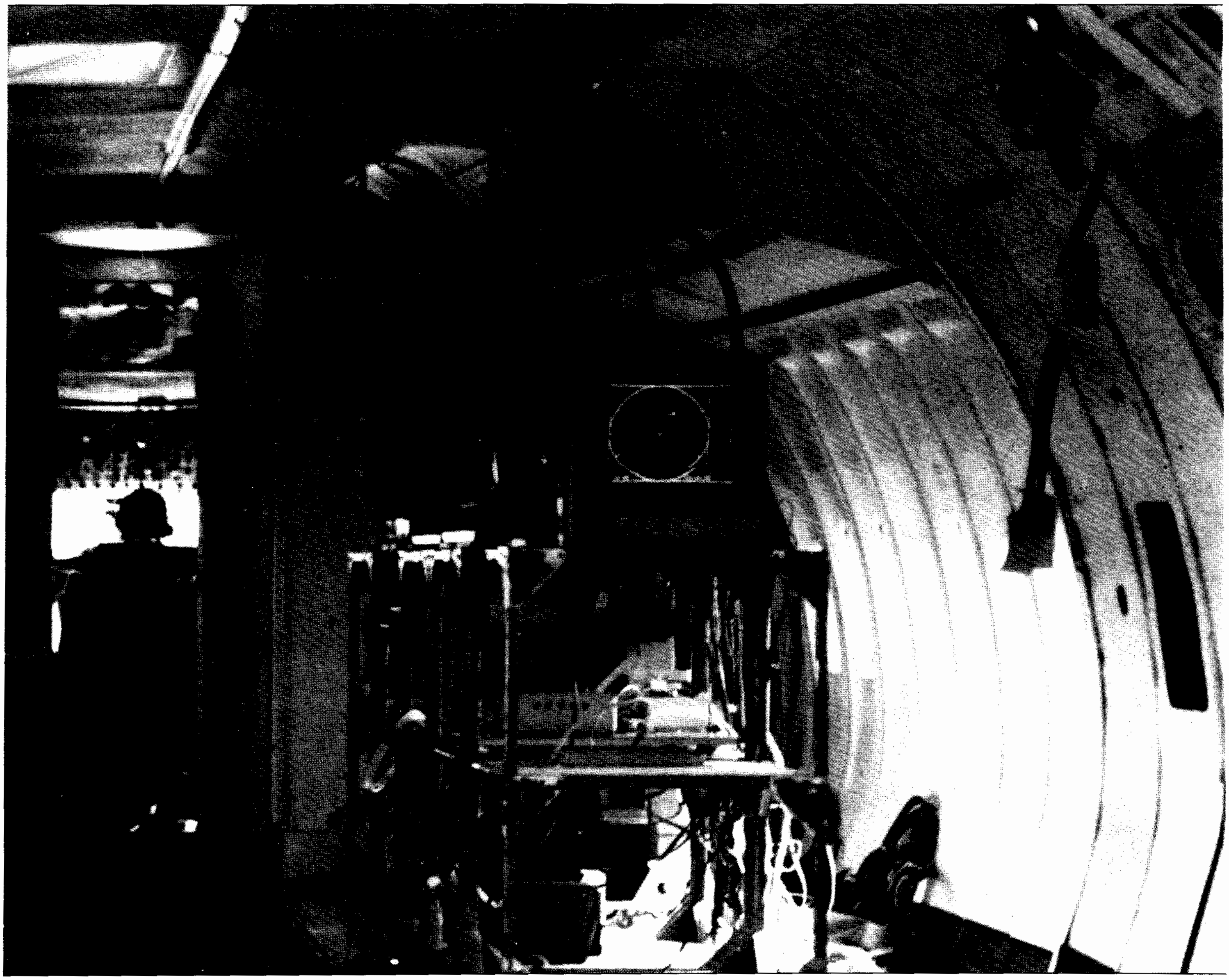
In 1986, the Commission allocated 27 MHz of spectrum in the L-Band and established licensing policies for a mobile satellite service. This service is expected to provide telephone service to rural areas, long-range vehicle dispatch and location service, emergency communications service, service to industries operating in remote locations and aeronautical communications service. The Commission concluded that only one system could be licensed for the first-generation system, and that joint ownership of this system would best permit a variety of mobile satellite services to be made available to the public in an expeditious manner. The Commission directed all qualified applicants to negotiate a joint venture contract and propose a mobile satellite system. The eight qualified applicants have reached a general agreement regarding the key principles of the joint venture and are expected to submit a definitive contract and system proposal in early 1988.

International Conference Activities

During 1987, the Commission was involved in several activities and preparatory meetings geared toward the second session of the Space World Administrative Radio conference (Space WARC/ORB-88) scheduled for August 29 through October 5, 1988. The objective of the Space WARC conference is to guarantee to all countries equitable access to the geostationary satellite orbit and to the frequency bands allocated to space services. The Commission's Industry Advisory Committee has continued to make major contributions to the preparations for the second session's agenda which includes allotment planning; a multi-lateral planning process; other simplified procedures for access to the orbit; and broadcasting satellite issues.

The Commission's staff has been working with NASA and other Government agencies to define priorities and positions for the second session and to develop and support appropriate computer capabilities to aid in the allotment planning effort. In particular, the Commission is working with NASA in testing its recently developed computer program called NASARC for determining orbital arc allotments. The Commission is also developing capabilities to use the Japanese-developed program called ORBIT-3 to assign orbital positions. The feasibility of linking the results of these two programs is also being studied.

From September 14 through October 16, 1987, the Commission's staff attended the Mobile World Administrative Radio Conference (Mobile WARC). The purpose of this meeting was to examine and revise the International Telecommunication Union (ITU) Radio Regulations that pertain to mobile services. The major results concerning space were the allocation of spectrum for Mobile Satellite Service and Radio Determination Service. The conference also provided for the implementation of Global Maritime Distress and Safety Systems.



FAA's Boeing 727 test aircraft and its Traffic Alert and Collision Avoidance System (TCAS) equipment in the forward cabin. Atop the racks is a display of TCAS III for an airborne technician to monitor. The spot in the center is the 727 aircraft. An intruder is about three miles away at one o'clock. On the rack below is an engineering model of the TCAS III computer.

Department of Transportation

The Federal Aviation Administration (FAA), a modal component of the U.S. Department of Transportation, is responsible for regulating air safety, ensuring the safe and efficient utilization of the national airspace system, and fostering the development of civil aviation. To support these responsibilities, FAA engages in a wide range of research and development activities. These activities can be grouped into two convenient categories: those concerned with enhancing safety and those designed to increase the efficiency of air navigation and air traffic control.

Aviation Safety

Traffic Alert and Collision Avoidance System

Since June 1981, the FAA has proceeded to implement a concept called Traffic Alert and Collision Avoidance System (TCAS). The concept was based on previous efforts in the Beacon Collision Avoidance System (BCAS) program, and on air-to-air communications techniques using the new Mode S radar beacon transponder. The objective of the TCAS approach has been to provide a range of aircraft collision avoidance equipment alternatives that could provide some degree of collision protection for the full spectrum of airspace users. The TCAS equipment would operate without dependence on ground equipment and would be active systems, utilizing air-to-air interrogations. The family of TCAS equipment contains TCAS I, a system that generates traffic advisories only; TCAS II, which generates traffic advisories and resolution advisories in the vertical plane; and TCAS III, which generates traffic advisories and resolution advisories in both the horizontal and vertical planes.

TCAS I. Active TCAS I is an air-to-air interrogation device that alerts the pilot to the presence of a nearby transponder-equipped aircraft that may pose a collision threat and advises the pilot of the approximate clock position of the intruder aircraft. Although active TCAS I does not provide resolution advisories, a significant amount of available data demonstrates that pilots who are alerted to the presence and clock position of a nearby airplane will locate the intruder more rapidly, even in conditions of poor visibility. By providing traffic advisories, TCAS I supports the see-and-avoid concept of aircraft separation assurance.

In accordance with recommendations of the Radio Technical Commission for Aeronautics (RTCA), a government-industry working group was formed to develop Minimum Operational Performance Standards (MOPS) for an active TCAS I. The MOPS complete by this group was adopted by RTCA on March 20, 1987. A draft Technical Standard Order (TSO) that would permit the active TCAS I to be manufactured under the TSO approval system was issued in September 1987.

To support the development of the MOPS, Lincoln Laboratory fabricated a TCAS I engineering unit for flight testing on both fixed-wing aircraft and helicopters. The bearing accuracy obtained was more than adequate to support proximity warning operations. Additional helicopter tests have been conducted at the FAA Technical Center, at Atlantic City, New Jersey.

A Notice of Proposed Rulemaking (NPRM) was published on August 26, 1987, to require TCAS I installation within 5 years after the effective date of the rule in air carrier aircraft operating under Parts 135 and 91 of the Federal Aviation Regulations with 10 to 19 passenger seats. The installation of TCAS I does not require the Mode S transponder.

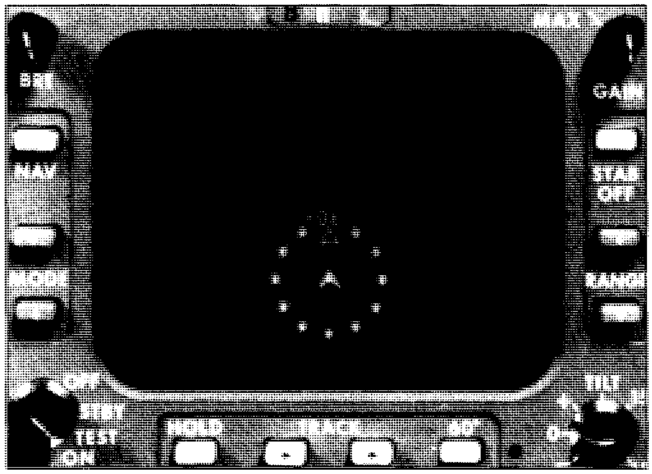
Although no TCAS I system has been built commercially to date, FAA believes that development of equipment that can meet the MOPS is well within the state of the art for manufacturers and that adequate quantities can be available within the required time period.

TCAS II. Engineering development of TCAS II has been completed and the program is now in its certification-implementation phase. The RTCA approved Minimum Operational Performance Standards for the system in September 1983, and the FAA issued a Technical Standard Order in October 1987. The principal area of the TCAS II efforts in 1987 has been the certification and installation of TCAS II units in airline aircraft for the purpose of operational evaluation. On March 19, 1987, the FAA began the in-service evaluation of a prototype TCAS II installed in a Piedmont Airline B-727 aircraft. The objective of this program is to observe and record system performance and flight crew integration in a real-world environment.

A major TCAS II implementation effort is the Limited Installation Program (LIP), the objective of which is to permit evaluation of production quality TCAS II by a number of airlines under normal scheduled operations. In support of this objective, cost-sharing contracts were awarded in 1984 to the Air Transport Division of Allied Bendix and to Sperry Dalmo Victor, Inc., to design and fabricate TCAS II units, as well as to evaluate them on air carrier aircraft for a period of 6 to 10 months. Bendix will provide units to United Airlines for installation in a B-737 and DC-8. Sperry Dalmo Victor will provide units to Northwest Airlines for installation in two MD-80's and to Piedmont Airlines for installation in two B-727 aircraft. Certification of these TCAS installations and the beginning of the flight evaluation is expected in early 1988.

The NPRM of August 26, 1987, proposes that installation of TCAS II be required in all turbine-powered aircraft operating under Parts 121, 129, and 135 of the Federal Aviation Regulations with 30 or more passenger seats.

TCAS III. In 1987, under the TCAS III Program, a sizable number of flight tests of an experimental system installed in an FAA B-727 aircraft were made in the vicinity of the agency's Technical Center. These flights and supporting computer simulations will be used to assess the performance of the second generation TCAS III logic. A second TCAS III engineering unit was installed in the FAA Technical Center's Convair 580. In the next series of tests, this equipment will provide the means to test the function that coordinates the TCAS resolution advisories provided to pilots as they approach each other on a potential collision course.



Traffic Alert and Collision Avoidance System (TCAS) II Display. The pilot of this TCAS II-equipped aircraft has traffic dead ahead 600 feet below him and another aircraft coming his way 400 feet above. He will receive an advisory to climb or descend if the TCAS computer calculates that a collision hazard exists.

The data obtained in the fight tests will provide RTCA the engineering basis for the specification of TCAS III characteristics in a MOPS. The first draft MOPS for the system is anticipated in the spring of 1988. The design of the TCAS II units is expected to permit subsequent upgrading to TCAS III units at minimum cost. Although there is no requirement at this time for mandatory installation of TCAS III, FAA is committed to support its implementation in airline aircraft. A decision was made in September 1987 to conduct a Limited Installation Program (LIP) for TCAS III similar to that described above for TCAS II.

Aircraft Crashworthiness

During 1986, the FAA issued Notices of Proposed Rulemaking (NPRM) addressing the dynamic evaluation of seat and restraint systems for all categories of civil aircraft. These proposed rules were based on the results of a comprehensive research program which employed a multifaceted systems approach in addressing the interfaces between the occupant, seat-restraint devices, and the airframe.

In 1987, the focus of research and development, which had been centered around metal structures, shifted to structures fabricated of advanced composite materials such as graphite-epoxy, glass-epoxy, and kevlar-epoxy. The increasing usage of these advanced high strength-to-weight ratio materials has posed a new challenge with respect to occupant survivability and the certification of aircraft. Indeed, the transition to aluminum alloy construction was a relatively simple one compared to the introduction of composites. Aluminum did not present the wide-ranging complexities of mechanical properties or the varieties of possible fiber matrix combinations and geometrics available with composites. Efforts were undertaken to generate data to address the effects that advanced structural materials would have on occupant survivability and aircraft structural airworthiness as defined by current regulations and advisory circulars.

In early 1987, the FAA instrumented a B-707 fuselage section at its Technical Center and conducted a number of static pull tests to determine the nominal strength of a narrow-body transport category airplane floor, seat track, and floor-fuselage interface. The results of these pull tests were factored into two longitudinal dynamic impact tests that were performed on another B-707 fuselage section at the Transportation Research Center of Ohio. These impact test results were used to determine transport fuselage/floor/seat transmissible effects; verify the analytical modeling program; and expand the existing data base for metal and composite structures.

Concurrent with these tests, the FAA developed a handbook (DOT/FAA/CT-87/9) for its personnel and other interested groups which provides basic information on the principles, fundamentals, and technical procedures relating to the manufacture and repair of fiber-reinforced composites used in aviation application. Also, Volume II of a two-volume textbook entitled *Fiber Composite Analysis and Design* was published. This volume addresses the analysis and design of fiber-reinforced composites ranging from their material properties through their structural applications. The textbook was developed primarily to assist certification and aircraft design engineers.

In order to avoid duplication of research on advanced composite materials, the FAA entered into three interagency agreements. Under these agreements, the FAA will engage in joint efforts with the Navy, to evaluate existing composite static strength and fatigue life data to develop an acceptable methodology for certificate testing of composite structures; with the Army, to investigate the crash impact characteristics of composite structures; and with the Air Force, to characterize the modes and develop the investigative techniques to identify the various types and sources of composite structural failures due to in-service and/or impact-related events.

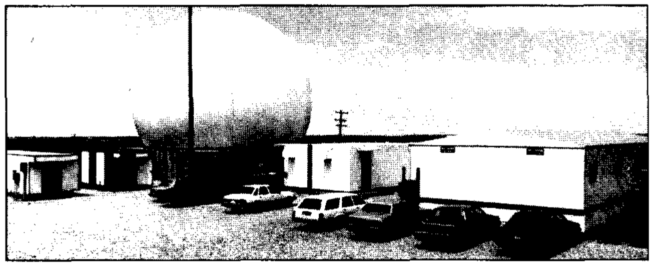
Aviation Weather

Wind Shear. Among aviation's most serious weather concerns is wind shear, a sudden change in wind speed and direction. Wind shear may be produced by thunderstorms and even cloud formations that appear to be harmless. Convective activity associated with thunderstorm conditions can generate both gust fronts, which do not represent a serious threat to aircraft, and small, intense downdrafts, which are potentially more dangerous. These downdrafts, called microbursts, descend rapidly to the ground and spread out in all directions. They are often no more than one or two miles in diameter and have an average life of seven minutes. An airplane flying through a microburst first encounters a headwind, then a tailwind. The latter causes a reduction in airspeed and may result in a substantial loss of lift. In some cases, aircraft performance will not be sufficient to fly through microburst conditions. In addressing the wind shear question, the FAA is pursuing a variety of detection, warning, and flight guidance programs in conjunction with other Federal agencies.

The FAA has continued to improve the 6-sensor Low Level Wind Shear Alert System (LLWAS), the ground-based wind shear detection system that is currently in operational use. The system provides wind shear alerts to air traffic controllers, who in turn issue advisories to departing and arriving aircraft. LLWAS uses computer processing to compare wind speed and direction from sensors located at the airport. It generates alerts whenever the center-field wind data differs, by a preestablished threshold, from data obtained from a wind sensor located around the perimeter of the airport. The current processing algorithms (computer procedures) are not sufficient to identify, positively, microburst conditions occurring within the boundary of the airport. In addition, the current siting of some of the sensors is affected by buildings and other objects which distort the wind flow in the vicinity of the sensors and may, in some cases, generate an unnecessary alert.

The FAA formed a team in 1986 to assess the siting of all LLWAS sensors at all airports in the United States. Information collected by the team also was used to identify nuisance alarms caused by events that are too brief or localized to be meteorologically significant. In addition, wind experts from Colorado State University and the National Center for Atmospheric Research (NCAR) developed new and more comprehensive siting criteria. By mid-1987, new algorithms were developed and tested to reduced the impact of false alarms and to enhance the microburst-detection capability. The algorithms will be incorporated into the LLWAS's during 1988. In addition, necessary resiting of the LLWAS sensors will be completed by August 1988.

New algorithms were also devised during 1986 for an expanded network LLWAS with up to 16 sensor sites. The algorithms and the additional sensor sites give the new system an even greater capability in detecting hazardous microbursts. They also permit the reporting of results in terms of runway coordinates, a form more useful to the pilot. The FAA conducted an evaluation of the new algorithms and a new tower cab display at Denver's Stapleton Airport in September 1987, and an evaluation report is scheduled for completion in January 1988. Commissioning of this expanded LLWAS is expected by mid-1990.



FAA's terminal Doppler weather radar test bed, operated by MIT's Lincoln Labs, is located in Buckley, Colorado.

Development of Doppler weather radar is an important approach to the problem of wind shear. This type of radar is capable of "seeing" inside storms to measure both rainfall intensity and the speed of winds moving toward or away from the antenna site. During 1987, the FAA carried out Doppler weather radar tests at Denver, Colorado, continuing a test series conducted in Tennessee and Alabama during the previous two years. The test facility included an S-band Doppler weather radar, fabricated by Lincoln Laboratory for the FAA. The University of North Dakota provided a C-band Doppler weather radar and a Cessna Citation aircraft instrumented for turbulence detection. In addition, 30 ground weather sensors were used.

In the 1987 tests, the facility was used to collect basic meteorological data, refine algorithms for weather detection, evaluate air traffic control operational issues, and continue Doppler weather radar functional and technical refinements. In 1988, the equipment will be used to conduct an operational evaluation. This will include evaluation of candidate displays for controller use and candidate presentation of information relative to hazardous weather in the terminal area. The potential impact of the operational scenarios on air traffic control operations also will be evaluated.

In the field of airborne detection systems, the FAA and NASA continued to cooperate under a memorandum of agreement providing for joint development of the system requirements for "forward-looking" wind shear sensors, using such techniques as Doppler radar, lidar, and infared. These sensors would work by "looking ahead" to detect wind shear before the aircraft enters the hazardous area. The FAA and NASA plan to provide approximately $24,800,000 under the agreement, which started in October 1986 and will last through September 1991. The two agencies are working closely with the aviation industry to ensure that the results of technology assessments and analysis capabilities are useful to the industry's design, development, and certification program. The emphasis of this program over the first year was the development of a definition of the hazard posed to aircraft, and an understanding of the phenomena below 1,500 feet. During 1987, technology assessments were conducted for the forward-looking sensor concepts, and initial work commenced on understanding the human factors issues associated with this equipment.

The industry has focused its attention on reactive wind shear sensors for aircraft systems that compare the inertial data of aircraft with air mass data. When a shear is encountered, an alert is sounded and the flight crews are provided with information on how to exit the shear. The FAA and NASA are working closely with the manufacturers of these reactive devices to ensure that they will work in harmony with the forward-looking sensors under development.

In recent years, action on wind shear training has been encouraged by a National Research Council report urging an educational campaign directed at all classes of pilots, and by recognition that wind shear training programs vary from airline to airline. In November 1985, the FAA awarded a $1.8 million contract to the Boeing Commercial Airplane Company to develop a wind shear training program. Boeing was supported with subcontracts to the Douglas Aircraft Company, Lockheed, United Airlines, and Aviation Weather Associates. The objective of the program was to provide operators with the tools to train pilots to avoid wind shear and to use standard techniques to escape from inadvertent encounters.

The products of this program were delivered on February 26, 1987, and included a wind shear pilot guide, an example wind shear training program, substantiating data, and a management overview. These materials were sent to all U.S. air carriers, commuter airlines, and scheduled air taxi operators, as well as to FAA inspectors and regional offices. Some copies were also sent to aviation interest groups for further distribution to their constituencies, and others were distributed internationally. Copies of the training aid can now be obtained through the National Archives and Research Administration's National Audiovisual Center. Reviews and updates of this material are planned on an annual basis to ensure that information is always responsive to the aviation industry.

Automated Weather Observing System. The majority of airports within the National Airspace System (NAS) do not have a local weather reporting capability. For example, operations for commercial operators under instrument flight rules are restricted at over 1,300 airports because of the unavailability of weather observations. The Automated Weather Observing System (AWOS) offers a means of improving this situation. Through the use of automated sensors, AWOS will make surface weather observations of aviation-critical weather data. It will process these data and disseminate the resulting information to a variety of users.

AWOS is available in three versions. An AWOS I contains sensors to measure wind speed and direction, ambient and dewpoint temperature, and altimeter setting. This version also computes density altitude. An AWOS II contains the AWOS I sensors plus a visibility sensor, and an AWOS III adds a cloud height sensor to an AWOS II. Most important, all versions are required to have the capability to broadcast a minute-by-minute update of the current weather to the pilot by radio, using a computer-generated voice. AWOS may also have a capability that enables such users as pilots engaged in pre-flight preparations to call the AWOS by telephone to obtain the current weather observation. In addition, the observation may be transmitted to the data bank within the national weather network.

Under the Airport Improvement Program (AIP), state and other local airport authorities may apply to the FAA for partial funding of AWOS, using dollar resources from the Airway Trust Fund. In 1986, the FAA completed the specification document that establishes the following criteria necessary to provide confidence in the quality of AWOS meteorological data: data and documentation submitted by the manufacturer must establish that the equipment provides the quality of information required by the aviation community; verification that the equipment is correctly installed and operating properly, and that the owner has the resources to maintain the system; and periodic visits are required to the operating AWOS by the FAA or other technical representatives to verify that the system continues to operate correctly. During 1987, the FAA certified two companies as suppliers of AWOS systems.

The FAA is preparing to procure 160 commercially available AWOS III type systems to meet its many safety requirements relating to instrument approach operations. These systems will be installed at various airports without towers to provide an early enhancement of safety and efficiency of flight operations by providing real-time weather data at facilities that currently do not have a local weather reporting capability. The FAA also is coordinating with the National Oceanic and Atmospheric Administration the procurement of additional and more sophisticated automated surface observing systems to meet the requirements at airports where FAA personnel currently make observations, and at additional nontowered airports with instrument approaches.

Atmospheric Electrical Hazards. Current-technology aircraft that employ large amounts of composite (non-metallic) materials in their structure and utilize low-voltage digital avionic systems are far more susceptible to the adverse effects of lightning and static electricity than conventional aircraft of all metallic construction. The FAA continued to gather, develop, and disseminate new scientific information on lightning and the threat that it poses to modern aircraft, an effort undertaken with the Department of Defense, Department of Commerce, National Aeronautics and Space Administration, the aircraft industry, and independent research organizations. The FAA published several documents during 1987 to facilitate the design, certification, maintenance, and operation of aircraft and avionics in the lightning environment, including the following:

- a draft advisory circular and draft users manual to protect aircraft electrical/electronic systems against the induced effects of lightning;

- seven digital-system validation reports for inclusion in the digital-system validation handbook;

- a report on avionics system design for high energy fields; and

- two draft reports that address electrical properties of composite materials and simulation test techniques to validate protection designs.

Icing. The formation of ice can threaten an aircraft through increased drag, loss of lift, and even loss of control, while the shedding of ice can lead to structural and engine damage. To ensure proper certification of aircraft and aircraft engines using new or modified ice protection designs, the FAA seeks to expand understanding of equipment limitations under various operating conditions. During 1987, the agency reported on two areas of concern: concepts and consideration for the application of engine inlet deicing equipment in which shed ice particles may be ingested by the engine; and engine icing certification testing criteria, when required testing conditions cannot be obtained readily due to facility limitations.

Aviation Security

During 1987, the FAA continued to make significant progress in the area of explosive detection. The development of two prototype thermal neutron activation (TNA) systems, which screen checked baggage and air cargo, was completed. The first TNA system, which utilizes a radioactive neutron source, began tests on checked baggage at San Francisco International Airport in June and has subsequently been tested at Los Angeles International Airport. The second TNA prototype, utilizing an electronic neutron source, was initially tested at San Francisco in August and subsequently at Los Angeles. Results have been excellent, with detection percentage in the 90's, a relatively low level of false alarms, and an average screening time of six seconds per item. The TNA system is the first "true" explosive detector to be operationally viable. X-ray data also was collected on the bags involved in these tests, and software is being developed and tested to combine data from the TNA and x-ray systems to further reduce false alarms.

In vapor detection of explosives, the FAA has pursued development of a portal screener for passengers that uses the detection technique of chemiluminescence. The agency began laboratory tests of a breadboard portal in December 1987, and a prototype portal will be tested at an airport in the summer of 1988. The FAA also has continued a feasibility study of a chemiluminescent system for screening carry-on baggage, and completed an evaluation of a mobile detector, developed for another agency, on its applicability for screening aircraft.

In 1987, the FAA initiated several studies involving new technologies and concepts for explosive detection. Most of these studies had their origin in two FAA solicitations for new approaches to explosive detection. Out of nearly 30 responses to the solicitations, four were considered sufficiently promising to merit awards for feasibility studies. In addition, several projects on new technologies initiated in prior years have been continued. The most important of these is the dual sensor approach which combines x-ray and TNA sensors and offers considerable promise of system performance surpassing TNA alone.

The FAA continued to explore the possibility of improving the discrimination capabilities of current generation metal detectors as a means of improving airport concourse security. The agency also conducted studies of infrared, millimeter wave, and acoustic techniques for detecting both metallic and nonmetallic weapons. Finally, the FAA proceeded with its investigation of the enhancement of concourse x-ray systems for automated detection of explosives and weapons in carry-on and checked baggage.

Medical Certification

During 1987, the FAA continued its evaluation of therapeutic agents that could impair performance in civil aviation. In a cooperative testing program with the University of Oklahoma, test subjects who had elevated blood pressure were administered a "beta-blocker" type of antihypertension medication. The subjects were then exposed to a profile of stressers reflective of civilian piloting that included altitude simulation to 12,500 feet; acceleration simulation to two accelerations of gravity (2G); a low level of physical exercise; and a battery of performance tests. The ability to define the determinants of G tolerance, impending incapacitation, and disruption of general performance and thought associated with this commonly administered hypertensive should facilitate future medical certification decisions. The same protocol can be adapted to evaluate the effect of a broad range of cardiovascular medications on civilian piloting skills.

In a separate but related area, the FAA reviewed the mental status examinations available to aviation medical examiners for use in screening candidates for civilian pilot medical certification who might have impaired mental function. Tests identified as potentially applicable for a quick screening approach in the medical office will be validated in 1988 by three contractors (Advanced Resource Development Corporation, Nova Technology, Inc., and the University of Illinois). The contractors will apply select batteries of tests to pilots and to subjects with known thought and performance deficits.

Airport Pavement Research

During 1987, the FAA completed development of new and updated criteria for increasing durability and reducing maintenance costs of airport pavement overlays through the use of recycled rubber in asphalt concrete pavements. Criteria to reduce premature cracking of new overlays by the crack-and-seat method of construction were completed. Through an interagency agreement with the Army Corps of Engineers, new criteria have been developed for the economical design of overlays for rigid pavements in need of rehabilitation; also, the effectiveness of criteria for the design of pavements for high traffic volume was assessed. Studies of the effects of pavement layer separation on performance, as well as criteria for the use of old concrete in providing new riding surfaces, were completed.

The FAA continued efforts to investigative additives for strengthening subgrades and concrete pavements serving heavy aircraft, and to investigate the effectiveness of devices for evaluating the strength parameters of in-service pavements. Work continued in developing acceptance standards for construction items, and in the field validation of new standards for material selection and construction methods for the prevention of frost and thaw damage to pavements. Also in 1987, through an interagency agreement with the Navy, work continued on the identification of sealants that effectively protect airport pavements from undercutting caused by water and the growth of vegetation in joints and cracks. In addition, development of smoothness criteria for acceptable riding comfort continued in 1987.

Other Safety Developments

General Aviation Fuels. In 1987, the FAA issued a report that identified a number of considerations on certifying general aviation aircraft fuel systems to use automotive gasoline. The agency's Engine/Fuel Safety branch also tested different grades of gasohols (blends of automotive gasoline with ethanol or methanol), methanol, ethanol, and a derivative of methanol called methyl-tertiary-butyl ether. Except for the gasoline ingredient in gasohol, these fuels can be produced from coal or renewable sources such as grain and wood. Thus, they offer the potential for reducing the Nation's dependency on foreign oil, and providing new answers to the general aviation community's desire for an alternate fuel to aviation gasoline. Research will continue, however, because the test and evaluation program conducted by FAA engineers uncovered several potential problems that must be solved before such fuels can be used safely in place of aviation gasoline. These problems include vapor lock, water compatibility, material compatibility, severe detonation in high-performance engines, and a degree of fuel loss due to evaporation and venting.

Jet Engine Bird Hazard Program. Birds are an ever-present hazard to aircraft. Aircraft collisions with, and ingestion of, birds during the course of a year cause damage estimated as high as $40 million or more. As part of its continuing effort to assess the adequacy of the current certification standards for jet engine bird ingestion, the FAA engaged in two parallel, two-year studies that will expand on the data presented in its previous report, *A Study of Bird Ingestions into Large High Bypass Ratio Turbine Aircraft Engines*, DOT/FAA/CT-84/13.

One of these studies, which entered the active research phase in 1987, concerned the bird ingestion history of the B-737 transport aircraft. Some models of this aircraft are powered by General Electric's CFM56 turbofan engines, with large inlet areas and a medium bypass ratio, while others still use the older Pratt and Whitney JY8D turbofans, with smaller inlet areas and a lower bypass ratio. The study will compare the bird ingestion experience of the two different engines on the same type of aircraft in the same bird ingestion environment.

The other study, initiated in 1987, will compile data on the bird ingestion history of small turbofan and turboprop engines of the type used to power commuter and business jets. The engines are Garrett's TFE731 turbofan and TPE331 turboprop, Avco's ALF502 turbofan, and Pratt and Whitney's JT15D turbofan.

Rotocraft Safety and Operational Improvements. The FAA has undertaken a program to enhance the safety of transport helicopters by determining the causes of the rising number of uncontained turbine engine rotor failures in the civil helicopter fleet during recent years. Data on operational service engine failures in the U.S. fleet was accumulated and reviewed during 1987. Preliminary results indicated that at least two turboshaft engine models suffer from a significant uncontained rotor failure rate. The FAA will continue to review operational service data on all civil helicopter powerplants to determine the causes, characteristics, and effects of such failures. New containment technology, materials, and propulsion system designs to reduce this hazard will be evaluated. The results of the program will be used by the agency to evaluate the adequacy of its current certification standards for helicopter engine rotor failure protection.

The FAA held a "Zero/Zero" Helicopter Certification Issues Forum to analyze the issues from the perspective of the agency, manufacturers, operators, and researchers. The basic premise behind this analysis is that rotocraft operations in conditions of "zero/zero" or extremely low visibility are feasible today from both technological and operation viewpoints. The questions and issues that were identified and need to be resolved are the following: What certification requirements are needed to ensure safety? Can procedures be developed that capitalize on the performance and maneuvering capabilities unique to rotocraft? Will extremely low visibility operations be economically feasible?

The report of the Issues Forum was prepared in three volumes that included an overview of the forum, presenting the consensus of 49 experts from Government, manufacturers, and the research community on 50 certification issues of operational requirements, procedures, airworthiness, and engineering capabilities; the operator perspectives (system needs), technical solutions, and "zero/zero" concepts developed up to the present time; and an issue-by-issue deliberation of the experts who supported the working groups of the forum.

Aircraft Rescue and Firefighting. The FAA completed an extensive series of tests involving 28 foam firefighting agents currently available for use by aircraft rescue and firefighting services at national and international airports. These agents were classified into two performance level types, each comprising two groups of foam firefighting liquids, based upon their chemical composition. The technical information and classification procedures were requested by the International Civil Aviation Organization for submission to the International Standards Organization study group for use in developing a revised international classification standard for foam firefighting agents.

After receiving the New Jersey Environmental Protection Agency's approval of the fire test facility for conducting large-scale tests on firefighting agents, the FAA began evaluation of foam agents determined to be promising in small-scale laboratory tests. The FAA also initiated tests and evaluation of rescue and firefighting equipment and clothing, as well as development of efficient rescue and firefighting systems for heliports and general aviation airports.

At the request of the Aviation Section of the National Fire Protection Association International, FAA presented the classification methodology at the International Conference on Aviation Fire Protection held in September 1987 at Interlaken, Switzerland.

Cabin Fire Safety. During 1987, FAA aircraft fire safety activities focused on the in-flight fire problem. Initial full-scale fire tests inside a wide body fuselage were conducted to examine the characteristics of fires originating in hidden or inaccessible aircraft areas. This and subsequent test data will be useful in assessing the adequacy of current in-flight fire detection and extinguishing techniques, and of materials' fire resistance. In addition, the FAA evaluated the effectiveness of the current practice of employing the aircraft environmental control system (ECS) to ventilate smoke from an in-flight fire. Because it was found that the ECS has limited capability for smoke venting, FAA has begun to examine the feasibility of several enhanced methods of smoke removal.

Low Impact Resistance Structures. In complying with Recommendations No. A-84-36 of the National Transportation Safety Board, the agency has been in the process of developing and installing Low Impact Resistance Structures (LIRS) in order to reduce the amount of damage sustained by a lightweight aircraft that might accidentally collide with air navigation equipment and support structures. During 1987, the fabrication of a 20-foot tower that offers low resistance to impact was completed and assembled at the fabrication shop prior to being shipped to the National Bureau of Standards for the start of a series of tests. Laboratory tests were completed on certain tower members and full size "breakaway mechanisms." Dynamic tests also were carried out on electrical conductors, and the break energy required was calculated. A report on the results of the conductor tests was completed.

Air Navigation and Air Traffic Control

National Airspace System Plan

Host Computer System. Since 1981, the FAA has proceeded to implement the National Airspace Systems (NAS) Plan, a technological blueprint for modernizing and increasing the capacity of the Nation's system of air navigation and air traffic control. A major step in this implementation occurred on May 29, 1987, when the first of a new generation of air traffic control computer systems was commissioned at the air route control center in Seattle, Washington. The Host Computer System uses the same basic instruction package as the IBM 9020 computers that it will replace at the 20 air route traffic control centers in the contiguous 48 states. The development of the new system began with a design competition in the summer of 1983 between IBM and Sperry-Univac. In 1985, FAA selected the IBM design, the key element of which is the 3083-BXI computer. The FAA's Technical Center subjected the new system to rigorous testing, including a 25-hour operational readiness test, before accepting it for delivery to Seattle.

The new host system is ten times faster and has four times the capacity of the older 9020. Tests conducted by IBM demonstrated that the host can handle the air traffic work load projected for 1995 using less than 40 percent of its capacity. This allows for unforeseen traffic growth, and also permits the FAA to add new automation functions and upgrade such existing capabilities as conflict alert and en route traffic metering.

During 1987, the delivery of all 20 Host Computer Systems was completed, and 9 of them were commissioned. Plans call for commissioning host computers at the remaining 11 air route traffic control centers by June 1988.

Advanced Automation System. The Advanced Automation System (AAS) includes new "sector suite" workstations for controllers, new computer software, and new processors. An AAS design competition between IBM and Hughes Aircraft has been underway since August 1984. To select a winner to produce and implement AAS, the FAA issued a request for proposals in August 1987. This contract is expected to be awarded in July 1988. It includes new Automation En Route Air Traffic Control (AREA) software, which is being developed as part of the AAS. This first installment of AREA software will automate certain air traffic control functions. The AAS provides improved productivity, capacity, and reliability, as well as the needed flexibility for future improvements in air traffic control automation.

Voice Switching and Control System. The FAA conducted the preliminary design review of two competing prototypes of the Voice Switching and Controlling System (VSCS). The prototypes are being built by AT&T Technologies and the Harris Corporation under a 35-month competitive contract awarded in October 1986, and the winning contractor will produce and install 24 of the systems. VSCS will provide controllers at air route traffic control centers with computer-controlled voice switching for air-ground communications, and intercom and interphone communications within and between FAA facilities. Compared to the present electromechanical switching system, VSCS will be faster and more flexible, as well as more reliable and economical to maintain.

New York TRACON

Upgrading of the automated air traffic control system at the New York Terminal Radar Approach Control Facility (TRACON) continued under a contract awarded in March 1986 to the UNISYS Corporation. The upgrade is required to increase the capacity of the current system, which services three major airports and 40 satellite airports in the New York metropolitan area. Stage I of this two-stage contract will include new, redesigned controller displays, solid state memory, and a local area network. The prototype Stage I equipment was delivered and installed in 1987, and initial integration testing was conducted at the FAA Technical Center.

Successful implementation of Stage I at the New York TRACON in 1988 will provide tracking of 1,700 aircraft within a 15,000-square-mile area. Stage II completion, scheduled for February 1990, will increase the tracking capability to 2,800 aircraft.

Airport Visual Aids and Lights

During 1987, the FAA continued the effort to standardize instrument flight rule approach lighting systems for heliports. After evaluating systems in actual weather and in simulation flights, a promising prototype was installed at the FAA Technical Center. Evaluation of the prototype under visual flight rules was completed, and evaluation under instrument flight rules was begun.

The Technical Center completed development of a visual aid system to indicate temporary runway closure. After several prototype systems were developed and tested, the most effective appeared to be an x-shaped visual aid using pulsating lights. Results of the evaluation showed that the visual aid provided an intuitive indication of a closed runway in adequate time for a pilot to execute a safe, missed-approach maneuver.

The FAA continued the development and evaluation of improved lighting systems for runways and taxiways in 1987. The lights will help maintain airport capacity by permitting aircraft operations in conditions of very low visibility.

Airport Capacity

Task Force Studies on Airport Capacity Enhancement and Delay Reduction. The FAA continued these site-specific studies in order to reduce aircraft delays at major airports. Participants in the task force efforts included airport sponsors, the Air Transport Association, airlines, consultants, and representatives from FAA regions, centers, and towers. During 1987, three of these studies were completed, and three new studies were initiated at Boston, Phoenix, and Salt Lake City.

Airspace and Airport Simulation Model. In 1987, a nine-year research program sponsored by the FAA resulted in the development of the Airport/Airspace Delay and Fuel Consumption Simulation Model (SIMMOD). An advanced computer model that simulates both airfield and airspace traffic operations, SIMMOD is a flexible, powerful, tool. It is capable of calculating the impacts of a wide variety of potential airport and airspace improvement options in terms of capacity, travel time, delay, and fuel consumption. SIMMOD is designed to "play out" operations within the computer to determine the real-world results that would be obtained if various operational, technological, or facility alternatives were actually implemented. The first application of the simulation model was to verify and quantify the benefits of proposed routings and sectorization developed as part of the Expanded East Coast Plan for more efficient air traffic control. SIMMOD is expected to play an important part in future operational planning by the FAA and the aviation community.

Precision Runway Monitor Program Plan. Because severe airport capacity problems are expect to worsen as traffic increases at an estimated 6 percent per year, it is becoming more and more urgent to exploit solutions that can be implemented in the next one to five years.

For airports with the appropriate runway geometrics, a much-studied way to maintain airport capacity has been the use of both dependent and independent multiple approach streams to separate parallel runways under Instrument Flight Rule (IFR), as is done under Visual Flight Rules (VFR). In dependent operations, standard diagonal separations between aircraft in adjacent streams are maintained in addition to the usual in-trail separations. In independent operations, aircraft are allowed to operate without reference to those in the other stream as long as they remain in their own stream and maintain in-trail separations. A precision runway monitor that would provide precise surveillance of landing aircraft under IFR would make it possible to control such independent approaches, and also would allow the FAA to safely reduce the distance required between closely spaced parallel runways. This could reduce capacity problems at some selected airports, and also would open possibilities for new runway construction under land-limited conditions.

To meet these objectives, the FAA has undertaken a comprehensive demonstration program, involving two different approaches, to find a suitable sensor for monitoring independent IFR approaches to parallel runways less than 4,300 feet apart. Both approaches are based upon the existing Air Traffic Control Radar Beacon System (ATCRBS). One approach is to modify the new Mode S version of this system, presently being procured for installation at all major airports, by adding another antenna. The other approach is to develop a high-update-rate sensor using off-the-shelf technology developed as part of the TCAS collision avoidance program described earlier in this report. The Mode S system uses mechanically rotated antennas, while the TCAS-based version uses fixed-phase array antennas and will have a higher update rate that may be needed at locations with runway spacings below 3,400 feet. Among existing airports with parallel runways, seven could benefit from the Mode S version and three require the high-update system. In the spring of 1988, a demonstration of the Mode S version will take place in Memphis, Tennessee, and in the fall of that year the TCAS-derived equipment will be demonstrated at Raleigh-Durham, North Carolina.

Helicopter Wake Vortex Study. In 1987, the FAA and the Transportation Systems Center of the Department of Transportation continued their joint investigation of helicopter wake vortex characteristics. Full-scale flight tests of the CH-47D and UH-60 helicopters involved measuring the vortex intensity, persistence, movement, and decay of the aircraft wake as a function of time. The Laser Doppler Velocimeter (LDV) was utilized to collect the flight data. Vortex probing with T-34 and Decathlon aircraft was conducted to determine the potential hazard to an aircraft encountering the wake. The FAA will use the information collected in this program to explore the feasibility of reduced air traffic control separation standards in mixed terminal area operations.

Office of Commercial Space Transportation

The Department of Transportation (DOT) was designated the lead agency within the Federal Government for encouraging, facilitating and coordinating the development of commercial expendable launch vehicle (ELV) operations by private U.S. enterprises as a result of Executive Order 12465 and the Commercial Space Launch Act of 1984. To carry out these responsibilities, DOT's Office of Commercial Space Transportation reviews Government policies affecting commercial launch activities, provides a single point within the U.S. Government for obtaining licenses for commercial ELV launches, and promotes and encourages commercial ELV operations by U.S. firms in domestic and foreign markets.

The President's commitment to encourage the development of a private sector space transportation industry has resulted in an emerging, internationally competitive American industry which has made inroads against the U.S. prime competitor, Arianespace. Currently, seven American launch firms are actively marketing their services: the three major aerospace manufacturers, Martin Marietta, McDonnell Douglas, and General Dynamics; and four smaller, entrepreneurial firms: Space Services, Inc., American Rocket Company, Conatec, Inc., and E'Prime Aerospace Corporation. By April 1987, American firms had reservations for the launch of 22 commercial and foreign satellites. By September, these firms had signed final contracts to launch eight satellites, and by the end of the year, the number had increased to 12 satellites. Major investments totaling approximately $400 million have been made in this emerging business by the commercial ELV companies, which may add as many as 8,000 new jobs to the current levels of employment already represented by launch services. Each satellite launch on a U.S. ELV adds between $40 million and $100 million to America's gross national product (GNP). The Department of Defense, an important customer for the launch vehicle industry, increased its procurement of expendable launch vehicles in 1987.

Martin Marietta, manufacturer of the Titan, the largest unmanned rocket in America's launch stable, signed contracts for four launches: two for the International Telecommunications Satellites Organization (INTELSAT), one for a Japanese Communications Satellite (JCSAT), and a fourth for British Skynet. McDonnell Douglas, manufacturer of the Delta rocket and the Air Force's Delta II (also known as the Medium Launch Vehicle or MLV), has three contracts to launch four commercial satellites: one for India's INSAT, two for British Satellite Broadcasting, Inc., and one for the International Maritime Satellite Organization (INMARSAT). General Dynamics announced at the 1987 Paris Air Show its plan to invest almost $100 million of its own funds to build 18 Atlas-Centaur rockets in anticipation of commercial orders. Since then, this company has been awarded contracts for four launches, including one for EUTELSAT (the European Telecommunications Satellite Organization) and three GOES weather satellites for the Department of Commerce. All told, these companies have signed contracts worth more than $500 million.

The entrepreneurial "startup" companies that offer rockets for smaller payloads were also successful in signing customers. Space Services, Inc., had eight launch reservations; Conatec submitted a license application for a suborbital launch of materials-processing experiments on behalf of a European customer; and E'Prime announced plans to launch a university research payload on a small sounding rocket as a precursor to commercial launches.

National Space Policy

The Office of Commercial Space Transportation participated in several public policy forums which addressed a variety of critical space policy issues, including the development of range use agreements and the allocation of risk and insurance requirements. In addition, DOT encouraged Government agencies to rely on commercial launch services whenever possible to meet their need for transportation.

A representative of the Office of Commercial Space Transportation served on the Air Force's MLV source selection advisory board. McDonnell Douglas was selected in January 1987 to produce 7 Delta II rockets immediately, and the Air Force holds an option to procure 13 more. Office representatives also served on a board advising NASA and the National Oceanic and Atmospheric Administration (NOAA) about procuring launch services for three Geostationary Operational Environmental Satellites (the GOES series of weather satellites). General Dynamics was selected to produce Atlas-Centaur launch vehicles for the GOES.

DOT also has played a major role in providing information and guidance to the U.S. Trade Representative on the policies and practices of U.S. launch companies. A notice was published in the *Federal Register* on February 26, 1986 to solicit data from industry aimed at a better understanding of commercial concern over international competition. American firms have been especially concerned about the nature of direct and indirect financial support by the European Space Agency (ESA) and ESA member states of Arianespace launches, particularly in the areas of range use, insurance, liability and accident investigations. This laid the groundwork for consultations held with ESA in July and October 1987 to gain a clearer understanding of the approaches that ESA and the United States are taking to affirm their commitments to their commercial launch industries. Future discussions between U.S. agencies are planned to decide whether it would be in the long-term interest of the United States to continue talks with ESA at this time.

The Office also represented the Department in international policy negotiations concerning the Space Station. An interagency delegation consisting of the Department of Commerce, Department of Defense, Department of State, Department of Transportation, and NASA is negotiating with ESA, Japan, and Canada on appropriate roles for each partner. The Office was successful in retaining language in the draft international agreement that will allow America's commercial launch industry to compete for contracts to transport facilities, equipment, and supplies to the Space Station.

In late 1987, the Department took an active role in an effort, led by the White House, to consolidate previous space policy directives into a single, comprehensive National Space Policy. This policy further reaffirmed and strengthened DOT's role as the lead agency for resolving issues associated with the commercial launch industry. The Department also participated in a series of meetings, sponsored by the Economic Policy Council's Commercial Space Working Group (CSWG), to develop recommendations, for the Council's consideration, on commercial space firms' concerns over Government impediments to commercialization.

Use of Government Launch Facilities

In 1987, the Office worked with the Air Force to develop the terms and conditions that will govern commercial use of the Nation's launch ranges. At the end of 1986, a landmark symposium on range use was held at Patrick Air Force Base in Florida. This symposium, cosponsored by DOT, NASA, and the Air Force, represented the first time that officials from Government agencies and industry met to discuss the procedures and requirements under which the Nation's launch facilities would be made available to commercial users.

DOT's Commercial Space Transportation Advisory Committee (COMSTAC) prepared an exhaustive analysis of a draft range use agreement that identified issues that needed to be addressed. These included billing procedures, launch scheduling priorities, and liability. In the first quarter of 1987, DOT initiated a review by the Commercial Space Working Group of those areas in the Air Force Model Range Use Agreement which DOT identified as potential barriers to commercial use of national launch ranges. As a result of the close cooperation between DOT, the Air Force, and NASA, many of the issues were successfully resolved and, in the early fall, both Martin Marietta and General Dynamics signed range use agreements with the Air Force. Space Services, Inc. already had a signed range use agreement with NASA regarding Wallops Island.

In addition, working through the Interdepartmental Radio Advisory Committee, the Office urged NASA and DOD to make their tracking, telemetry and control frequencies available on a transitional basis to commercial launch vehicles. This effort, which also involves the commercial launch industry, the National Telecommunications and Information Administration, and the FCC, will identify the radio frequencies that will be available to support commercial operations.

During the latter half of 1987, in cooperation with the Air Force, the Office of Commercial Space Transportation developed an environmental assessment of the commercial space transportation programs at Vandenberg Air Force Base (VAFB). The Department of Transportation licenses commercial space launches from the National Ranges, one of which is VAFB. This programmatic assessment evaluated the impacts that existing launch vehicles, launch facilities and propellants would have upon the environment in and around VAFB when used in commercial operations.

Commercial Launch Licensing Programs

In August 1987, Martin Marietta received mission approval for two INTELSAT payloads. Launches are scheduled to take place from Cape Canaveral in 1989 and 1990. Conatec, one of the smaller firms, applied for a launch license in July to launch two foreign payloads (microgravity research). American Rocket Company conducted motor tests of its Industrial Launch Vehicle (ILV) under an agreement with the Air Force's Rocket Propulsion Laboratory in California; and E'Prime, under DOT sponsorship, worked with the Air Force to select a pad area at Cape Canaveral for its vehicles, the EPAC Star A and Star B.

In addition to authorizing the licensing of commercial vehicles, the Department is also authorized to license commercial ranges. The State of Hawaii has indicated interest in commercial space initiatives, and in August completed a study which investigated the feasibility of building a commercial spaceport. Hawaii has initiated a follow-on study to identify the best site locations for such a facility. Texas, Florida, and Virginia have also expressed tentative interest in the possibility of locating commercial spaceports or launch ranges within their states.

In an effort to react expeditiously to all licensing requests, the Office awarded two major research contracts in 1987 to develop data bases to strengthen capabilities of safety oversight and establish appropriate levels of insurance. One contract assists the Office in refining its license application review criteria, and in its examination of the level of public exposure to hazards that derive from commercial launch activities. The second contract examines the major safety issues inherent in commercial launch activities, and identifies potential safety standards that may be applicable to them. Final results of both studies are expected in 1988.

During 1987, the Office took decisive steps in policy forums, rulemaking, and planned contractual efforts to address and resolve issues facing the commercial launch industry. The number of commercial contracts signed this year—and the alacrity with which commercial firms secured them in an intensely competitive international environment—testifies to the Department's progress in creating an environment that is conducive to the establishment of a vigorous, innovative U.S. launch services industry.

Environmental Protection Agency

The U.S. Environmental Protection Agency (EPA), through its Environmental Monitoring Systems Laboratory in Las Vegas, Nevada (EMSL-LV), routinely conducts research and technical support using remote sensing as part of an overall environmental monitoring program. Large-scale aerial photography is collected and interpreted to support the provisions of the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA); medium-scale photography is collected and interpreted to support non-point pollution studies, wetlands protection, coastal zone studies, and forest ecosystem decline due to acid deposition; and high-altitude photography is interpreted for broad area studies in the coastal zone and to contribute land use/land cover information in risk assessment studies. Airborne and satellite multispectral scanner data are collected and interpreted to support water quality, non-point pollution, hazardous waste, and acid deposition investigations. Airborne laser systems are developed which contribute to air and water monitoring, and a geographic information system (GIS) is used to integrate multiple data sets in support of all EPA programs.

Hazardous Waste

Large-scale aerial photography is used to develop site characterization data during the remedial investigation/feasibility study (RI/FS) portion of remedial actions under CERCLA (the SUPERFUND). Aerial photographs are collected from a variety of archival sources which may date from the late 1920's and continue to the present. A site history is developed by visually interpreting the historical photography, annotating changes at the site. This provides vital information on the location of drums, pits, and lagoons, as well as the level of activity at the site over time. Further photographic interpretations provide documentation of cleanup progress and are sometimes used to monitor post-cleanup status. The same photographs are also used to develop detailed topographic maps of each site, which are critical to the cleanup process.

Aerial photography is also used to support site selection and monitoring at hazardous waste facilities operating under RCRA. During the site selection process, aerial photographs, airborne multispectral scanner data, and satellite imagery are interpreted to develop a detailed site characterization. The interpretations are then used with collateral data (such as soils, geology, and groundwater data) to determine applicability under the site selection criteria. Aerial photography is routinely used to monitor development, operation, and closure activities once a site has been approved for operation.

Aerial photography also supports emergency actions during spills and accidents. Photographs are acquired through local contractors and are interpreted and sent to the field within 24 to 48 hours of an accident or spill. These photographs of existing conditions form a permanent record of the on-scene conditions and are used to develop control and remedial strategies.

Water Quality

Remote sensing systems are developed and used by EPA to support the provisions of the Clean Water Act. The Landsat satellite system and an airborne multispectral scanner are used in conjunction with water samples to map the extent of Chlorophyll a, Secchi depth, turbidity, dissolved organic carbon, and a variety of other water-quality parameters in both freshwater lakes and near-coastal marine environments. A Laser Fluorosensor system is being developed to augment the passive scanner systems, increasing the number of variables measured and the accuracy of measurement of current variables.

Aerial photography and satellite data also support non-point pollution studies. Satellite imagery provides the broad view of land cover, while aerial photographs provide detailed interpretations of the distributions of feeder lots, poultry farms, and other activities requiring high spatial resolution. These data are input to models, such as Purdue University's "Answers Model," to determine nutrient loadings to aquatic ecosystems.

Air Quality

EPA is currently using an airborne two-frequency Light Detection and Ranging (LIDAR) system to monitor particulates associated with major urban plumes and emissions sources and is developing (with NASA support) an airborne Ultraviolet DIfferential Absorption LIDAR (UV DIAL) to simultaneously measure ozone, sulfur dioxide, and particulates. These instruments provide range-resolved profiles under the aircraft which can be used to monitor pollutant transport in coastal areas and complex terrain where models function poorly and where air pollution transport problems are most severe.

In conjunction with the National Park Service, EPA is also conducting remote measurements of visibility in Class I areas (National Parks and Wilderness Areas). Photographic and electro-optical sensors are deployed to monitor scenic vistas to determine atmospheric extinction coefficients. Variations in extinction coefficients are then related to variations in air pollutant levels.

Data Integration

Often, single-media monitoring and modeling do not provide sufficient scientific explanation of the complex environmental phenomena which affect human and ecological health. A geographic information system (GIS) is being implemented in EPA to provide a tool for multimedia data integration and analysis. The GIS is used to overlay and combine data from remote sensing, existing spatial data bases, and tabular data from state, local, and EPA national data bases to provide analyses of complex environmental situations for programs such as wetlands and estuarine protection, water quality, acid deposition, global climate, and hazardous waste cleanup.

National Science Foundation

The National Science Foundation (NSF) remains the largest Federal supporter of academic research in the atmospheric sciences and ground-based astronomy. The advent of supercomputing power has made possible new advances in these disciplines. NSF support is provided partly in the form of grants to individuals and partly through contracts and cooperative agreements with universities and consortia operating observatories and other large facilities.

The Foundation launched a new initiative, Global Geosciences, to study past, present, and future events in the Earth, ocean, and atmosphere on a worldwide scale. This major effort is closely coordinated with other U.S. Government agencies, and with agencies of other nations through the International Council of Scientific Unions.

Astronomical Sciences

On February 23, 1987, the brightest supernova observed since 1604 was seen in the Large Magellanic Cloud, which is located 160,000 light years from the Earth. The nearness of this exploding star means that astronomers will be able to study the evolution of its remnant in great detail. The supernova is being observed using U.S. facilities located at Cerro Tololo in Chile. Also, preparations were made to launch observing equipment in Antarctica using an 11.6 million cubic foot balloon to carry it into the stratosphere.

Evidence was found that our own Milky Way galaxy is part of a supercluster complex that contains millions of galaxies and stretches one-tenth of the distance across the observable universe. The existence of inhomogeneities on this scale poses a severe challenge to present-day cosmological theories, which assume that matter is distributed uniformly across the universe.

Astronomers observed a galaxy in its earliest stage of development. By analyzing the spectrum of this object, which was first located through its powerful radio emission, the astronomers deduced that it has not yet produced the bulk of its stellar population.

Evidence was found of the presence of massive black holes at the center of two galaxies close to our own Milky Way, called M31 and M32. The scientists who made the observations theorized that these black holes are 10 to 100 million times the mass of the Sun. The black holes are favored to explain the energy source of quasars—objects that emit enormous amounts of radiation across their entire spectrum.

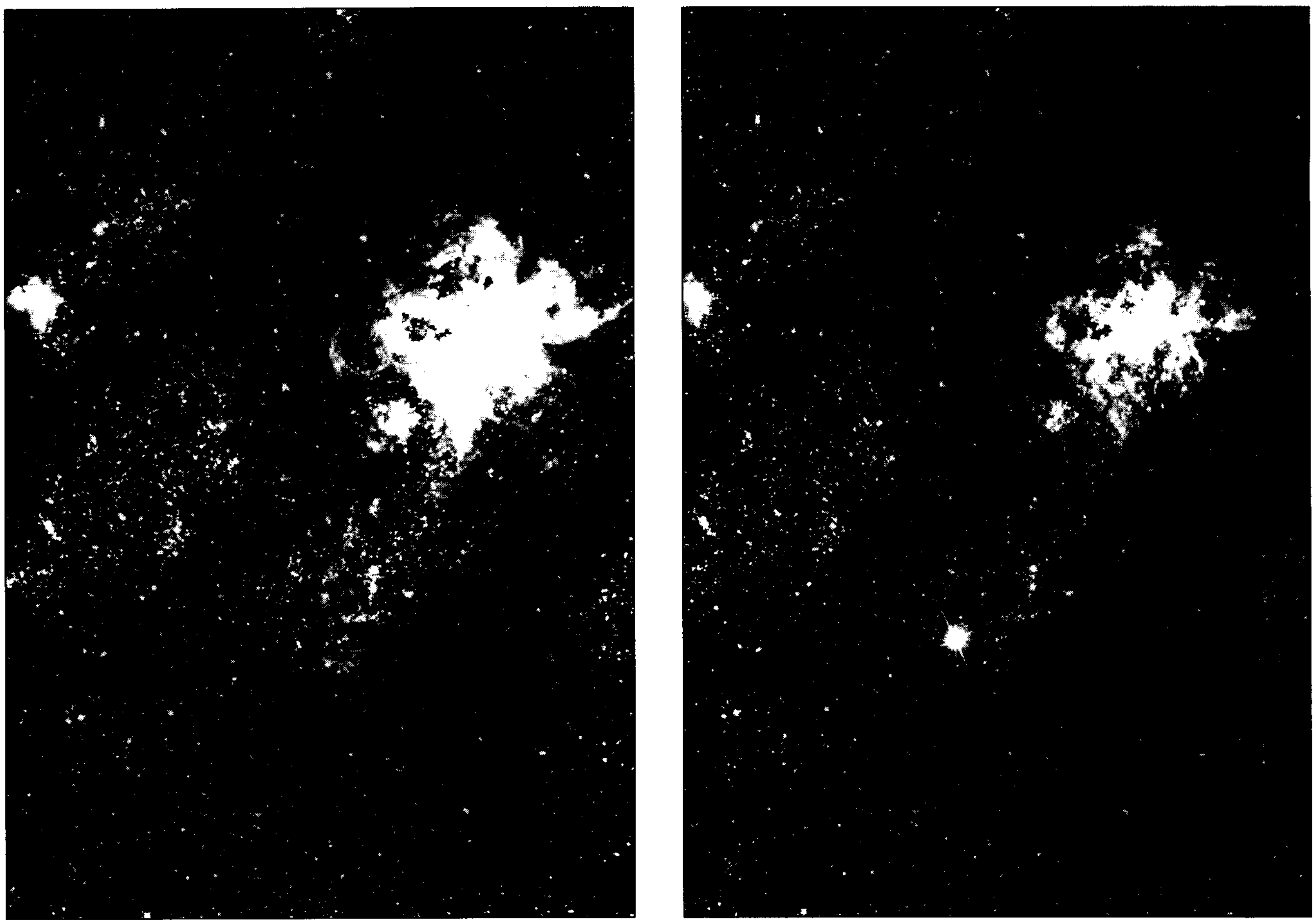
Scientists found evidence of clear regions in the dust clouds surrounding three nearby stars. The regions may have been "swept up" by planet-sized objects orbiting these stars. Our own solar system may be enclosed in such a dust cloud. This discovery has profound implications for the theory of planet formation.

Atmospheric Sciences

A breakthrough occurred with the recognition of a long-suspected relationship between sunspots and the weather. This resulted from the analysis of polar stratospheric temperatures, taking into account the quasi-biennial (27 months) oscillation of tropical stratospheric winds and the 11-year solar cycle. A consistent pattern of changes in atmospheric circulation, North Atlantic storm tracks, and the mildness or severity of winters in the eastern United States has become apparent. Following further research to understand the mechanism, it should be possible to improve significantly long-range seasonal forecasts.

A large field experiment called the Genesis of Atlantic Lows Experiment (GALE) was centered on the Atlantic Coast of North Carolina. One of its goals is to investigate why rapid storm intensification occurs at this location. A recurring region of banded clouds and precipitation was identified and found to be almost stationary over the Gulf Stream. The existence of this phenomenon is attributed to large heat and moisture fluxes from the warm water of the Gulf Stream affecting the colder, overlying air. It is clear that the intensity of this persistent rainband, as revealed by radar and measurements of lightning activity, indicates that rainbands could play an important role in the intensification of winter storms on the east coast.

In August 1987, the second National Ozone Expedition (NOZE II) was dispatched to study the depletion of stratospheric ozone over the Antarctic Continent. Support was provided by the NSF, NASA, NOAA, and the Chemical Manufacturers Association. Research results from the 1986 NOZE expedition provided a better understanding of ozone depletion over Antarctica. Results from NOZE II are expected to provide additional insights into the processes contributing to ozone depletion in the Antarctic stratosphere.



Before ***After***

Ground-based observations of the Large Magellanic Cloud before and after the explosion of Supernova 1987a.

Smithsonian Institution

The Smithsonian Institution contributes to national space goals through basic research programs of the Smithsonian Astrophysical Observatory (SAO) in Cambridge, Massachusetts, and through public exhibits, lectures, and education programs of the National Air and Space Museum (NASM) in Washington, DC. NASM's Center for Earth and Planetary Studies (CEPS) also conducts basic research in planetary geology and terrestrial remote sensing.

Space Sciences

High-Energy Astrophysics

Scientists at SAO continued the reduction and analysis of x-ray data obtained by the HEAO-1 and HEAO-2 (Einstein) Satellites. A major effort in 1987 was the preparation of an Einstein source catalog containing a list and contour diagrams of all images gathered by the spacecraft. This x-ray information is available through the Einstein Data Bank, and about 130 scientists used that source in 1987.

The Einstein Medium Sensitivity Survey sustained a major extension in 1987, with more than 830 x-ray sources selected. About 550 of these sources are already identified and cataloged, providing detailed information on the x-ray properties of celestial sources, ranging from quasars to clusters of galaxies.

The Einstein data also continue to produce intriguing results on a host of phenomena, including compact galactic binaries, low-mass neutron stars, and black hole candidates. Studies in which x-ray data from space observations are compared directly with data in other wavelengths provide a more comprehensive picture of many astrophysical processes. For example, x-rays constitute only a small part of a galaxy's total luminosity, but these emissions seem closely tied to the galaxy's stellar population and may provide a tool for examining galaxy evolution.

Infrared Astronomy

Refined maps of the infrared sky were produced from data obtained by a helium-cooled, infrared telescope (IRT) successfully operated aboard the Spacelab 2 flight of the Shuttle in July 1985. Developmental work continued on a 2-m balloon-borne telescope and on a diffraction-limited, infrared array camera for the Space Infrared Telescope Facility (SIRTF).

Ultraviolet Astronomy

The International Ultraviolet Explorer (IUE) Satellite was used for extensive studies of Supernova (SN) 1987A, which was discovered in February. By comparing ultraviolet spectral data from IUE with pre-explosion astrometric measurements of candidate stars, astronomers identified the progenitor of SN 1987A as a blue supergiant star known as Sanduleak-69 202.

Space Technology

Several researchers at SAO, who will participate in the first tethered satellite mission in the early 1990's, continued studying the dynamics of tethered satellite systems, as well as their potential for electromagnetic wave generation and possible application in Space Station science programs.

Planetary Sciences

A detailed survey of rock types from an Apollo 15 lunar sample collection was conducted. Material from a geologically complex site on the lunar highlands produced two examples of Fe-enriched norite, a previously unrecognized variety of igneous rock. When isotopic analyses are complete, the new lithology could provide insight into the grand scheme by which the Moon's primeval crust separated into layers bearing distinct chemical signatures.

Another SAO project involved mapping from rectified Voyager photographs of geological formations on the surface of Ganymede. The maps reveal that, unlike Earth's Moon, this large, icy satellite of Jupiter shows evidence of thermal expansion as well as meteorite bombardment.

Planetary research at NASM's CEPS concentrated on the origin of major structural landforms seen on the surface of Mars, and their implications for the geologic evolution of that planet. Mars' southern hemisphere is marked by numerous impact craters providing a chronological record of events responsible for the dichotomy between its ancient terrain and the smooth northern plains. By using crater counts and models for the impact flux in the vicinity of Mars, several episodes of faulting and erosional events responsible for the modification of this boundary in the eastern hemisphere have been identified.

Comparative studies of ridges on Mars and similar features on the Columbia Plateau of Washington provided further insight into the mechanics of the formation of such landforms on both planets. Structural models deduced from remote sensing and field studies of the Columbia ridges also helped establish more precisely the origin of apparently similar features on the basalt plains of Mars.

Terrestrial Studies

Field and remote sensing studies of Earth by CEPS staff concentrated on the arid regions of Sudan, Egypt, Mali, and Botswana. Similar dune forms are present in all regions, but with variations caused by vegetation cover or human influences. During 1987, field work in Botswana suggested that most of the spectra variations seen in the orbital data resulted from differing vegetation types on dune and interdune flats. Studies in Egypt and Sudan also revealed much higher rates of sand movement than expected.

Department of State

The Department of State is responsible for evaluating and advancing U.S. foreign policy interests in the context of space activity. In this capacity, it considers space programs, policies and agreements, and advises the President on international space matters. It also represents the U.S. Government in international government-to-government negotiations, in international organizations involved in space, and in foreign countries.

In 1987, the United States moved nearer to agreement with its partners on international participation in the multibillion dollar, permanently manned Space Station project. Working closely with other interested agencies, State Department and NASA officials met with European, Japanese, and Canadian representatives to negotiate agreements governing long-term cooperation on the detailed design, development, operation, and utilization of the Space Station. The Department of State strongly supports the Space Station as a concrete demonstration of U.S. leadership in space, a stimulus for exploring new areas of science and technology, and a model for cooperation with friends and allies on large-scale, high-technology endeavors.

The Department actively participated in interagency working groups which considered such issues as U.S. commercial space policy, the U.S. private launch industry, international trade talks on space launch services, and resumption of the Shuttle program. As part of a major Government-wide effort, the State Department worked with other agencies on consolidating U.S. space policy into a single, consistent policy document.

In April, Secretary of State Shultz signed a new space cooperation agreement between the United States and the Soviet Union. This agreement establishes 16 bilateral cooperative space science projects. Two joint working groups met in 1987 to begin implementation of the agreement. The United States also negotiated space cooperation agreements with Senegal, the Gambia and Australia.

In addition to U.S. policy formulation and bilateral negotiations, the Department of State represents the U.S. Government in international organizations involved in space issues. Among these international bodies are the United Nations (UN) and COSPAS/SARSAT.

Activities Within the United Nations

Committee on the Peaceful Uses of Outer Space (COPUOS)

The year 1987 was the 29th year of the 53-member COPUOS. During its earlier years, it was a productive channel for the exchange of scientific information and the forum for establishing the four UN conventions widely accepted as the basis of international space law. However, during the last few years, the United States has worked hard to prevent a deterioration in the Committee's work by steering it away from extraneous political factors and issues which fall outside its purview. During 1987, some progress was made to revitalize COPUOS and restore scientific and technical utility to its work.

At the February meeting of the Scientific and Technical Subcommittee, the United States joined with other Western members to push for strengthening the technical content of the Subcommittee's work. A chairman's working paper introduced several proposals, which were accepted.

The central issue at the March meeting of the Legal Subcommittee concerned the choice of a new agenda. With Western member support, the United States proposed measures to base future legal work on practical, noncontroversial questions and to increase the efficiency of the Legal Subcommittee's work. The Soviet and East European members rejected this approach.

At the June COPUOS meeting, the West introduced a similar initiative to strengthen the Committee and increase its efficiency. This also met with Eastern resistance and inconclusive results.

UN General Assembly

On the recommendation of the Special Political

Committee, the 42nd session of the UN General Assembly adopted the omnibus resolution "International Cooperation in the Peaceful Uses of Outer Space." The resolution sets the agenda of COPUOS and its subcommittees for 1988. Extensive consultations were held regarding a new item for the Legal Subcommittee. While no agreement was reached, the General Assembly requested that questions be settled at the Subcommittee's next session in 1988. Western countries reiterated their disappointment over the unwillingness by many members to consider making COPUOS more effective, and noted that their concerns were over proposals from the Eastern Bloc to replace COPUOS with a new world space organization.

COSPAS/SARSAT

During a meeting from November 2 through 6, representatives of the United States, Soviet Union, France and Canada completed an ad referendum text for a 15-year cooperative, operational agreement to continue the COSPAS/SARSAT program. Begun in 1979, COSPAS/SARSAT is a satellite-based, global emergency distress and location system. It is designed to help agencies throughout the world quickly and accurately find small boats and aircraft in trouble. It uses French and Canadian equipment on U.S. meteorological satellites in conjuction with an interoperational Soviet system.

International Telecommunications

Telecommunications technology is developing at an increasingly rapid pace as the "information revolution" creates both new means and new needs for more sophisticated and capable communication networks. More than ever before, the United States must advocate and promote free markets in international telecommunications.

International Telecommunications Satellite Organization (INTELSAT)

In April 1987, an Extraordinary Assembly of Parties of INTELSAT (112 members) approved a proposal allowing Pan American Satellite Corporation (PanAmSat) to provide satellite communication services between the United States and Peru, separate from INTELSAT services. This was the culmination of an extensive U.S. diplomatic initiative, and opens a new market for U.S. commercial participation.

International Maritime Satellite Organization (INMARSAT)

The United States initiated the process of accepting the 1985 amendments to the INMARSAT convention. These amendments will permit INMARSAT to offer satellite-based aircraft communication services.

International Radio Conference

In 1987, the International Telecommunication Union was involved in two major events dealing with space radio services. The World Administrative Radio Conference (WARC) on Mobile Services was held in Geneva from September 14 through October 17. The United States sought and obtained frequency allocations for radio determination satellite services. Conceived by U.S. entrepreneurs, RDSS uses satellites to pinpoint locations of objects on land, at sea or in the air. The United States also sought global frequency allocation for mobile satellite service (MSS) for land communication and both ships and aircraft. While not fully achieving U.S. goals for MSS, significant progress was made to provide this new type of service.

The Department of State continued preparations for the Second Session of the Space Services WARC to be held in 1988. The International Frequency Registration Board made progress in its planning exercises for fixed satellite service, primarily as a result of the U.S. contribution of computer software developed by NASA's Lewis Research Center. In addition, the International Radio Consultative Committee finished a report in December which answered numerous technical questions that will be discussed at the Space Service WARC in 1988.

Arms Control and Disarmament Agency

The United States Arms Control and Disarmament Agency (ACDA) was established in 1961 to advise the President on arms control policy. As potential uses of space become technologically more feasible, ACDA's role in the development of policy for and support of arms control in outer space has expanded.

The U.S. position on arms control in space was enunciated by President Reagan on July 4, 1982, when he said:

> *The United States will continue to study space arms control options. The United States will consider verifiable and equitable arms control measures that would ban or otherwise limit testing and deployment of specific weapons systems, should those measures be compatible with U.S. national security.*

That policy was reaffirmed by the President on March 31, 1984, in a report to the Congress on Anti-Satellite (ASAT) Arms Control.

Bilateral Discussions on Space Arms Control

In 1987, at the Defense and Space Talks in Geneva, the United States discussed with the Soviet Union how to jointly manage a stable transition to a deterrence based increasingly on defense, rather than on the threat of retaliation by offensive nuclear weapons. In an effort to reach agreement, the United States proposed to the Soviets a mutual commitment through 1994, to continue to adhere to the ABM Treaty and to refrain from deploying strategic defenses not permitted by the treaty. During that period both countries would strictly observe all ABM Treaty provisions, while continuing the research, development, and testing permitted by the treaty.

Such a commitment would be contingent upon implementation of 50-percent reductions in U.S. and Soviet strategic offensive arms under specified conditions. In response to Soviet concerns, the United States also has proposed a set of confidence-building measures to enhance predictability, as both sides proceed with work on strategic defenses.

Multilateral Discussions on Space Arms Control

During 1987, ACDA continued to deal with multilateral space arms control issues, both in the United Nations General Assembly and in the Conference on Disarmament (CD) in Geneva. In February 1987, for the third consecutive year, the CD established an *Ad Hoc* Committee, with a non-negotiating mandate, to examine issues relevant to the prevention of an arms race in outer space. The agenda adhered to by the *Ad Hoc* Committee in 1987 included examination and identification of issues, required agreements, proposals, and future initiatives for the prevention of an arms race in outer space. The United States and its allies participated actively in the work of the *Ad Hoc* Committee, especially in reviewing the arms control aspects and implications of the current outer space legal regime.

The United States also pursued its arms control objectives for outer space during the disarmament debate in the UN General Assembly's First Committee. In 1987, four resolutions on outer space arms control were considered by the First Committee. The United States supported a draft resolution presented by France on behalf of the Western countries, advocating a continuation of the CD's non-negotiating mandate which was supportive of the bilateral U.S.-USSR space talks. However, the United States opposed all three draft resolutions tabled by the Soviet Union, China, and the neutral and non-aligned group, primarily because they called for ill-defined negotiations in the CD. The only outer space arms control resolution that was voted upon was the neutral and non-aligned draft, which the United States voted against.

Space Policy

ACDA is an active participant in formulating U.S. space policy. It co-chairs the Interagency Group on Defense and Space, which is involved in arms control issues, and is a member of the interagency group that defines U.S. policy for the Strategic Defense Initiative. The agency provides administrative support, senior representatives, advisors, and legal experts for all U.S. arms control negotiations; and participates in the Senior Interagency Group on Space, which deals with a wide range of space issues, including development of the manned U.S. Space Station. Also, representatives from ACDA are part of other interagency groups involved in space activities, including the sale of space-related items. In addition, ACDA helps direct U.S. technical collection assets used to verify compliance with arms control agreements. These include space-based assets that are part of the national technical means of verification.

United States Information Agency

The public diplomacy efforts of the United States Information Agency (USIA) reflect its strong commitment to the promotion of worldwide awareness of U.S. achievements in space research and development and the peaceful uses of space. USIA makes use of satellite television and radio broadcasts, news coverage, feature stories, overseas visits by astronauts and scientists, interviews, exhibits, video taped programs, and cultural center and library resources in 134 countries to convey to the foreign public U.S. advances in space technology and exploration.

Voice of America

The Voice of America's weekly program on developments in science, technology and medicine, "New Horizons," broadcasts bi-monthly reports on a variety of NASA activities. VOA programs, broadcast in 44 languages, focused on major themes in the U.S. space program: the Galileo probe of Jupiter, Supernova Shelton, the Project Ulysses Sun probe, use of the Landsat satellite for remote sensing, the Search and Rescue Satellite Aided Tracking System (SARSAT), and U.S. space goals and directions for the 1990's and beyond.

Television Service

The ever-expanding TV network, WORLDNET, which links Washington via satellite with U.S. embassies and other organizations overseas, often explores NASA activities. USIA's TV news magazine, *America Today*, covers the gamut of NASA developments in short segments in its daily 60-minute program to Europe. The Satellite File weekly series of TV news clips, used by 140 broadcasters in 99 countries, included clips on several NASA-related issues and events. The monthly television series "Science World" also carried longer segments on plans for and eventual uses of the Space Station.

WORLDNET programs featured Astronaut Franklin Chang-Diaz, Dr. Robert T. Watson of the Global Habitability Project, Mr. Andrew Stofan, Associate Administrator for Space Station, and Noel W. Hinners, Chairman of NASA's Strategic Planning Council. Astronaut Chang-Diaz's program was beamed to four Latin American countries; Dr. Watson's three separate discussions on protection of the ozone layer included scores of participating journalists and scientists representing more than a dozen countries. A year-end WORLDNET segment with Mr. Stofan and Dr. Hinners detailed plans for America's future in space.

Televised electronic dialogues (telephone press conferences) also used the talents of several NASA personnel. Carlos Carrion, Voyager engineer, spoke with a group of journalists in Mexico; Philip Culbertson, NASA's Associate Administrator for Policy and Planning, made important points for scientists and media leaders in Tel Aviv and Singapore; and Alan Ladwig, Director for Program Support and Special Projects in NASA's Office of Exploration impressed Indian journalists with his forthright answers to questions regarding the future of the U.S. space program.

Films and video tapes acquired from NASA continued to be enjoyed in USIA's cultural centers and libraries throughout the world. In 1987, a new program about the Space Station and a presentation by the Jet Propulsion Laboratory on discoveries in the solar system were distributed to posts worldwide. Another popular program was the "Serendipity Machine" which explored the spinoffs from NASA's space research. Many posts were able to place this program, or portions of it, on foreign networks. The ever-popular 13-part series, "Life in the Universe", was re-broadcast over WORLDNET, and continues to generate interest around the world.

Other USIA Activities

Through a satellite data transmission system, USIA's Press and Publications Service offered a steady stream of feature articles, editorials and commentaries on space-related developments to posts worldwide. These materials are placed in local media outlets and published in USIA magazines, pamphlets and newsletters. They also provide background information used in discussions with local opinion leaders and Government officials.

In 1987, particular emphasis was given to international cooperation on development of the Space Station; NASA rocket tests and the projected 1988 Space Shuttle launch; U.S.-Soviet space cooperation; innovative uses of remote sensing technology; NASA launches of satellites for foreign countries; the debate on plans to build a Moon base; the Young Astronaut Program; and the preservation of the Earth's ozone layer.

Two particularly successful articles examined the prospects for space over the next 25 years, and reviewed "Who's Who" in space during the first 25 years of space travel and exploration. Photo packages on NASA's ozone mapping spectrometer carried aboard the Nimbus-7 spacecraft, and the crew selected for the 26th Space Shuttle mission complemented the articles.

Also, USIA magazines covered NASA and space activities. *American Illustrated* (USIA's monthly Russian language magazine distributed in the Soviet Union under a reciprocal exchange agreement), *Al Majal* (a monthly roundup of news and features from the United States to the Arab world) and *Span* (an English-language monthly distributed to more than 75,000 intellectuals on the Indian subcontinent) carried articles on the subject of Moon rocks, Space Shuttle Atlantis, U.S. advances in remote sensing, milestones in Indo-U.S. space research cooperation, and the International Summer Students' program, respectively.

Under the American Participant program, USIA arranged meetings for U.S. astronauts and scientists with foreign government officials, scientists, scholars and journalists. In 1987, this program generated extensive media coverage when Astronauts John Young visited Australia, Marsha Ivins traveled to Papua, New Guinea, and Jerry Ross discussed the U.S. space program in Panama.

Appendixes

APPENDIX A-1

U.S. Spacecraft Record

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

Calendar Year	Earth Orbit[a]		Earth Escape[a]		Calendar Year	Earth Orbit[a]		Earth Escape[a]	
	Success	Failure	Success	Failure		Success	Failure	Success	Failure
1957	0	1	0	0	1972	33	2	8	0
1958	5	8	0	4	1973	23	2	3	0
1959	9	9	1	2	1974	27	2	1	0
1960	16	12	1	2	1975	30	4	4	0
1961	35	12	0	2	1976	33	0	1	0
1962	55	12	4	1	1977	27	2	2	0
1963	62	11	0	0	1978	34	2	7	0
1964	69	8	4	0	1979	18	0	0	0
1965	93	7	4	1	1980	16	4	0	0
1966	94	12	7	1[b]	1981	20	1	0	0
1967	78	4	10	0	1982	21	0	0	0
1968	61	15	3	0	1983	31	0	0	0
1969	58	1	8	1	1984	35	3	0	0
1970	36	1	3	0	1985	37	1	0	0
1971	45	2	8	1	1986	11	4	0	0
					1987	9	1	0	0
					TOTAL	1,121	143	79	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.

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

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

Calendar Year	United States	U.S.S.R.	France	Italy	Japan	People's Republic of China	Australia	United Kingdom	European Space Agency	India
1957		2								
1958	5	1								
1959	10	3								
1960	16	3								
1961	29	6								
1962	52	20								
1963	38	17								
1964	57	30								
1965	63	48	1							
1966	73	44	1							
1967	57	66	2	1			1			
1968	45	74								
1969	40	70								
1970	28	81	2	1[a]	1	1				
1971	30	83	1	2[a]	2	1		1		
1972	30	74		1	1					
1973	23	86								
1974	22	81		2[a]	1					
1975	27	89	3	1	2	3				
1976	26	99			1	2				
1977	24	98			2					
1978	32	88			3	1				
1979	16	87			2				1	
1980	13	89			2					1
1981	18	98			3	1			2	1
1982	18	101			1	1				
1983	22	98			3	1			2	1
1984	22	97			3	3			4	
1985	17	98			2	1			3	
1986	6	91			2	2			2	
1987	8	95			3	2			2	
TOTAL	867	2,017	10	8	34	19	1	1	16	3

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

Successful U.S. Launches—1987

Launch Date (GMT), Spacecraft Name, COSPAR Designation, Launch Vehicle	Mission Objectives, Spacecraft Data	Apogee and Perigee (km), Period (min), Inclination to Equator(°)	Remarks
Feb. 12 Defense 15A Titan IIIB	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	Not available.	In orbit.
Feb. 26 GOES 7 22A Delta 179	Objective: To launch satellite into planned geostationary position. Spacecraft: Cylindrical, 2.15 m in diameter and 4.46 m long from top of S-band omni antenna mast to bottom of apogee boost motor. Apogee boost motor ejected after synchronous orbit achieved. Weight at liftoff: 840 kg. Weight at geostationary position: 456 kg.	35 796 35 783 1436.3 0.1	Eighth in series of operational environment monitoring satellites; launched by NASA for National Oceanic and Atmospheric Administration. Turned over to NOAA Mar. 25 after successful apogee motor fire Feb. 27. Spacecraft joins GOES 6 (WEST) as GOES 7 (EAST) part of a two-satellite operational system. In orbit returning data.
Mar. 20 Palapa B-2P 29A Delta 182	Objective: To successfully launch communications satellite. Spacecraft: Drum-shaped, telescoping cylinder, with antennas deployed 22.1 ft. high, and 7 ft. in diameter. Liftoff weight: 7,515 lbs. Weight in geosynchronous orbit: 1,437 lbs.	35 788 35 788 1436.2 0.0	Fifth in series of Indonesian communications satellites. Launched by NASA for Republic of Indonesia. Will replace Palapa B2 launched by orbiter Challenger in Feb. 1984 and malfunctioned. Palapa B-2P to join Palapa B1 orbited by shuttle in June 1983. Part of two-satellite system providing service to more than 13,000 islands. In orbit, operating satisfactorily.
May 15 Defense 43A Atlas H	Objective: Development of spacecraft techniques and technology. Spacecraft: Not announced.	Not available.	In orbit.
June 20 DMSP F-8 53A Atlas E	Objective: To launch meteorological observation satellite into planned orbit. Spacecraft: Same basic configuration as DMSP F-6. Weight: 1421 kg.	857 835 101.9 98.8	Third satellite in Block 5D-2 series. Data also used by National Oceanic and Atmospheric Administration. In orbit, returning data.
Sep. 16 Defense 80A Scout	Objective: To place satellite into an orbit which will enable the successful achievement of Navy objectives. Spacecraft: Not announced.	1175 1017 107.2 90.3	Launched by NASA for the DoD. One of two Transit satellites launched by Scout vehicle. In orbit.
Sep. 16 Defense 80B	Objective: To place satellite into successful orbit from which Navy objectives can be met. Spacecraft: Not announced.	1181 1014 107.2 90.3	Second of two Transit satellites launched by NASA for DoD on same Scout. In orbit.
Oct. 26 Defense 90A Titan 34D	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	Not available.	Still in orbit.
Nov. 29 Defense 97A Titan 34D	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	Not available.	Still in orbit.

U.S.-Launched Applications Satellites, 1981–1987

Date	Name	Launch Vehicle	Remarks
		COMMUNICATIONS	
Feb. 21, 1981	Comstar D-4	Atlas-Centaur	Fourth in series for Comsat General Corp.
May 23, 1981	Intelsat V F-1	Atlas-Centaur	Second in series for INTELSAT, positioned over Atlantic.
Aug. 6, 1981	Fltsatcom 5	Atlas-Centaur	Fifth in DoD series.
Sept. 24, 1981	SBS 2	Thor-Delta (TAT)	Second in series for Satellite Business Systems.
Nov. 20, 1981	RCA-Satcom 3-R	Thor-Delta (TAT)	Fourth in series for RCA, replacement for RCA-Satcom. [3]
Dec. 15, 1981	Intelsat V F-3	Atlas-Centaur	Third in series. To be positioned over Atlantic.
Jan. 16, 1982	RCA-Satcom 4	Thor-Delta (TAT)	Fifth in series for RCA.
Feb. 26, 1982	Westar 4	Thor-Delta (TAT)	First in a series of second-generation for Western Union Co.
Mar. 5, 1982	Intelsat V F-4	Atlas-Centaur	Fourth in series; positioned over Pacific.
Apr. 10, 1982	Insat 1A	Thor-Delta (TAT)	First in series for India Department of Space.
June 9, 1982	Westar 5	Thor-Delta (TAT)	Second in series of second-generation for Western Union Co.; replaces Westar 2.
Aug. 26, 1982	Anik D-1	Thor-Delta (TAT)	Launched for Telesat Canada as replacement for in-orbit satellites.
Sept. 28, 1982	Intelsat V F-5	Atlas-Centaur	Fifth in series; positioned over Indian Ocean.
Oct. 27, 1982	RCA-Satcom 5	Thor-Delta (TAT)	Joined 4 operational satellites launched for RCA.
Oct. 30, 1982	DSCS II, DSCS III	Titan III(34) D/IUS	Defense communications (dual launch), including first in series of uprated satellites.
Nov. 11, 1982	SBS 3	Space Shuttle, PAM-D	Third in series for Satellite Business Systems.
Nov. 12, 1982	Anik C-3	Space Shuttle, PAM-D	Second in new series for Telesat Canada.
Apr. 4, 1983	TDRS 1	Space Shuttle, IUS	First in series. System to provide continuous satellite communication. Leased by NASA from Space Communications Co. (Spacecom).
Apr. 11, 1983	RCA-Satcom 6	Delta 3924	Replacement for RCA-Satcom 1, launched for RCA.
May 19, 1983	Intelsat V F-6	Atlas-Centaur	Sixth in series; positioned over Atlantic Ocean.
June 18, 1983	Anik C-2	Space Shuttle, PAM-D	Launched for Telesat Canada.
June 19, 1983	Palapa B-1	Space Shuttle, PAM-D	Indonesian domestic communications.
June 28, 1983	Galaxy 1	Delta 3920/PAM-D	Launched for Hughes Communications, Inc.
July 28, 1983	Telstar 3A	Delta 3920/PAM-D	Launched for American Telephone and Telegraph Co.
Aug. 31, 1983	Insat 1-B	Space Shuttle, PAM-D	Indian domestic communications.
Sept. 8, 1983	RCA-Satcom 7	Delta 3924	Replacement for RCA-Satcom 2, launched for RCA.
Sep. 22, 1983	Galaxy 2	Delta 3920/PAM-D	Second in series, launched for Hughes Communications, Inc.
Feb. 3, 1984	Westar-6	Space Shuttle, PAM-D	Launched for Western Union, PAM-D failed to fire properly, satellite retrieved by Shuttle, and returned to earth for refurbishment.
Feb. 6, 1984	Palapa-B2	Space Shuttle, PAM-D	Launched for Indonesia, booster motor failed, satellite retrieved and returned to Earth by Shuttle.
Mar. 1, 1984	Uosat-2	Delta 3920	Secondary payload with Landsat-5, for amateur radio communications.
June 9, 1984	Intelsat V F-9	Atlas-Centaur	Seventh in series, launch vehicle failure, satellite reentered Oct. 24.
Aug. 31, 1984	SBS-4	Space Shuttle, PAM-D	Launched for Satellite Business Systems, Inc.
Aug. 31, 1984	Syncom IV-2	Space Shuttle	Launched for Hughes Communications, Inc.
Sept. 1, 1984	Telstar-3C	Space Shuttle, PAM-D	Launched for American Telephone and Telegraph Co.
Sept. 21, 1984	Galaxy-3	Delta 3920/PAM-D	Third in series, launched for Hughes Communications, Inc.
Nov. 9, 1984	Anik-D2	Space Shuttle, PAM-D	Launched for Telsat Canada.
Nov. 10, 1984	Syncom IV-1	Space Shuttle	Launched for Hughes Communications, Inc.
Nov. 14, 1984	NATO IIID	Delta 3914	NATO defense-related communications satellite.
Mar. 22, 1985	Intelsat VA F-10	Atlas-Centaur	First in series of six improved satellites.
Apr. 12, 1985	Telesat-I	Space Shuttle	Launched for Telsat Canada.
Apr. 13, 1985	Syncom IV-3	Space Shuttle	Launched for US Navy.
June 17, 1985	MORELOS-A	Space Shuttle	Launched for Mexico.
June 18, 1985	Arabsat-1B	Space Shuttle	Launched for Arab Satellite Communication Organization (ASCO).
June 19, 1985	Telstar-3D	Space Shuttle	Launched for the American Telephone and Telegraph Company (AT&T).
June 30, 1985	Intelsat VA F-11	Atlas-Centaur	Second in series of improved satellites launched for INTELSAT.
Aug. 27, 1985	AUSSAT-1	Space Shuttle	Launched for Australia's National Satellite Company.
Aug. 27, 1985	ASC-1	Space Shuttle	Launched for American Satellite Company.
Aug. 29, 1985	Syncom IV-4	Space Shuttle	Launched for US Navy.

U.S.-Launched Applications Satellites, 1981–1987

Date	Name	Launch Vehicle	Remarks
			COMMUNICATIONS *continued*
Sep. 29, 1985	Intelsat VA F-12	Atlas-Centaur	Launched for INTELSAT.
Nov. 27, 1985	MORELOS-B	Space Shuttle	Launched for Mexico.
Nov. 27, 1985	AUSSAT-2	Space Shuttle	Second satellite launched for Australia's National Satellite Company.
Nov. 28, 1985	RCA Satcom K-2	Space Shuttle	Launched for RCA American Communications, Inc.
Jan. 12, 1986	RCA Satcom K-1	Space Shuttle	Launched for RCA American Communications, Inc.
Dec. 5, 1986	Fltsatcom 7	Atlas-Centaur	Launched for DoD.
Mar. 20, 1987	Palapa B-2P	Delta 182	Indonesia domestic communications.
			WEATHER OBSERVATION[a]
May 22, 1981	GOES 5	Thor-Delta (TAT)	Fifth of polar-orbiting series for NOAA.
June 23, 1981	NOAA-7	Atlas F	Replacement for NOAA-B.
Dec. 21, 1982	DMSP F-6	Atlas E	DoD meteorological satellite.
Mar. 28, 1983	NOAA-8	Atlas E	Joined NOAA 7 as part of 2-satellite operational system; launched for NOAA.
Apr. 28, 1983	GOES 6	Delta 3914	Launched for NOAA, operational as GOES-West.
Nov. 18, 1983	DMSP F-7	Atlas E	Second in block 5D-2 series, DoD meteorological satellite.
Dec. 12, 1984	NOAA-9	Atlas E	Launched for NOAA, to replace NOAA-7.
Sep. 17, 1986	NOAA-10	Atlas E	Launched for NOAA.
Feb. 26, 1987	GOES 7	Delta 179	Launched for NOAA, operational as GOES-East.
June 20, 1987	DMSP F-8	Atlas E	Third in block 5D-2 series, DoD meteorological satellite.
			EARTH OBSERVATION
July 16, 1982	Landsat-4	Thor-Delta (TAT)	Fourth experimental earth resources satellite. First use of thematic mapper (TM).
Mar. 1, 1984	Landsat-5	Delta 3920	Fifth experimental earth resources satellite, to replace ailing Landsat-4.
			GEODESY
Mar. 13, 1985	GEOSAT	Atlas E	Measure ocean surface height.
			NAVIGATION[a]
May 15, 1981	Nova-1	Scout	First of improved Transit system satellites, for DoD.
July 14, 1983	Navstar-8	Atlas E	Global Positioning System satellite.
Feb. 5, 1984	IRT	Space Shuttle	Balloon to test Shuttle rendezvous radar.
June 13, 1984	Navstar-9	Atlas E	Global Positioning System satellite.
Sept. 8, 1984	Navstar-10	Atlas E	Global Positioning System satellite.
Oct. 12, 1984	Nova-3	Scout	Second of improved Transit system satellites, for DoD.
Aug. 3, 1985	Oscar 24	Scout	Part of Navy Transit System.
Aug. 3, 1985	Oscar 30	Scout	Part of Navy Transit System.
Oct. 9, 1985	Navstar-11	Atlas E	Global Positioning System satellite.

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

U.S.-Launched Scientific Satellites, 1981–1987

Date	Name	Launch Vehicle	Remarks
Aug. 3, 1981	Dynamics Explorers 1, 2	Thor-Delta (TAT)	DE 1 and 2 to measure magnetospheric-ionospheric energy coupling, electric currents and fields, plasmas.
Oct. 6, 1981	SME	Thor-Delta (TAT)	Solar Mesosphere Explorer to measure changes in mesospheric ozone.
Oct. 6, 1981	UOSAT (Oscar 9)	Thor-Delta (TAT)	Secondary payload with SME, for amateur radio and science experiments.
Jan. 26, 1983	IRAS	Delta 3910	Infrared sky survey.
May 26, 1983	EXOSAT	Delta 3914	European Space Agency study of x-ray sources.
June 22, 1983	SPAS 01	Space Shuttle	Reusable free-flying platform deployed and retrieved during STS 7; 6 scientific experiments from West Germany, 2 from ESA. NASA experiments tested spacecraft technology.
June 27, 1983	HILAT (P83-1)	Scout	Propagation effects of disturbed plasma on radar and communication systems, for DoD.
Apr. 6, 1984	Long Duration Exposure Facility (LDEF-1)	Space Shuttle	Scientific experiments designed for retrieval from space by Shuttle.
Aug. 16, 1984	Charge Composition Explorer (CCE)	Delta 3924	Measurement of Earth's magnetosphere, one of three satellites composing Active Magnetosphere Particle Tracer Explorers Mission (AMPTE).
Aug. 16, 1984	Ion Release Module (IRM)	Delta 3924	Second of three satellites of AMPTE Mission, launched by same vehicle.
Aug. 16, 1984	United Kingdom Satellite (UKS)	Delta 3924	Third of three satellites of AMPTE Mission, launched by same vehicle.
Oct. 5, 1984	Earth Radiation Budget Satellite (ERBS)	Space Shuttle	First of three satellites in Earth Radiation Budget Experiment Research Program. NOAA-9 and NOAA-G carrying other instruments in Program.
Apr. 29, 1985	NUSAT-1	Space Shuttle	Northern Utah Satellite (air traffic control radar system calibrator).
June 20, 1985	Spartan-1	Space Shuttle	Reusable free-flying platform.
July 29, 1985	Plasma Diagnostic Package (PDP)	Space Shuttle	Reusable experimental platform.
Oct. 30, 1985	GLOMR	Space Shuttle	Global Low Orbiting Message Relay satellite.
Nov. 14, 1986	Polar Bear	Scout	Experiments to study radio interference caused by Aurora Borealis, for DoD.

U.S.-Launched Space Probes, 1975–1987

Date	Name	Launch Vehicle	Remarks
Aug. 20, 1975	Viking I	Titan IIIE-Centaur	Lander descended, landed safely on Mars on Plains of Chryse, Sept. 6, 1976, while orbiter circled planet photographing it and relaying all data to Earth. Lander photographed its surroundings, tested soil samples for signs of life, and took measurements of atmosphere.
Sept. 9, 1975	Viking 2	Titan IIIE-Centaur	Lander descended, landed safely on Mars on Plains of Utopia, July 20, 1976, while orbiter circled planet photographing it and relaying all data to Earth. Lander photographed its surroundings, tested soil samples for signs of life, and took measurements of the atmosphere.
Jan. 15, 1976	Helios 2	Titan IIIE-Centaur	Flew in highly elliptical orbit to within 41 million km of Sun, measuring solar wind, corona, electrons, and cosmic rays. Payload had same West German and U.S. experiments as Helios 1 plus cosmic-ray burst detector.
Aug. 20, 1977	Voyager 2	Titan IIIE-Centaur	Jupiter and Saturn flyby mission. Swung around Jupiter in July 1979, arrived Saturn in 1981, going on to Uranus by 1986, Neptune by 1989.
Sep. 5, 1977	Voyager 1	Titan IIIE-Centaur	Jupiter and Saturn flyby mission. Passing Voyager 2 on the way, swung around Jupiter in Mar. 1979, arrived at Saturn in Nov. 1980, headed for outer solar system.
May 20, 1978	Pioneer Venus 1	Atlas-Centaur	Venus orbiter; achieved Venus orbit Dec. 4, returning imagery and data.
Aug. 8, 1978	Pioneer Venus 2	Atlas-Centaur	Carried 1 large, 3 small probes plus spacecraft bus; all descended through Venus atmosphere Dec. 9, returned data.

U.S. and Soviet Manned Spaceflights, 1961–1987

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

U.S. and Soviet Manned Spaceflights, 1961–1987

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

U.S. and Soviet Manned Spaceflights, 1961–1987

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Soyuz 17	Jan. 10, 1975	Aleksay A. Gubarev Georgiy M. Grechko	29 : 13 : 20	Docked with Salyut 4 and occupied station.
Anomaly	Apr. 5, 1975	Vasiliy G. Lazarev Oleg G. Makarov	0 : 0 : 20	Soyuz stages failed to separate; crew recovered after abort.
Soyuz 18	May 24, 1975	Petr I. Klimuk Vitaliy I. Sevastyanov	62 : 23 : 20	Docked with Salyut 4 and occupied station.
Soyuz 19	July 15, 1975	Aleksey A. Leonov Valeriy N. Kubasov	5 : 22 : 31	Target for Apollo in docking and joint experiments of ASTP mission.
Apollo (ASTP)	July 15, 1975	Thomas P. Stafford Donald K. Slayton Vance D. Brand	9 : 1 : 28	Docked with Soyuz 19 in joint experiments of ASTP mission.
Soyuz 21	July 6, 1976	Boris V. Volynov Vitaliy M. Zholobov	48 : 1 : 32	Docked with Salyut 5 and occupied station.
Soyuz 22	Sept. 15, 1976	Valeriy F. Bykovskiy Vladimir V. Aksenov	7 : 21 : 54	Earth resources study with multispectral camera system.
Soyuz 23	Oct. 14, 1976	Vyacheslav D. Zudov Valeriy I. Rozhdestvenskiy	2 : 0 : 6	Failed to dock with Salyut 5.
Soyuz 24	Feb. 7, 1977	Viktor V. Gorbatko Yuriy N. Glazkov	17 : 17 : 23	Docked with Salyut 5 and occupied station.
Soyuz 25	Oct. 9, 1977	Vladimir V. Kovalenok Valeriy V. Ryumin	2 : 0 : 46	Failed to achieve hard dock with Salyut 6 station.
Soyuz 26	Dec. 10, 1977	Yuriy V. Romanenko Georgiy M. Grechko	37 : 10 : 6	Docked with Salyut 6. Crew returned in Soyuz 27; crew duration 96 days 10 hrs.
Soyuz 27	Jan. 10, 1978	Vladimir A. Dzhanibekov Oleg G. Makarov	64 : 22 : 53	Docked with Salyut 6. Crew returned in Soyuz 26; crew duration 5 days 22 hrs 59 min.
Soyuz 28	Mar. 2, 1978	Aleksey A. Gubarev Vladimir Remek	7 : 22 : 17	Docked with Salyut 6. Remek was first Czech cosmonaut to orbit.
Soyuz 29	June 15, 1978	Vladimir V. Kovalenok Aleksandr S. Ivanchenkov	79 : 15 : 23	Docked with Salyut 6. Crew returned in Soyuz 31; crew duration 139 days 14 hrs 48 min.
Soyuz 30	June 27, 1978	Petr I. Klimuk Miroslaw Hermaszewski	7 : 22 : 4	Docked with Salyut 6. Hermaszewski was first Polish cosmonaut to orbit.
Soyuz 31	Aug. 26, 1978	Valeriy F. Bykovskiy Sigmund Jaehn	67 : 20 : 14	Docked with Salyut 6. Crew returned in Soyuz 29; crew duration 7 days 20 hrs 49 min. Jaehn was first German Democratic Republic cosmonaut to orbit.
Soyuz 32	Feb. 25, 1979	Vladimir A. Lyakhov Valeriy V. Ryumin Nikolay N. Rukavishnikov	108 : 4 : 24	Docked with Salyut 6. Crew returned in Soyuz 34; crew duration 175 days 36 min.
Soyuz 33	Apr. 10, 1979	Georgi I. Ivanov	1 : 23 : 1	Failed to achieve docking with Salyut 6 station. Ivanov was first Bulgarian cosmonaut to orbit.
Soyuz 34	June 6, 1979	(unmanned at launch)	73 : 18 : 17	Docked with Salyut 6, later served as ferry for Soyuz 32 crew while Soyuz 32 returned unmanned.
Soyuz 35	Apr. 9, 1980	Leonid I. Popov Valeriy V. Ryumin	55 : 1 : 29	Docked with Salyut 6. Crew returned in Soyuz 37. Crew duration 184 days 20 hrs 12 min.
Soyuz 36	May 26, 1980	Valeriy N. Kubasov Bertalan Farkas	65 : 20 : 54	Docked with Salyut 6. Crew returned in Soyuz 35. Crew duration 7 days 20 hrs 46 min. Farkas was first Hungarian to orbit.
Soyuz T-2	June 5, 1980	Yuriy V. Malyshev Vladimir V. Aksenov	3 : 22 : 21	Docked with Salyut 6. First manned flight of new-generation ferry.
Soyuz 37	July 23, 1980	Viktor V. Gorbatko Pham Tuan	79 : 15 : 17	Docked with Salyut 6. Crew returned in Soyuz 36. Crew duration 7 days 20 hrs 42 min. Pham was first Vietnamese to orbit.
Soyuz 38	Sept. 18, 1980	Yuriy V. Romanenko Arnaldo Tamayo Mendez	7 : 20 : 43	Docked with Salyut 6. Tamayo was first Cuban to orbit.
Soyuz T-3	Nov. 27, 1980	Leonid D. Kizim Oleg G. Makarov Gennadiy M. Strekalov	12 : 19 : 8	Docked wtih Salyut 6. First 3-man flight in Soviet program since 1971.

U.S. and Soviet Manned Spaceflights, 1961–1987

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Soyuz T-4	Mar. 12, 1981	Vladimir V. Kovalenok Viktor P. Savinykh	74 : 18 : 38	Docked with Salyut 6.
Soyuz 39	Mar. 22, 1981	Vladimir A. Dzhanibekov Jugderdemidiyn Gurragcha	7 : 20 : 43	Docked with Salyut 6. Gurragcha first Mongolian cosmonaut to orbit.
Space Shuttle Columbia (STS 1)	Apr. 12, 1981	John W. Young Robert L. Crippen	2 : 6 : 21	First flight of Space Shuttle, tested spacecraft in orbit. First landing of airplanelike craft from orbit for reuse.
Soyuz 40	May 14, 1981	Leonid I. Popov Dumitru Prunariu	7 : 20 : 41	Docked with Salyut 6. Prunariu first Romanian cosmonaut to orbit.
Space Shuttle Columbia (STS 2)	Nov. 12, 1981	Joe H. Engle Richard H. Truly	2 : 6 : 13	Second flight of Space Shuttle, first scientific payload (OSTA 1). Tested remote manipulator arm. Returned for reuse.
Space Shuttle Columbia (STS 3)	Mar. 22, 1982	Jack R. Lousma C. Gordon Fullerton	8 : 4 : 49	Third flight of Space Shuttle, second scientific payload (OSS 1). Second test of remote manipulator arm. Flight extended 1 day because of flooding at primary landing site; alternate landing site used. Returned for reuse.
Soyuz T-5	May 13, 1982	Anatoliy Berezovoy Valentin Lebedev	211: 9 : 5	Docked with Salyut 7. Crew duration of 211 days. Crew returned in Soyuz T-7.
Soyuz T-6	June 24, 1982	Vladimir Dzhanibekov Aleksandr Ivanchenkov Jean-Loup Chretien	7 : 21 : 51	Docked with Salyut 7. Chretien first French cosmonaut to orbit.
Space Shuttle Columbia (STS 4)	June 27, 1982	Thomas K. Mattingly II Henry W. Hartsfield, Jr.	7 : 1 : 9	Fourth flight of Space Shuttle, first DoD payload, additional scientific payloads. Returned July 4. Completed orbital flight testing program. Returned for reuse.
Soyuz T-7	Aug. 19, 1982	Leonid Popov Aleksandr Serebrov Svetlana Savitskaya	7 : 21 : 52	Docked with Salyut 7. Savitskaya second Soviet woman to orbit. Crew returned in Soyuz T-5.
Space Shuttle Columbia (STS 5)	Nov. 11, 1982	Vance D. Brand Robert F. Overmyer Joseph P. Allen William B. Lenoir	5 : 2 : 14	Fifth flight of Space Shuttle, first operational flight; launched 2 commercial satellites (SBS 3 and Anik C-3); first flight with 4 crew members. EVA test cancelled when spacesuits malfunctioned.
Space Shuttle Challenger (STS 6)	Apr. 4, 1983	Paul J. Weitz Karol J. Bobko Donald H. Peterson Story Musgrave	5 : 0 : 24	Sixth flight of Space Shuttle, launched TDRS 1.
Soyuz T-8	Apr. 20, 1983	Vladimir Titov Gennady Strekalov Aleksandr Serebrov	2 : 0 : 18	Failed to achieve docking with Salyut 7 station.
Space Shuttle Challenger (STS 7)	June 18, 1983	Robert L. Crippen Frederick H. Hauck John M. Fabian Sally K. Ride Norman T. Thagard	6 : 2 : 24	Seventh flight of Space Shuttle, launched 2 commercial satellites (Anik C-2 and Palapa B-1), also launched and retrieved SPAS 01; first flight with 5 crew members, including first woman U.S. astronaut.
Soyuz T-9	June 28, 1983	Vladimir Lyakhov Aleksandr Aleksandrov	149: 9 : 46	Docked with Salyut 7 station.
Space Shuttle Challenger (STS 8)	Aug. 30, 1983	Richard H. Truly Daniel C. Brandenstein Dale A. Gardner Guion S. Bluford, Jr. William E. Thornton	6 : 1 : 9	Eighth flight of Space Shuttle, launched one commercial satellite (Insat 1-B), first flight of U.S. black astronaut.
Space Shuttle Columbia (STS 9)	Nov. 28, 1983	John W. Young Brewster W. Shaw Owen K. Garriott Robert A. R. Parker Byron K. Lichtenberg Ulf Merbold	10 : 7 : 47	Ninth flight of Space Shuttle, first flight of Spacelab 1, first flight of 6 crew members, one of whom was West German, first non-U.S. astronaut to fly in U.S. space program.

U.S. and Soviet Manned Spaceflights, 1961–1987

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Space Shuttle Challenger (STS-41B)	Feb. 3, 1984	Vance D. Brand Robert L. Gibson Bruce McCandless Ronald E. McNair Robert L. Stewart	7 : 23 : 16	Tenth flight of Space Shuttle, two communication satellites failed to achieve orbit. First use of Manned Maneuvering Unit (MMU) in space.
Soyuz T-10	Feb. 8, 1984	Leonid Kizim Vladimir Solovev Oleg Atkov	62 : 22 : 43	Docked with Salyut 7 station. Crew set space duration record of 237 days. Crew returned in Soyuz T-11.
Soyuz T-11	Apr. 3, 1984	Yuriy Malyshev Gennadiy Strekalov Rakesh Sharma	181 : 21 : 48	Docked with Salyut 7 station. Sharma first Indian in space. Crew returned in Soyuz T-10.
Space Shuttle Challenger (STS-41C)	Apr. 6, 1984	Robert L. Crippen Frances R. Scobee Terry J. Hart George D. Nelson James D. van Hoften	6 : 23 : 41	Eleventh flight of Space Shuttle, deployment of LDEF-1, for later retrieval, Solar Maximum Satellite retrieved, repaired, and redeployed.
Soyuz T-12	July 17, 1984	Vladimir Dzhanibekov Svetlana Savistskaya Igor Volk	11 : 19 : 14	Docked with Salyut 7 station. First woman extravehicular activity.
Space Shuttle Discovery (STS-41D)	Aug. 30, 1984	Henry W. Hartsfield Michael L. Coats Richard M. Mullane Steven A. Hawley Judith A. Resnick Charles D. Walker	6 : 0 : 56	Twelfth flight of Space Shuttle. First flight of U.S. non-astronaut.
Space Shuttle Challenger (STS-41G)	Sept. 5, 1984	Robert L. Crippen Jon A. McBride Kathryn D. Sullivan Sally K. Ride David Leestma Paul D. Scully-Power Marc Garneau	8 : 5 : 24	Thirteenth flight of Space Shuttle, first flight of 7 crewmembers, including first flight of two U.S. women and one Canadian.
Space Shuttle Discovery (STS-51A)	Nov. 8, 1984	Frederick H. Hauck David M. Walker Joseph P. Allen Anna L. Fisher Dale A. Gardner	7 : 23 : 45	Fourteenth flight of Space Shuttle, first retrieval and return of two disabled communications satellites (Westar 6, Palapa B2) to Earth.
Space Shuttle Discovery (STS-51C)	Jan. 24, 1985	Thomas K. Mattingly Loren J. Shriver Ellison S. Onizuka James F. Buchli Gary E. Payton	3 : 1 : 33	Fifteenth STS flight. Dedicated DoD mission.
Space Shuttle Discovery (STS-51D)	Apr. 12, 1985	Karol J. Bobko Donald E. Williams M. Rhea Seddon S. David Griggs Jeffrey A. Hoffman Charles D. Walker E. J. Garn	6 : 23 : 55	Sixteenth STS flight. Two communications satellites. First U.S. Senator in space.
Space Shuttle Challenger (STS-51B)	Apr. 29, 1985	Robert F. Overmyer Frederick D. Gregory Don L. Lind Norman E. Thagard William E. Thornton Lodewijk Vandenberg Taylor Wang	7 : 0 : 9	Seventeenth STS flight. Spacelab-3 in cargo bay of shuttle.
Soyuz T-13	June 5, 1985	Vladimir Dzhanibekov Viktor Savinykh	112 : 3 : 12	Repair of Salyut-7. Dzhanibekov returned to Earth with Grechko on Soyuz T-13 spacecraft, Sept. 26, 1985.

U.S. and Soviet Manned Spaceflights, 1961–1987

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Space Shuttle Discovery (STS-51G)	June 17, 1985	Daniel C. Brandenstein John O. Creighton Shannon W. Lucid John M. Fabian Steven R. Nagel Patrick Baudry Sultan bin Salman bin Abdul-Aziz Al-Saud	7: 1 : 39	Eighteenth STS flight. Three communications satellites. One reusable payload, Spartan-1. First U.S. flight with French and Saudi Arabian crewmen.
Space Shuttle Challenger (STS-51F)	July 29, 1985	Charles G. Fullerton Roy D. Bridges Karl C. Henize Anthony W. England F. Story Musgrave Loren W. Acton John-David F. Bartoe	7 : 22 : 45	Nineteenth STS flight. Spacelab-2 in cargo bay.
Space Shuttle Discovery (STS-51I)	Aug. 27, 1985	Joe H. Engle Richard O. Covey James D. van Hoften William F. Fisher John M. Lounge	7 : 2 : 18	Twentieth STS flight. Launched three communications satellites. Repaired Syncom IV-3.
Soyuz T-14	Sept. 17, 1985	Vladimir Vasyutin Georgiy Grechko Aleksandr Volkov	64 : 21 : 52	Docked with Salyut-7 station. Viktor Savinykh, Aleksandr Volkov and Vladimir Vasyutin returned to Earth Nov. 21, 1985, when Vasyutin became ill.
Space Shuttle Atlantis (STS-51J)	Oct. 3, 1985	Karol J. Bobko Ronald J. Grabe Robert A. Stewart David C. Hilmers William A. Pailes	4 : 1 : 45	Twenty-first STS flight. Dedicted DoD mission.
Space Shuttle Challenger (STS-61A)	Oct. 30, 1985	Henry W. Hartsfield Steven R. Nagel Bonnie J. Dunbar James F. Buchli Guion S. Bluford Ernst Messerschmid Reinhard Furrer Wubbo J. Ockels	7 : 0 : 45	Twenty-second STS flight. Dedicated German Spacelab D-1 in shuttle cargo bay.
Space Shuttle Atlantis (STS-61B)	Nov. 27, 1985	Brewster H. Shaw Bryan D. O'Connor Mary L. Cleve Sherwood C. Spring Jerry L. Ross Rudolfo Neri Vela Charles D. Walker	6 : 22 : 54	Twenty-third STS flight. Launched three communications satellites. First flight of Mexican astronaut.
Space Shuttle Columbia (STS-61C)	Jan. 12, 1986	Robert L. Gibson Charles F. Bolden, Jr. Franklin Chang-Diaz Steven A. Hawley George D. Nelson Roger Cenker Bill Nelson	6 : 2 : 4	Twenty-fourth STS flight. Launched one communications satellite. First member of U.S. House of Representatives in space.
Soyuz T-15	Mar. 13, 1986	Leonid Kizim Vladimir Solovyov	125: 1 : 1	Docked with MIR space station on May 5/6 transferred to Salyut 7 complex. On June 25/26 transferred from Salyut 7 back to MIR.
Soyuz TM-2	Feb. 5, 1987	Yuriy Romanenko Aleksandr Laveykin	174: 3 : 26	Docked with MIR space station. Romanenko established long distance stay in space record of 326 days.

U.S. and Soviet Manned Spaceflights, 1961–1987

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Soyuz TM-3	July 22, 1987	Aleksandr Viktorenko Aleksandr Aleksandrov Mohammed Faris	160 : 7 : 16	Docked with MIR space station. Aleksandr Aleksandrov remained in MIR 160 days, returned with Yuriy Romanenko. Viktorenko and Faris returned in Soyuz TM-2, July 30 with Aleksandr Laveykin who experienced medical problems. Mohammed Faris first Syrian in space.
Soyuz TM-4	Dec. 21, 1987	Vladimir Titov Musa Manarov Anatoliy Levchenko	In progress.	Docked with MIR space station. Crew of Yuriy Romanenko, Aleksandr Aleksandrov, and Anatoliy Levchenko returned Dec. 29 in Soyuz TM-3. At end of 1987 still docked with MIR.

Appendix D

U.S. Space Launch Vehicles

Vehicle	Stages	Propellant[a]	Thrust (kilonewtons)	Max. Dia. x Height (m)	Max. Payload (kg)[b] 185-Km Orbit	Max. Payload (kg)[b] Geosynch.-Transfer Orbit	Max. Payload (kg)[b] Circular Sun-Synch. Orbit	First Launch[c]
Scout	1. Algol IIIA	Solid	431.1	1.14x22.9	255	--	155[d]	1979(60)
	2. Castor IIA	Solid	285.2		205[d]			
	3. Antares IIIA	Solid	83.1					
	4. Altair IIIA	Solid	25.6					
Delta 2900 Series (Thor-Delta)	1. Thor plus	LOX/RP-1	912.0	2.44x35.4	2,000	705	1,250[d]	1973(60)
	9 TX 354-5	Solid	147 each		1,410[d]			
	2. Delta	N_2O_4/Aerozine-50	44.2					
	3. TE 364-4	Solid	65.8					
Delta 3900 Series (Thor-Delta)[e]	1. Thor plus	LOX/RP-1	912.0	2.44x35.4	3,045	1,275	2,135[d]	1982(60)
	9 TX 526-2	Solid	375 each		2,180[d]			
	2. Delta	N_2O_4/Aerozine-50	44.2					
Atlas E	1. Atlas booster & sustainer	LOX/RP-1	1,722.0	3.05x28.1	2,090[d f]	--	1,500[d]	1972(67)
Atlas-Centaur	1. Atlas booster & sustainer	LOX/RP-1	1,913.0	3.05x45.0	6,100	2,360	--	1984(72)
	2. Centaur	LOX/LH_2	146.0					
					185-Km Orbit	Direct Geo-synch. Orbit	Sun-synch. Transfer Orbit	
Titan IIIB-Agena	1. LR-87	N_2O_4/Aerozine	2,341.0	3.05x48.4	3,600[d]	--	3,060[d]	1966
	2. LR-91	N_2O_4/Aerozine	455.1					
	3. Agena	IRFNA/UDMH	71.2					
Titan III(34)D/IUS	1. Two 5½-segment, 3.05 m dia	Solid	11,564.8	3.05x48.0	14,920	1,850[d]	--	1982
	2. LR-87	N_2O_4/Aerozine	2,366.3					
	3. LR-91	N_2O_4/Aerozine	449.3					
	4. IUS 1st stage	Solid	275.8					
	5. IUS 2nd stage	Solid	115.7					
Titan III(34)D/ Transtage	Same as Titan III(34)D plus:			3.05x46.9	14,920	1,855[d]	--	1984[h]
	4. Transtage	N_2O_4/Aerozine	69.8					
					280- to 420-Km Orbit			
Space Shuttle (reusable)	1. Orbiter; 3 main engines (SSMEs) fire in parallel with SRBs	LOX/LH_2	1,670 each	23.79x37.24 wing span long	29,500 in full performance configuration			1981
	2. Two solid-fueled rocket boosters (SRBs) fire in parallel with SSMEs	AL/NH_4CLO_4/PBAN	11,790 each	3.71x45.45				
	Mounted on external tank (ET)			8.40x46.88				

[a] Propellant abbreviations used are as follows: liquid oxygen and a modified kerosene = LOX/RP,RJ; solid propellant combining in a single mixture both fuel and oxidizer = Solid; inhibited red-fuming nitric acid and unsymmetrical dimethylhydrazine = IRFNA/UDMH; nitrogen tetroxide and UDMH/N_2H_4 = N_2O_4/aerozine; liquid oxygen and liquid hydrogen = LOX/LH_2; aluminum, ammonium perchlorate, and polybutadiene acrolonitrile terpolymer = AL/NH_4CLO_4/PBAN.

[b] Due east launch except as indicated.

[c] The date of first launch applies to this latest modification with a date in parentheses for the initial version.

[d] Polar launch.

[e] Maximum performance based on 3920, 3920/PAM configurations. PAM = payload assist module.

[f] With dual TE 364-4.

[g] With 96° flight azimuth.

[h] Initial operational capability in December 1982; launch to be scheduled as needed.

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

Appendix E-1

Space Activities of the U.S. Government

Historical Budget Summary—Budget Authority

(in millions of dollars)

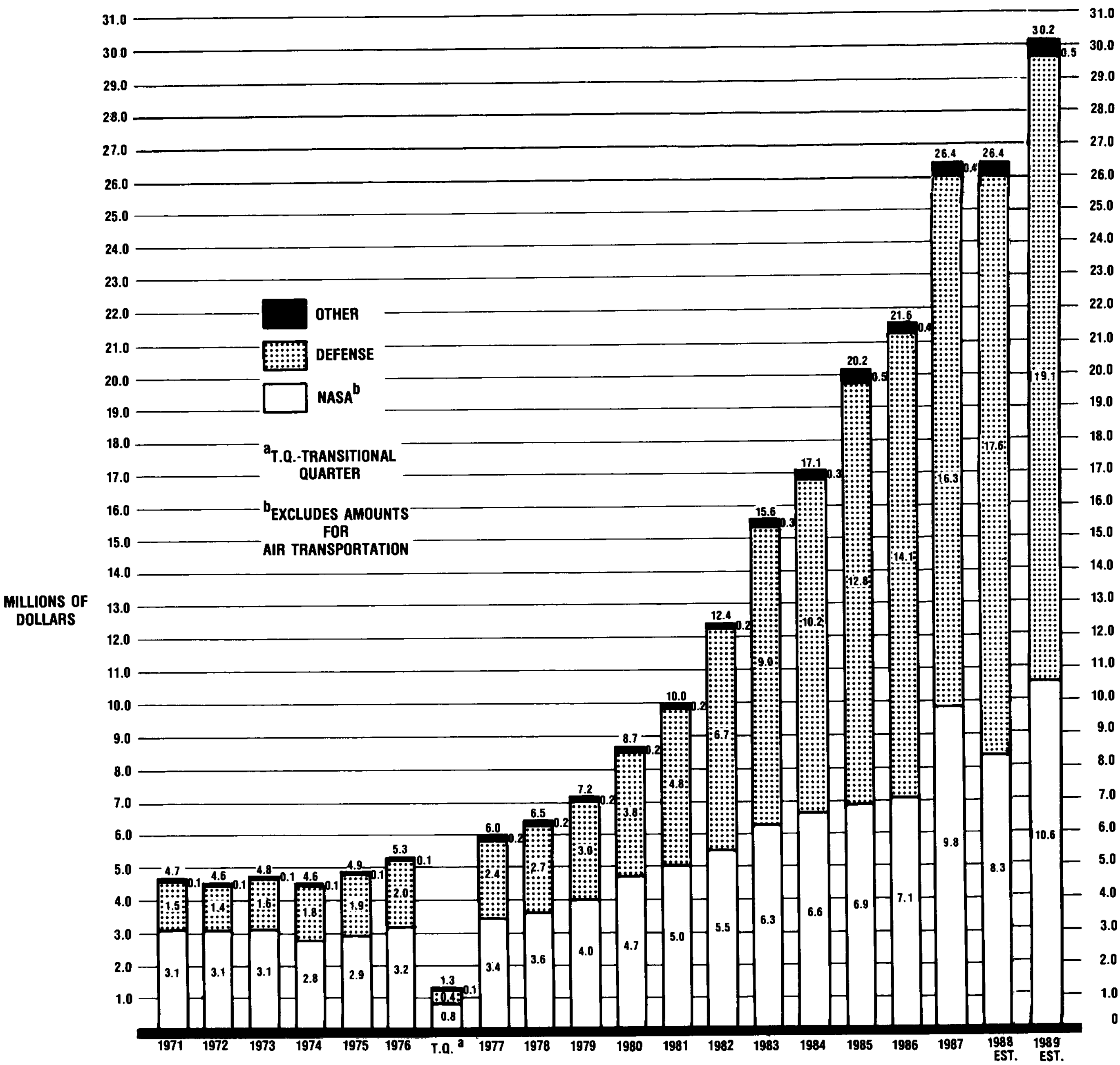
Fiscal Year	NASA		Defense	Energy	Com-merce	Interior	Agricul-ture	NSF	DOT	Total Space
	Total	Space[a]								
1959	330.9	260.9	489.5	34.3	. . .	. . .	. . .	. . .	. . .	784.7
1960	523.6	461.5	560.9	43.3	. . .	. . .	. . .	0.1	. . .	1,065.8
1961	964.0	926.0	813.9	67.7	. . .	. . .	. . .	0.6	. . .	1,808.2
1962	1,824.9	1,796.8	1,298.2	147.8	50.7	. . .	. . .	1.3	. . .	3,294.8
1963	3,673.0	3,626.0	1,549.9	213.9	43.2	. . .	. . .	1.5	. . .	5,434.5
1964	5,099.7	5,016.3	1,599.3	210.0	2.8	. . .	. . .	3.0	. . .	6,831.4
1965	5,249.7	5,137.6	1,573.9	228.6	12.2	. . .	. . .	3.2	. . .	6,955.5
1966	5,174.9	5,064.5	1,688.8	186.8	26.5	. . .	. . .	3.2	. . .	6,969.8
1967	4,965.6	4,830.2	1,663.6	183.6	29.3	. . .	. . .	2.8	. . .	6,709.5
1968	4,587.3	4,430.0	1,921.8	145.1	28.1	0.2	0.5	3.2	. . .	6,528.9
1969	3,990.9	3,822.0	2,013.0	118.0	20.0	0.2	0.7	1.9	. . .	5,975.8
1970	3,745.8	3,547.0	1,678.4	102.8	8.0	1.1	0.8	2.4	. . .	5,340.5
1971	3,311.2	3,101.3	1,512.3	94.8	27.4	1.9	0.8	2.4	. . .	4,740.9
1972	3,306.6	3,071.0	1,407.0	55.2	31.3	5.8	1.6	2.8	. . .	4,574.7
1973	3,406.2	3,093.2	1,623.0	54.2	39.7	10.3	1.9	2.6	. . .	4,824.9
1974	3,036.9	2,758.5	1,766.0	41.7	60.2	9.0	3.1	1.8	. . .	4,640.3
1975	3,229.1	2,915.3	1,892.4	29.6	64.4	8.3	2.3	2.0	. . .	4,914.3
1976	3,550.3	3,225.4	1,983.3	23.3	71.5	10.4	3.6	2.4	. . .	5,319.9
Transitional Quarter	931.8	849.2	460.4	4.6	22.2	2.6	0.9	0.6	. . .	1,340.5
1977	3,817.8	3,440.2	2,411.9	21.7	90.8	9.5	6.3	2.4	. . .	5,982.8
1978	4,060.1	3,622.9	2,738.3	34.4	102.8	9.7	7.7	2.4	. . .	6,518.2
1979	4,595.5	4,030.4	3,035.6	58.6	98.4	9.9	8.2	2.4	. . .	7,243.5
1980	5,240.2	4,680.4	3,848.4	39.6	92.6	11.7	13.7	2.4	. . .	8,688.8
1981	5,518.4	4,992.4	4,827.7	40.5	87.0	12.3	15.5	2.4	. . .	9,977.8
1982	6,043.9[b]	5,527.6	6,678.7	60.6	144.5	12.1	15.2	2.0	. . .	12,440.7
1983	6,875.3[c]	6,327.9	9,018.9	38.9	177.8	4.6	20.4	. . .[d]	. . .	15,588.5
1984	7,248.0	6,648.3	10,194.9	34.1	236.0	3.0	19.4	. . .	. . .	17,135.7
1985	7,572.6	6,924.9	12,767.9	34.0	422.9	2.0	14.8	. . .	. . .	20,166.5
1986	7,766.0	7,165.0	14,126.0	34.6	308.9	2.0	22.9	. . .	. . .	21,659.4
1987	10,507.0	9,809.0[e]	16,286.8	47.6	277.9	7.6	18.5	. . .	0.5	26,447.9
1988 [est.]	9,025.8	8,302.4	17,678.7	75.2	288.4	7.6	20.0	. . .	0.8	26,373.1
1989 [est.]	11,488.0	10,616.0	19,100.0	91.0	358.6	7.6	20.4	. . .	2.1	30,195.7

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

SOURCE: Office of Management and Budget.

U.S. Space Budget—Budget Authority FY 1971-1987

(may not add because of rounding)



SOURCE: OFFICE OF MANAGEMENT AND BUDGET

Appendix E-2

Space Activities Budget

(in millions of dollars by fiscal year)

Federal Space Programs	Budget Authority 1987 Actual	Budget Authority 1988 Estimate	Budget Authority 1989 Estimate	Budget Outlays 1987 Actual	Budget Outlays 1988 Estimate	Budget Outlays 1989 Estimate
Federal agencies:						
NASA[a]	9,809.0	8,302.4	10,616.0	7,254.0	8,450.5	9,998.2
Defense	16,286.8	17,678.7	19,100.0	14,264.3	15,528.4	16,868.0
Energy	47.6	75.2	91.0	37.4	67.5	87.0
Commerce	277.9	288.4	358.6	261.9	273.1	341.7
Interior	7.6	7.6	7.6	7.3	7.3	7.3
NSF[b]	0.0	0.0	0.0	0.0	0.0	0.0
Agriculture	18.5	20.0	20.4	18.5	20.0	20.4
Transportation	0.5	0.8	2.1	0.5	0.8	2.1
TOTAL	26,447.9	26,373.1	30,195.7	21,843.9	24,347.6	27,324.7

[a]Excludes amounts for air transportation.
[b]NSF funding for balloon research transferred to NASA.

SOURCE: Office of Management and Budget.

Appendix E-3

Aeronautics Budget

(in millions of dollars by fiscal year)

Federal Aeronautics Programs	Budget Authority 1987 Actual	Budget Authority 1988 Estimate	Budget Authority 1989 Estimate	Budget Outlays 1987 Actual	Budget Outlays 1988 Estimate	Budget Outlays 1989 Estimate
NASA[a]	698.0	723.4	872.0	622.0	678.8	830.2
Department of Defense[b]	4,179.4	5,222.5	5,063.4	4,181.8	4,655.8	4,895.5
Department of Transportation[c]	946.3	1,261.5	1,755.0	1,062.2	1,172.7	1,239.1
TOTAL	5,823.7	7,207.4	7,690.4	5,866.0	6,507.3	6,964.8

[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.

Agreement Between the United States of America and the Union of Soviet Socialist Republics Concerning Cooperation in the Exploration and Use of Outer Space for Peaceful Purposes

The United States of America and the Union of Soviet Socialist Republics, hereinafter referred to as the Parties;

Considering the role of the two States in the exploration and use of outer space for peaceful purposes;

Desiring to make the results of the exploration and use of outer space available for the benefit of the peoples of the two States and of all peoples of the world;

Taking into consideration the provisions of the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, and other multilateral agreements regarding the exploration and use of outer space to which both States are Parties;

Noting the General Agreement Between the Government of the United States of America and the Government of the Union of Soviet Socialist Republics on Contacts, Exchanges, and Cooperation in Scientific, Technical, Educational, Cultural, and other fields, signed on November 21, 1985;

Have agreed as follows:

ARTICLE 1

The Parties shall carry out cooperation in such fields of space science as solar system exploration, space astronomy and astrophysics, earth sciences, solar-terrestrial physics, and space biology and medicine.

The initial agreed list of cooperative projects is attached as an Annex.

ARTICLE 2

The Parties shall carry out cooperation by means of mutual exchanges of scientific information and delegations, meetings of scientists and specialists and in such other ways as may be mutually agreed, including exchange of scientific equipment where appropriate. The Parties, acting through their designated cooperating agencies, shall form joint working groups for the implementation of cooperation in each of the fields listed in Article 1. The recommendations of the joint working groups shall be subject to the approval of each Party in accordance with its appropriate national procedures prior to implementation. The designated cooperating agencies shall notify each other of the action taken by the Parties on the recommendations within three months of their adoption by the joint working groups.

ARTICLE 3

The joint working groups shall begin their work with the projects listed in the Annex to this Agreement. Revisions to the list of projects in the Annex, which may include the identification of other projects in which cooperation would be of mutual benefit, may be effected by written agreement between the Parties through a procedure to be determined by them.

ARTICLE 4

Cooperative activities under this Agreement, including exchanges of technical information, equipment and data, shall be conducted in accordance with international law as well as the international obligations, national laws, and regulations of each Party, and within the limits of available funds.

ARTICLE 5

This Agreement shall be without prejudice to the cooperation of either Party with other States and international organizations.

ARTICLE 6

The Parties shall encourage international cooperation in the study of legal questions of mutual interest which may arise in the exploration and use of outer space for peaceful purposes.

ARTICLE 7

This Agreement will enter into force on the date of signature by the Parties and will remain in force for five years. It may be extended for further five-year periods by an exchange of notes between the Parties. Either Party may notify the other in writing of its intent to terminate this Agreement at any time effective six months after receipt of such notices by the other Party.

IN WITNESS WHEREOF the undersigned, being duly authorized by their respective Governments, have signed this Agreement.

DONE at Moscow, in duplicate, this 15th day of April, 1987, in the English and Russian languages, both texts being equally authentic.

George P. Shultz

FOR THE UNITED STATES OF AMERICA:

Eduard Shevardnadze

FOR THE UNION OF SOVIET SOCIALIST REPUBLICS:

[ANNEX]

AGREED LIST OF COOPERATIVE PROJECTS

1. Coordination of the Phobos, Vesta, and Mars Observer missions and the exchange of scientific data resulting from them.
2. Utilization of the U.S. Deep Space Network for position tracking of the Phobos and Vesta landers and subsequent exchange of scientific data.
3. Invitation, by mutual agreement, of co-investigators' and/or interdisciplinary scientists' participation in the Mars Observer and the Phobos and Vesta missions.
4. Joint studies to identify the most promising landing sites on Mars.
5. Exchange of scientific data on the exploration of the Venusian surface.
6. Exchange of scientific data on cosmic dust, meteorites and lunar materials.
7. Exchange of scientific data in the field of radio astronomy.
8. Exchange of scientific data in the fields of cosmic gamma-ray, x-ray and sub-millimeter astronomy.
9. Exchange of scientific data and coordination of programs and investigations relative to studies of gamma ray burst data.
10. Coordination of observations from solar terrestrial physics missions and the subsequent exchange of appropriate scientific data.
11. Coordination of activities in the study of global changes of the natural environment.
12. Cooperation in the Cosmos biosatellite program.
13. Exchange of appropriate biomedical data from U.S. and U.S.S.R. manned space flights.
14. Exchange of data arising from studies of space flight-induced changes of metabolism, including the metabolism of calcium, from both space flight and ground experiments.
15. Exploration of the feasibility of joint fundamental and applied biomedical experiments on the ground and in various types of spacecraft, including exobiology.
16. Preparation and publication of a second amplified edition of the joint study "Fundamentals of Space Biology and Medicine."

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