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Aeronautics and Space Report of the President

1980 Activities

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Aeronautics and Space Report of the President

1980 Activities

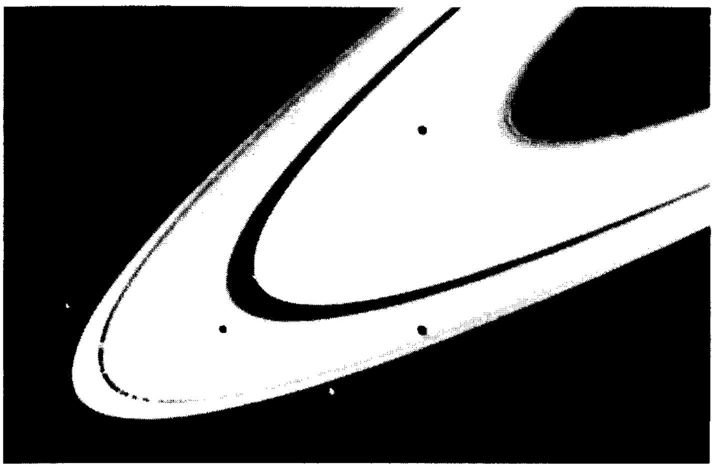
National Aeronautics and Space Administration
Washington, D.C. 20546

Contents

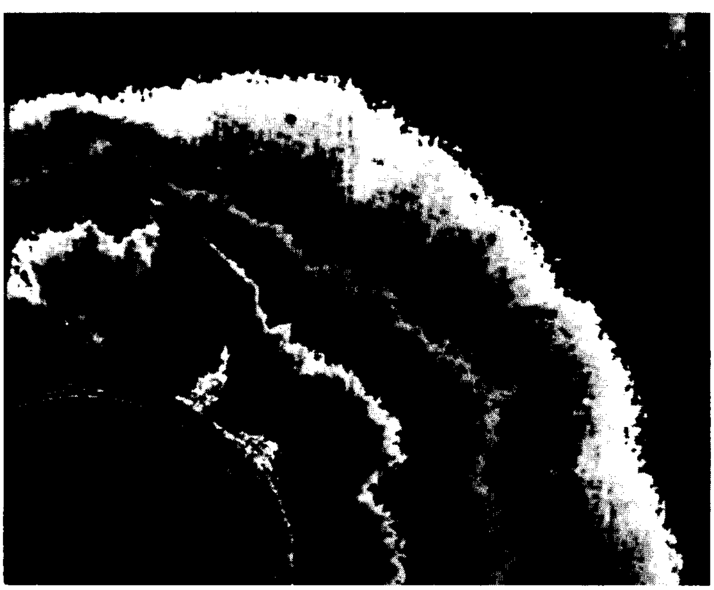
Appendixes

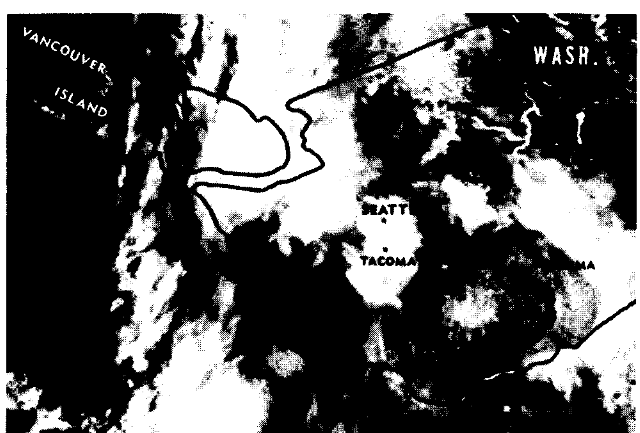
Aerospace Events of 1980

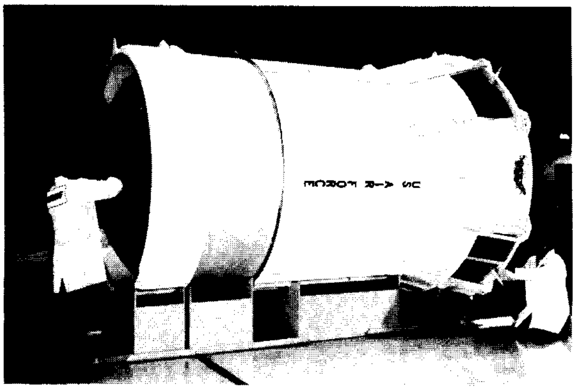
Voyager 1 flew past the planet Saturn in November 1980, discovering new planetary rings, photographing six new moons, and sending back other surprising data. At left, Saturn and two of its moons, Tethys and Dione, were photographed by *Voyager 1* on 3 November from 13 million kilometers away. The shadow of Tethys and three rings are cast onto the cloudtops, and the limb of the planet shows through the Cassini Division separating rings A and B. Two new moons, the 13th and 14th (middle left photo), were photographed 25 October from 25 million kilometers away. The smaller, innermost of the two, at the bottom edge of ring A, is about 500 kilometers in diameter.



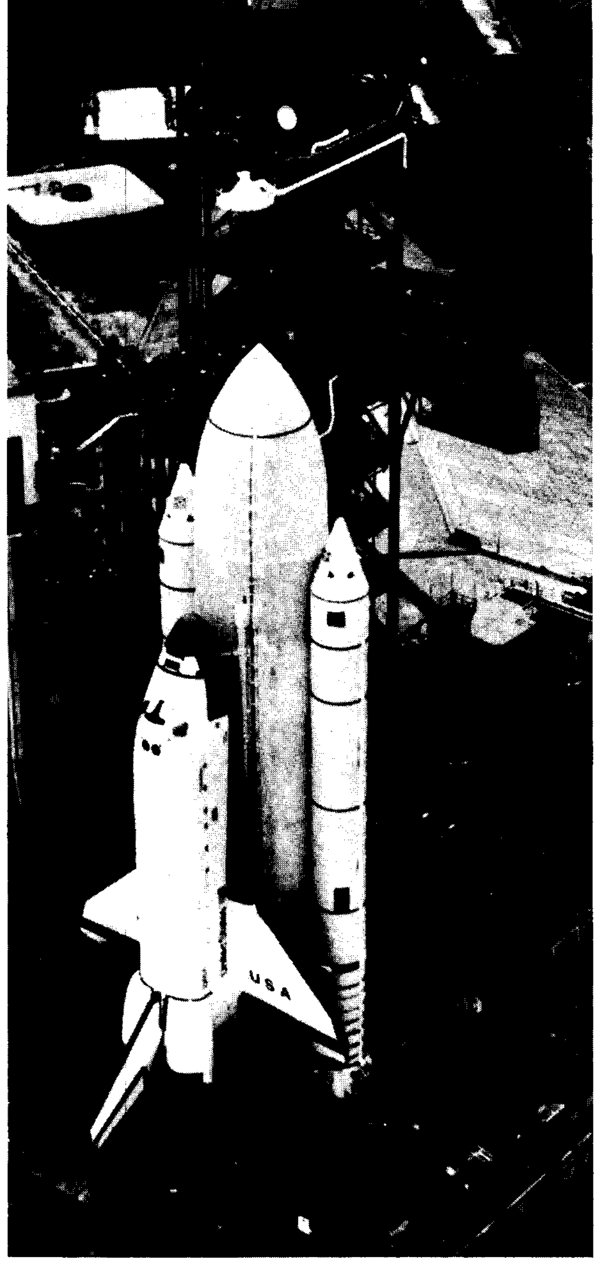
Spacecraft also kept watch on the sun and the earth. The *Solar Maximum Mission* satellite, orbited in February 1980, returned important data on solar activity during the peak of the 11-year sunspot cycle. A flare 7 April caused the major disruption in the solar corona seen in the picture (left, below) prepared from data sent back by the coronagraph polarimeter. The shading from dark to light represents densities of the corona. The May 1980 eruption of Mount Saint Helens in Washington (below) was monitored by satellites *Goes 3, Noaa 6,* and *Sage* and by aircraft. *Noaa 6* photographed the massive plume mushrooming from the volcano at 9:54 PDT 18 May, 84 minutes after the explosion. Satellite information on the spread of smoke and ash and communications via *ATS 3* aided rescue and cleanup.

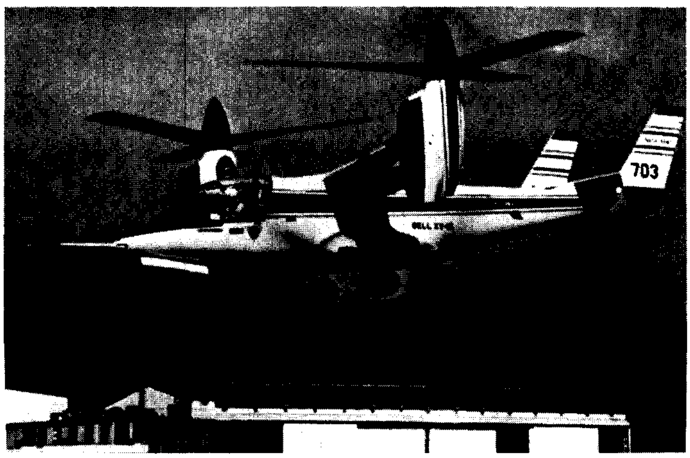






The first Space Shuttle (right) arrived at Kennedy Space Center's Launch Complex 39 on 29 December 1980 for extensive on-the-pad testing before its 1981 launch. The airplanelike reusable orbiter *Columbia* is mated to the towering external tank and reusable rocket boosters. Above, the inertial upper stage is being developed by the Air Force to deliver NASA and military payloads to higher orbits than the Shuttle alone can reach.





A joint NASA-Army-Navy flight program began in 1980 to evaluate the XV-15 tilt-rotor research aircraft (upper left). The versatile, vertical- or short-takeoff and landing craft completed flight-envelope-expansion tests, reaching a speed of 555 kilometers per hour. In a NASA-Navy research program, the QSRA (quiet short-haul research aircraft, lower left) made precision landings on the deck of the carrier *Kitty Hawk* without arresting gear and took off without catapult.

Summary

Discoveries in the outer solar system and enlarged understanding of the sun marked the United States space program in 1980, and the Space Shuttle was readied for its first launch. In aeronautics, technical advances were made in energy efficiency, environmental compatibility, safety, traffic control, and improved performance of military and civil aircraft.

As the year ended, the *Voyager 1* spacecraft headed for the outer solar system and beyond after flying within 123 600 kilometers of Saturn in November to discover new planetary rings, photograph six new moons, and send back other surprising data about that giant planet. *Voyager 2* continued toward its August 1981 encounter with Saturn.

The Space Shuttle *Columbia* was rolled out to the launch pad in December in preparation for the first flight into space of a reusable earth-to-orbit vehicle, scheduled for spring 1981. In November, the European Space Agency delivered the first engineering model of Spacelab, the laboratory that will be carried on Shuttle missions.

Of 15 U.S. launches into space on expendable vehicles in 1980, 13 orbited 16 payloads, but 1 payload failed to reach operational orbit. Of these, the National Aeronautics and Space Administration (NASA) orbited 7 in 7 launches, but an environment-monitoring satellite for the National Oceanic and Atmospheric Administration (NOAA) went into a highly elliptical orbit where it could not operate effectively. The Department of Defense (DoD) had 6 successes in 8 launches—1 with 3 payloads on one vehicle and 1 with 2—orbiting 9 payloads, including 2 Navstar Global Positioning Satellites. NASA's launches also included 2 communications satellites for DoD, 2 commercial communications satellites, 1 successful weather satellite for NOAA, and 1 satellite for NASA's own science program, to study solar flare mechanisms and effects on the earth during the Solar Maximum Year.

Satellite communications services continued to expand, with 6 International Telecommunications Satellite Organization satellites and 8 U.S. domestic commercial satellites in service. And 20 more domestic launches were approved—in addition to growing maritime and military networks. For earth resource inventories and monitoring, 14 ground stations in 11 countries were receiving data from Landsat satellites and other countries were adding stations. Weather satellites observed the entire earth four times a day, and new sensors and methods were being tested to improve forecasts.

Space research and technology programs advanced the performance, reliability, and efficiency of space vehicles and operations. Energy programs made progress in the use of solar-cell and nuclear energy in space and of solar, wind-turbine, and other kinds of energy on the earth.

This section summarizes 1980 highlights of the U.S. aeronautics and space program by function. Subsequent sections then take up in more detail the work of the agencies participating in the program.

Communications

Communications satellites have led to a growing and profitable industry and also have become indispensable for command and control of U.S. military forces.

Operational Space Systems

INTELSAT. The first of the new high-capacity Intelsat V communications satellites—with double the capacity of the Intelsat IVA series—was launched in December 1980 to replace one of the six spacecraft in the global system of the 105-nation INTELSAT organization. *Intelsat V F-2* will operate in the 6- to 4-and 11- to 14-gigahertz bands. Of nine satellites planned in the series, to meet traffic demands now increasing by more than 25 percent annually, five will be able to provide maritime services and can be launched on either expendable vehicles or the Space Shuttle. Direct communication links with more than 280 ground-station antennas served some 140 countries at the year's end, as INTELSAT prepared specifications for the follow-on VI series.

Domestic Communications Satellites. The Federal Communications Commission in December authorized 8 companies to launch 20 commercial domestic communications satellites, to join or replace the 8 satellites in service in 1980. In addition, 1 just launched was to go into service in 1981 and 2 more were scheduled for 1981 launch. The first Satellite Business Systems satellite was launched in November 1980 to provide voice, data, and image service in the 12- to 14-GHz bands for large industrial and government users beginning in March 1981. Two RCA American Communications Satcoms, three Western Union Westars, and three American Telephone & Telegraph Comstars were providing message toll service, television distribution, and single and multiple channels for voice, data, TV, and digital data to more than 3500 ground stations.

Military Communications Satellites. The Department of Defense operates its own satellite communications system and also leases commercial service for command and control of U.S. military forces. The third and fourth of five planned Fleet Satellite Communications System satellites were launched in January and October 1980 to provide moderate-capacity, mobile-user service to the U.S. Navy and Air Force. Fleet broadcast receivers had been installed in some 420 ships and 109 submarines, and 236 ships were equipped for secure, long-range voice operations. The FCC has authorized Hughes Communications Services to construct the near-global LEASAT system to begin replacing the FLTSATCOM system. Since LEASAT can be launched only on the Shuttle, the first launch is not expected until mid-1984, paced by Shuttle availability.

Development continued on a qualification model and two flight models of the DSCS III, a new-generation satellite. Four active DSCS II satellites and two on-orbit spares were providing nearly global, secure, voice and high-data-rate support to critical command, control, and crisis management users. *DSCS III A-1,* scheduled for 1981 launch, was to include an additional jam-resistant, single-channel transponder as a secondary payload for emergency-action message dissemination. Similar transponders were also planned for launch in the Strategic Satellite System in the mid-1980s.

The Air Force Satellite Communications (AFSATCOM) System, which uses FLTSATCOM and other satellites for command and control of nuclear-capable forces and other high-priority users, in 1980 was procuring terminals for 1981 installation in ICBM launch control centers. Thirty-one low-rate, initial-production, multichannel, SHF, tactical terminals in the Tactical Ground Mobile Forces' Satellite Communications System had been deployed by the U.S. Army in Europe for use with the DSCS system. Production began on 210 UHF vehicle terminals for use with FLTSATCOMS in support of tactical nuclear forces, and first terminal delivery in Europe was expected in late 1981.

Marisat. Commercial maritime service was being provided to more than 500 ships through the Marisat system in the Atlantic, Pacific, and Indian ocean areas; ultimately up to 8000 ships are expected to be equipped for satellite communications. The 29-nation International Maritime Satellite Organization (INMARSAT), established in 1979 with Comsat Corp. as the largest shareholder, approved an operational plan in November 1980 for its first-generation space segment. Two Marecs spacecraft manufactured by the European Space Agency, one Marisat spacecraft, and payloads on three Intelsat V spacecraft were to make up the segment, expected to begin operations in 1982 in a transition from Marisat. Also in November, the Intergovernmental Maritime Consultative Organization (IMCO) approved requirements for a future global distress and safety system.

Military Navigation Satellites. The fifth and sixth Navstar Global Positioning System satellites were launched in February and April in the joint-service program to improve weapon delivery and worldwide rapid force deployment with continuous, three-dimensional positioning and navigation. The developmental system was providing up to six hours of accurate positioning data with five of the six satellites operating. By late 1987, the operational 18-satellite system is to provide positioning data accurate to 16 meters, velocity accurate to 0.1 meter per second, and time synchronized to within 0.1 microsecond. The satellite design is being modified for Shuttle compatibility, and the Navy, Army, and Air Force are using the present system to test military concepts, missiles, and equipment.

Space Communications Experiments

Experimental Satellites. ATS 1 and *ATS 3,* Applications Technology Satellites launched in 1966 and 1967, continued important public service communications experiments in 1980. In addition to supporting emergency medical assistance to isolated areas, *ATS 3* aided search and rescue operations and disaster assessment after the eruption of Mount Saint Helens in Washington. In the Pacific basin, *ATS 1* supplied disaster relief, medical, and educational services. The first satellite carrying the demonstration Search and Rescue Satellite (SARSAT) equipment, built by the United States and including subsystems from France and Canada, was expected to be launched by mid-1982. Two spacecraft interoperable with the SARSAT system were to be provided by the Soviet Union under a 13 August 1980 understanding.

To fulfill its international mission in public service satellites, the National Telecommunications and Information Administration (NTIA) of the Department of Commerce was planning a three-year educational exchange program to begin in June 1981 for persons from less developed countries. The program, part of a joint effort with the Agency for International Development (AID), would emphasize the application of satellite communications to the delivery of social services. Also, NTIA and NASA were cooperatively funding an examination of the technical, regulatory, and program requirements for enhancing communications in the islands of the Pacific basin.

Communications Research. NASA began studies and awarded 12 technology development contracts toward high-capacity satellite equipment able to use a new frequency band, to meet the congestion of both the geostationary orbit and the present bands, which will probably be saturated by the 1990s. An experimental satellite was under consideration for necessary conceptual tests and to resolve technical uncertainties facing future commercial systems.

DoD developed new components for operation in the EHF band and also completed testing an air-to-ground laser communication link with very high data rates and high jamming protection. Development continued on an orbital laser communications package for launch on the *P80-1* spacecraft in 1983.

Communications Negotiation. The Federal Communications Commission began preparations for the 1983 regional and 1984 world administrative radio conferences, which will establish principles and criteria for the geostationary satellite orbit and frequency bands allocated to space services. U.S. radio regulations carrying out international decisions made at the 1979 world conference were being prepared.

NTIA began discussions with the People's Republic of China about that nation's future use of satellite communications. A delegation visited China in April 1980 to explore mutual interests, focusing on U.S. technology that might profitably be applied to needs of the Chinese people.

Direct Broadcast Satellites. The FCC studied technical and policy issues concerning proposed communications satellites for broadcasting—probably television—directly to small, inexpensive antennas in individual homes or communities. A notice of inquiry invited public comment by 1981 on reports on these issues. Consideration of draft principles governing direct broadcast continued in the U.N. Committee on Peaceful Uses of Outer Space. Organizations of the National Academy of Sciences held a symposium on technical, financial, legal, and regulatory influences on putting direct broadcast into practical use.

Earth's Resources and Environment

Use of information from sensors on aircraft and spacecraft continued to increase, nationally and internationally, for inventorying and monitoring resources and changes of the earth's land surface, waters, and atmosphere.

Inventorying and Monitoring

Earth Resources. The Departments of Agriculture, Commerce, and the Interior, with NASA, completed the first year of the Agriculture and Resources Inventory Survey through Aerospace Remote Sensing (AgRISTARS) program. The broad-based research and development program uses data from environmental, communications, and Landsat satellites and airborne sensors to determine applications of aerospace technology to agriculture and renewable resources. USDA focused on research in crop-yield models and on assessment and early warning of crop conditions, as well as land cover and resources. NASA during 1980 developed several improved techniques for estimates and spectral measurements of crops, as well as completing two exploratory experiments for forecasting foreign crop production. AID will evaluate applications of aerospace technology in developing countries.

In addition to research, USDA used Landsat data operationally in 1980 to assess important crops in major producing regions of the world, to classify and map forests, and to develop a forest-fire fuels data base. The Department of the Interior also studied fuel mapping for fire control.

On 16 November 1979, the president assigned NOAA management responsibility for all civil operational remote-sensing activities from space. In consonance with the presidential directive, NOAA with NASA and other federal user agencies developed a recommended plan for transition from the existing, experimental NASA Landsat program to an operational NOAA program for land remote-sensing.

A public document, *Planning for a Civil Operational Land Remote Sensing Satellite System: A Discussion of Issues and Options* issued 20 June 1980, identified policy and technical issues to be resolved: continuity of data during the 1980s; user requirements and performance options for the fully operational system; revenues, pricing policies, and financial assistance; institutional approaches to private sector ownership; market expansion; international implications; and required legislative and regulatory authorities.

Under the plan, NASA's Landsat-D satellite, already in development, and the associated ground system would be transferred to NOAA. Under NOAA, emphasis would shift from research and development to operational requirements, with appropriate launch schedule changes. Service by the operational system would be tailored to users' needs and ultimate participation by the private sector.

Requests for data from *Landsat 2* and *3*, orbiting the earth since 1975 and 1978, again showed increasing worldwide interest in environmental and resources applications. Ground stations in India and Australia became operational in 1980, and 10 other stations in 9 countries continued active. Argentina's station began receiving test data. Thailand, the People's Republic of China, and South Africa took steps toward acquiring their own stations, and 5 more countries have expressed interest. The Geological Survey and AID held remote-sensing workshops for 40 scientists from 17 countries, in addition to other international training and cooperative applications projects. The Survey is lead agency in a U.N.-sponsored project developing techniques for mineral and energy exploration.

The major environmental event of 1980, the eruption of Mount Saint Helens, was monitored and tracked by both polar-orbiting and geostationary satellites. Information on the movement, density, and spread of the resulting smoke and ash plume was used in evacuation and cleanup activities, as well as for routing aircraft. Estimates of the location and movement of the plume were provided to numerous U.S. and foreign government agencies and television stations.

The Census Bureau continued to use Landsat data to update its statistics on land and water areas of the United States. An interactive computer system was being developed using digital county boundary files and Landsat images to distinguish water from land.

Investigations were completed in use of computer-processed Landsat data for showing land-cover changes and delineating urban zones around two sample metropolitan areas under a NASA applications pilot test agreement. Digital registration of Landsat scenes over several different years and related processing show significant land-cover change. Statistical and pictorial results were being compared with changes interpreted from aircraft photography.

The Department of the Interior used earth observations from satellites and aircraft to map water use and availability, wildland vegetation, and wetlands; give early warning of floods; improve park management; and assess habitats of endangered species.

NASA expanded its research in remote sensing for identifying mineral and energy resources, moving from emphasis on visible and near-infrared portions of the electromagnetic spectrum to use of more of the spectrum. Results from the NASA-Geosat Test Case substantially encouraged the use of satellite remote sensing for geologic resource assessment and exploration.

The *Magsat* satellite, completing its mission in 1980, obtained the first global measurements of the earth's vector magnetic field. *Magsat* data are expected to give insights into the subsurface structure of mineral frontier regions in the Arctic, Africa, and South America.

In geodynamics, space technology was used to study polar motion and earth rotation, movement and deformation of the earth's tectonic plates, deformation of the earth's crust, and other processes related to earthquakes. Analysis of data taken regularly since 1972 has established motion along the San Andreas fault in California—between Pacific and North American plates—of 7 to 11 centimeters a year. Measurements were begun to detect separation of Eurasian and North American plates. The International Astronomical Union's Measurement of Earth Rotation and Intercomparison of Techniques (MERIT) program began, working toward a new, more accurate, global monitoring system. The Smithsonian Astrophysical Observatory acted as coordinator for MERIT and provided laser tracking coverage for geophysical research, focusing on the high-orbiting *Lageos* satellite and others in near-earth orbit.

Monitoring the Sea State. Observations from *Seasat, Nimbus 7,* and GEOS satellites continued to provide information on the oceans for scientists and commercial marine industries. The *Seasat* scatterometer proved it could measure speed of surface winds, an improvement over inferring winds from cloud movements. The radar altimeter proved accurate for mapping such features as Gulf Stream circulation, coastal tides, and sea ice.

Environmental Analysis and Protection

Operational and experimental programs continued to collect data for analysis and prediction of climate changes and natural and man-made changes in the atmosphere.

Weather Satellite Operations. During 1980, *Tiros-N* and *Noaa 6* continued as the two polar-orbiting satellites operated by the National Earth Satellite Service (NESS). *Noaa-B,* launched in May as NOAA's second operational satellite of this series, failed to achieve operational orbit. *Tiros-N* and *Noaa 6,* operating in sun-synchronous orbits of 870 and 830 kilometers to observe the environment of the entire earth four times each day, have already significantly improved global weather predictions. Redundancy is achieved by the two similar satellites rather than by identical instruments on a single satellite.

NOAA's Geostationary Operational Environmental Satellite (GOES) system is the successor to NASA's prototype Synchronous Meteorological Satellites (SMS). Since 1974, two SMS and four GOES satellites have been launched. *SMS 2* and *Goes 3* now cover the Western Hemisphere, with *SMS 2* at 75° west longitude and *Goes 3* at 135°. *SMS 1, Goes 1,* and *Goes 2* are on standby and provide limited operational support in weather facsimile and data collection. The primary instrument on these satellites is the visible infrared spin-scan radiometer (VISSR).

Goes 4 was successfully launched 9 September 1980, to orbit 35 000 km above the equator at 98° west longitude. Equipped with a new radiometer, the VISSR atmospheric sounder (VAS), *Goes 4* will record atmospheric temperature and water vapor content at various altitudes in addition to the traditional images of the earth's surface and cloud cover. It is the first environmental satellite launched with a combined research and operational capability. When NOAA is not using it operationally, NASA will use it to test the VAS, which offers multispectral imaging with 12 operational channels instead of the VISSR's 1, ability to use these channels to derive temperature and moisture data, and ability to select areas, data, and frequency of coverage. A new feature has been added to the space environment monitor (SEM) on *Goes 4*; a high-energy-proton and alpha detector expands the dynamic range of the instrument. The SEM detects unusual solar flares with high levels of radiation, measures the intensity of solar winds, and measures the strength and direction of the earth's magnetic field.

DoD's Defense Meteorological Satellite Program supports strategic and tactical needs for weather information, depending on two satellites obtaining data from all points on the earth at least four times a day. During 1980 the system adequately supported needs for seven months. In July a satellite launched to replace a degrading DMSP failed to achieve orbit, and service has since been supplemented by civilian systems as the Air Force accelerates replacement satellite production.

Weather Research. NASA and NOAA continued work to improve weather forecasts by advances in technology. The Global Weather Experiment, a year of international observation ending November 1979, collected the largest set of atmospheric data yet attempted. Inclusion of satellite data in prediction models showed dramatic improvement in selected two- to five-day forecasts. The experiment also showed the importance of monitoring the Southern Hemisphere, where intermittent outbursts of air cross the equator to alter mid-latitude weather in the Northern Hemisphere within several days.

NASA and NOAA proceeded with the pilot Centralized Storm Information System at the National Severe Storms Forecast Center in Kansas City. Reception time for satellite images decreased from 45 minutes to 6, as the project worked toward overlaying all observations, maps, images, and forecasts on computerized video terminals for quick reaction to severe storms.

In the National Climate Program, NASA was assigned lead responsibility for studying solar and earth radiation effects on climate change. An experiment team from NASA, NOAA, the academic community, and several foreign countries worked on software development, data validation, ground-truth observations, and scientific analyses in the earth radiation budget experiment (ERBE). Three sets of instruments were planned for launch in the mid-1980s, two on NOAA sun-synchronous satellites and one on a NASA satellite. NASA has selected the contractor for its ERBS spacecraft.

Atmospheric Research. Progress was made during the year in monitoring the chemistry, radiation exchange, and dynamics of the upper atmosphere for predicting effects of human activities on these upper regions. NASA's estimate that man-made chemicals will reduce ozone in the ozone layer by 14 to 18 percent by the year 2050 supports the National Academy of Sciences' prediction of 16 percent. New laboratory and field measurement techniques, including remote sensing, have increased understanding of ozone chemistry. Seven years' global ozone data from the *Nimbus 4* satellite and additional data from *Nimbus 7* will help establish the effects of the oxides of nitrogen on ozone, and *Nimbus 6* and *7* temperature data indicate the variations in winds that transport atmospheric constituents. Sounding rocket measurements by several countries confirmed the precision of satellite measurements.

Observations by aircraft and the *Sage* satellite, launched in 1979, of the dispersion of material from the Mount Saint Helens eruption indicated the importance of wind transport in the stratosphere. And *Sage* observations of this and other eruptions led to the belief that, in the short run, large volcanic eruptions have a more significant effect on surface temperatures than do increases in carbon dioxide. The National Science Foundation supported aircraft and balloon flights through the Mount Saint Helens plume to sample particles and gases for constituents that could affect the ozone layer and climate.

NASA and the Environmental Protection Agency (EPA) continued joint work to understand pollution in the lower atmosphere, developing and using satellite and aircraft systems to gather data for studying air masses and the transport and transformation of oxidants and other pollutants in the northeastern United States. Some 36 research groups from federal agencies—including EPA, NASA, and the Department of Energy—continued work in the Interagency Energy/Environment Program (IEEP) toward ensuring that national energy development goals are met with minimal harm to human health and the environment.

Space Science

Space science seeks to understand the dynamic processes that shape the earth's environment, including the interaction of the sun's emissions with the environment, and to understand the origin and evolution of the universe and of life in that universe.

Sun-Earth Studies

The *Solar Maximum Mission*, launched into orbit in February to study solar flares and other solar activity during the peak of the 11-year sunspot cycle, was the most important achievement in NASA's 1980 solar and heliospherics program. Among *SMM* discoveries affecting the theory of solar flares was that the very high energy x-rays emitted at the beginning of flares appear to originate in pairs of spots within the flares, at the bottom of loops of the magnetic field that creates the flares. The spacecraft also measured heat and light from the sun for investigation into relations between the sun's luminosity and our climate.

The National Science Foundation was responsible for ground-based research in the Solar Maximum Year, with observations at more than 100 observatories; and the NSF's National Center for Atmospheric Research, under NASA contract, provided the coronagraph-polarimeter flown on the *SMM*. Telescope observations at the South Pole confirmed the existence of pulsations of the sun's surface with a period of five minutes—and also possibly longer periods that could revise concepts of the sun's structure.

The three-satellite International Sun-Earth Explorer (ISEE) system begun in 1977 by NASA and the European Space Agency completed its primary objectives of determining the thickness and motion of the earth's bow shock and the changes induced by solar wind fluctuations. The third satellite, *ISEE 3* orbiting a point between the earth and the sun, has improved understanding of the solar wind and has also measured the temperature of solar coronal holes as high as 3.5 million kelvins. The earth's magnetic field diverts most of the solar wind, but some interacts to produce plasma waves, some transfers energy inside the magnetosphere, and some is thrown back toward the sun.

Development neared completion on two Explorer satellites to be launched in 1981: the Dynamics Explorer to study interaction of the earth's magnetosphere and ionosphere and the Solar Mesospherics Explorer to determine how solar ultraviolet radiation interacts with the atmosphere. Development also continued on instrumentation for a fourth cooperative project of NASA and the Italian Space Commission to study atmospheric phenomena. Detailed study continued on future Explorers: the two-element Active Magnetospheric Particle Tracer Explorer (AMPTE) program, with one German and one U.S. spacecraft to be launched in the mid-1980s; and the Solar Corona Explorer (SCE), to study rotation and evolution of coronal holes and the origin of the solar wind.

For the cooperative NASA-ESA International Solar Polar Mission (ISPM), launch of an ESA spacecraft in the mid-1980s was under consideration to explore interplanetary space above the poles of the sun for the first time.

The National Academy of Sciences' Space Science Board, a principal adviser for NASA since 1958, began a study at NASA's request to recommend future research in solar physics.

Study of the Planets

Unmanned spacecraft sent back quantities of new planetary data during 1980, including scientific surprises and spectacular images from Saturn and its moons and continued observations of Mars and Venus.

Saturn. After flying past Jupiter in 1979, *Voyager 1* came close to the giant, ringed Saturn in November 1980, returning thousands of high-resolution images and extensive, exciting data. Saturn's rings are far more numerous than thought, and far more complex; *Voyager 1* found hundreds, perhaps thousands, of elliptical rings and one that appears to be several twisted or "braided" ringlets. Even the Cassini division was found to hold nearly two dozen rings. The spacecraft photographed six new moons, some that had not been seen before and some that had been reported but not confirmed. Titan, the largest of Saturn's moons and the only moon in the solar system to have an atmosphere, was found to be slightly smaller than Jupiter's Ganymede, rather than the largest in the solar system. Its atmosphere was found to be largely nitrogen rather than methane, resembling a prehistoric Earthlike atmosphere in deep freeze.

At the end of 1980, *Voyager 1* was headed out of the solar system. Its sister craft, *Voyager 2*, journeyed toward its August 1981 encounter with Saturn and then on toward a 1986 flyby of Uranus.

Jupiter. Scientists faced challenges and questions presented by the discoveries and torrents of data sent from Jupiter by *Voyager 1* and *2* flybys in 1979. An underlying order to the turbulent atmosphere, the diverse worlds of the Galilean moons, Jupiter's magnetospheric boundaries and tail similar to Earth's, three new moons, and a planetary ring system unknown before invited further investigation. The Galileo mission, planned for the late 1980s, is designed to study the Jovian system in detail with more sophisticated instruments. One spacecraft is to orbit the planet for 20 months, flying close to some of the moons, and a probe is to descend into Jupiter's atmosphere.

Mars. At the end of 1980, the *Viking 1* lander was still transmitting images and scientific data from the surface of Mars, five years after arrival. Periodic interrogations of the lander were planned into 1994. The second Viking lander and orbiter ended their missions during the year, as the analysis team studied the high-resolution pictures and atmospheric and meteorological data transmitted through the second Martian year.

Venus. The *Pioneer-Venus* orbiter, launched in 1978, continued to provide valuable information on the atmosphere of Venus and was expected to operate until 1986, returning important data on atmospheric variations with time and on regions near the planet that were not accessible from the spacecraft's first orbits.

Ground-Based Research and Analysis. In addition to other teams of scientists from universities and federal agencies analyzing results from the planetary explorations, the Space Science Board continued to define scientific strategies for the space program. Its 1980 publications included *Origin and Evolution of Life: Implications for the Planets,* and the Board began a study of the role of theory in the design of space missions and interpretations of results.

Study of the Universe

A combination of astronomy and physics, astrophysics seeks to understand the basic laws of the observable universe, investigating radiation reaching Earth from all sources in the cosmos.

Research with Spacecraft. The High Energy Astronomy Observatory (HEAO) series of spacecraft study x-rays, gamma rays, and cosmic rays—the highest detectable energy rays. *Heao 2* and *3,* launched in 1978 and 1979, continued to make new observations in 1980. *Heao 2,* carrying the first true imaging x-ray telescope, increased the number of quasars detected as x-ray emitters to more than 100, from the 3 that could be detected by *Heao 1.* And its unexpected data on the constituents of remnants of supernova explosions raised questions about nuclear physics theory.

Heao 3, measuring quantities of very high energy atomic nuclei in the galaxy, also sent data that raised questions about supernovae, as well as about the origin of these nuclei. *Heao 3* pioneered observation of true nuclear gamma-ray line radiation, observing radiation from the formation of heavy hydrogen (deuterium) in a solar flare and annihilation radiation from the center of the Milky Way. Radiation from destruction of antimatter positrons in collision with electrons in the Milky Way may shed light on how antimatter can be produced and confined in the nucleus of the galaxy.

Orbiting Astronomical Observatory *OAO 3* ended its science operations in December after eight years of transmitting data, including first satellite measurements of the ultraviolet spectra of the chromospheres and coronas of stars other than the sun. Observations in 1980 by the International Ultraviolet Explorer *IUE,* launched in 1978, confirmed the discovery of a hot halo of gas around the Milky Way and verified that the space between isolated galaxies is transparent and contributes little to the mass of the universe. *IUE* also continued to contribute to knowledge of the stars, comets, and their composition.

Major analysis programs of the principal investigators, the Smithsonian Astrophysical Observatory, and hundreds of scientists in NASA's guest investigator program interpreted data from these satellites, often in combination from suborbital vehicles and ground-based observations.

The Gamma Ray Observatory *GRO,* planned for late 1980s launch, is designed to extend observation of the universe into the highest energy reaches of the electromagnetic spectrum—to see nuclear processes near neutron stars and black holes and to investigate supernovae, gamma-ray bursts, and gamma-ray sources. *Space Telescope* subsystems and instruments made progress in fabrication and assembly, but development was rephased to remain within fiscal 1980 and 1981 funding. The European Space Agency is providing the telescope's solar arrays and faint-object camera.

Most of the hardware was completed for the first-of-its-kind cryogenically cooled telescope the United States is providing for the Infrared Astronomical Satellite *IRAS,* a joint project with The Netherlands and the United Kingdom to study the cold infrared universe in 1982. Planning continued for the future Advanced X-ray Astrophysics Facility *AXAF,* to improve x-ray observations of the universe by 50 times the sensitivity of previous missions.

The Space Science Board completed recommendations for solar system space physics; explorations of asteroids, comets, and meteoroids; and gravitational physics. The National Academy of Sciences' Astronomy Survey Committee continued assessment of opportunities and requirements for the 1980s, nearing completion of an integrated space-and-ground program.

Research from Suborbital Vehicles. Aircraft, balloon, and sounding rocket investigations provided scientific data unobtainable in other ways, complementing the research on spacecraft missions. A wide-field ultraviolet imaging telescope designed to fly on Spacelab was flown on a sounding rocket, making the first wide-field images of our nearest spiral galaxy. A balloon-borne instrument made the first detection of an intrinsic, large-scale anistropy of the universe, suggesting that the universe became clumpy far earlier than previously thought. And a balloon-borne telescope provided evidence of large-scale star-forming areas in our galaxy.

Research from the Ground. Further observations appeared to confirm that twin quasars discovered in 1979 were actually produced by a single light source and thus do indeed represent a gravitational lens in action. Other research in 1980, supported by NSF, also advanced the gravitational lens theory; observations with the multiple-mirror telescope operated by the Smithsonian and the University of Arizona indicated that spectra of three close images were identical, evidence of a single light source for the triple image.

Study of Life Sciences

Better methods were being developed to monitor movements of the human heart, and simulated spaceflight furthered understanding of cardiovascular difficulties of the astronaut in the space environment. Physiologists also studied how the body senses the speed and motion that cause space motion sickness. In still another project, studies of animal vestibular apparatus revealed ionic shifts in fluid in the inner ear that may explain astronaut disturbances in spaceflight. Results from USSR studies continued to supplement U.S. work.

In 1980, a fully integrated prototype was completed of a system to recycle air in a spacecraft cabin, regenerating oxygen from carbon dioxide. Selection of proposals began for research into recycling wastes to regenerate food, air, and water for fully autonomous life support away from Earth.

Life science experiments for Spacelab 1, 2, and 3—to fly on the Space Shuttle—are in the hardware phase, and proposals were studied for Spacelab 4.

Transportation

Extensive research, development, and testing continued in 1980 toward new transportation systems and improved operations and flexibility of existing systems in the United States aeronautics and space programs.

Space Transportation System

An integrated approach to travel and exploration in space, the Space Transportation System—with its reusable earth-to-orbit Space Shuttle—is designed to provide efficient, economical, flexible access to space for NASA, DoD, and other domestic and international users of space. The STS includes the Shuttle's airplanelike orbiter that will carry crew and payload into orbit and return for reuse, two solid-fueled rocket boosters that fire during ascent and fall away for recovery and reuse, and the external tank carrying liquid oxygen and liquid hydrogen to fuel the orbiter's main engines. The first flight-configuration Space Shuttle was on the launch pad for early 1981 launch. Its first test flight would be the first U.S. manned spaceflight since 1975.

The European Space Agency is developing Spacelab, a variable combination of laboratory and instrument platform to fly into orbit in the Shuttle's cargo bay. DoD is developing the inertial upper stage to boost payloads beyond the reach of the Shuttle alone. And U.S. aerospace industries are developing "spinning solid upper stages" to boost smaller payloads into geosynchronous orbit.

Space Shuttle. The first flight orbiter, *Columbia*—mated to its rocket boosters and external tank in November 1980—was rolled out to the launch pad in December, where final testing proceeded toward a spring 1981 launch. The orbiter can carry crews of four to seven and up to 29 500-kilogram payloads—such as the laboratory or satellites to be put into orbit. It will return to land on conventional runways much as airplanes do. Follow-on production of orbiters *Challenger, Discovery,* and *Atlantis* was in progress.

More than 90 000 seconds of testing had demonstrated flight readiness of the main engine, actually a cluster of three engines. A major advance in propulsion technology, each engine has a rated thrust of 2 000 000 newtons (470 000 pounds) and a long operating life—the first liquid-fueled rocket engines designed for reuse for up to 55 missions.

The 46.8-meter-long external tank, containing more than 700 000 kg of propellants for the main engine, is the structural backbone of the Shuttle during launch. Just before entering orbit, the orbiter's main engines cut off and the tank separates from the orbiter and falls to break up over a designated remote ocean area. The first flight tank was mated to the orbiter and was on the launch pad at the end of 1980; the second was in final checkout; and five others were being manufactured. Work had begun on a lightweight tank, an improved design to save 2700 kg.

Four development and three qualification static-firings were completed on the solid-fueled rocket boosters, the largest to be flown and the first designed for reuse. The first flight boosters were mated with the external tank and the orbiter *Columbia*, to provide added thrust during ascent before descending by parachute for reuse.

Ground Facilities. Shuttle flights will be launched from Kennedy Space Center in Florida or Vandenberg Air Force Base in California, to meet NASA and DoD needs. At the end of 1980, all KSC facilities were ready for the first launch, and the computerized launch processing system had been used extensively for Shuttle testing. Vandenberg was scheduled to be ready for operations by June 1984. The mission control center and Shuttle mission simulator at Johnson Space Center were ready to support the first flight. Seven full-duration integrated simulations had been completed, besides shorter runs.

Planning for Operations. The first few years of Shuttle operations had been fully booked by U.S. civil and military agencies, domestic and foreign governments, and commercial users for a wide range of space activities. Nine additional commercial and foreign users in 1980 made payments or deposits on reservations. More than 300 small, self-contained, individual payloads had also been confirmed in NASA's program permitting individuals, educational institutions, and industries to use the Shuttle on a space-available basis at reasonable prices.

Spacelab. The orbital laboratory being developed by the European Space Agency to fit into the Shuttle cargo bay will provide access to space for scientists, engineers, and commercial users from many nations. It will offer a choice of a pressurized shirtsleeve environment for experimenters or a platform (pallet) to expose instruments to space. Design life is for 50, 7-day flights—although Spacelab can remain in orbit 30 days. The engineering model of Spacelab was delivered to KSC in December 1980. Processing and testing of the first flight unit and of the instrument pointing system for the pallet continued in Germany. A second pointing system was authorized for 1983 delivery. The JSC simulator was ready to train crews in 1983.

The first two payloads for Spacelab were integrated during 1980. OSTA 1, an applications payload for earth resource observations, will be the first to fly on the Shuttle. OSS 1, a space science payload, will study solar physics, the space environment near the orbiter, and thermal control. Development began on three additional missions for solar-array testing, materials experiments, and study of nonrenewable earth resources. Spacelab hardware will be verified on its first and second missions, and Spacelab 3 will be the first operational mission. Development of hardware for the first two flights neared completion in Europe and the United States, and integration was under way.

Inertial Upper Stage. The DoD-developed, solid-propellant, two-stage IUS—to be deployed from the Shuttle orbiter in low earth orbit—will boost DoD and NASA payloads primarily into geosynchronous orbits. DoD's development of the IUS is proceeding on a schedule for an early 1982 launch from the Titan launch vehicle and a late 1982 launch of the Tracking and Data Relay Satellite from the Space Shuttle,

Centaur. The Centaur upper stage is being studied for potential use with the Space Transportation System for planetary and heavier geosynchronous missions beginning in early 1985. Preliminary designs show an increase in size of the propellant tanks to add 50 percent more capacity (Wide-Body Centaur) and to make the stage compatible with the Shuttle.

Spinning Solid Upper Stage. U.S. aerospace industries continued work on two sizes of the SSUS, which they are developing at their own expense to launch smaller spacecraft from the Shuttle into geosynchronous-transfer orbit. SSUS-D is designed for satellites now using the Delta expendable launch vehicle, and the SSUS-A for those using the Atlas-Centaur. Designs have been completed and qualification begun. NASA has ordered the SSUS-A for Intelsat V missions, and commercial users are buying the SSUS-D from the developer.

Expendable Launch Vehicles. The United States space program totaled 12 successes in 15 launches in 1980. Two launches orbited multiple payloads, bringing total payloads in orbit to 16, 1 of which—launched by NASA for NOAA—failed to reach operational orbit because of a malfunction in the Atlas F launch vehicle. In addition, 2 DoD launches failed because of malfunction of a Thor and an Atlas E/F. Space launches this year used Atlas-Centaur, Atlas E/F, Delta, Thor, and Titan IIIB and IIID launch vehicles.

Research for Spacecraft Improvement

Research projects in a number of fields advanced the usefulness, performance reliability, and cost-effectiveness of space vehicles and operations.

Materials and Structures. During 1980, three new materials were adopted for the Shuttle orbiter's thermal protection system. One material is a gap filler with improved high-temperature stability. Another is a fibrous, refractory composite insulation with high-temperature resistance, high strength, and low weight. The third is a silicon-felt "blanket" for the upper surfaces of the Space Shuttle.

Experiments confirmed the predicted dynamic characteristics of a half-scale model of a deployable, 36-element, truss structure. Large-space-structure concepts for a hoop-column antenna and an electrostatic-membrane antenna were developed during the year.

The National Bureau of Standards was investigating two aluminum alloys used in the Space Shuttle to determine how variations in processing affect their microstructure and physical properties. Study of nondestructive evaluation procedures and other material parameters has already yielded information on physical properties—and thus the safety—of specific batches of alloy used in portions of the Shuttle.

Electronics. A NASA project completed first demonstration of autonomous "hand-eye" machine coordination required for robotic techniques in space assembly, inspection, and repair. The system picked up a single-crystal solar cell, inspected it, and placed it on a solar array. DoD fabrication of an autonomous navigation system for satellites neared completion.

Space Power. Development of a deep-discharge reconditioning technique in 1980 doubled the operational life of nickel-cadmium batteries, and NASA achieved the first solar pumping of a laser, which may lead to substantial progress in high-power transmission. Data from the Air Force test program's *Scatha* satellite launched in 1979 are updating preliminary models in the joint USAF-Navy-NASA spacecraft-charging technology program. DoD also demonstrated high-efficiency, radiation-hardened silicon solar cells and evaluated long-life, monopropellant thrusters.

Information Systems. A computer modeling and simulation capability that allows end-to-end simulation of NASA data systems became operational in 1980. Some 20 spacecraft were simulated and their critical performance computed.

Military and civilian aeronautical development programs continually seek to improve the nation's operational airborne and airway systems.

Operational Airborne Systems. In the United States national system of aeronautical transportation, DoD has responsibility for operational airborne systems.

BOMBER AIRCRAFT. Modifications under way to improve U.S. B-52 squadrons include incorporating nuclear-hardened digital subsystems into a modernized bombing-navigation system and adding the air-launched cruise missile (ALCM) with updated avionics. The first B-52 flight with the modified navigation system was made in September 1980, one month ahead of schedule. Tests were to end in September 1981, with the first full squadron scheduled for alert in December 1982. Congress has directed DoD also to develop a new multirole bomber, to be operational by 1987. It is to be able to launch cruise missiles, carry conventional munitions, and deliver nuclear weapons in both tactical and strategic roles.

TRANSPORT AIRCRAFT. A request for proposals was issued to industry in October for the C-X, an aircraft that can transport the oversize firepower and support equipment of a modern army over intercontinental ranges. Full-scale development was programmed for the summer of 1981.

HELICOPTERS. The advanced attack helicopter (AAH) was in the final stage of full-scale engineering development. All prototype helicopters were modified for new target-acquisition designation sights, pilot-night-vision sensors, stabilators, and other changes, and operational tests were to begin. The Army was assessing effects of the loss of one prototype in a fatal collision in flight in November. Full-scale production of the CH-47D beginning in 1981 was authorized; the entire CH-47 fleet will be modernized to give the Army a medium-lift helicopter to serve into the year 2000. The first complete unit of 24 helicopters was planned for early 1984.

REMOTELY PILOTED VEHICLE (RPV). The small, unmanned, Army air vehicle RPV will perform target-acquisition, aerial-reconnaissance, and artillery-adjustment missions. Full-scale engineering development, begun in 1979, continued into 1980, with first flight scheduled for August 1981.

CRUISE MISSILES. Boeing Aerospace Company's AGM-86B air-launched cruise missile was selected for production after a 1979 competitive flyoff. Boeing was given a fiscal 1980 contract for 225 missiles with an option for 480 more in fiscal 1981, and the Air Force planned to buy some 3000 for use on B-52G aircraft during the 1980s. First alert capability of one B-52G with 12 ALCMs was scheduled for September 1981, and the first full squadron by December 1982. Development continued on the Tomahawk, a high-subsonic, turbofan, long-range missile to be fired from a submarine torpedo tube but also launchable from surface ships, aircraft, and mobile ground platforms. It is being developed in a conventionally armed antiship version and in nuclear and conventionally armed land-attack versions. The ground-launched cruise missile (GLCM) will integrate the Tomahawk into an air-transportable ground-mobile system. The first launch of a Tomahawk from an engineering test unit was in May 1980, and operational capability was planned for 1983.

Operational Airway Systems. The Federal Aviation Administration (FAA) of the Department of Transportation is responsible for the safety of air operations on the nation's airways, operation of a common system of air navigation and traffic control for civil and military aviation, promotion of aviation security, development of an effective national airport system, and ensuring to the fullest extent possible compatibility of air operations with the environment. Many FAA research, development, and engineering programs are conducted with other agencies, including the Department of Commerce, NASA, and DoD.

AIR SAFETY. FAA undertook a number of joint aviation safety initiatives during 1980. One was a study with the U.S. Army of helicopter icing; another, a survey with the Canadian government of helicopter certification requirements in IFR operations. In still another, FAA, NASA, and DoD worked together on the choice of future flight systems.

The final report of the Special Aviation Fire and Explosion Reduction (SAFER) Advisory Committee examining the factors affecting the ability of aircraft cabin occupants to survive after a crash was received late in the year. It held that FAA's efforts to develop an effective antimisting kerosene (AMK) technology could well prove to be the single most significant safety action it could take to reduce post-crash fires. It made other recommendations on the design of fire-resistant fuel tanks and procurement of fire-resistant cabin interior materials.

FAA's predeparture screening program to deter acts of terrorism and sabotage aboard transport aircraft was soon to be supplemented by automatic devices to detect explosives hidden in lockers, checked baggage, cargo holds, and cargo compartments. Development and testing of advanced technology x-ray, thermal-neutron-activitation, nuclear-magnetic-resonance, and electronic-vapor-explosive detection devices was pursued during the period. Several of the new automatic devices were expected to be operating in 1981.

AIR TRAFFIC CONTROL. Among new air navigation and traffic control systems, the microwave landing system (MLS) was accepted by the International Civil Aviation Organization in 1978 as the international standard. Testing and demonstration of three versions continued during 1980, as well as collection of operational data for handbooks and flight instruction. The discrete-address beacon system (DABS), to become FAA's primary automated tracking system, was nearing the procurement stage at the end of the year. A unique-identity code for each transponder-equipped aircraft ends overlapping and garbling of replies from aircraft flying near each other. The direct-access radar channel (DARC), expected to be in commission by mid-1981, was developed to take over when computers fail; it will provide controllers automatic information on aircraft identity and altitude.

Research for Aeronautics Improvement

NASA and DoD completed some projects, continued others, and began new ones to improve performance, energy efficiency, environmental compatibility, and safety of future civil, military, and general-aviation aircraft.

Engines. NASA continued to demonstrate fuel-conserving and derivative commercial turbofan engines while investigating causes of engine performance deterioration. Industry has committed seven improved engine components to production. NASA also explored the technology base for next-generation, high-bypass-ratio, turbofan engines with low fuel consumption, higher performance retention, and reduced operating costs.

Aerodynamics. The joint NASA-USAF flight-test program evaluating winglets on a KC-135 tanker aircraft was completed in 1980. Test results substantiated a predicted 7.1-percent reduction in cruise drag over that of an unmodified KC-135.

Low-Speed Aircraft. The XV-15 tilt-rotor program completed flight-envelope-expansion tests, reaching a maximum speed of 555 kilometers per hour, with government acceptance of the second aircraft scheduled for 1981. Pilot evaluation of the versatile, vertical- or short-takeoff and landing aircraft in the joint NASA-Army-Navy program has been favorable in all flight modes.

Structures. NASA made progress toward validating structural characteristics and fabrication technology of low-weight composite structures for commercial transports. FAA certification requirements were completed for composite elevators for the B-727 transport, the first composite horizontal stabilizer for the B-737 was flown in late 1980, and the first full-scale composite aileron for the L-1011 was fabricated. Air Force wind-tunnel tests demonstrated that aeroelastic tailoring with advanced composite material can control the behavior of a wing under a broad range of flight conditions. And contracts are to be awarded in 1981 to develop, fabricate, and test airframe sections and then a complete helicopter incorporating advanced structural concepts and composite materials.

Improvement of Long- and Short-Haul Aircraft. NASA research for future long-haul supersonic aircraft focused on aerodynamics, structures, propulsion, and propulsion-airframe integration required for a cost-effective, environmentally acceptable aircraft. In propulsion, engine tests demonstrated near-prediction noise benefits for the variable-cycle engine concept. Wind-tunnel tests of an axisymmetric, translating, centerbody engine inlet provided major improvements in advanced analytical processes and computational procedures for off-design performance. NASA continued to investigate the oblique-wing concept for low-supersonic-speed aircraft, using the AD-1 research vehicle. NASA also demonstrated the very low noise of its quiet short-haul research aircraft (QSRA). In a joint program with the Navy, the QSRA demonstrated catapult-free takeoffs and precision, unarrested landings on the Navy carrier *Kitty Hawk*.

General Aviation. NASA's major efforts included flight research into the causes of light-aircraft stalls and spins, crash survivability by means of aircraft energy-absorbing structures and impact load-limiting seats, improved fuel efficiency of engines, and increased flight efficiency of aircraft designs. It also demonstrated a low-cost, low-maintenance automated pilot advisory system (APAS), which improves traffic flow and safety at airports that do not require tower control.

Environmental Research. FAA's High-Altitude Pollution Program (HAPP) reported findings that large-scale aircraft operations in the stratosphere did not reduce atmospheric ozone. An earlier DOT study had found that they did. HAPP will continue the study to resolve the conflict.

Space Energy

Radioactive-isotope-decay energy for satellites and interplanetary probes, solar-cell technology, and ways to use solar energy in space and on the earth are continuing subjects of research and development.

Energy for Use in Space

Radioisotope Generators. The Department of Energy's improved heat-source materials and components entered production for a new radioisotope thermoelectric generator for NASA's planned Galileo mission to Jupiter. And DOE completed the preliminary design for a general-purpose heat-source RTG to be used for Galileo and also for the planned NASA-ESA International Solar Polar Mission. Technology verification continued for the dynamic isotope power system for possible use in DoD space missions.

Space Reactor Technology. Development of component technologies and test facilities continued in 1980 to establish a technology base for a high-temperature, compact, nuclear-electric reactor system producing power of 10 to 100 kilowatts. The future system is expected to be capable of supplying power for a space-based radar spacecraft, electric mail systems, advanced television, holographic teleconferencing, and other civilian and military uses.

Energy for Use on Earth

Satellite Power System. NASA completed an investigation of technology demands and opportunities in beaming solar energy from a position in space to antennas on the earth, as part of a NASA-DOE study. Reports and recommendations were being prepared. A research program focusing on critical areas, as well as studies of improved concepts, was being considered.

Solar Thermal Electric Conversion. One of the reimbursable programs managed by NASA for DOE investigates parabolic reflector systems that concentrate solar energy to produce heat or electricity. Several concentrator systems capable of producing up to 1 million watts of electric power have been defined by studies and technology demonstrations. Testing of two experimental parobolic concentrators began during 1980.

Solar Heating and Cooling. NASA supports DOE in demonstrating selected active solar-heating-and-cooling systems. During 1980, 55 of 120 installations in commercial buildings were completed. The remaining sites were scheduled to become operational in 1981.

Terrestrial Solar-Cell Development. NASA is also supporting DOE in the development of low-cost, long-life photovoltaic modules for large-scale terrestrial production. In 1980, major advances were made in developing production processes for advanced silicon material, to reduce the costs of solar-cell power systems.

National Aeronautics and Space Administration

The National Aeronautics and Space Administration (NASA) is responsible for planning, directing, and conducting civil research and development in space and aeronautics. A number of other federal, state, local, and foreign governments share in these activities. The Department of Defense (DoD) conducts space activities that are solely military; in aeronautics, NASA supports DoD with research and test data.

NASA's long-standing goals in space have been to develop technology to make space operations more effective; to enlarge the range of practical applications of space technology and data; and to make scientific investigations of the earth and its immediate surroundings, the natural bodies in our solar system, and the origins, entities, and physical processes of the universe. In aeronautics, the goal has been improving aerodynamics, structures, engines, and overall performance of aircraft, to make them more efficient, more compatible with the environment, and safer.

Applications to the Earth

NASA programs made substantial progress in 1980 in applying space research and technology to specific needs of the nation and the world. Emphasis continued on improving technology for space communications, observing the earth to assess its environment and resources, and experimenting in space to acquire new knowledge about materials.

Communications

The NASA communications program, which was largely restructured in 1979, continues to focus on relief of orbit and frequency congestion and on maintaining the competitive position of U.S. industry in the communications markets of the world. Principal components of the program include advanced research and development, public service communications development, development and support of U.S. positions in international and national regulatory organizations, and data system development.

Advanced Research and Development. NASA-sponsored studies in 1979 predicted that, with present technology, satellite communications capacity at the C and K_u frequency bands will be saturated in the early 1990s. A preview of the congestion of the geostationary arc in the next decade was provided during 1980 when competing applications were filed for six different locations along the Western Hemisphere segment of this arc. Several studies have shown that future growth is most readily accommodated by starting operation in a new frequency band (K_a, 30 to 20 gigahertz) with high-capacity satellites employing new technology.

During 1980 NASA began studies to develop and refine concepts for such future systems and awarded 12 technology development contracts for major subsystems. The data and hardware from these contracts will provide a foundation for designing future advanced communications satellite systems.

Public Service Communications Development (including Search and Rescue). NASA continues to conduct important public service communications experiments with *ATS 1* and *ATS 3* satellites. Launched in 1966 and 1967, these satellites continue to provide highly useful services.

In the U.S., *ATS 3* is supporting emergency medical experiments in conjunction with the Southern Regional Medical Consortium (SRMC) in Alabama, Louisiana, and Mississippi. Some 25 000 medical emergencies occur each day in the United States, nearly 40 percent of them in rural or isolated areas. Major experiments include fast response to trauma and cardiac cases among the 60 000 oil-rig workers stationed up to 160 kilometers off shore in the Gulf of Mexico, and movement of the critically ill who may be up to 240 kilometers from specialized medical treatment.

The most recent and dramatic use of *ATS 3* was in May 1980 in connection with the eruption of Mount Saint Helens in Washington. After the eruption, communications for search and rescue operations and disaster assessment were critical needs. Local power and telephone lines were destroyed or out of service and conventional mobile radio equipment in the remote and mountainous region was severely limited in range. Emergency personnel were unable to communicate with each other.

The day after the eruption, an Air Force communications jeep equipped to operate with *ATS 3* was flown to the disaster site. General Electric Company provided personnel and an *ATS 3* base station in New York. This system permitted emergency personnel throughout the disaster area to communicate with each other and coordinate all emergency activities.

In the Pacific basin, *ATS 1* supplies communications services (disaster relief, medical, and educational services) in Fiji, Western Samoa, and many other South Pacific islands. When sea waves swept over the island Majuro in November and December 1979, leaving 4000 persons homeless, the 13-year-old *ATS 1* satellite was the principal communications channel for coordinating relief operations.

The satellite-aided search and rescue program to locate crashed aircraft and ships in distress is projecting start of a first full field test in mid-1982. The host NOAA spacecraft will be completed by the United States, and the search and rescue subsystems have been delivered by the French and Canadian partners in the program. Ground stations to process the search and rescue signals will be delivered in late 1981.

International and National Regulatory Organizations. NASA's technical consultation and support (TCS) program played an important role in developing U.S. positions at the 1979 World Administrative Radio Conference (WARC). These U.S. initiatives resulted in WARC approval of more than 50 frequency allocations for remote sensing and in provisions permitting satellite land-mobile communications in the 806- to 890-megahertz band. The international decisions led in turn to beginning the U.S. national regulatory process implementing them, including ratification of the final acts of the WARC and the domestic rule-making procedure. The TCS program is participating in preparation of the national radio regulations and has provided major position papers as part of this process.

During 1980, NASA began technical and regulatory support for a possible program to provide a capability for multiservice, thin-route, narrow-band services by satellite. The postulated system, augmenting terrestrial land-mobile communications in the 806- to 890-MHz band, could meet many public and private-sector, thin-route, communications needs.

Data Systems. In 1980 NASA established in-house pilot projects at three field centers to support requirements for atmosphere, ocean, and earth resources data systems. The pilot projects are serving as test beds to develop and evaluate potential data and data-system standards; to evolve common system approaches to inventorying, cataloging, and managing space applications and related data; and to develop transportable data-handling software systems for multidisciplinary research.

When interconnected through commercially available network services in 1982, these pilot data systems will form the nucleus of an evolutionary Applications Data Service by providing remote electronic access to distributed space applications data catalogs and data bases.

Environmental Observations

Upper Atmosphere. Progress was made during 1980 in monitoring and assessing the upper atmosphere. One purpose is to understand the chemistry, radiation exchange, and dynamics of the atmosphere well enough to predict the effect of human activities on this region.

NASA's present estimate that man-made chlorofloromethanes will reduce total ozone in the ozone layer 14 to 18 percent by about the year 2050, is consistent with the 16-percent reduction estimated by the National Academy of Sciences. The roles of water, nitrogen oxides, and chlorine in ozone formation and reduction are now better understood and the importance of other species is being assessed.

New laboratory and field measurement techniques have enhanced understanding of ozone chemistry. Two remote-sensing techniques, far-infrared-emission spectrometry and laser heterodyne radiometry, have been used to measure chlorine oxide and hydrogen peroxide, which play vital roles in catalytic ozone cycles.

Global ozone data from a seven-year span are now available from the *Nimbus 4* backscatter ultraviolet (BUV) instrument. Data from *Nimbus 7*'s scanning BUV and total ozone monitoring spectrometer and its limb-infrared monitor of the stratosphere are being processed. These measurements of temperature, ozone, water-vapor, nitric acid, and nitrogen dioxide will help determine global and diurnal variability and will aid in establishing the effects of the oxides of nitrogen on ozone.

The precision of satellite ozone measurements was evaluated during the past year, the United States and four other countries making rocketsonde comparisons of several sensors used for "ground truth" testing of satellite data. The profiles and vertical distribution showed good agreement.

Transport of atmospheric constituents may be studied using stratospheric wind fields from temperature maps obtained from the *Nimbus 6* limb-radiance inversion radiometer and *Nimbus 7* sensors. The maps compare well with those derived from rockets and cover much greater space. The analyses indicated the variability in winds as determined by altitude and latitude.

The dispersion of the material from the eruption of Mount Saint Helens demonstrated the importance of wind transport in the stratosphere, as observed by both aircraft and the stratospheric aerosol and gas measurement experiment (the *Sage* satellite launched in February 1979). Information on the movement of volcanic ash permitted predictions of ash fallout, cloud formation, and the effect on atmospheric ozone.

A Shuttle mission in 1984 will carry the atmospheric trace molecules observed by spectroscopy experiment (ATMOS), to establish a data base from which to measure long-term changes in the stratosphere. During the past year the ATMOS interferometer system was successfully tested.

Studies using dedicated space platforms with supporting ground, aircraft, and balloon investigations form the next step in examining the ozone layer. Planning continued on the Upper Atmospheric Research Satellites (UARS) program. The program will make integrated, comprehensive, long-term measurements of the key parameters and will improve ability to predict stratospheric perturbations. Tentative payloads for the UARS system have been selected, and experimental and theoretical investigators have been chosen.

Tropospheric Air Quality. NASA worked with the Environmental Protection Agency (EPA) to improve understanding of pollution events in the lower atmosphere. The two agencies jointly studied persistent events of elevated pollution over the Ohio River Valley and polluted air movement in the Northeast.

Three instruments—the high-spectral-resolution lidar, the ultraviolet-differential-absorption lidar (UV-DIAL) system, and a laser absorption spectrometer—were flown on aircraft to determine mixing-layer height, ozone, and aerosol concentration profiles; aerosol optical properties; and total ozone below the aircraft. The UV-DIAL measures the differences in light absorbed at different levels in a column of air, producing an ozone profile in one measurement. The sensor, flown on aircraft, has produced the first regional measurements of tropospheric mixing-layer heights, essential components of air-pollution transport models.

Global Weather. NASA continued to work with the National Oceanic and Atmospheric Administration (NOAA) to improve weather forecasts by advances in modeling, simulations, and technology for observations. NASA participates in the Global Weather Experiment (GWE), whose goals are to identify parameters for an international observing system and to define a basis for improving present forecast capabilities.

The year of international observation ended in November 1979, with the largest set of atmospheric observations yet attempted. Inclusion of satellite data to begin numerical weather-prediction models has shown dramatic improvement in selected two- to five-day forecasts. By collecting data over other data-sparse areas such as the oceans, satellites can contribute information essential for an accurate weather forecast.

The importance of the tropics' and Southern Hemisphere's influence on global circulation and weather was demonstrated by GWE observations. GWE data have shown that intermittent energetic outbursts of air originating in the Southern Hemisphere cross the equator and alter the mid-latitude weather in the Northern Hemisphere within several days. Observation of the tropical areas appears to be a prerequisite for improvement in the short-term forecast.

Full weather coverage is now provided by the combination of *Tiros-N* and *Noaa 6*. The operational meteorological satellites of the *Tiros-N* series have already significantly improved global weather prediction. With its Tiros operational vertical sounder system—which consists of an infrared tropospheric sounder, an infrared stratospheric sounder, and a microwave sounder—the series is providing quantitative observations of the structure of the atmosphere with accuracy and reliability superior to any previous remote-sensing system. The inclusion of these data in numerical forecast models has improved accuracy where the conventional radiosonde network does not obtain data: over the oceans of the Northern Hemisphere and over both oceans and continents of the Southern Hemisphere.

Severe Storms. NASA, working with NOAA, proceeded with a pilot project, the Centralized Storm Information System (CSIS) at the National Severe Storms Forecast Center (NSSFC) in Kansas City. Reception time for satellite images has been decreased from 45 minutes to 6. In about one year, NOAA will be able to receive and overlay all available weather observations, maps, images, forecasts, and analyses on computerized video terminals for quick reaction to developments in severe storms.

Another development is the visible infrared spin-scan radiometer (VISSR) atmospheric sounder (VAS) launched in September on *Goes 4*. The instrument provides temperature and moisture profiles more frequently than the earlier VISSR, thus improving regional and local weather forecasts.

Oceanic Processes. Satellite observations and their derived products continued to provide valuable information for both the scientific oceanographic community and commercial marine industries. Efforts last year were directed toward proving the capability to measure winds, waves, and surface temperatures from remotely sensed oceanic data.

Instruments on GEOS, *Seasat*, and *Nimbus 7* satellites have all yielded useful products. The *Seasat* scatterometer has proved its utility by providing quantitative surface-wind-speed measurements, an improvement over inferring surface winds from the motions of cloud patterns.

The radar altimeter has proved accurate and versatile. New uses for its data are continuously being discovered, including the mapping of circulation features such as the Gulf Stream and cold core rings and the mapping of coastal tides. Ice charting from space, which has many commercial applications, has been demonstrated with the radar altimeter, microwave radiometer, and the synthetic-aperture radar.

Climate. NASA's role in the National Climate Program is to apply space technology to understand large-scale seasonal and interannual climate fluctuations with specific focus on the role of the earth's radiation budget. During the past year, NASA was assigned lead responsibility for coordinating the program's principle thrust on solar and earth radiation.

Development of the earth radiation budget experiment (ERBE) is well under way. An experiment team—with members from NASA, NOAA, the academic community, and several foreign countries—is responsible for software development, data validation, ground-truth observations, and initial scientific analyses of the ERBE data. Three instrument sets will be launched from 1983 to 1985, two on NOAA sun-synchronous satellites and one on a dedicated NASA free-flyer. Ground data-processing and software development have been under way for the past two years. The contractor for the NASA spacecraft, to be called ERBS, has been selected.

The dedicated NASA satellite will also carry the halogen occultation experiment (HALOE) to measure the upper-atmospheric ratio of hydrogen fluoride, a man-made chemical, to hydrogen chloride, a chemical that occurs both naturally and as a result of human activities. The measurements will help determine the extent of the release into the atmosphere of man-made substances that can destroy ozone.

In addition to monitoring the eruption of Mount Saint Helens, the stratospheric aerosol-gas experiment satellite *Sage* observed the Sierra Negra volcanic eruption in the Galapagos Islands in 1979. This explosion received little publicity, but *Sage* found that it had injected 10 times the amount of material into the atmosphere as had La Soufrière, also observed by *Sage*. In the short run, large volcanic eruptions are believed to cause more significant changes in global surface temperatures than do increases in carbon dioxide.

Resource Observations

Renewable Resources. Research and development pertaining to renewable resources has focused on acquiring, processing, analyzing, and using remotely sensed data to improve the management of the nation's agriculture, forest, range, land, and water resources.

The Agricultural and Resources Inventory Survey through Aerospace Remote Sensing (AgRISTARS) completed its first year in 1980 as an interagency effort of NASA, USDA, NOAA, DOI, and AID (see Department of Agriculture section). NASA is responsible for selected research and development, exploratory and pilot testing, and support in areas where it has specialized capabilities. It serves as lead agency for two of the eight major projects in the six-year program: the Supporting Research project and the Foreign Commodity Production Forecasting project.

The Supporting Research project researches and develops improved remote-sensing techniques for crop identification and development stage assessment, crop area estimation, yield modeling, crop stress assessment, and soil delineation. A major accomplishment during 1980 was the development and successful testing of an improved technique for estimating the area planted in specific crops over a large geographic region. Additionally, a method to extend point meteorologic-station measurements of precipitation and temperature geographically for input to yield models was developed, and an inexpensive radiometer was developed to obtain improved spectral measurements of crops in the field. The technical advances will benefit all of AgRISTARS' projects, but the research tasks are primarily intended to support the Foreign Commodity Production Forecasting (FCPF) project.

The FCPF goal is to develop and test aerospace and related technology for more reliable crop production forecasts in foreign countries, specifically for wheat, barley, corn, soybean, and rice grown in Canada, USSR, Australia, Brazil, Argentina, and India. During 1980, two exploratory experiments were completed, developing, assessing, and integrating components of a production forecasting system in U.S. regions where confirming ground-reference data are available. One experiment forecast wheat and barley production in the Great Plains; the other, corn and soybean production in three corn belt states. Crop-area estimates obtained by old and new procedures are being compared over a variety of test sites. Accuracy assessment techniques are also being developed for foreign areas where ground-reference data are not available. These preliminary efforts will lead to pilot experiments in 1981 to demonstrate techniques emerging from the exploratory experiments in U.S. regions similar to the foreign areas of interest. Demonstrated technology and results will be evaluated by USDA for large-scale-application tests in foreign countries.

Application pilot tests (APTs) are cooperative projects to develop, test, and transfer remote-sensing technology that has validity for research but requires further development for operational use. Three APT projects completed in 1980 put Landsat digital image-processing and information systems into operation in the St. Regis Paper Company's Southern Timberlands Division, the Bureau of Land Management Denver

Service Center, and the Navajo Nation Department of Natural Resources.

Two APTs are continuing into fiscal 1981. The first, in cooperation with the California Department of Water Resources, tests the use of Landsat data to inventory irrigated lands for water management. The second, in cooperation with Cotton, Inc., tests the use of Landsat data to measure areas planted in cotton.

Three APTs were begun during 1980. A project with the Pennsylvania Department of Environmental Resources will develop and test the use of Landsat data for monitoring defoliation of hardwood forests by insects. NASA has begun cooperation with the U.S. Geological Survey to develop and test Landsat technology for mapping irrigated cropland on western acquifers. The third new project is to develop and test a geographic information system based on Landsat data for the Missouri Farmers' Association, to provide timely information for commodity storage, distribution, and marketing decisions.

Nonrenewable Resources. Working with representatives from mineral and energy industries, government agencies, and the academic research community, NASA has reoriented the nonrenewable resources program. In the past this research program primarily emphasized remote-sensing techniques in the visible and near-infrared portions of the electromagnetic spectrum for mineral and hydrocarbon exploration. Future emphasis will be on a broader range of techniques and phenomena.

The *Magsat* mission, completed in 1980, obtained the first global measurements of the earth's vector magnetic field, exceeding mission objectives in volume and quality of data collected. A group of domestic U.S. and foreign investigators are analyzing the data to relate observed variations in the strength and direction of the earth's magnetic field to internal earth processes (such as circulation in the core and convection in the mantle) and to the structure and composition of the earth's crust. Improved crustal models based on analysis of *Magsat* data are expected to contribute new geological insight into the subsurface structure of mineral frontier regions in the arctic, Africa, and South America.

Landsat-D. The Landsat-D program took on new tasks and new significance from the decision in 1979 to create an operational land-observing system, for which NOAA is to have management responsibility. After the checkout period, the satellite and ground system assets of the Landsat-D program are planned to be transferred to NOAA as the core of the initial operating capability.

A new schedule has been developed around the need to launch the satellite at the earliest time the instruments and the ground system can be ready. The standard multispectral scanner and the new and much more capable thematic mapper have made good progress during the year and will be ready for launch in the third quarter of 1982, when the new ground facilities will be ready to receive and process data.

The thematic mapper instrument will provide data in several additional spectral bands and will have better than twice the resolution of the multispectral scanner, which is the main element of the present experimental capability. Much of the research program in both renewable and nonrenewable resources requires data of the quality to be provided by this mapper. After an experimental period, data from the new instrument will be available through NOAA to satisfy a large number of urgent user requirements.

Landsat Operations. A major portion of the past year's effort has been devoted to ensuring continuity of remotely sensed data for researchers and operational users. Requests for Landsat data during 1980 again reflected increasing worldwide interest in applying the technology to environmental and resource-management problems. Landsat ground stations in India and Australia began receiving test data in 1979 and became operational in 1980. Argentina's station was completed early in 1980 and is now receiving test data. Thailand has requested construction bids for a station. A memorandum of understanding was signed with the People's Republic of China, which is to purchase a Landsat-D ground station from U.S. industry under the United States-China understanding of 31 January 1979.

A memorandum of understanding with South Africa was also signed in 1980, and the station near Johannesburg is now receiving test data. Ten Landsat receiving stations in nine other countries are active. Chile, Kenya, New Zealand, Romania, and Upper Volta have expressed interest in receiving capability. Requests for coverage from other countries continue at a high level. Among users in the United States, the largest demand is for agricultural studies, especially during the growing season when repetitive coverage in nine-day cycles and rapid data delivery offer successful crop monitoring and yield prediction.

Geodynamics

The goal of the geodynamics program is to advance understanding of the solid earth by the application of space methods and space technology. The major objectives are to support the national and international program of research in geodynamics and to study dynamic processes related to the occurrence of earthquakes, thereby supporting the national program in earthquake hazard reduction.

In support of this program, laser ranging to the moon and to artificial satellites equipped with cube corner retroreflectors, as well as very-long-baseline interferometry (VLBI) using signals from radio stars, measures position and change in position with time to accuracies not possible with conventional geodetic methods. Information derived from these measurements is being analyzed to study tectonic plate motion, internal plate deformation, regional crustal deformation in tectonically active regions, and polar motion and earth rotation.

During the past year, NASA, NOAA, Geological Survey, National Science Foundation, and the Defense Mapping Agency concluded geodynamic studies, and a Crustal Dynamics Project Office was established at Goddard Space Flight Center. VLBI measurements in Southern California in late 1979 and early 1980 detected for the first time an unusually large and rapid aseismic crustal movement. Analysis of laser ranging data taken regularly since 1972 has established the relative contemporary motion between the Pacific and North American plates at their boundary along the San Andreas Fault in California as between 7 and 11 centimeters a year. In 1980, initial measurements were made of several baselines from the eastern United States to VLBI stations in Germany and Sweden. Measurements are planned at regular intervals to detect the separation of the Eurasion and North American plates. In addition, VLBI measurements between the East and West Coasts of the U.S. were continued. Analysis of four years of observations for those baselines has established an upper limit on internal deformation of the North American plate at one centimeter a year. The transportable laser ranging station (TLRS), built by the University of Texas at Austin, was deployed in California to extend the earlier measurements and to begin an intensive program of measuring crustal deformation.

The International Astronomical Union's Measurement of Earth Rotation and Intercomparison of Techniques (MERIT) program began. Laser and VLBI observations obtained by NASA and institutions in other countries will be compared with satellite doppler methods and conventional optical star techniques. This effort will eventually lead to a new and more accurate global operational system for monitoring polar motion and earth rotation.

An engineering unit of the satellite-emission, radio-interferometric, earth-surveying (SERIES) receiver was completed and tests begun. SERIES uses radio signals from the Global Positioning System (GPS) satellites and is being developed to demonstrate a new technique for accurate geodetic measurements using a VLBI mode. In a related effort, studies of an airborne laser ranging system were begun. Both systems are unique in that they could be deployed rapidly to capture co-seismic and post-seismic motions associated with a major earthquake.

Materials Processing in Space

Materials processing in space has advanced on all projected fronts: science, technology, hardware, operations, and plans. NASA has pursued a broad research base for the science and technology of materials processes, with emphasis on crystal growth, solidification, fluids, and containerless studies. The fluid-experiments-system, vapor-crystal-growth experimental facility—for use with Spacelab and the Space Transportation System for orbital materials research and processing applications—progressed through critical design review. The space-processing applications rocket SPAR made three sounding flights carrying a total of 11 experiment payloads. Other ground-based experiment facilities, such as drop tubes and parabolic-trajectory aircraft, tested solidification phenomena and containerless positioning. In program planning, NASA added new disciplines and began advanced concept studies in both payload systems and future applications.

To improve plans and develop further approaches consistent with the emphasis on advanced ground-based research, NASA has continued to work with its advisory committee of distinguished materials scientists. Theoretical work during the past year has identified a new, unstable, fluid dynamics mechanism of importance to crystal growth and to solidification processes. This mechanism normally prevents the formation of uniform compositions in earth-surface processes, especially highly concentrated solid-solution crystal growth, when density gradients due to temperature and composition are present simultaneously. Calculations during the year indicate that this unstable behavior can be eliminated in reduced gravity. In other work, the preparation of new composite metal structures, from a class of alloy systems known as monotectics, is being pursued. In particular, new droplet migration phenomena have been revealed as significant at low gravity. The phenomena occur when there is disturbance of the uniform distribution of the second-phase materials that are responsible for the desired properties. Also of importance to crystal growth is work in floating-zone methods, which has developed new approaches to characterizing melt surfaces and their motions. These results should serve as a basis for developing techniques to inhibit surface-induced convection effects in floating-zone processes.

In containerless processing, extensive research has been carried out on a variety of positioning force fields and on novel methods to use them to manipulate, study, and process materials. Electromagnetic positioning fields have been studied for application to nucleation (solidification) behavior of metals, to thermophysical properties of high-melting-temperature materials, and to high-coercivity magnetic alloy systems. Extensive research has been performed on acoustic fields that will permit optimum access to the material being processed and yet retain positioning stability over a wide range of sample temperatures. Possible applications include glass formation (for lightwave communications) and glass shell production (for power systems using laser fusion). Electrostatic positioning and deflection fields permit studies of the fundamental oscillation and vibration modes in (charged) drops of fluid.

Of special note is the formation of the Materials Processing Center at the Massachusetts Institute of Technology. The center is devoted to establishing a multidisciplinary research base for materials processes and will deal with issues such as process dynamics, automation, control, and adaptation to constraints on energy, economics, and environment, as well as system engineering approaches to the management of national materials problems.

Advanced technology development is necessary in every facet of the program. Specific results to date include measurements on transparent models that permit quantitative interpretation of convection in fluids during crystal growth. Another example is a quantitative study of wave-guiding phenomena and nonlinear streaming effects in acoustic-positioning-system configurations. Electrophoretic separators, used in the purification of biological materials, are also being designed for possible use in a zero-g environment, where the absence of convective stirring should increase efficiency.

Technology Transfer

To assist in making NASA technology available to a wide range of users, the technology transfer program maintains two-way links with a variety of communities. The users articulate information needs, and NASA identifies and transfers applications technology to meet these needs. Cooperative projects with the National Conference of State Legislatures and the National Governor's Association emphasize remote sensing (from the Landsat satellites) for meeting the needs of state government. Programs are carried out through the applications systems verification and transfer program, the regional remote-sensing applications program, and the university applications program.

The primary mechanism for transferring Landsat technology to state government users has been the regional remote-sensing applications program. NASA regional centers at Ames Research Center, National Space Technology Laboratories, and Goddard Space Flight Center have worked with states to apply Landsat technology to resource management activities. In 1980, 408 agency members had "hands-on" experience in Landsat processing and analysis. Joint Landsat applications projects were completed in 13 states, and new projects were begun in Arkansas, Illinois, Maine, Montana, and Washington. Computer systems and software to process Landsat data were installed in state agencies or supporting universities in Montana, Iowa, Minnesota, Kentucky, Maryland. Through 1980, more than 1500 state agency employees have been trained in 43 states, joint application projects have been conducted in 40 states, and 16 states now have the capability for computer processing and analysis of Landsat data.

Similar transfer mechanisms were begun with local government organizations in 1980. Through the user requirements and awareness program, cooperative projects are now under way with the National Association of County Officials and the Southeastern Michigan Technical Assistance Program. County officials will provide information to NASA, the administration, and Congress on county interests and needs in the same manner that has proved successful in projects with state governments. Environmental Research Institute of Michigan and local community colleges transferred Landsat applications technology to users through a network of community colleges. In 1980, low-cost, interactive computer terminals were placed in three community colleges in southeast Michigan for short courses on Landsat processing and analysis offered to local business and government. The project will be completed in 1981. If the concept proves successful, the project could be expanded to a national network of community colleges.

Science

The NASA space science program seeks to understand the origin and evolution of the universe, origin and distribution of life in the universe, and dynamic processes that shape the earth's environment. The program also uses space technology and research to advance knowledge in medicine and biology.

Study of the Sun and Its Effects on Earth

International Sun-Earth Explorers. Results from the *ISEE 3* spacecraft, in a "halo" orbit between the earth and sun outside the earth's magnetosphere since late 1978, have improved understanding of the solar wind. The temperature of solar coronal holes has been measured at 3.5 million kelvins using the ratio of charge states of atomic oxygen, O VI and O VII. Short-term fluctuations of the ratio of helium-4 to helium-3 have been found highly variable. Values as high as the 1000–5000 range have been found during quiet conditions, in contrast to 2250–2450 measured by foil on Apollo missions, but they can fall as low as 20 when the sun is active. *ISEE 3*—with *ISEE 1* and *2*, which followed a common trajectory traversing the bow shock region—has completed the primary mission objectives of determining the thickness of the bow shock and the changes induced by solar wind fluctuations.

In addition, *ISEE 3* has observed electrons that carry energy from the earth's bow shock toward the sun. Although the earth's magnetic field diverts most of the solar wind, some interacts, producing plasma waves; some transfers energy inside the magnetosphere; and some is hurled back toward the sun.

Solar Maximum Mission. The *SSM* was the most important achievement of 1980 in NASA's solar and heliospheric physics program. The 2300-kilogram spacecraft, launched from Kennedy Space Center on a Delta rocket 14 February 1980, was placed in the desired 570-kilometer-high orbit and has been operating well ever since. Its prime objective is to study solar flares and other solar activity during the current peak of the 11-year sunspot cycle.

Seven instruments on this spacecraft observe flares in wavelengths, or "color," ranging from visible light to the very highest energy gamma rays, which are produced in nuclear reactions that take place in the most powerful flares. A flare 7 April 1980 caused a major disruption of the corona surrounding the sun. For the first time we can now study the flare itself, which occurs below the corona on the surface of the sun, and resulting coronal disruption that travels outward into interplanetary space toward the earth. Among important *Solar Maximum Mission* discoveries is that the very high energy x-rays emitted in rapid (10-second) bursts at the beginning of flares appear to originate in pairs of spots within the flare. These spots are the footpoints of loops of the magnetic field that somehow creates the energy of flares. The discovery has important implications for the theory of solar flares.

International Solar Polar Mission. The ISPM, a cooperative flight program with the European Space Agency to explore for the first time the interplanetary space above the poles of the sun, was revised from two spacecraft to a one-spacecraft mission, with the launch delayed to 1986. Even with the single, European spacecraft, the exploratory mission will be of significant scientific value.

Solar Terrestrial Explorers. Development neared completion on two Explorer projects, the Dynamics Explorer (DE) and the Solar Mesospheric Explorer (SME), scheduled to be launched in 1981. The DE will investigate the interaction of the earth's magnetosphere and ionosphere, while the SME will determine the effect of solar ultraviolet radiation and certain nitrogen and hydrogen compounds on upper atmospheric ozone. Development continued also on the San Marco-D missions in a cooperative project with Italy, leading to launches in 1981 and 1983.

Detailed study continued on two future Explorers. The two-element Active Magnetospheric Particle Tracer Explorer (AMPTE) program, to be started in fiscal 1981 with a launch in 1984, is a cooperative program with the Federal Republic of Germany. The Germans will provide a spacecraft to release the particles (to become ions); the United States will provide a spacecraft carrying diagnostic instruments and the launch of both spacecraft. Objectives are to study the solar wind at the subsolar point and indentify particle-exiting windows, entry mechanisms, energization, and transport mechanisms into the magnetosphere.

The Solar Corona Explorer (SCE) will study the rotation and evolution of coronal holes as tracers of subsurface magnetic fields. It will also study the origin of the solar wind in the inner corona and, if flown in the correct time frame, can provide correlative observations of the solar corona for the International Solar Polar Mission. Development of the SCE mission was expected to begin in fiscal 1984 or 1985.

Study of the Planets

The U.S. planetary exploration program obtained large quantities of new data during 1980 as an unmanned spacecraft took a closeup look at Saturn and a first look at its moons, while other spacecraft continued operations at Mars and Venus. These and other planetary data were acquired in a broad range of disciplines and will make significant contributions to comparative planetology.

Voyager 1 and 2. These very sophisticated spacecraft, launched in 1977, encountered the planet Jupiter and its moons in 1979. Extensive information was returned, including thousands of pictures of this complex planet. Some significant discoveries were a belt-zone pattern of east-west winds near Jupiter's poles, anticyclonic motion of material around the Great Red Spot, massive lightning bolts and auroral emissions in the cloud tops of polar regions, the existence of a planetary ring around Jupiter, the existence of a 5-million-ampere magnetic-flux tube between the planet and its satellite Io, three additional Jovian satellites, a well-defined bow shock wave, magnetospheric boundaries and tail that are similar to Earth's, and active volcanoes erupting on Io, making it only the second body in the solar system known to possess such activity.

At Jupiter, the two Voyagers used the planet's immense gravity to bend and accelerate their trajectories toward the giant ringed planet Saturn. *Voyager 1* encountered Saturn on 12 November 1980, one day after flying past the unique satellite Titan and discovering that its atmosphere is cold, dense, and mainly nitrogen, with numerous hydrocarbon compounds. Thousands of high-resolution images of the once-mysterious planet and several of its moons were obtained—moons which until then had been observed as specks of light. The number of rings was revealed to be hundreds—perhaps thousands—and not the half-dozen or so previously observed. Particles were measured from dust size to boulder size material. Two ringlets were elliptical, and one ring was observed to be apparently three braided or intertwined ringlets. Three previously unknown satellites were discovered and the existence of several others, including two sharing the same orbit, was confirmed.

Voyager 1 at the end of 1980 was on a course that will take it out of the solar system, while *Voyager 2* was to reach Saturn in August 1981, after which it will begin its journey toward a January 1986 flyby of the planet Uranus.

Viking. A United States spacecraft on Mars continued active almost five years after arrival at that planet. At the end of 1980, one Viking lander was still returning imaging, meteorology, and radio science data. This craft, near the equator, has been programmed to allow periodic interrogations into the year 1994. Operation of the other lander and the second orbiter ended this year after returning some of the best high-resolution pictures to be obtained during the mission and collecting atmospheric and meteorological data through the second Martian year of observation. A substantial analysis team continues to study the Viking data.

Pioneer-Venus. Operation of the orbiter passed into a third Venusian year and the spacecraft continued to provide valuable information about the time-varying nature of that planet's atmosphere. Data were being gathered to extend temporal coverage and to provide coverage in previously inaccessible areas. *Pioneer-Venus* was expected to operate at least until 1986.

Pioneer 10 and 11. During the year, both spacecraft continued on their journeys out of the solar system. *Pioneer 10* was more than 23 astronomical units (3.4 billion kilometers) from the sun at the end of 1980 while *Pioneer 11*—moving in the opposite direction—was 10 AU (1.5 billion km) from the sun. Both continued to return basic information about the charged particles and electromagnetic fields of interplanetary space where the sun's influence is diminishing. *Pioneer 10* and *11* will be tracked and interrogated for several more years. Thereafter they will continue their silent journey, reaching the midway point to the nearest star about 40 000 A.D.

Galileo. Designed to study the Jovian system in great detail, Galileo was in the development stage. An orbiter and a probe are to be launched in the mid-1980s and to arrive at Jupiter in the late 1980s. The orbiter will send back imaging, remote-sensing, and magnetospheric information about the planet and its satellites for 20 months, with flybys of the satellites as close as 200 km. On arrival at Jupiter, the probe will descend into the atmosphere carrying instruments to make detailed measurements of its chemical and physical properties to a pressure equivalent to 10 Earth atmospheres.

Recent Galileo activity was directed at completing the preliminary design. All subsystem preliminary design reviews including that of the retropropulsion module contributed by the Federal Republic of Germany, were completed for the orbiter spacecraft. Major contracts were renegotiated according to the new launch schedule.

Research and Analysis

The research and analysis program continued to provide the scientific framework for planetary exploration and additional analysis of spacecraft data. It also provided direct support for the spacecraft programs, such as the telescopic observations of Saturn in the spring of 1980 in preparation for *Voyager 1*'s flyby in November. In the spring, the rings of Saturn appeared edge-on to astronomers on Earth, providing a favorable opportunity to find new satellites. Three possible new satellites were identified, and *Voyager 1* was subsequently programmed to search for these satellites during its passage by the planet.

An important new element in solar-terrestrial physics in 1980 was the initiation of an independent theory program that will help integrate theoretical understanding of the way the sun affects Earth's environment. Fourteen groups of solar and plasma physicists throughout the country are coordinating theoretical modeling of solar-terrestrial relationships, using the most recently acquired observational results.

Discoveries in 1980 included the energization of electrons when a low-power argon-plasma gun was operated at a height of 220 km on a rocket launched from the Poker Flat Research Range in Alaska. Similarly, precipitation of more energetic electrons at the edge of an aurora was observed when an energetic electron beam was injected from a rocket into the ionosphere in the auroral zone. These experiments throw further light on natural instabilities, acceleration processes, and production of auroras.

Studies of the Universe

The astrophysics program is directed toward a better understanding of the basic laws of governing all aspects of the observable universe. A combination of the sister sciences of astronomy and physics, the program uses the radiation incident upon Earth from the whole range of matter and temperature environments in the cosmos to provide a much more comprehensive physics laboratory than could be designed on Earth. A large part of this radiation cannot effectively penetrate the atmosphere; most astrophysical research must be conducted in space.

High Energy Astronomy Observatories. The HEAO series of spacecraft study the highest detectable energy radiation: x-rays, gamma rays, and cosmic rays. *Heao 1,* launched in 1977 and reentering Earth's atmosphere in 1979, surveyed the sky over the whole x-ray energy range. It cataloged more than 1000 x-ray emitting objects, ranging from nearby stars to distant quasars. The initial data analysis discovered several new kinds of sources, including stellar systems that are some 1000 times more flare-active than the sun, and "cataclysmic variables" exhibiting intense short-term increases that are probably triggered by nuclear reactions on the surfaces of "white-dwarf" stars. The continuing detailed data analysis has been highly productive as well. For example, the new detection in the data in 1980 of a "superbubble" in the constellation Cygnus with a radius of thousands of light-years, is testament to the occurrence of hundreds of supernovae in that portion of our galaxy during the past few million years.

The second HEAO spacecraft, launched in November 1978, continued to provide excellent data with the first true imaging stellar x-ray telescope. The sensitivity increase is so great that virtually all types of stars in our galaxy can now be observed in the x-ray band, and the number of quasars detected as x-ray emitters has increased from the 3 that could be detected with *Heao 1* to well over 100. The guest investigator program has included the participation of hundreds of scientists from all over the world and has elevated x-ray astronomy to an experimental science equal in stature to optical and radio astronomy.

During the past year, the study of exploding stars called supernovae continued to be particularly interesting. Long considered the source of a variety of otherwise inexplicable puzzles nature has presented to us, supernovae refused to conform to expectations. Neutron stars were not detected as expected in remnants of many supernova explosions, for example. And new *Heao 2* data indicated that the characteristic spectral radiation does not exhibit iron in overabundance, relative to lower atomic-number elements, as was expected from the best current theory. Nobody is ready to give up the idea that supernovae are the origin of both neutron stars and heavy elements via nucleosynthesis, but nuclear physics theory must ultimately conform to the new and unexpected *Heao 2* data. This is another example of the impact of astrophysical observations on fundamental physical theory.

The attack on understanding supernovae has been continued by *Heao 3,* launched in September 1979. Devoted to cosmic-ray and low-energy gamma-ray astrophysics, the two cosmic-ray instruments are measuring much more precisely the quantities of the very-high-energy atomic nuclei that thread our galaxy. In several respects, the results appear inconsistent with the theoretical models, which had the atomic nuclei synthesized and accelerated in supernovae explosions. For example, rapid nucleosynthesis should produce uranium, but there is none. Nor does the differential composition of intermediate atomic-number species, zinc through zirconium, fit any of the popular nucleosynthesis models. Further, the relative paucity of cobalt in comparison with iron and nickel suggests that at least three years must have elapsed between the creation of these isotopes and their acceleration to cosmic-ray energies. Most investigators tend to agree that rejection of the supernova origin hypothesis would be overreaction to these new data. What probably will emerge is a modification of the nucleosynthesis and acceleration models to conform to what supernovae do in nature, rather than to what was predicted in computer simulations on the basis of lower quality data.

The gamma-ray astronomy experiment on board *Heao 3* has pioneered the observation of true nuclear gamma-ray line radiation, which we expect to be a prime objective of the Gamma Ray Observatory program. The observation of 2.2-megavolt line radiation from the formation of heavy hydrogen (deuterium) in a solar flare is one example of this new capability, as is the measurement of annihilation radiation from the center of the Milky Way. The latter radiation, representing the destruction of antimatter positrons in collision with electrons, has interesting implications as to how such antimatter can be produced and confined in the nucleus of our galaxy. These measurements indicate the great potential for discovery which the increased sensitivity of the Gamma Ray Observatory will provide.

Gamma Ray Observatory. GRO, planned for launch by the Space Shuttle in the late 1980s, will extend the view of the universe into the highest energy reaches of the electromagnetic spectrum. It will permit a penetrating look at the nuclear process in the vicinity of neutron stars and black holes and will facilitate investigation into the formation of elements in supernovae, origin of gamma-ray bursts, and detailed physical nature of the recently discovered gamma-ray sources. *GRO* has been defined in detail, and definition studies on five scientific instruments continued during 1980. Experiment confirmation was planned for March 1981 following a comprehensive review of experiment cost and status.

Space Telescope. Critical design reviews of all subsystems of the optical telescope assembly for the *Space Telescope* were completed during 1980. The metering truss, a graphite epoxy structure that supports the secondary mirror, was assembled, and fabrication of the other major elements was begun. The backup primary mirror, the second of two 2.4-meter primary mirror blanks, was polished to the desired figure. The first primary mirror blank was expected to be polished and ready for coating early in 1981.

Design of four of the five scientific instruments was completed in 1980, and they were in fabrication and assembly. The fifth instrument, the wide-field planetary camera, required major redesign to reduce its weight and will be ready for critical design review in July 1981. However, *Space Telescope* development was rephased to remain within budgeted fiscal 1980 and 1981 funds.

Design and critical design reviews of the support systems module were to be completed in March 1982. Contracts with the major subcontractors were negotiated, and most of this effort was in fabrication and assembly. Pointing-and-control engineering-model verification testing was completed in October

1980. Detailed design of the solar arrays was also completed. The European Space Agency, which is providing the solar arrays, was to complete the critical design reviews of the arrays early in 1981.

The contract for development of the hardware and software for the *Space Telescope* payload operations control center was awarded to Ford Aerospace and Communications Corporation. The request for proposals for the science operations ground system was released in December 1980. The Association of Universities for Research in Astronomy (AURA) was selected for negotiation of a contract to operate the ST Science Institute, which will be at Johns Hopkins University and will conduct the integrated science program, including selection and support of telescope observers, science planning and scheduling, and data analysis.

Orbiting Astronomical Observatories (OAO). OAO 3, also named *Copernicus,* operated successfully for more than eight years after its launch in 1972. Although designed for only one year in orbit, the satellite and experiment have operated flawlessly and returned important scientific data over a longer period than any other astrophysics satellite ever launched. Because of recent degradation in the experiment's detection system (due to high levels of solar activity) science operations were ended 31 December 1980. *OAO 3*'s pioneering work includes the discoveries of clumpy structures and shocked million-degree gas in the interstellar medium, as well as the first satellite measurements of the ultraviolet spectra of the chromospheres and coronas of stars other than the sun.

International Ultraviolet Explorer (IUE). In 1980, *IUE* observations confirmed the discovery of a hot halo of gas surrounding the Milky Way. Such haloes have also been discovered around our two nearest neighboring galaxies, the Magellanic Clouds. These results seem to indicate that such galactic haloes may be ubiquitous. New data from *IUE* also verified expectations that space between *isolated* galaxies is highly transparent and contributes very little to the total mass of the universe. *IUE* continued to make important contributions to knowledge of stars and solar system objects. Extensive observation of active binary stars demonstrated that stellar magnetic fields and rotation probably combine to cause the tremendous levels of solarlike activity we detect in many classes of such stellar systems. Closer to home, *IUE* provided the first detailed studies of comets throughout their active cycle in the inner solar system, providing important new clues to their internal composition.

Other Astrophysics Explorers. Development was nearing completion for the cosmic-ray isotope experiment (CRIE) that will be launched on a Department of Defense satellite. The CRIE mission will measure the isotopes of energetic solar and cosmic ray particles.

Development was also continuing on the Infrared Astronomical Satellite *IRAS,* the first spacecraft designed to study the cold infrared universe. This cooperative project with The Netherlands and United Kingdom was scheduled to place a "first-of-its-kind" cryogenically cooled telescope system in orbit in 1982. The primary mission is to produce an unbiased all-sky survey of discrete sources to identify the location and variety of objects radiating in the infrared. The telescope system, being furnished by the United States, is managed by Jet Propulsion Laboratory and Ames Research Center. Most of the telescope hardware had been completed, and assembly of the telescope was in process. After a final system test, the telescope system will be shipped to The Netherlands for integration with the Dutch spacecraft.

Detailed study continued on four future Explorers. Work on the Cosmic Background Explorer (COBE), which will measure the residual three-kelvin background radiation believed to be a remnant of the "Big Bang" origin of the universe, was planned to start early in fiscal 1982, with a probable flight in 1986. The Extreme Ultraviolet Explorer (EUVE) was also planned for a fiscal 1982 start. This mission will open up an unexplored portion of the electromagnetic spectrum, observing very hot objects such as white dwarfs. The X-ray Timing Explorer (XTE), which will make high-time-resolution studies of transient x-ray sources, is a possible cooperative program with The Netherlands. It would be the third in a series of cooperative U.S.-Netherlands projects, preceded by the *ANS* flown in 1974 and *IRAS,* still under development. The Gravity Probe-B (GP-B) is an experiment to test Einstein's Theory of General Relativity by measuring the precession of ultraprecise gyroscopes in orbit caused by the presence of a rotating Earth. In July 1980, a technology review committee concluded that the required technology was available and recommended that definition studies be started.

Suborbital Programs. The NASA suborbital program flies instruments on aircraft, balloons, and sounding rockets to make investigations ranging from terrestrial research to astrophysical observations of cosmological significance. These investigations not only provide scientific data unobtainable any other way, but significantly contribute to the development of instruments, techniques, and technology to be used in future activities, such as Spacelab investigations.

In 1980, a wide-field ultraviolet-imaging telescope that will also fly on Spacelab was launched on a sounding rocket and obtained the first wide-field images in the UV of M31, the nearest spiral galaxy. This instrument will eventually add significantly to *Space Telescope* observations. NASA also launched the first operational flight of the highest performance sounding rocket to date. The 895-kg payload was lofted to almost 370 km. The scientific instrument, a grazingincidence Wolter x-ray telescope, will be upgraded for following flights and will eventually fly on the Shuttle or on a space platform.

A balloon-borne instrument made the first detection of an intrinsic, large-scale anistropy of the universe, which suggests that the universe was more clumpy at a far earlier time after the "Big Bang" than previously thought. In addition, a balloon-borne telescope provided evidence for large-scale star-forming areas in the inner region of our galaxy and along its plane.

Life Sciences

NASA's life sciences program conducts research, development, and operations to maintain the health and performance of astronauts, to use space as a laboratory to advance knowledge of biology, to support life in spaceflight, and to understand the origin and evolution of life in the universe.

Medical Flight Operations. Maintaining the health and safety of Space Shuttle crew members continued to be of prime concern in preparing for Space Transportation System operations. Anti-g suits have been developed to counter any adverse effects of returning crew members to the earth's gravity, when the flow of blood to the head is diminished. A comprehensive drug-screening program selected motion sickness medications with the fewest side effects for men and women; a procedure that permits the drug to be absorbed through the skin appeared promising. Physiological and biomedical changes resulting from repeated and frequent STS missions will be systematically documented.

Biomedical Research. Biomedical research focused on medical problems expected to be of concern to STS users. Investigators, aware that the body loses part of its blood volume in response to the space environment, are using simulated spaceflight to find out more about how the human body controls this volume. Understanding the process is expected to lead to more effective ways of preventing cardiovascular difficulties in astronauts, either in space or on return to the earth. Better methods are being developed to monitor the movements of the heart and to predict the effects of injury to such structures as the coronary blood vessels.

Motion sickness has been tackled not only by a search for effective drugs but also by trying to understand how the body senses the speed and direction of its movements and how it accommodates to weightlessness. Physiologists studying the complicated neural networks that process this information are learning how the system malfunctions and how malfunctions can be corrected.

Under exchange agreements, the findings of U.S. investigators concerning these and other problems are being supplemented by results from extensive work in the USSR space program.

Space Biology. Gravity has a major influence on the growth and physiology of higher plants. Recent research indicates that the same gravity-sensing mechanism is present in many responses in several species of plants. Other forms of mechanical stress—including vibration, movement, and tactile stimulation—alter plants' response to gravity through this common mechanism. Light and gravity control plant growth through a common calcium-dependent, biochemical reaction. This research should lead to methods of cultivating plants in a gravity-free environment.

Studies of the structure and function of the animal vestibular apparatus have revealed that the otoconial crystals within the inner ear are not inert, but rather a dynamic composite of calcite and organic material. The calcium content is dependent on the ionic composition of the inner-ear fluid. Ionic shifts in the fluid, with resultant widespread effects including changes in the calcium content of the otoconial crystals, could be a reasonable explanation for the vestibular disturbances experienced by astronauts during the first few days of spaceflight.

Biological Systems Research. In 1980, research into systems to maintain life in space included completion of a fully integrated prototype of a system to recycle air in a spacecraft cabin, regenerating oxygen from carbon dioxide, removing contaminants, and adjusting the oxygen-nitrogen balance. In addition, selection was begun of proposals for longer range research into recycling wastes to regenerate food as well as air and water, to achieve fully autonomous life support for missions that may have to be independent of supplies from the earth.

Preliminary studies were begun for research on the global biosphere as an integrated biological system. Modern instrumentation and observing technology have begun to make it possible to construct working descriptive theories of large-scale biophysical processes in the normal and perturbed biosphere. Workshops and studies are developing approaches to analysis of large-scale natural phenomena, to formulate predictive models of the fundamental controlling processes. While these studies will be pursued as a program in basic science, results are expected to be of value to problem-oriented environmental research.

Exobiology. Understanding how the origin and evolution of life were affected by the origin and evolution of the solar system itself is a prime objective of the exobiology program, which seeks to delineate the nature and distribution of life throughout the universe. Exciting recent discoveries propose a mechanism for the origin of the genetic code, the fundamental process by which every life form transmits information to succeeding generations. The new system is simple, requires few components, and these are readily synthesized in systems that mimic the chemical and environmental conditions of the primitive earth. Other experiments demonstrated for the first time that simple polymers approaching biological size are synthesized nonbiologically in the presence of simple catalysts that are expected to be present on primitive, evolving planets. These and related studies support the concept that essential life processes might originate as a result of planetary evolution rather than as a chance or rare occurrence. This concept, in turn, strengthens the argument that similar processes may have occurred on other planets around other stars, and provides a conceptual framework for the development of a program to search for life beyond our solar system.

Flight Program. Life sciences experiments for Spacelab 1, 2, and 3 were in the hardware phase. In 1980, 90 proposals for experiments selected in October 1979 underwent definition studies; in the spring of 1981, some 30 were to be selected as candidates for the first dedicated life sciences Spacelab mission, planned for Spacelab 4.

Spacelab Payloads

The NASA Spacelab program plans missions to be flown on the Shuttle in support of most space science and application disciplines. During 1980, the first two payloads using Spacelab hardware were integrated. OSTA 1, the first payload for the Shuttle, is an applications payload emphasizing earth resourses observations. OSS 1, a space science payload, is to study solar physics, space environment, and thermal control techniques. Development work has begun on OAST 1, a technology payload to test the solar array of the solar electric propulsion system (SEPS) and solar cell calibration; OSTA 2, for materials processing experiments; and OSTA 3, for nonrenewable earth resources study.

Two basic Spacelab configurations, module and pallet, are to be verified on Spacelab missions 1 and 2. Development of hardware for mission 1 neared completion, and the European Space Agency began integration of its half of the payload. Integration of the NASA half was to begin and development of software to be completed in 1981. Several European and Asian nations are planning instruments for Spacelab missions.

Space Transportation

Space Shuttle

The Space Shuttle will be the first reusable earth-to-orbit vehicle, meeting the needs of NASA, DoD, and other domestic and international users of space. It will provide efficient, economical access to space and will enhance the flexibility and production of space missions, producing savings in the cost of space operations that cannot be achieved with today's expendable launch vehicle systems.

All major system elements in the Shuttle development program were proceeding in test and manufacture at the end of 1980 and major ground-test programs neared completion. The first flight-configuration Space Shuttle stood on the launch pad. Additional testing of the vehicle was under way; qualification testing of flight-configured elements continued toward a spring 1981 launch.

Orbiter. The orbiter vehicle will carry a crew of two (with provisions to carry up to seven) and payloads to orbit. It will remain in orbit, usually for seven days, and will return to the earth with its personnel and payloads. It will carry up to 29 500 kilograms in its 4.6- by 18.3-meter payload bay. Landings will be made on a conventional runway in a manner similar to airplane landings.

Structual elements of the orbiter, primarily of aluminum, consist of the forward fuselage containing the crew module, the mid-fuselage, the aft fuselage including the engine thrust structure, the wing, and the vertical tail. The exterior is covered with materials that protect the spacecraft from solar radiation and the extreme heat of atmospheric reentry.

Orbiter crew and passengers will occupy a two-level cabin within the crew module at the forward end of the vehicle. The upper section, or the flight deck, contains the controls and displays used to control and monitor orbital maneuvering, atmospheric entry, and landing phases of the mission and to control the mission payloads. Crew seating for up to four is on this level. Seating for three passengers or scientists and the habitability provisions are on the lower level.

The first flight orbiter, *Columbia* was in final processing at Kennedy Space Center in December, with the first Space Shuttle launch scheduled for the spring of 1981. The orbiter was mated with the solid-fueled rocket boosters (SRBs) and external tank (ET) in November 1980 and rolled out to the launch pad 29 December. The final flight hardware had been delivered and was being used for vehicle checkout. Hardware and thermal protection system certifications were nearly complete.

Main Engine. Three high-pressure hydrogen-oxygen engines, each with a rated thrust of 2 000 000 newtons (470 000 pounds) are in the orbiter's aft fuselage. This engine cluster is a major advance in propulsion technology. The very-high-performance engine has a long operating life and ability to throttle the thrust over a wide range.

Among the key components of each engine are its four turbopumps (two low- and two high-pressure), two preburners, the main injector, the main combustion chamber, the nozzle, and the hot-gas manifold. The manifold is the structural backbone of the engine. It supports the two preburners, the high-pressure pumps, the main injector, the pneumatic control assembly, and the main combustion chamber with the nozzle.

The Space Shuttle main engine is the first rocket engine to use a built-in electronic digital controller. The controller will accept commands from the orbiter for engine start, shutdown, and change in throttle setting and also will monitor engine operation. In the event of a failure the controller will automatically correct the problem or shut down the engine safely.

The original goal of achieving 80 000 seconds of engine test time before the first orbital flight, STS-1, was surpassed. More than 90 000 seconds of testing had demonstrated readiness of the highly advanced engine for the first Space Shuttle launch.

External Tank. The external tank has a dual role in the Shuttle program: to contain and deliver propellants—liquid hydrogen and liquid oxygen—to the engines and to serve as the structural backbone of the Shuttle during launch operations. The tank actually consists of two tanks, a large hydrogen tank and a smaller oxygen tank, joined to form one large propellant-storage container, 46.8 meters long and 8.4 meters in diameter.

Outer surfaces are protected by superlight ablator (SLA-561) and foam insulation sprayed on the forward part of the oxygen tank, the intertank, and the sides of the hydrogen tank. The insulation will reduce ice or frost formation during launch preparation, protecting the orbiter from free-falling ice during flight; minimize heat leaks into the tank and avoid excessive boiling of the liquid propellants; and prevent liquification and solidification of the air next to the tank.

The external tank contains more than 700 000 kilograms of propellant for the main engines. Just before orbital insertion, the main engines will cut off and the tank will separate from the orbiter, descend through a ballistic trajectory, and break up over a predesignated remote ocean area. At the end of 1980, the first flight tank had been mated to the solid rocket boosters and the orbiter vehicle for the first Space Shuttle launch. The second flight tank was in final checkout before delivery to KSC. Five other tanks were in various stages of manufacture. Work had begun on the first lightweight tank for operational flights, an improved design that will save some 2700 kilograms.

Solid Rocket Booster. The solid-fueled rocket booster is made up of six subsystems: the rocket motor, structures, thrust vector control, separation, recovery, and electrical and instrumentation subsystems. The overall length of the booster is 45.5 meters and the diameter 3.7 meters. The heart of each booster is the motor, the largest solid-fueled rocket motor ever flown and the first designed for reuse. It is made up of 11 segments joined to make 4 loading segments, which are filled with propellant at the manufacturer's site. The segmented design facilitates fabrication, handling, and transportation. The exhaust nozzle in the aft segment of each motor, in conjunction with the orbiter engines, will steer the Space Shuttle during the powered phase of launch.

Two solid rocket boosters, attached to the external tank, will burn in parallel with the main engines to provide thrust during ascent. At completion of burn, the boosters will separate, descend by parachutes, and land in the ocean 280 kilometers downrange, to be recovered for refurbishment and reuse.

By the end of December, four development and three qualification static-firings had been completed. The rocket segments, structural components, and other components for the first flight boosters had been delivered, assembled, and mated with the external tank and orbiter at KSC.

Launch and Landing. Space Shuttle flights will be launched from two sites, Kennedy Space Center in Florida and Vandenberg Air Force Base in California. The sites were selected to meet NASA, DoD, and commercial needs for projected payloads.

In December, all facilities at KSC were complete and in place for the first launch. The computerized launch processing system had been used extensively for Shuttle testing and facility activation. The high-energy fuel systems had been checked out. All Shuttle elements (orbiter, external tank, and solid rocket boosters) were assembled in the Vehicle Assembly Building, and the integrated test was completed.

Flight Test Support. The mission control center and Shuttle mission simulator facilities at Johnson Space Center were ready to support the first Space Shuttle flight. The flight crew and ground flight controllers had used these facilities extensively for training and procedure development and verification. Seven full-duration (54-hour) integrated simulations had been successfully conducted, with numerous individual phase (ascent, orbit, entry, and landing) runs completed. The mission flight rules and launch-commit criteria had been completed. Increasing effort was being devoted to mission design and flight-test planning of the second, third, and fourth flights.

Follow-On Production. Follow-on orbiter production activities were in progress, leading to the currently approved four-orbiter fleet for national Space Transportation System needs in the future. The structural test article, which had completed its development test use, was being modified to a flight-configured orbiter, the *Challenger*. Secondary and primary structural installations were under way, and thermal protection installations had begun, for vehicle delivery in June 1982. Detailed parts manufacturing and long-lead procurement for orbiter 103, *Discovery*, were under way. This vehicle is scheduled for delivery in September 1983. Orbiter 104, *Atlantis*, is to be delivered in December 1984; long-lead procurement of material was under way for that vehicle.

In the main engine program, production of full-power-level (FPL) engines for development and certification testing for flight use will continue. The first FPL engine (engine 2008) was delivered to NASA's National Space Technology Laboratories in August 1980, to be used for development and certification testing.

Inertial Upper Stage (IUS). The Department of Defense is designing and developing the two-stage IUS system to extend the reach of the Space Shuttle into orbits beyond the capability of the Shuttle alone. The solid-propellant IUS and its payload will be deployed from the orbiter in low earth orbit; the IUS will then be ignited to boost its payload to a higher energy orbit. NASA and DoD will use the IUS primarily to achieve geosynchronous orbit. Full-scale development continued, with NASA coordinating non-DoD requirements into the DoD IUS program to ensure its utility for NASA and commercial applications. The IUS hardware development was proceeding on a schedule for an early 1982 launch on the Titan launch vehicle and a late 1982 launch of the Tracking and Data Relay Satellite from the Space Shuttle.

Centaur. The Centaur upper stage is being studied for use with the STS for planetary and heavier geosynchronous mission applications scheduled to begin in early 1985. The proposed modifications will be primarily to increase the size of the propellant tanks to add about 50 percent more propellant capacity (Wide Body Centaur) and to make the stage compatible with the Shuttle.

Spinning Solid Upper Stage (SSUS). Two sizes of SSUSs are being developed by U.S. aerospace industries, at their own expense, for launch of smaller spacecraft into geosynchronous-transfer orbit. SSUS-D is configured for satellites that have been using the Delta expendable launch vehicle, and SSUS-A for those using the Atlas-Centaur. SSUS designs have been completed and the qualification program begun. Production was proceeding, with most flight hardware manufactured and ready for assembly. NASA has ordered the SSUS-A for Comsat Corporation's Intelsat V communications satellite missions. Commercial users are buying the SSUS-D directly from the developer. The first flight of the SSUS-D on the Delta launched the SBS spacecraft in November 1980.

Advanced Programs

Investigations continued during 1980 into concepts to improve the utility, flexibility, and effectiveness of the Space Transportation System, with special emphasis on the Space Shuttle orbiter. Studies and premission development of critical subsystems were conducted for the power extension package, which is to provide additional electrical power through a solar array deployed by the orbiter's remote manipulator.

Definition studies for a Space Platform, formerly called Power Utilization Platform, to support science, applications, and commercial experiments began in June 1980, to be concluded in December 1981. The platform is a Shuttle-tended, free-flying platform designed for indefinite life with servicing from the Shuttle. A multipurpose facility, it will provide support (electrical power, stabilization, communications, etc.) to a series of payloads that will be transported to and from the platform by the Shuttle and operated for varying lengths of time.

Preliminary in-house studies of manned space platforms were completed, and industry studies of a manned Space Operations Center (SOC) awarded.

Alternative definition studies of a solar electric propulsion system (SEPS) were also contracted with industry and completed.

Studies of orbital transfer vehicle (OTV) concepts by two vehicle contractors and three engine contractors were continued. The OTV, to be defined by these efforts, is to be a reusable vehicle to transport Space Shuttle payloads to and from high earth orbits, and on solar system exploration missions.

Operation of the Space Transportation System

An operational Space Transportation System in 1982 will make possible a greatly expanded range of space activities. Many users—civilian and military components of the U.S. government, as well as domestic and foreign customers, both governmental and private—have already made firm commitments to the system. They will be able to place a wide variety of payloads and experiments in earth orbit. Payloads can be refurbished in orbit or returned to the earth for repair and relaunch; space laboratories can be launched, operated, and returned to the earth for examination; scientists can fly along to operate their experiments; geosynchronous or planetary missions will be possible with the aid of supplemental upper stages.

Policies and Procedures. Policies on user charges during the early years of operations have been published in the Federal Register, describing the price structure and stipulating other conditions under which NASA will furnish launch services and flight hardware to government and commercial users. A reimbursement guide describing kinds and costs of standard and optional services was published in 1980.

Following extensive negotiations during the past year, nine commercial and foreign users—including Comsat, Western Union, RCA, Telesat Canada, and the governments of India, Indonesia, and the Federal Republic of Germany—made payments or deposits on STS flight reservations. With NASA's own payloads and firm commitments for DoD and other U.S. government agencies, the first few years of STS operations are fully scheduled.

NASA began a program to provide for small, self-contained payloads in 1977. Individuals, educational institutions, and industries can fly small payloads, requiring minimal support from the Shuttle, on a space-available basis at very reasonable prices. Both in the United States and abroad, this program has been successful in attracting new users; by the end of 1980, advance payments had been received for more than 300 individual payloads, with a wide variety of ideas and experiments. The response from educational institutions indicated renewed interest from young people in space research and exploration. Several universities were offering science scholarships or grants for students to develop payloads.

The Department of Defense continued to develop its launch and recovery facilities at Vandenberg AFB for high-inclination missions. Maximum commonality of ground equipment at Kennedy Space Center and Vandenberg was reducing both acquisition and operating costs.

Spacelab

Spacelab is an orbital laboratory being designed and developed by the European Space Agency to be carried in the cargo bay of the Shuttle. It will provide access to space for a variety of experimenters from many nations and in fields such as materials science, space processing, biology and medicine, meteorology, communication and navigation, and space technology.

Spacelab offers experimenters two options, a pressurized shirtsleeve laboratory (the module) and an unpressurized platform exposed to the space environment (the pallet). It also offers standardized support services. A normal mission will last 7 days, although it can remain in orbit for up to 30 days. Design life expectancy is 50 flights of 7-day duration over a 10-year period. As many as four payload specialists can operate the experiments aboard the laboratory. Payload weights will range from 4800 to 8800 kilograms.

In 1973, the European Space Agency and NASA agreed that ESA would design, develop, and manufacture the first Spacelab flight unit and an engineering model, two sets of ground support equipment, and initial spares to support the first two missions. ESA's cost-to-completion estimate is $800 million (1980 dollars). NASA's responsibility is for operation of Spacelab; development of ancillary equipment, such as the tunnel between the Spacelab and the cabin of the Shuttle; development of the mission verification equipment; and procurement of one additional Spacelab unit from ESA.

In 1980, Spacelab activity in Europe brought considerable progress in test and checkout of the engineering model and first flight unit. The engineering model was delivered to KSC in December, the largest delivery to date under the memorandum of understanding. The model will be used to verify the facilities and ground systems at KSC in preparation for the flight-unit processing beginning in 1981.

In Bremen, Germany, Entwicklungs Ring Nord (ERNO)—prime contractor for Spacelab development—continued to process the flight unit hardware. Subsystem testing was completed in August. The flight-unit integrated-system test was continuing, with deliveries scheduled for June 1981 and September 1981. Development of operational software was completed. The Spacelab ground-computer operating-system software was being used with the automatic test equipment to test and operate the Spacelab at ERNO and eventually at KSC. The remaining tests were scheduled for completion next year.

NASA continued to prepare for general operations support of the early Spacelab missions. The critical design reviews for the verification flight instrumentation, which will be used to verify satisfactory performance of Spacelab during its first and second missions, were completed. A critical design review of the crew tunnel, which provides access to the Spacelab from the orbiter, was also successfully completed. The final version of the experiment computer operating system had been delivered to NASA and Spacelab Payload Integration Center, Europe (SPICE). The configuration was decided for Spacelab mission 2, which will be the second and final verification mission and the first flight for the ESA-developed instrument pointing system. NASA continued with integration and development of software. The simulator at JSC was scheduled to be ready for training Spacelab flight crews in January 1983. ESA production of a second instrument pointing system was authorized 23 May 1980, with delivery scheduled for October 1983. This IPS was part of the follow-on procurement contract for a second Spacelab, signed in January 1980. NASA also negotiated a supplemental agreement with ESA to provide an initial increment of Spacelab spare parts.

Expendable Launch Vehicles

Seven launches made up NASA's expendable launch vehicles schedule for 1980, three on the Delta, three on the Atlas-Centaur, and one on the Atlas F. Of the seven, only one was for NASA; the other six were reimbursable launches for other U.S. government, international, and domestic commercial missions. (See appendix A-3.)

Space Research and Technology

The goal of the NASA space research and technology activity is to provide a technology base that covers a wide range of disciplines, minimizes project risks, and creates opportunities for future capabilities at an affordable cost. The 1980 accomplishments are organized into three areas: development support of present agency activities, enhancing technologies required for planned near-term programs, and enabling technologies for new mission opportunities.

Development Support

Technology activities that provide development support to ongoing programs produce products to be applied in one to six years. They have also provided consultation services and facility-dependent tests for the Space Shuttle. Wind-tunnel tests completed in 1980 increased the total support of the Shuttle development to more than 60 000 hours since 1972. While wind-tunnel development testing is near completion, support during the flight-test phase will be provided as needed. Three new thermal protection materials were adopted for Shuttle Orbiter heatshields. One material is fibrous, refractory, composite insulation, which has greater temperature resistance, is stronger, and weighs less than the materials it is replacing. The second material is an improved gap filler with better high-temperature stability. The last is a silicon-felt "blanket" that will eventually replace most of the tiles on the upper Shuttle surfaces.

Significant progress also was made on Shuttle payloads and orbiter experiments. The induced environmental contamination monitor (IECM) will make baseline measurements of the orbiter environment and assess the effect of the environment on Shuttle experiments. During the past year the IECM was integrated into the payload bay of orbiter 102. Other experiments have been integrated on Spacelab pallets: the thermal canister experiment, to assess the feasibility and capability for controlling the temperature environment of the sensitive electronic equipment; and the feature identification and location experiment, to provide versatile, automatic landmark tracking, feature recognition capability, and real-time classification. Features that are identified include water, bare land, vegetation, clouds, snow, and ice.

During 1980, a laboratory system simulation was performed on the infrared imagery of Shuttle (IRIS) experiment. Hardware and computer software for the data analysis is operational. On STS-1, IRIS will obtain infrared images of the lower surface of the orbiter to define its actual thermal environment.

The space research and technology program also provided development support for the planetary program and earth-orbiting spacecraft programs. Computational chemistry techniques were used to analyze the ablation that will occur when the planned *Galileo* probe enters Jupiter's hydrogen-helium atmosphere. The analysis confirmed that ablation will block much of the radiation emanating from the shock layer—permitting the heatshield mass to be halved, and hence the scientific payload increased.

In chemical propulsion systems, high-temperature thermal-barrier coatings have been developed to extend rocket-engine combustor cycle life. Such coatings normally do not adhere well under severe thermal stress. However, an extremely strong bond has been demonstrated in a new "inside-out" combustor-wall fabrication process.

Enabling Technology

Enabling technologies create or respond to opportunities that might lead to breakthroughs in science and technology and thereby greatly extend capabilities to exploit and explore space. Significant achievements occurred across the whole range of space technology disciplines.

One of the barriers to planetary-return missions has been the cost and complexity of return propulsion. Planetary-return or stop-over missions would be less costly if propellant could be produced at or on the planet. During the past year, methods for producing liquid oxygen from a simulated Martian atmosphere by using electrolytic techniques were successfully demonstrated.

Progress was also made on the nuclear electric propulsion (NEP) concept, which will be needed if NASA is to complete the exploration of the outer planets. The principal components of a NEP system are a reactor, thermal-to-electric conversion systems, and electric thrusters. During the past year, a thrust stand was completed at Princeton University, and the first direct measurements of a magnetoplasmadynamic thruster were made. The measured values agreed very closely with theory. In the thermal-electric conversion technology, the thermoionic emission of textured chemical-vapor-deposited emitters was increased 25 percent over that obtained from smooth surfaces.

Another technology with high potential for future power transmission and propulsion is the solar-pumped, high-power laser. During the last year, a solar-pumped laser research facility was completed, and the application of theoretical techniques has produced a more realistic treatment of collision dynamics in the laser process. Such basic understanding of the physics of such systems, coupled with measurements of critical operating parameters, may permit a breakthrough in high-power transmission.

Battery performance is a major limitation on satellite orbital life. During the past year, significant insights into the operational lifetime of nickel-cadmium batteries have been achieved. Batteries have been developed that tolerate deep-discharge reconditioning, potentially doubling operational life.

Enhancing Technology

Several recent achievements have potential for improving agency missions 6 to 15 years in the future.

A submillimeter radiometer is one of the primary instruments planned for upper-atmospheric research satellites. During 1980, the capability was extended from a wavelength of 183 GHz to 635 GHz. It can now measure the relative abundance of more atmospheric trace gases with accuracies exceeding those of other techniques, to increase understanding of the stratosphere, mesosphere, and lower thermosphere.

During 1980, a computer modeling and simulation capability became operational that permits end-to-end simulation of NASA data systems. Over several months, 20 spacecraft were simulated and critical performance parameters calculated.

In the 1980s, expanded sensor capability will increase the volume of data from earth-observation spacecraft. The high data output will strain the transmission capability of onboard spacecraft systems as well as of the Tracking and Data Relay Satellites. In 1980, a K_u-band modulator-exciter capable of a data rate of 2.5 billion bits per second was designed, tested, and fabricated. Using microwave integrated-circuit technology, it is smaller, weighs less, and requires less power than conventional systems.

In space power technology, a number of activities are being pursued to make multihundred-kilowatt space power systems an affordable reality. Efforts to demonstrate the feasibility of a fuel-cell electrolysis system began in 1980. Preliminary analysis and tests of cell components such as electrolytes, electrodes, and catalysts have provided a data base for designing a five- to seven-kilowatt breadboard demonstration. A comprehensive study of alternative design approaches for low-cost solar-cell arrays was completed, to identify designs that have a potential for reducing cost per watt 10 times—to a goal of \$30—while increasing the specific power. A low-concentration-ratio approach was chosen as the most promising approach. Fundamental understanding of radiation damage in silicon solar cells continued to be extended. Recent insights and the evolving capability for inflight repair and annealing should greatly extend the power-generating capability of silicon arrays.

The first demonstration of autonomous "hand-eye" machine coordination necessary for robot techniques in space assembly, inspection, and repair was completed in 1980. A unique manipulator was developed using force-feedback logic to handle fragile objects such as single-crystal solar cells. Software was also developed to extract from a video image information on the size, orientation, and object to be manipulated and to direct manipulator motion.

Among large-space-structure concepts developed in 1980 were the hoop-column antenna and the electrostatic membrane antenna. For the hoop-column antenna, joints for a hundred-meter aperture were fabricated, and acceptable kinematic behavior was demonstrated. In addition, environmental and RF testing of graphite-fiber cables showed satisfactory performance characteristics. For the membrane antenna, a five-meter-diameter membrane was shaped electrostatically at a 60 000-volt bias for the first large-scale verification of this capability. The concept holds high potential for use in configuration control of large, very-high-precision, actively shaped antennas.

During 1980, significant progress was made in thermal protection systems. Titanium multiwall panels, with a density comparable to that of the Shuttle insulation system, were fabricated and successfully tested at temperatures up to 500°C, giving thermal performance equivalent to the Shuttle thermal protection system. In a different concept, a brazed, lightweight, honeycomb sandwich for hot structures was constructed. The development of a new noncorrosive brazing alloy made it possible to fabricate Rene 41 superalloy panels, a first step toward establishing the feasibility of fuel tanks integral to the primary vehicle structure, offering substantial weight reductions in advanced transportation systems.

NASA Energy Programs

NASA seeks to ensure effective use of its experience and technology in support of national energy needs. Aeronautics and space technologies as well as related facilities are used to satisfy the specific energy research, development, and demonstration needs of the Department of Energy (DOE) and other government organizations.

Automotive Research and Development. NASA is supporting DOE in the areas of gas turbine and Stirling engine development, electric and hybrid vehicle development, alternative fuel evaluations, diesel emissions research, and on-the-road evaluations of industry-developed automotive technologies.

In 1980, two industry teams, Detroit Diesel Allison (DDA) and Pontiac Divisions of General Motors Corporation and AiResearch/Ford, began development of experimental gas turbine engines. The objectives are to demonstrate by 1985 the potential for improved fuel economy, lower exhaust emissions, and multifuel use. Component design and the design and fabrication of all test rigs for the turbomachinery components—regenerator, combustor, and electronic control systems—were begun on schedule. Cold-regenerator-rig tests were conducted at AiResearch and cold-turbine-rig tests at DDA. A supporting ceramic technology program is developing high-temperature ceramic components. In 1980, tests were successfully conducted at 1038°C on ceramic parts that eventually will be tested in an existing larger turbine engine at 1132°C.

In the automotive Stirling engine project, buildup of the first test engine is well under way. This engine offers the same potential as a comparable turbine engine for significant fuel economy and emission reduction. Full-scale tests of the engine will begin early next year. In the past year, laboratory engines accumulated 4000 hours of testing experience at 820°C, the projected operating temperature.

In 1980, testing of the first "ground-up" electric automobile, designed and built by GE and Chrysler, continued to produce important data. The goal is a car with a 160-km range by 1986. Testing of a second car, designed and built by AiResearch/Garrett, was also begun. In this car, a flywheel stores energy for use during acceleration. In addition, substantial design and development work was completed on an experimental hybrid vehicle that will be powered by a combination electric-internal-combustion engine.

Wind Energy. Since NASA was assigned responsibility for technical management of large-wind-turbine development in 1973, seven machines have been developed and are operational. These turbines, funded by DOE, range in electric power production capability from 100 000 watts to 2 500 000 watts. Six of them are operated by utility companies and produce power for local consumption.

Two wind turbines became operational in 1980. On 3 July, the fourth and final experimental wind turbine in the 200 000-watt class was dedicated at Kahuku, Hawaii. In November, the largest wind turbine yet constructed began operation in the Goodnoe Hills near the Columbia River Gorge in Washington. This turbine, equipped with blades 92 meters from tip to tip, is the first of a cluster of three scheduled to be operating at that site by mid-1981. If manufactured at a rate of 100 per year, this turbine could produce electric power for less than five cents per kilowatt-hour (in 1980 dollars), a price competitive with conventional power in many parts of the nation.

During 1980, contracts were signed to design, develop, and test four advanced-technology wind turbines: three for multiple-machine wind farms servicing utilities and one for remote-power applications. The new turbines are expected to be the basic ones for meeting the goal of the Wind Energy Systems Act of 1980, which requires that large wind turbines producing 700 million watts of electrical power be operational in 1988.

Solar Thermal Electric Conversion. NASA is providing technical management for DOE in a program to investigate parabolic reflector systems concentrating solar energy to produce heat or electricity. Studies and technology demonstrations have defined several systems capable of producing up to 1 million watts of electric power for remote communities and heat for industry.

During 1980, two experimental parabolic concentrators were erected. The 10-meter-diameter concentrators focus the sun's rays to a 20-centimeter-diameter circle, producing an intensity level of "3000 suns." Equipment that will convert such energy to electricity is now being tested on the concentrators. Four field experiments using these concepts could be operational in 1982 to 1984.

Solar Heating and Cooling. Marshall Space Flight Center supports DOE in management of selected active systems for solar heating and cooling, including system development, commercial building demonstrations, and assisting in the Solar Federal Buildings Program.

During 1980, all system development hardware was delivered. Test and evaluation should be completed in 1981. The commercial building demonstration program is nearing completion. Of the original 120 sites assigned to NASA, 55 were completed in 1980 and the remainder were scheduled to become operational in 1981.

In the Federal Buildings Program, begun in 1979, 17 agencies work to demonstrate solar heating, heating and cooling, and hot water technology in government facilities. About 900 proposals were developed and evaluated during 1980. More than 800 sites were selected and designs initiated. Construction was scheduled to start during 1981.

Terrestrial Solar-Cell Development. Advances made in 1980 toward developing automated production of silicon material may substantially reduce the cost of solar-cell power systems for terrestrial applications. Also, the Lewis Research Center's role in supporting DOE has expanded to help increase international use of solar-cell power systems. Negotiations began with the government of Gabon to provide power to four villages by 1982.

Progress continues in photovoltaic development and support for the Agency for International Development. Solar-cell-powered health-delivery systems will be installed in pilot projects in Guyana and Kenya. Sites were evaluated in Ecuador, Peru, and Zaire to determine the feasibility of installing similar systems. A renewable-energy project was initiated in Tunisia, to combine several solar technologies for services to the village of Hamman Biadha and the surrounding agricultural community. Upper Volta requested a doubling of capacity for the highly successful unit in the village of Tangaye.

Space Data Services

NASA communicates with, commands, tracks, and processes data from deep space probes and earth-orbital spacecraft through two worldwide tracking networks. A global communications system links tracking sites, control centers, and data processing facilities, providing real-time data processing for mission control and orbit and trajectory determination, as well as routine processing for engineering and scientific telemetry.

Preparation for Shuttle Support

Network readiness activities have been under way for the past several years in preparation for Space Shuttle missions. Necessary hardware changes were completed in 1980, and software programs were developed and checked out at ground stations. Verification and compatibility testing of the systems was completed in October. Requirements for upgraded communications circuits were met. Some air-to-ground communications equipment used in the Apollo program was modified to provide additional communications with astronauts on Shuttle missions.

Network Operations

The tracking system continued to support NASA earth-orbital missions, including *Landsat 2* and *3*, *Solar Maximum Mission*, High Energy Astronomy Observatories *Heao 1* and *2*, and the International Ultraviolet Explorer satellite *IUE*. Launch and in-orbit support was also provided other government agencies, commercial firms, and foreign governments.

The Deep Space Network (DSN), supporting interplanetary spacecraft, was significantly upgraded for *Voyager 1*'s November encounter with the planet Saturn. Conversion of a 26-meter-diameter S-band antenna to a larger, more efficient 34-meter S- and X-band antenna at each DSN station was completed. Low-noise X-band maser amplifiers, among the most sensitive radio receivers built, were installed on existing 64-meter-diameter antennas. These enhancements were integrated by "arraying" the two antennas through a real-time combiner assembly at each station complex. Electronically combining the spacecraft signals received by the two antennas provided about 35 percent more images from Saturn than could be obtained with a 64-meter antenna alone.

Data Systems

Six control centers supported some 25 spacecraft in orbit in 1980, and work was under way on a seventh center to support the planned *Space Telescope* mission. Control centers issue commands to monitor onboard conditions such as power and thermal status to ensure health and safety of the spacecraft. Computers calculate the spacecraft orbit, compute the attitude of the craft to assist in maneuvers, and manage command memory.

Tracking and Data Relay Satellite System (TDRSS)

A major capability to become operational in 1984 is the TDRSS, a system of two data-relay satellites that will take over tracking and acquiring data from all low-earth-orbiting spacecraft. TDRSS will significantly upgrade support capability and effect economies by station closings, network consolidation, and automation of some operations. NASA has entered a service contract with the Space Communications Company to procure TDRSS services for 10 years.

Progress Made. Considerable progress was made in manufacture of the spacecraft. In the TDRSS ground segment, comprehensive system tests were begun, with integration and environmental testing of the first spacecraft to be completed in the winter of 1980-1981. Most of the delivered equipment was installed and initial testing on major components completed at the White Sands, New Mexico, ground station. The Network Control Center at Goddard Space Flight Center, Greenbelt, Maryland, was making good progress.

Network Consolidation. When TDRSS becomes operational in 1984, low-earth-orbital spacecraft will be supported only by TDRSS. High elliptical and synchronous missions will be supported by the three remaining Spaceflight Tracking and Data Network (STDN) ground stations at Goldstone, California; Madrid; and Australia. Since the STDN stations are in the same geographical areas as the Deep Space Network (DSN) stations, they will be consolidated with the DSN stations under the management of the Jet Propulsion Laboratory by the mid-1980s, for significant operating cost savings.

Aeronautical Research and Technology

NASA's aeronautical research seeks advancements in the performance, efficiency, and safety of existing aircraft and a base of high technology that designers can use to improve aircraft of the next generation. These objectives include establishing and maintaining a strong technological base, reducing energy consumption of aircraft, improving terminal-area operations, advancing long-haul and short-haul aircraft, and providing technical support for the military.

Maintaining a Strong Technology Base

NASA's aeronautical research and technology programs cover the basic disciplines of aerodynamics, materials and structures, propulsion, avionics and flight control, and human factors. Significant progress was made during 1980 in measurement and control of turbulent flows, advanced materials for airframe and propulsion systems, fuels research and aircraft controls, and navigation and guidance.

Aerodynamics. An important aspect of the research on turbulent flows has been the development of geometrical surface deformations to reduce turbulent skin friction. One concept introduces V-grooves, or "riblets," into an aerodynamic surface. The grooves, about the size of grooves in a phonograph record, may reduce drag by as much as seven percent. While reduced drag can be seen empirically, work is continuing to understand this phenomenon.

In a related area, a laser-doppler anemometer has been developed to measure high-resolution turbulence in large-scale wind tunnels. Previous measurements of turbulence in wakes, jets, and boundary layers using laser optical techniques have been confined to relatively small facilities. The new instrument has the long-range sensing capability (2 meters) and the spatial resolution (0.2 millimeters) to permit investigation of the details of turbulent boundary layers and thin wakes. It has been combined with a computerized data-acquisition system to reduce overall test and wind-tunnel operating costs.

Materials and Structures. Significant advances continue to be made on composite materials for airframe applications. Recent work in understanding the interactive behavior of composite constituents, resin synthesis and processing, and composite construction and design promise a second generation of material with reduced costs, increased reliability (i.e., improved toughness, damage tolerance, and environmental resistance), and reduced weight. Existing composite materials offer a 25-percent weight reduction over comparable aluminum structures; the new composites have shown a potential for an additional weight saving of 20 percent.

One important aspect of research on materials for propulsion systems focuses on gaining a better understanding of the structural dynamic characteristics of the blades of rotating components in a gas turbine engine. During 1980, an experimental facility was made operational at Lewis Research Center in which an instrumented test rotor of up to 50 centimeters in diameter can be spun to speeds of 18 000 rpm in either a normal atmospheric environment or one near total vacuum. Two electrodynamic shakers reproduce the complex vibration patterns characteristic of fan, compressor, and turbine blades under conditions of load. Data obtained will guide and verify the development of analytical predictive methods.

Propulsion. As reported in past years, NASA continues to make advancements in analytical computer codes and numerical techniques for modeling complex flow fields in aerodynamics, both the internal flow in turbomachinery components and the external flow associated with integration of propulsion system and airframe. The principal focus of the latter area is to understand and minimize the drag effects of engine installations. A significant accomplishment in 1980 was the development of numerical techniques that approximate the complex flow field exiting the nozzles of a two-engine aircraft. These codes have been compared with similar experimental data and show excellent correlation except for a small region where flow separation is most pronounced.

Major uncertainties about supply, quality, and cost of aviation turbine fuels has prompted NASA to expand its investigation of the effects that fuels with broader properties (such as higher freezing point, boiling point, and aromatic content) can have on aircraft-engine and fuel-system performance. Advanced combustor concepts that will accommodate such fuels are being evaluated.

Research in multizone lean-burning combustors indicates that flame radiation levels can be minimized by burning at fuel-lean conditions during high-power operation. During 1980, these concepts were verified in tests in which an advanced, double-annular (multizone) combustor was compared with a conventional, single-annular design.

Noise research in 1980 focused on concepts to suppress noise generated by coaxial jet flows typically associated with turbofan engines. Scale-model tests have proved that changing the relative eccentricity of the nozzles (moving the core-stream nozzle off center relative to the fan-stream nozzle) can lead to circumferential variations in the sound field and thus can reduce jet noise in selected directions. These tests clearly demonstrated that it is possible to shape jet nozzles geometrically to tailor the sound field.

Avionics and Flight Controls. Research into controls in 1980 was directed toward suppressing pilot-induced oscillations (PIO) inherent in some aircraft when performing precision-control tasks. Refueling in air, air-to-air tracking, close-formation flying, and precision landing are high-work-load tasks that sometimes lead to PIO. The problem usually results from a particular combination of control system characteristics, aircraft dynamics, and high-work-load tasks that require intense pilot concentration. A special filter (computer code), designed and tested on the F-8 digital fly-by-wire experimental aircraft at Dryden Research Center, showed effectiveness in suppressing PIO.

Avionics and Human Factors. Work continues on the joint NASA-FAA cockpit-display-of-traffic-information (CDTI) program to assess advantages and limitations in presenting traffic information to the pilot. CDTI symbols and format were evaluated and refined during 1980 by dynamic simulation experiments and flight tests in the terminal control vehicle at Langley Research Center. Tests showed that while a 7.5- by 10-cm display was satisfactory in maintaining required aircraft spacing, superior performance was achieved using a 15.5- by 15.5-cm display. Two projects in research methodology were completed in fiscal 1980. A standardization of work-load measures was developed for assessing the effects of CDTI on pilots.

Reducing Energy Consumption

NASA made progress in 1980 in developing technology to reduce fuel consumption in derivative and future subsonic, commercial, transport aircraft by as much as 50 percent.

Engine Systems. The agency continued to provide fuel-saving improvements for new and derivative JT8D, JT9D, and CF6 turbofan engines. Technical activities have been completed on 9 of the 16 engine components selected for development. Demonstrated fuel savings have been very close to predictions. Seven improved engine components have been committed to production and four are in commercial service. The new technology is especially timely since new derivative engines are under development. Each application of the technology leads to repayment of the NASA investment by industry; an initial return of $200 000 was received in 1980.

Industry has adopted more of the NASA information generated to isolate and quantify causes of performance deterioration in JT9D and CF6 turbofan engines. NASA investigations indicate that about 1-percent improvement in specific fuel consumption during cruise and as much as 50-percent reduction in expensive, unscheduled, engine changes are achievable. Additional tests are studying the effect of flight loads on engine-component running clearances and the related deterioration in engine performance. New engine designs will benefit from these tests.

For the next generation of fuel-efficient, performance-deterioration-resistant, and economical turbofan engines, NASA has begun testing major engine components. New turbofan engines are expected to consume 14 to 22 percent less fuel and to have 5 to 10 percent lower direct operating costs, 50 percent less performance deterioration, and lower noise and emission levels than large turbofan engines now in service.

NASA is demonstrating high-speed propeller technology for commercial transports and short-haul commuter aircraft. A series of subscale models, 62 centimeters in diameter, has been fabricated. These models have 10 blades and are expected to be about 20 decibels quieter and one percent more efficient than any other models tested. A wind-tunnel test of an advanced 8-bladed, high-speed propeller model mounted on a nacelle on a swept, supercritical wing identified the basic installation drag and propeller-wing interactions.

Aerodynamics Systems. In research to improve the efficiency of commercial transport aircraft, the three major contractors demonstrating advanced aerodynamics and active-control concepts prepared for major flight tests. Bench tests of reduced-static stability components, leading to projected fuel savings of three to four percent, were under way. Fabrication of winglets for the DC-10-30 neared completion. The initial configuration of an advanced, integrated, active-controls system was evaluated. The joint NASA-USAF flight-test program of winglets on a KC-135 tanker was completed in 1980, confirming a predicted 7.1-percent reduction in cruise drag below that of the unmodified KC-135. Efforts continue to obtain detailed structural load data for possible retrofit modification of KC-135 aircraft.

Research in the control of laminar (smooth) air flow close to wing surfaces aims at demonstrating a practical, reliable system that will reduce drag by 20 to 40 percent, depending on the extent of application and aircraft range. In 1980, preparations began for flight-testing two state-of-the-art concepts for laminarizing the flow over a wing leading edge.

Structural Systems. Structures research focuses on advanced graphite-fiber-reinforced composite structures for transport aircraft. Developing the technology for three secondary and three medium-primary aircraft structural components is expected to save up to 25 percent in structural weight and 10 to 15 percent in fuel.

Two of the three secondary-component technology programs were nearly completed in 1980. The first full-scale Lockheed L-1011 composite aileron has been fabricated. Development testing is scheduled to start in 1981. The Boeing program has completed test requirements for Federal Aviation Administration certification of the B-727 composite elevators. The Douglas DC-10 composite rudder was certified by the FAA. The 10 rudder units manufactured indicated that production cost of composite rudders will be lower than the comparable metal part after 50 to 100 units are produced.

Design and fabrication of two of the three medium-sized primary structures components have been completed. The full-scale composite spars and skins of the L-1011 vertical fin have been fabricated, and development-testing of the fin spars has begun. DC-10 vertical-stabilizer fabrication is near completion. B-737 horizontal-stabilizer subcomponents have successfully completed static, fatigue, and fail-safe testing. The first B-737 stabilizer was flown in late 1980.

Improving Terminal Area Operations

In cooperation with FAA, NASA is developing technology for advanced airborne guidance, flight control, navigation and display systems, and flight procedures that can improve terminal operations.

NASA used its highly modified B-737 aircraft to develop symbols for cathode-ray-tube displays and flight procedures for using them. Improved autoland flare laws reduced touchdown dispersion to one-third that of conventional flare laws during recent flight tests. Control laws have also been developed for automatic high-speed turnoff using a magnetic leader cable for guidance. These activities led to industry's designing similar control laws for possible retrofit of present and new production aircraft.

Safety. In 1980, substantial progress was made in defining atmospheric hazards and demonstrating advanced fire-safety technology. Flights near electrical storms were continued in a specially instrumented NASA F-106B aircraft. Lightning strikes on and near the aircraft provided new data about electric fields and magnetic fields. Flight data also made some inroads in mapping severe weather and correlating aircraft and ground-measured data.

NASA research in cooperation with FAA pursues technology to improve chances for surviving the conditions that follow aircraft crashes. In 1980 an anti-misting kerosene (AMK) concept, demonstrated in small-scale experiments, showed that it may be possible to avoid ignition of fuel mist following impact. The effects of AMK on turbojet engine components have been defined after a one-year experimental research effort using a JT8D engine. Changes that may be required of engine components are being identified.

Advancing Long-Haul and Short-Haul Aircraft

NASA is progressing well in the development of technology sufficient to make rational decisions concerning future military and civil supersonic-cruise aircraft. Research efforts also are addressed to quiet short-haul aircraft that operate at very low approach speeds, rotorcraft, and general-aviation aircraft.

Supersonic Research. Supersonic-cruise research programs in 1980 continued to focus on aerodynamics, structures, propulsion-airframe integration, and propulsion. Related requirements for reduced noise and reduced fuel consumption were also studied.

The propulsion research includes two concepts: the variable-stream-control engine and the double-bypass engine. In 1980 the variable-cycle-engine components program completed major experimental demonstrations of the noise-reduction capabilities of the coannular ejector nozzle of the variable-stream-control engine and the aerodynamic performance of the core-driven fan stage of the double-bypass engine.

During 1980, wind-tunnel tests validated predicted lift-to-drag ratios over the full speed-range and determined the flow-field effects of podded nacelles installed on highly swept supersonic wings. Adhesive bonding techniques, cold forming of the beta alloy, and several approaches to the superplastic-forming diffusion-bonding process have been demonstrated for advanced titanium structures. Selected composite material systems have accumulated more than 20 000 hours of life-testing. Significant supersonic-wind-tunnel tests were completed this year using an axisymmetric translating centerbody inlet.

Rotorcraft. Tests of a full-scale, advanced, bearingless main rotor in the NASA 40- × 80-foot wind tunnel provided an extensive aeroelastic-stability and performance data base to substantiate design methodology for improved operational rotor systems. Also in 1980, a full-scale model of the XH-59 advancing-blade-concept aircraft was tested in the tunnel to investigate drag reduction and interaction of rotor, airframe, and propulsion system.

Helicopter flight research evaluated promising guidance and control systems for safe, automatic helical-path landings near the boundaries of airports with heavy fixed-wing traffic.

Substantial progress was made in computational methods for optimizing rotor-blade performance and dynamics and for predicting the structural dynamics of complex helicopter-airframe and rotor system design.

General Aviation. NASA's general-aviation research in 1980 continued to improve aircraft safety, energy efficiency, utility, and environmental impact.

Research continued on light-aircraft stalls and spins, including additional spin-tunnel model tests and flight tests of several manned aircraft. Wind-tunnel tests were conducted at Langley Research Center on a full-scale, low-wing aircraft to understand better the aerodynamic principles of a wing with drooped-outboard leading edge that proved effective in delaying stall, reducing stall severity, and preventing flat spins in the test aircraft. The characteristics of a representative high-wing aircraft were also determined in full-scale flight tests. The data base is being used to extract the governing parameters for a comprehensive analysis of single-engine aircraft characteristics.

Research with FAA on energy-absorbing structures for greater ability to survive crashes continued investigations of fuselage subfloors and seats. Dynamic tests showed that the notched corner and corrugated beam are two of the best subfloor structural concepts. Two more full-scale aircraft were crash-tested at the Langley crash test facility, to total 25 since this research began in 1974. The tests provided new data on large-deflection inelastic behavior of different structural configurations. Besides contributing to a basic understanding of this behavior, the data will be used to check the validity of recently developed analytical prediction methods, to improve design techniques.

Extending previous research, wind-tunnel tests were conducted at Langley on a specially configured flapped airfoil, designed to maintain natural laminar flow over the first 40 percent of the upper surface and 60 percent of the lower surface under climb and cruise conditions for typical light aircraft. Test data indicate the airfoil's drag under these conditions is substantially lower than that of the GA(W)-1 airfoil developed for general aviation several years ago, and also lower than that of early laminar-flow airfoils developed by NACA during World War II for higher speed aircraft. If this extent of laminar flow can be realized in full-scale aircraft, reduced drag could improve energy efficiency at least 10 percent for representative general-aviation light aircraft.

The NASA demonstration advanced-avionics system (DAAS) program evaluates an integrated-avionics system concept specifically addressed to single-pilot requirements typical of general aviation. DAAS displays and controls are designed so that the pilot can use the system after minimum training. In 1980, a DAAS simulator was fabricated; 12 pilots from the private sector and government operated it and recommended only minor changes, which were incorporated. The DAAS design includes provision for incorporating the discrete-address beacon system

(DABS) now being developed by FAA. The DAAS flight-demonstration hardware has been fabricated and software elements completed, and DAAS will be checked out in a light two-seat aircraft in 1981.

In environmental impact studies, primary emphasis has been on noise reduction. Low-noise-propeller designs were begun in 1980 for two-, three-, and four-blade propellers. A two-blade propeller design was fabricated and flight-tested on a Cessna 172 aircraft. Preliminary results indicate that, as predicted, it produces five decibels less noise than the conventional two-blade propeller. This propeller is being evaluated by Cessna Aircraft's McCauley Division as a possible replacement for the standard Cessna 172 propeller.

Technical Support for the Military

NASA aeronautical programs include broad-based research to improve future military aircraft.

Highly Maneuverable Aircraft Technology (HiMAT). A joint NASA-USAF program is investigating advanced high-risk technology with potential applicability to high-performance aircraft. Since the first flight of the subscale 44-percent-scale model of a remotely piloted research vehicle in July 1979, six additional flights have concentrated on expanding the flight envelope into high transonic and supersonic speeds.

Quiet Short-Haul Aircraft. Following documentation of the flight characteristics of NASA's quiet short-haul research aircraft (QSRA), the vehicle was used in a joint program with the U.S. Navy to judge the feasibility of adapting propulsive-lift, short-takeoff-and-landing (STOL) technology to shipboard operation. In the first phase, NASA and Navy pilots determined techniques for landing on or taking off from a carrier through more than 500 land-based simulated carrier operations with the 22 700-kilogram QSRA. The second phase, operating the QSRA on the carrier *Kitty Hawk* at sea, substantiated the shore-based results. Aircraft using this propulsive-lift technology will have sufficient performance and controllability to make precision approaches to the deck of an aircraft carrier at sea, at speeds permitting unarrested landings, and to take off without use of a catapult. The effects of the carrier's aerodynamic wake, ship motions, and ground effects were determined and STOL and carrier operational criteria were obtained for future use by the Navy.

Tilt-Rotor Research Aircraft. The contractor's development flight tests of the XV-15 aircraft were successfully completed at the Bell Helicopter Textron plant. The aircraft achieved a speed of 555 kilometers per hour and demonstrated good flight characteristics in all flight regimes. In this joint NASA-Army-Navy program, the first XV-15 aircraft was accepted by the government in 1980 and completed concept-evaluation flight research. A second was to be accepted in 1981. One of the two will be exhibited at the 1981 Paris Air Show and will be returned to NASA for a NASA-Army concept-evaluation program during 1981.

Rotor System Research Aircraft (RSRA). In a joint NASA-Army-Navy program, the RSRA research vehicle in helicopter configuration was checked out by the pilot and baseline flight-tested at Ames Research Center during 1980; it has begun a flight research program to evaluate vertical drag in hover and at low forward speeds. Design studies have been completed on a modern four-blade system for flight research on the RSRA. The other research vehicle in the compound configuration (wing and auxiliary-thrust engines added) has been extensively calibrated in a new facility, analyzed, and had some empennage structural components strengthened during 1980.

V/STOL Aircraft Technology. In a cooperative program with the Navy, good low-speed performance, stability, and control characteristics were measured for a high-subsonic, twin-turbofan V/STOL concept in tests of a large-scale model in the NASA 40- × 80-foot tunnel. The model had TF-34 engines. Vanes in the engine exhausts provided control at very low speeds and hover.

Exploratory tests were also made to determine the general performance and control characteristics of a four-tenths-scale model of a twin-engine fighter-attack V/STOL in the 40- × 80-foot tunnel. The model was designed for taking off and landing vertically, and the tunnel tests were conducted over the very large angle-of-attack range that such a concept encounters. The cruise and maneuver flight characteristics of several twin-engine V/STOL fighter concepts were investigated by tests of small-scale models in transonic and high-subsonic tunnels at Ames.

Department of Defense

The Department of Defense has a vital interest in space and aeronautics for the purpose of national security. Evidence of the growing importance of space and aeronautics activities is the significant increase in annual funding for these defense efforts over the past five years, with further increases projected for the future. The primary areas of emphasis are communications, navigation, weather prediction, surveillance, and space science. While these programs are military, DoD maintains a close liaison with NASA and other agencies of the government through which DoD programs can provide shared benefits. In 1980, several important events covered a wide range of space activities, including the launch of two more Global Positioning System satellites and the launch of two Fleet Satellite Communications System satellites. Aeronautical activities continued, with new design concepts evaluated in several joint flight programs with NASA. Activities also included application of new aircraft structural designs and development of advanced flight control and navigation systems.

Space Activities

Military Satellite Communications

Satellite communications systems have become an important asset for both commercial and military applications because they offer a number of distinct capabilities: worldwide coverage, service to isolated areas, wide transmission bandwidths, and contingency operations. DoD operates its own satellite communications system and also leases commercial satellite service to support needs for worldwide command and control of U.S. military forces. Defense requirements call for three categories of capability: (1) high-capacity, high-data-rate, long-haul, point-to-point communications for fixed users; (2) moderate-capacity, low-data-rate communications for mobile users; and (3) low-capacity, low-data-rate communications for command and control of strategic nuclear forces. Military satellite communications systems that satisfy these mission capabilities must be hardened against nuclear effects and have jamming and cryptographic protection. These additional system requirements and high-capacity communication links are unique to DoD, enhancing communications and command and control continuity in a hostile or crisis environment. These three categories of capabilities are now satisfied by: (1) the Defense Satellite Communications System Phase II (DSCS II); (2) Fleet Satellite Communications System (FLTSATCOM), plus leased services on the Marisat Satellite System (Marisat); and (3) the Air Force Satellite Communications System (AFSATCOM), consisting of transponders on the Satellite Data System (SDS), FLTSATCOM, and other host satellites. During the coming decade, these systems will be replaced in an evolutionary manner by DSCS III and the Leased Satellite (LEASAT) System.

Defense Satellite Communications System (DSCS). The mission of the DSCS is to provide high-data-rate communications in support of unique and vital national security requirements for worldwide military command and control and crisis management. The DSCS supports critical globally distributed communication requirements of the National Command Authorities, the Worldwide Military Command and Control System, the Ground Mobile Forces, the Defense Communications System, the Diplomatic Telecommunications Service, the White House Communications Agency, NATO, and other U.S. allies.

The DSCS system consists of four active DSCS II satellites and two on-orbit spares, providing nearly global (excepting polar) coverage. To ensure continuity of essential communications and enhance survivability during crisis situations and in hostile communications environments, evolving DSCS satellites will include an improved anti-jam capability in addition to nuclear-effects hardening.

The next generation of DSCS satellites will be DSCS III models, with improved performance capabilities and protective devices to enhance survivability. During 1980, development of a qualification-model satellite, two flight satellites (*DSCS III A-1* and *A-2*), and ground command-and-control equipment continued. The first satellite (*DSCS III A-1*) was scheduled for launch in 1981 for about six months of test and evaluation, after which it would be placed in operational use. *DSCS III A-2* was scheduled for launch in mid-1982 and a comparable test period before operational use.

The DSCS III satellites will have six independent transponders to handle efficiently a mix of users (with small and large terminals), with improved anti-jam protection through multibeam antennas capable of nulling or minimizing uplink jamming signals. In addition to the normal S-band tracking, telemetry, and command functions performed by the U.S. Air Force, the DSCS III satellite will have an SHF command capability, controlled operationally by the Defense Communications Agency. This capability will improve response time for reconfiguration of its antenna systems. The satellite will conform to nuclear survivability guidelines and will have a design life of 10 years. Since the Space Shuttle will become operationally available during the life of the DSCS III program, the DSCS III satellite is being designed to be Shuttle-compatible. The SHF communications satellite requirements of the 1980s and beyond will be satisfied by the increased capability and flexibility of the DSCS III satellite.

Air Force Satellite Communications (AFSATCOM) System. The AFSATCOM system provides communications for command and control of the nuclear-capable forces and other selected high-priority users. The space segment includes UHF transponders on the Fleet Satellite Communications (FLTSATCOM) system, the Satellite Data System (SDS) and other spacecraft. In 1980, the AFSATCOM terminal segment was being installed in ground command posts, airborne command posts, and strategic bomber forces. Terminals were being procured for the ICBM launch control centers, and installations were planned to begin in 1981. An initial operational capability was achieved in May 1979. Full operational capability was planned for 1983.

The Satellite Data System (SDS) is a major part of AFSATCOM. It provides critical two-way transpolar command and control communications for our nuclear-capable forces. In 1982-1986, the AFSATCOM payload on SDS will become the backbone of the AFSATCOM system as the U.S. Navy FLTSATCOM satellites begin to reach the end of their useful lives. During this time, SDS will be developing a spacecraft optimized for the Space Shuttle and an AFSATCOM payload with increased jam resistance. SDS also supports a data communications network among tracking stations and the Satellite Test Center.

Fleet Satellite Communications System (FLTSATCOM). Moderate-capacity, mobile-user service will be provided by FLTSATCOM. Its objective is to develop, procure, and put into operation a satellite communications system to satisfy the most urgent, worldwide, tactical-peacetime and crisis-management communications requirements of the Navy and strategic communications requirements of the Air Force. Production contracts for five FLTSATCOM spacecraft had been awarded, and the first four were launched in February 1978, May 1979, January 1980, and October 1980. Installation of fleet broadcast receivers was virtually complete, with systems installed in some 420 ships and 109 submarines. Additionally, 236 ships were equipped for reliable, long-range, secure voice operation. Shipboard terminal equipment was operating through both the Marisat and FLTSATCOM systems.

Army Satellite Communications Activities. The Army Satellite Communications Ground Environment program includes developing, procuring, and supporting strategic and tactical satellite communications ground terminals for use by the military departments. Two major projects are the Defense Satellite Communications System (DSCS) Phase II and the Ground Mobile Forces Tactical Satellite Communications (GMF-TACSATCOM) program. A third project is devoted to the exploratory development required to support the two major Army projects and other space programs being developed by the Department of Defense.

Army Exploitation of Defense Satellite Communications System (DSCS). Recently, 14 new, medium, satellite-communication terminals (AN/GSC-39 units) were approved for Army procurement for the DSCS. Added to the 21 terminals previously approved and being fabricated, the 14 new terminals will permit replacement of all the old and obsolete AN/TSC-54 and AN/MSC-46 terminals. Three additional gateway stations were approved for the program, which will further enhance tactical-strategic communications interoperability and survivability, and provide the military departments added flexibility to execute national policy decisions worldwide.

The Army began to develop and put into operation the real-time adaptive control subsystem, which, when completed in 1984, will provide computerized and fully automated control of the DSCS III satellites in orbit and the communications passing through them. The 23 digital communications subsystems originally shipped to the field were being phased into operation at the end of 1980. An additional 16 subsystems had been shipped to the field and were being installed and tested. No problems had been met in the contract for the new anti-jam, spread-spectrum, multiple-access equipment being procured for the DSCS. The initial delivery of the new AN/USC-28 units was scheduled for September 1981, and all 55 AN/USC-28s were scheduled to be incorporated into the system by mid-1982. The first of the new AN/TSC-86 transportable and Joint Chiefs of Staff contingency satellite terminals were to be deployed in late December 1981.

Tactical Satellite Communications (TACSATCOM). Thirty-one low-rate, initial-production, multichannel, SHF, tactical terminals had been deployed by the U.S. Army in Europe by the end of 1980, for use with the DSCS II space segment. A full-production contract for 226 additional terminals was awarded in September 1979 with first deliveries scheduled for 1982. Production began on 210 UHF vehicular terminals scheduled for use with FLTSATCOM satellites, with an operational date of late 1981. UHF manpack contract negotiations were under way for production of 170 terminals, with delivery to begin in 1982. Studies had begun on future system architecture. Research and development decisions were near on developing a single-channel terminal fully protected from jamming. Terminal fielding would be in the early 1990s.

Advanced Space Communications Technology. New space components were developed for operation in the EHF bands. The primary component technologies under investigation are solid-state amplifiers, adaptive antennas, spaceborne processors, and airborne terminals. Additional development was under way to provide high jamming protection coupled with very high data rates, via laser communications. The Air Force completed flight tests of a gigabit-per-second, aircraft-to-ground link; and development of an orbital laser communications package for launch in 1983 continued on schedule.

Navigation Satellite Activity

The Navstar Global Positioning System (GPS) is a joint program of the Air Force, Army, Navy, and Defense Mapping Agency, with the Air Force as the executive agency. It will improve weapon delivery effectiveness and worldwide rapid force deployment with continuous, precise, three-dimensional positioning and navigation. The developmental system in 1980 provided up to six hours a day of accurate positioning worldwide with five satellites of the six in space (one satellite is not operating). The fifth and sixth satellites were launched in February and April 1980. By late 1987, the operational 18-satellite constellation is to provide positioning accurate to 16 meters, velocity accurate to 0.1 meter per second, and precise time synchronized to within 0.1 microsecond.

Department of Defense users will derive mission benefits from operating within the common positioning grid automatically provided by Navstar, as well as from the superior accuracy and global coverage. Additionally, the reliability of a system unaffected by weather and concealed by passive operation (users receive signals and do not radiate any energy) provides an improved capability to weapon delivery, intelligence, and reconnaissance missions.

The system concept was validated in 1978-1979 with the launching of four developmental satellites and extensive field testing of advanced-development equipment on a wide variety of aircraft, ships, and ground platforms. At the end of 1980, the operational system was in full-scale engineering development. The satellite design was being modified for Space Shuttle launch compatibility and to add the ability to deny system accuracy to adversary military forces. The control segment was being designed to command and control the full constellation of satellites and to maintain full system accuracy and reliability. The user equipment was being developed to meet the needs of a wide range of Army, Navy, and Air Force weapon platforms and to achieve economies of production and maintenance through common parts and modules. All developmental contracts were under way, leading toward a decision to deploy the system by late 1983 after initial operational test and evaluation.

The concept-validation system and hardware were supporting additional testing of military concepts of operation, such as passive terrain-following and precision air drop of cargo pallets. The Navy was using Navstar to check the accuracy of submarine-launched ballistic missiles. The Air Force was planning to use Navstar for similar testing of the MX missile system. Midcourse guidance of air-to-ground missiles also was being examined. Army participation in the program is for the purpose of developing and testing a family of aircraft, vehicle, and manpacked user equipment to meet a broad variety of requirements for en route navigation, artillery, engineer surveying, and target acquisition. The Landsat-D satellite, to be launched in late 1981, will use Navstar to determine satellite positions in space for correlation with earth photography.

The Defense Mapping Agency in 1980 was developing two significant subsystems that will use the GPS-Navstar systems in mapping, charting, and geodesy. The first development was a continuation of work on a space-qualified GPS receiver. The engineering model of this unit functioned satisfactorily under laboratory conditions; it simultaneously tracked four GPS satellites and provided a navigational solution. The first prototype system was to be completed in February 1981. The system was planned for inclusion in the next Landsat mission and will permit precise location of the satellite in real time. This unit and similar units could be included on future geophysical satellites.

The second development, begun in 1980, was an effort to design and build a geodetic receiver that will derive its positional information from the Navstar constellation. The receiver, using a novel approach to processing GPS transmissions, offers a potential for improved accuracy with greatly reduced time-on-site required by the user.

Meteorological Activities

Defense Meteorological Satellite Program (DMSP). DMSP supports DoD strategic and tactical needs for weather information. Its operational requirements dictate the use of two satellites continuously in orbit, obtaining weather information from all points on the earth at least four times each day. Global weather data is stored on the satellites and later transmitted to the Air Force Global Weather Center or to the Navy Fleet Numerical Weather Center. Satellite weather data is also transmitted in real time to transportable read-out stations at key locations worldwide to support Army, Navy, and Air Force tactical operations.

During 1980, the Air Force-managed joint-service DMSP system adequately supported DoD strategic and tactical needs for weather information for the first seven months. A satellite for the early morning orbit was launched in July to replace a degrading asset, but failed to achieve orbit because of third-stage malfunction. DMSP support was being supplemented by NOAA weather systems, although the data was far from satisfactory for DoD requirements. The Air Force accelerated the follow-on satellite production schedule, and "work-around" activities were able to sustain peacetime operations.

Surveillance Activities

Early Warning Satellites. Defense support is given by satellites that provide data to the National Command Authorities, the Strategic Air Command, and the North American Air Defense Command. During 1980, work was begun to replace computers in the ground stations to provide increased computational power for new, more capable satellites. Development of modifications also was continued to ensure compatibility of the satellite payloads with the Titan III(34)D inertial upper stages (IUS) and Shuttle-IUS, as well as development of improvements in the satellite communications elements. Newly developed improvements were being incorporated into satellite procurement and retrofitted into existing spare satellites, promising to increase system accuracy and operational life. Plans were made for satellites with increased survivability for the middle to late 1980s.

Surveillance and Warning. The Defense Advanced Research Projects Agency (DARPA) in 1980 continued developing advanced concepts and technology for strategic and tactical surveillance from space. Programs included development of space experiments to demonstrate the application of technology base components to mission performance. Radiation source monitoring from space was being demonstrated with the DARPA 301 gamma-ray spectrometer, orbited by the USAF Space Test Program in early 1979. The experiment continued to operate successfully, including demonstration of the long-life cryogenic refrigerators developed for this flight. The experiment achieved a gamma-ray spectral resolution of 3000 electron volts, the highest yet measured in space, and provided new information on the character of radiation backgrounds and sources.

Development of surveillance technology for infrared mosaic detector arrays, onboard signal processing, cryogenic refrigerators, large optics, and structures continued in 1980. A new generation of detector arrays, physically integrated with preprocessing electronics in a planar configuration, was tested. The breadboard model of a lightweight, large-data-capacity, onboard processor was successfully demonstrated against real target and background data from the Hi-Camp airborne imaging spectroradiometer. The Teal Ruby space experiment to demonstrate detection and to space-qualify first-generation infrared mosaic detectors was being prepared for Space Shuttle launch in 1983. Quantity production of Teal Ruby mosaic chips using the fully automated cryogenic test set was performance-qualified. DARPA completed the system requirements review of the advanced sensor demonstration program to demonstrate advanced surveillance missions and the technology base developed to support them; an integrated-sensor spacecraft was being designed for launch into geosynchronous orbit in 1987. Technology development continued for key components and concepts for space-based radar, including transmitter, large lightweight phased arrays, and onboard signal processing components. Miniature low-cost radar transceiver modules were designed using integrated-circuit technology, and test circuits were fabricated. DARPA continued design and analysis for the Talon Gold experiment to develop space technologies for precision acquisition, tracking, and pointing at long range.

In missile surveillance technology, a successful rocket probe experiment in May 1980 at White Sands Missile Range obtained rocket plume data for design of a follow-on surveillance system. A successful test flight of a new high-altitude balloon platform design in May 1980 paved the way for future missions to provide required earth background data. Future rocket probes will gather data over a larger variety of conditions. Measurements from laboratory experiments and from other platforms will round out this comprehensive measurements program.

The Distant Early Warning (DEW) Line constructed in the 1950s is our only atmospheric tactical warning system. Replacement and upgrading of this capability was being considered by the Air Force because the installation provides a marginal capability. During 1980, an effort was started to identify space-based and ground-based alternatives to improve this capability. Near-term and far-term multimission space-based alternatives making use of two different phenomenologies were designed. Additional effort was planned to advance selected alternatives from a conceptual design into full-scale engineering development during the 1980s.

Space Shuttle Activities

The National Aeronautics and Space Administration has overall responsibility for development of the Space Transportation System (STS); DoD is fully committed to using it. By the mid-1980s, DoD will be nearly totally dependent on the Shuttle for supporting national security space missions.

The Air Force, acting as the agent for DoD, has responsibility for developing the inertial upper stage (IUS), which will deliver DoD spacecraft to higher orbital altitudes and inclinations than can the Shuttle alone. In 1980, IUS development continued, with some problems; technical difficulties and cost overruns were being resolved, and the IUS was expected to be ready for planned missions. The Air Force also plans to use the IUS on the Titan III(34)D launch vehicle during the transition from Titan III to Shuttle.

DoD also will provide a Shuttle launch and landing capability at Vandenberg Air Force Base to support high-inclination, sun-synchronous polar or near-polar orbital launches. Performance loss in launches to these orbits from the East Coast Kennedy Space Center would be unacceptable. The Air Force continued work in 1980 to complete construction of the Vandenberg facility. Initial operational capability is scheduled for 1984.

Space Research and Technology

Environmental Studies. The Air Force Geophysics Laboratory (AFGL) has begun, with NASA, a program to specify environmental conditions in space that affect space systems. Critical focus on this area is recent and is a result of identifying spacecraft-environment interactions as the cause of certain satellite failures. AFGL is studying environmental effects on large space structures and system applications, with programs studying the radiation belts, cosmic ray effects, and charged-particle beam interactions in space. The cryogenic infrared radiance instrumentation for Shuttle (CIRRIS) project will closely examine atmospheric background for an increasing number of system applications in infrared technology. It was sheduled for an early Shuttle flight and will also examine the Space Shuttle contamination issues.

Space Subsystems. In a continuing effort to improve space subsytems, fabrication of an autonomous navigation system for satellites was nearing completion, and a semioperational model of a fault-tolerant computer was demonstrated. Both of these subsystems will reduce the dependence of satellites on ground stations. Future emphasis will continue on increasing satellite autonomy by augmenting onboard processing and fault recovery. Lightweight metal-gas batteries have been tested in space, and future efforts will optimize performance. High-efficency, radiation-hardened silicon solar cells have been demonstrated; future efforts will exploit greater gains from new materials. Long-life, monopropellant, secondary propulsion thrusters have been successully evaluated. Future emphasis will be placed on high-performance, precision, electronic thrusters for attitude control and station-keeping.

Spacecraft Charging Technology. The Air Force Geophysics Laboratory is still active in the joint USAF-Navy-NASA spacecraft-charging technology program. Preliminary models of the natural environment leading to spacecraft electrical charging have been developed. Data from the Air Force test program's Spacecraft Charging at High Altitudes *Scatha* satellite, launched in January 1979, are being used to update these models. *Scatha* satellite instrumentation, supplied by the Air Force, included electrostatic analyzers, charged-particle flux spectrometers, and electron and ion beam systems that have demonstrated the feasibility of controlling satellite charging and discharging. Close coordination between the interdependent activities of the Air Force, Navy, and NASA continues through the joint program.

Space Applications for High-Energy Lasers. The Air Force and DARPA are assessing the feasibility of space deployment of high-energy laser systems for a variety of potential mission applications. System definition for weapon-grade lasers on space platforms will be a major effort, as will determining the effectiveness of laser systems as compared to other technologies proposed for the same applications. Preliminary results of this effort, begun in late fiscal 1980, were to be completed in the middle of fiscal 1981, with refined system analyses to follow.

Cryogenic Cooler for Space Infrared Sensors. The Air Force has successfully integrated a high-capacity cryogenic refrigerator with a large infrared sensor needed for advanced space surveillance satellites. An important part of the overall Space Defense Systems program is the development of advanced infrared sensors for use on Air Force satellites in essential surveillance and detection missions. Critical components in these sensors must be cooled to very low (cryogenic) temperatures. The cryo-coolers must have very little vibration to be compatible with the sensors and must be rugged and efficient for use on a spacecraft for long periods of time.

A high-capacity Vuilleumier-cycle cryogenic refrigerator was used to test the space infrared sensor (SIRE), which marked a major milestone in the development of cryo-coolers for space applications.

The cryo-coolers easily provided the very low temperatures needed for sensor operation.

Space Ground Support

DoD space and missile activities are principally supported by the Air Force's Eastern and Western Space and Missile Centers, Satellite Control Facility, Arnold Engineering Development Center, and the Army's White Sands and Kwajalein Missile Ranges. These facilities are available for use by federal agencies and industry, and support a wide variety of tests.

Eastern Space and Missile Center (ESMC). ESMC supports a variety of DoD space and ballistic missile operations, NASA space programs, and commercial or international satellite launches under the sponsorship of NASA. During 1980, ESMC supported Navy testing of Poseidon and Trident fleet ballistic missiles. Launch and data-acquisition support was provided to NASA's programs, the European Space Agency's Ariane launch vehicle program, satellites for commercial organizations, and operational space payloads for the Air Force. ESMC supported the Air Force's short-range attack missile and the Army's Pershing programs. The center also tested the DoD tracking network in support of the Space Shuttle, to be launched for orbital test flights from the Kennedy Space Center in 1981.

Western Space and Missile Center (WSMC). WSMC is a major test facility, providing range tracking, data acquisition, and flight safety support for DoD ballistic missile and NASA and DoD space launches, as well as aeronautical tests at Vandenberg AFB. Some 75 ballistic missile launches, space launches, and aeronautical flights were conducted in 1980. The major aeronautical program was the air-launched cruise missile. WSMC is planning and constructing launch, logistic, and maintenance facilities to support Space Shuttle and MX launches from Vandenberg.

Satellite Control Facility (SCF). The Department of the Air Force controls orbiting spacecraft through the SCF, a worldwide network of seven remote tracking sites and the Satellite Test Center (STC) at Sunnyvale, California.

During 1980 the SCF supported 13 launches, including 8 DoD orbital missions, 1 NASA orbital mission, and 4 ballistic flight tests. Although major refurbishment of two tracking stations slightly reduced the network support available, 84 800 contacts totaling 69 000 hours of support were provided to DoD satellite programs. Station projects included construction at Thule, Greenland, and antenna drive and radome overhaul at the Indian Ocean Station. The data system-modernization project continued through the stage I development phase. It consolidates data processing functions into a centralized system at the Satellite Test Center and provides much needed capacity and reduced operating costs. The stage II production contract will be awarded in January 1981, with initial operations starting early in 1985.

Consolidated Space Operations Center (CSOC). The CSOC will be a USAF ground control center housing the command and control functions required to conduct DoD Space Shuttle and satellite missions. The Satellite Test Center, a single critical control element, is vulnerable to possible natural catastrophe or hostile acts. In addition, the Satellite Control Facility work load has increased 125 percent in the last two years. By 1985 the STC will have to support some 65 satellites; a second facility is needed to share the increasing work load and to eliminate dependence on the single control element at Sunnyvale. In February 1979 the Office of Management and Budget requested DoD and NASA to evaluate whether a joint mission control center or separate DoD and NASA facilities should be used to meet post-1985 Space Shuttle mission requirements. The agencies recommended a separate DoD facility to provide greater security for military missions.

The two mission elements of satellite control and Space Shuttle operations are to be combined for management, operational, and economic efficiencies into CSOC. The satellite control element of CSOC will perform communications and command and control service functions for orbiting spacecraft. The Shuttle control element will conduct DoD flight planning, readiness, and control functions. It will provide direct mission authority over DoD Shuttle missions, respond to national priorities, and protect national security data.

The preferred location for the CSOC is the Peterson Air Force Base and Colorado Springs area, with alternate locations at either Kirtland AFB, New Mexico, or Malmstrom AFB, Montana. Construction was scheduled to begin in fiscal 1983, with an initial operating capability in fiscal 1986.

White Sands Missile Range. WSMR continued to support DoD and NASA aeronautics and space programs, including NASA's Space Shuttle, upper atmospheric sounding rockets and balloons, and a variety of astronomical test programs. The range was continuing preparation for a Shuttle landing. Past and ongoing efforts include constructing a second landing strip; constructing facilities for landing, deservicing, and departure; preparing a public affairs plan for visitors to the range during and after a landing; providing overall security support; and conducting astronaut recovery exercises. WSMR was training chase aircraft pilots for rendezvous and also is testing tracking acquisition and data transmission.

Kwajalein Missile Range (KMR). KMR is operated by the U.S. Army as the major test range for our strategic missile forces, both offensive and defensive. The United States possesses no other comparable capability to collect signature data on objects outside the earth's atmosphere, record missile reentry phenomena, provide terminal trajectory and impact data, recover reentry vehicles when required, and transmit near-real-time data to mission sponsors. Missiles fired into KMR achieve mutual offensive and defensive test objectives and a continuous interchange of data among all developmental programs.

Arnold Engineering Development Center (AEDC). AEDC provides essential aerodynamics, space environment, and propulsion tests to accelerate development of aeronautical and space systems. It has supported virtually every major U.S. aerospace program. Operating 24 of 29 test units for more than 50 000 test hours in 1980, it supported such projects as MX, air-launched cruise missile, Space Shuttle, intercontinental ballistic missile, and launch rocket motor tests. The Aeropropulsion System Test Facility will be ready for use in 1985 to test the large, high-performance turbojet and turbofan engines in a more realistic environment than can be attained today. Another test unit in planning is the turbine-engine load simulator (TELS), a centrifuge that will stress engines to simulate an in-flight environment and at the same time x-ray the engine to determine abnormalities caused by g forces. TELS will reduce development and life-cycle maintenance costs.

Aeronautical Activities

Aircraft and Airborne Systems

B-52 Squadrons Development Projects. Development programs for B-52 squadrons are dedicated to increasing their survivability and effectiveness. The offensive avionics system (OAS) will replace high-cost, low-reliability elements of the bombing-navigation system with nuclear-hardened digital subsystems on B-52G and H aircraft. The introduction of the air-launched cruise missile (ALCM) weapon system has also been included in the B-52G modification program. Updated avionics will integrate this new weapon and ensure its effectiveness. The first flight of an OAS-modified B-52 was in early September 1980 (one month ahead of schedule) at Boeing Military Airplane Company in Wichita. The test program was scheduled to end with launches of the short-range attack missile (SRAM) and ALCM in September 1981. The first full squadron was scheduled for alert in December 1982. Although the first priority has been improving B-52G and H effectiveness, through the 1980s other development projects will examine modification requirements for directed missions, evaluate aircraft nuclear hardness, and update the radar system. These latter programs seek aircraft survivability in the roles which the B-52 must face in its remaining life.

Multirole Bomber. Although the B-52 aircraft should remain effective and economical as a standoff cruise-missile carrier into the 1990s, its ability to carry out the important penetration mission will be seriously degraded in the late 1980s by steadily escalating defensive threats. For this reason, the Congress directed the Department of Defense to pursue vigorously the development of a new mulitrole bomber, to be operational no later than 1987. The specific aircraft had not been selected in 1980; however, the leading candidates were variants of the B-1, a stretched and re-engined version of the FB-111 (termed the FB-111B/C), and advanced technology aircraft. Congress directed that the aircraft be able to launch cruise missiles, carry conventional munitions, and deliver nuclear weapons in both the tactical and strategic role. DoD was required to provide a progress report to the Congress no later than 15 March 1981.

Advanced Attack Helicopter (AAH). The advanced attack helicopter was in the final stage of full-scale engineering development. In April 1980, Martin Marietta Aerospace was selected as the contractor for the target-acquisition designation sight (TADS) and pilot night-vision sensor (PNVS). By the end of 1980, all prototype helicopters had been modified for the TADS/PNVS, a new stabilator, and other phase II changes, and were committed to qualification of the total weapon system, to include TADS/PNVS, the Hellfire missiles, 30 mm cannon, and 70 mm rockets. In late 1980, Army test pilots conducted tests to establish flight envelopes for operational AAH tests. On 22 November 1980, one of the prototypes and a T-28 aircraft collided in flight, causing three fatalities and loss of both aircraft. The Army was assessing the effect of this loss on the program.

CH-47 Modernization. The CH-47 modernization program will give the Army a medium-lift-helicopter capability beyond the year 2000. Engineering development begun in June 1976 has produced three prototype CH-47D models. The deputy secretary of defense on 20 October 1980 authorized full-scale production of the CH-47D beginning in fiscal 1981. The approved program will modernize the entire fleet of 436 CH-47A, B, and C helicopters. Fielding of the first complete unit of 24 CH-47D helicopters was planned for early 1984.

Remotely Piloted Vehicles (RPV). The U.S. Army RPV system will perform target-acquisition, designation, aerial-reconnaissance, and artillery-adjustment missions. The system consists of a small unmanned air vehicle, its mission payload, launch and recovering equipment, and a ground control station. Collected video imagery and target-location information are returned to the station via a jam-resistant data link. A contract was awarded to Lockheed Missiles and Space Company on 31 August 1979 for full-scale engineering development of the RPV system, and work has continued during 1980. Finally delivered hardware will consist of 22 air vehicles, 18 mission payload subsystems, 4 ground control stations, and 3 launcher and 3 recovery subsystems. First flight of the system was scheduled for August 1981.

C-X Transport. In November 1979 the C-X program was initiated to provide airlift capability to reinforce NATO or Korea rapidly and to make possible rapid response to contingencies worldwide. The program began with a comprehensive analysis of the overall airlift requirement and then concentrated on establishing the exact nature of the requirement for the C-X. A request for proposals was issued to industry on 15 October 1980, with responses due January 1981. The C-X requirement is for an aircraft that can transport the outsize and oversize firepower and support equipment of a modern army over intercontinental ranges. Full-scale development of the C-X was programmed in the summer of 1981.

Air-Launched Cruise Missile (ALCM). A competitive flyoff between the Boeing Aerospace Company's AGM-86B and General Dynamics' AGM-109 ALCM was conducted during 1979. The Boeing AGM-86B was selected as the winner. The secretary of defense on 30 April 1980 approved full production of the ALCM. Boeing was awarded a fiscal 1980 contract for 225 missiles with an option for 480 more in fiscal 1981. The Air Force planned to buy more than 3000 missiles for use on the B-52G aircraft during the 1980s. First alert capability of one B-52G loaded with 12 external ALCMs at Griffiss AFB, New York, was scheduled for September 1981. The initial operational capability of the first B-52G squadron, each with 12 externally loaded missiles, was planned for December 1982. All B-52Gs will be equipped with 20 ALCMs each (12 external, 8 internal) by 1990.

Tomahawk Cruise Missile. Tomahawk is a high-subsonic, turbofan, long-range missile sized to be fired from a submarine torpedo tube, but also launchable from surface ships, aircraft, and mobile ground platforms. This missile is being developed in a conventionally armed antiship version and in nuclear and conventionally armed land-attack versions. The antiship Tomahawk will be an important complement to carrier-based aircraft in extending the Navy's antiship capability over a broad ocean area. The stand-off capability afforded by Tomahawk will pose a credible threat to enemy surface forces at minimum risk to our launch platforms. Development of the land-attack missile will diversify the Navy's theater nuclear and conventional strike power and complement carrier aircraft in strikes against heavily defended targets.

Ground-Launched Cruise Missile (GLCM). The GLCM will be part of the long-range theater-nuclear-force modernization to enhance deterrence, protect against failure of conventional forces, and increase theater nuclear firepower. The Air Force plans to procure 560 missiles. The GLCM system will integrate the Tomahawk cruise missile into an air-transportable ground-mobile system, which consists of a transporter-erector-launcher and a launch control center. The first launch of a Tomahawk from an engineering test unit was on 16 May 1980 at Dugway Proving Ground in Utah. Test objectives were achieved. At the end of 1980, the system was in full-scale engineering development with operational capability planned for 1983.

Advanced Cruise-Missile Technology. The advanced cruise-missile technology program develops technologies to increase cruise missile and carrier survivability against evolving enemy air defense systems. The program develops new cruise missile engines, advanced technology airframes, and more capable guidance and avionics systems. Propulsion work is directed at increasing thrust and reducing fuel consumption to improve range and performance of the missile as well as survivability of the carrier. The airframe development work is focused on reducing radar and infrared signatures to improve en route and target area survivability of the missile. Guidance and avionics work is aligned toward improving obstacle clearance capabilities at low altitude and improving terrain-following for survivability.

Aeronautical Research and Development

Joint Tactical Information Distribution System (JTIDS). The JTIDS will be a crypto-secure, high-capacity, digital information-distribution system. Using spread-spectrum and time-division multiple-access technology, it will be capable of interconnecting all participants in tactical military operations to provide jam-resistant communications, position references in a common set of grid coordinates, and secure identification of friendly force elements. The initial application of the system will be in the Air Force E-3A airborne warning and control system (AWACS). Flight-testing of the E-3A terminal had been completed, and performance requirements successfully demonstrated. Full-scale development of a fighter aircraft terminal was to begin in early 1981.

Power-by-Wire Control. The Air Force has designed, fabricated, and bench-tested an electromechanical actuation unit to demonstrate the feasibility of moving aircraft flight-control surfaces without hydraulic power. The electromechanical actuation unit converts the fly-by-wire electrical flight-control signal directly to rotary surface motion by using electrical power only (the power-by-wire concept). It features innovative use of samarium-cobalt, permanent-magnet, brushless motors with electronic communication. The unit is 10 centimeters in diameter and integrated with the control surface hingeline. Testing in the laboratory demonstrated that the unit provided the performance and redundancy characteristics required for the B-52 dual-tandem, hydraulic-elevator actuator.

Conventional airplane secondary power systems provide both electrical and hydraulic power, the latter exclusively for actuation. Once electromechanical actuation can be shown to be competitive with hydraulic actuation—i.e., giving equivalent performance for the same weight and space—the way is paved to remove hydraulics, and its unique problems and combat hazards, from future airplanes.

Aeroelastic Tailoring of Composite Materials. Wind-tunnel tests by the Flight Dynamics Laboratory of the Air Force demonstrated that, through the use of aeroelastic tailoring with advanced composite material, the behavior of a wing under loading can be controlled. Aeroelastic tailoring orients the directional properties of fibrous composite materials in wing skins in optimum directions to obtain desired wing flexure. By aeroelastic tailoring the aerodynamic performance of a wing can be optimized over a broad range of flight conditions, thus making more options available to the aircraft designer.

Aircraft Propulsion Subsystem Integration (APSI). The APSI program is a joint Air Force and Navy program. A unique effort integrates the advanced high-pressure core engine components from the advanced turbine-engine gas-generator (ATEGG) program with new low-pressure components (fans, fan turbines and controls) from the APSI program to form a full-scale technology demonstrator engine. This effort combined with independent demonstration and assessment of inlets, exhaust nozzles, and afterburners permits the characterization of advanced engine technologies as complete propulsion systems. Accomplishments include initial performance-testing of the joint-technology demonstrator engine (JTDE) for longer durability, initial application of life-cycle cost models to the evaluation of advanced component designs, verification of structural life-prediction and correlation models, and assessment of the operational benefits of variable-cycle engines. Follow-on JTDE testing will emphasize comprehensive mechanical integration and performance-testing and durability characterization.

Advanced Digital-Optical Control System. This program is to provide Army helicopters with an advanced flight-control system that substantially increases mission effectiveness while reducing cost and weight. Redundant digital-optical hardware will be developed to protect against lightning, electromagnetic pulse, and nuclear radiation. Optics are completely immune to electrical interferences and will therefore provide protection even with the newer composite structures that offer no inherent electrical shielding.

Reducing pilot work load has been a long-standing requirement. Previous studies have shown that the improved handling qualities and control laws attainable with modern flight-control technology will significantly improve mission effectiveness and reduce pilot work load. In fiscal 1980, 10 component development and conceptual design contracts were awarded to start industry working on optical-control system elements. In late fiscal 1981, a contract will be awarded to design, fabricate, and flight-test a redundant optical system, in a government-furnished helicopter. After optimization and Army preliminary evaluation, the helicopter will be used to demonstrate the control-system improvement to the user community.

Circulation Control Rotor. The circulation control rotor being developed by the Navy has a potential for increased hover-lift capability that could significantly increase cargo or troop lift capacity for vertical replenishment and marine assault missions. It is basically a shaft-driven rotor system with boundary layer control employing a unique air-blowing technique. By tangential blowing through a hollow blade over a rounded trailing edge, the rotor can generate high lift. Cyclic control and higher harmonic control are provided by blowing modulation.

Conventional helicopter components such as flapping hinges, lead-lag hinges, and associated swash plates are therefore eliminated. Whirl-tower tests have demonstrated a lift capability of more than 7700 kilograms on the 13.5-meter-diameter rotor. NASA Ames wind-tunnel tests showed the rotor capable of trimmed flight of 260 kilometers per hour. The first hover flight was made in September 1979. During the last flight in November 1979, control problems in the pitch mode were met during transition to forward flight. After redesign and engineering to correct this problem, final testing began in November 1980.

Synthetic Flight-Training System (SFTS). Following Army testing, the flight simulator for the AH-1 attack helicopter was classified as standard in May 1980. A closed-circuit television system and a three-dimensional terrain model board provide a realistic visual display for the first Army flight simulator that can support flight and aerial weapon qualifications and proficiency training. A multiyear production contract for five AH-1 simulators was to be awarded in calendar 1981, with deliveries through fiscal 1985. The prototype simulator was being used in an aviator training program at Fort Rucker, Alabama.

The Army accepted the UH-60A Black Hawk prototype flight simulator from the contractor in February 1980 at Fort Rucker. Developmental and operational testing was to continue during fiscal 1981, leading to type classification. The prototype simulator was developed with two cockpit training stations, one incorporating a closed-circuit-television visual-presentation system and the other a computer image-generation system. The latter will be fully evaluated during operational testing to determine the most effective approach to visionics for the final production unit.

Advanced Composite Airframe Program (ACAP). Previous design studies and test results have shown that the weight and cost of the major structural components of a helicopter can be reduced by application of advanced structural concepts and composite materials. ACAP is a concerted effort to demonstrate improvements in system performance and capability (reduced weight and cost; increased producibility; and potential for improvements in reliability, maintainability, vulnerability, safety, and survivability) by developing and flight-testing a helicopter incorporating these materials and concepts for both primary and secondary structures. It is a three-phased program for design, fabrication, structural test, and flight demonstration. The primary components to be developed, the airframe and landing gear, will be designed for a utility helicopter with a design gross weight of 4500 kilograms or less.

In phase I, multiple contracts were awarded 31 August 1979 to Bell Helicopter, Boeing-Vertol, Hughes Helicopters, Kaman Aerospace, and Sikorsky Aircraft for preliminary design and analysis. Phase I includes establishment of a baseline aircraft design; development of advanced structural, ballistic-weapon-tolerant, and low radar-cross-section airframe design concepts; evaluation of compatible manufacturing techniques; and identification of technical risk areas.

Two contracts were to be awarded for phase II and III, with a planned award date of March 1981. Phase II will consist of detailed development, fabrication, and test of critical airframe sections (e.g., joints, cutouts, and attachments) to ensure efficient structures and compatible manufacturing techniques and to minimize technical risks for the remainder of the ACAP effort.

Phase III will consist of final detailed design of the ACAP vehicle, fabrication of full-scale hardware, laboratory structural tests, flight-vehicle ground tests, and about 25 hours of flight test.

Relations with NASA

Aeronautics and Astronautics Coordinating Board

The Aeronautics and Astronautics Coordinating Board (AACB) is the principal formal coordination mechanism between DoD and NASA, taking up major policy issues of mutual interest in aeronautics and space activities. During 1980 significant adjustments were made in the NASA Space Transportation System (STS) and IUS development schedules. These changes required continuing review by the AACB to ensure that DoD and NASA activities remain carefully keyed to each other.

In March 1980, the NASA-DoD memorandum of understanding on management and operation of the STS was revised to reflect current understandings on policies, principles, organizational roles and responsibilities.

The board also reviewed the STS survivability plan, which proposed additional measures for protection and maintenance of the system. Elements of the plan were being coordinated with NASA. The major element was increased physical protection at the launch bases. Also reviewed were requirements for protection of classified information at other STS operating locations (Kennedy Space Center and Goddard Space Flight Center) and additional protection for the command links on the Tracking and Data Relay Satellite System. Programs to correct deficiencies in these areas were in coordination with NASA.

Cooperative Programs

DoD continued to participate in joint activities with NASA and other agencies during 1980. One of the most important projects, the Space Shuttle, has been previously described. Other programs of interest are:

Rotor Systems Research Aircraft (RSRA). A joint Army-NASA contract for design and fabrication of two rotor-system research aircraft led to completion and acceptance of two aircraft to serve as "flying wind tunnels" for helicopter research. The design permits inflight testing of full-scale main rotor systems having from two to six blades. The design also permits addition of fixed wings and thrusting engines for rotor testing at flight speeds up to 555 kilometers per hour. These two aircraft will provide data to help solve aerodynamic problems that are now mathematically intractable and cannot be solved without precise flight research results. The aircraft with the first set of rotor blades completed its developmental flight testing as a pure helicopter, as a compound with thrusting engines, and as an all-up compound with thrusting engines and augmenting wings and was at NASA's Ames Research Center. The RSRA vehicles will be used to test and optimize the performance of various candidate rotor designs and to obtain data for prediction methodology.

XV-15 Tilt-Rotor Research Aircraft. The tilt-rotor research aircraft program achieved several major milestones in 1980. The XV-15 aircraft development phase was completed in September 1979, after which the flight envelope was expanded to a speed of 555 kilometers per hour and to altitudes of about 4570 meters. Proof-of-concept tests were completed at the contractor's facility in July 1980. Aircraft no. 2 (NASA 703) was then transported to the Dryden Flight Research Center for ground and tiedown tests, which were completed, and the aircraft was made ready for continuation of envelope expansion and beginning of flight tests leading to government acceptance, scheduled for 1981.

At Ames, aircraft no. 1 (NASA 702) was refurbished and restored from its wind-tunnel configuration to flight status in September 1980. Testing at Ames was to begin in 1981.

Pilot evaluation of the tilt-rotor research aircraft has been favorable in all flight modes. In the helicopter mode, the aircraft is a stable platform that permits precision hover and agility with low pilot work load. Conversions and reconversions between the helicopter and the airplane mode are uncomplicated, easy to perform, and provide accelerations or decelerations that are impressive. Although handling qualities are excellent within the envelope investigated to date, some unusual gust responses will require further investigation. Overall, the structural, aeroelastic, and flying characteristics of the XV-15 demonstrate that the tilt rotor is a viable, versatile, and unique V/STOL concept with potential for both civil and military application.

Department of Commerce

Department of Commerce agencies taking part in the nation's aeronautics and space programs are the National Oceanic and Atmospheric Administration (NOAA), the National Bureau of Standards (NBS), the National Telecommunications and Information Administration (NTIA), the Maritime Administration (MARAD), and the Bureau of the Census (BOC).

NOAA's mission is to ensure the safety and welfare of the general public and improve the quality of life through efficient use of its resources. To accomplish this mission, NOAA operates, manages, and improves the nation's operational environmental satellite systems; observes and reports weather conditions, issues forecasts and warnings of severe weather and floods, and assists community preparedness programs for weather-related national disasters; uses satellite data and aerial photography for charting, coastal mapping, and geodetic research; employs satellite data to improve the assessment and conservation of marine life; archives and disseminates satellite data to meet the needs of users in the public, private, and scientific communities; and uses satellite data in research programs aimed at improving the nation's environmental services.

NBS maintains and develops the national standards of measurement and provides government, industry, and academia the measurement services and fundamental physical, chemical, and engineering data to achieve national goals. In the nation's aeronautics and space program, NBS provides measurement support services for space and satellite systems, atmospheric and space research, and aeronautical programs.

NTIA, 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, explores applications for telecommunications technology, makes applied scientific and engineering analyses to improve technology, and provides technical assistance to other federal agencies.

MARAD works to improve ship safety, operations, and management. Use of satellites increases the efficiency of commercial ship communication, navigation, and operation.

BOC improves information on population trends, urban growth, and the internal structure of national land areas by using satellite data for demographic studies and population estimates.

Space Systems

Satellite Operations

Polar-Orbiting Satellites. During 1980, *Tiros-N* and *Noaa 6* continued as the two polar-orbiting satellites operated by the National Earth Satellite Service (NESS). On 30 May 1980, *Noaa-B* was launched but failed to achieve an operational orbit because of a launch vehicle malfunction.

Tiros-N and *Noaa 6,* operating in sun-synchronous orbits of 870 and 830 kilometers, provide environmental observations of the entire earth four times each day. *Tiros-N* crosses the equator in a northward direction at 3:30 p.m. local time, and *Noaa 6* crosses the equator in a southward direction at 7:30 a.m. local time.

Redundancy is achieved by two similar satellites rather than by identical instruments on a single satellite. The NOAA system satellites carry four primary instruments: an advanced very-high-resolution radiometer; a Tiros operational vertical sounder, consisting of three complementary sounding instruments, one provided by the United Kingdom; an Argos data-collection and platform-location system furnished by France; and a space environment monitor.

Geostationary Satellites. NOAA's Geostationary Operational Environmental Satellite (GOES) system is the successor to NASA's prototype Synchronous Meteorological Satellites (SMS). Since 1974, two SMS and four GOES satellites have been launched. At the end of 1980, *SMS 2* and *Goes 3* were covering the Western Hemisphere—*SMS 2* over the equator at 75° west longitude and *Goes 3* at 135°. *SMS 1, Goes 1,* and *Goes 2* were on standby, providing limited operational support for weather facsimile service and data collection. The primary instrument on these satellites is the visible-infrared spin-scan radiometer (VISSR). They each also carry a space environment monitor, a data-collection system, and weather facsimile broadcast service.

On 9 September 1980, *Goes 4* was successfully launched. In orbit 35 800 kilometers over the equator at 98°W., *Goes 4* is equipped with a new radiometer, the VISSR atmospheric sounder (VAS). In addition to traditional images of the earth's surface and cloud cover, the VAS will record atmospheric temperatures and water vapor content at various altitudes. *Goes 4* is the first environmental satellite in the nation's space program launched with a combined research and operational capacity—a dual use designed to save funds. Except when NOAA is using the satellite operationally, NASA will use it to test the VAS. The new sounder has several potential advantages over the VISSR instrument carried by *Goes 1, 2,* and *3*: multispectral imaging with 12 infrared channels instead of the VISSR's 1; ability to use these channels to derive temperature and moisture data; and ability to select area of interest, data of interest, and frequency of coverage.

A new feature was added to the space environment monitor on *Goes 4*. The system—which detects unusual solar flares with high levels of radiation, measures intensity of solar winds, and measures strength and direction of the earth's magnetic field—is the same as on previous GOES satellites except for the addition of a high-energy-proton and alpha detector to expand its dynamic range.

The reception of imagery from the Japanese Geostationary Meteorological Satellite, *Himawari* (launched by NASA in 1977), became fully operational by mid-1980. This imagery, received every six hours, provides excellent weather information for aviation, shipping, and other purposes from Hawaii to eastern Asia, India, and Australia. Images, received at Honolulu, also are sent directly to Washington for use by NOAA's National Meteorological Center, and from there relayed to Anchorage to support NOAA's weather forecasting activities in Alaska.

Land Satellites. On 16 November 1979, the president assigned NOAA management responsibility for all civil operational remote-sensing activities from space. The Department of Commerce was directed to develop a transition plan for moving to an operational, land remote-sensing satellite system. Accordingly, NOAA, with NASA and other interested federal agencies, has developed the plan for transition from the present, experimental, NASA Landsat program to an operational NOAA program.

A public document, *Planning for a Civil Operational Land Remote Sensing Satellite System: A Discussion of Issues and Options* issued by NOAA's Satellite Task Force on 20 June 1980, identified policy and technical issues to be resolved for a fully operational system: continuity of data during the 1980s; user requirements and performance options; revenues, pricing policies, and financial assistance; institutional approaches to private sector ownership; market expansion; international implications; and required legislative and regulatory authorities. The document also discussed the creation of an interagency Program Board for continuing federal coordination and regulation and a Land Remote Sensing Advisory Committee of 15 representatives from the interested, domestic nonfederal users.

More than 1500 copies of the plan were distributed to members of Congress, foreign governments, state and local organizations, and private industry. NOAA was assessing comments and developing its budget and legislative proposals for submission to Congress.

Satellite Data Distribution. During 1980, NESS eliminated the photo laboratory at its San Francisco Satellite Field Services Station (SFSS) and now uses a dry-paper, image-processing device for satellite image display. The second phase of the SFSS upgrade will begin with the initial delivery of the electronic animation system that provides image display using video storage. Significant dollar savings have already been made, and further savings are anticipated. The new system offers low capital investment, low cost for expendables, reliability, and unattended operation.

The GOES weather facsimile (WEFAX) service is broadcast from three geostationary satellites located at 75°W, 105°W, and 135°W. WEFAX users in 1980 numbered some 88 national and international fixed land stations, more than 60 mobile stations on ships, and military strike teams. More than 230 sectors are broadcast over this system every day, in addition to standard meteorological products.

"AM Weather"—the TV weather program produced by the Maryland Center for Public Broadcasting in cooperation with NOAA, the Federal Aviation Administration (FAA), and the Aircraft Owners and Pilots Association—improved its program during 1980. Agriculture and marine weather information was added to the aviation-oriented program. Also, new electronic equipment made possible the automatic animation of geostationary satellite images. For example, "AM Weather" devoted special attention to Hurricane Allen. For Puerto Rico and the Virgin Islands, this was the only satellite animation the public had available to watch the daily progress of this record storm.

The GOES Data Collection System (DCS) at the end of 1980 had more than 1200 data-collection platforms operated by 54 national and international users. Two new direct-readout stations went into use in 1980, with three more expected to become active during the next year. Revised platform certification standards were developed to cover emergency, interrogation, random reporting, and self-timed platforms. These new standards extend the oscillator stabilities to −40°C, improving performance in cold environments.

After the GOES DCS automated monitoring system becomes operational in 1981, a random reporting feature will be added. Random reporting permits a data-collection platform to transmit a short emergency message, based on preset thresholds, on the same channel that it routinely uses to report. The present emergency system requires an alternate channel to be used for nonscheduled broadcasts.

The GOES-Tap system, which became operational in 1975 to disseminate over standard telephone circuits satellite weather images by geographic sectors, continues to expand. In 1980, installation of GOES-Taps for all FAA Air Route Traffic Control Centers (ARTCC) was completed, allowing FAA controllers to monitor changing weather systems every half hour and improving the NWS short-range forecast service to them. The FAA program includes a Washington Central Facility, 22 ARTCCs, and many of the Enroute Flight Advisory Service stations. The original GOES-Tap program, which included lines at 50 National Weather Service Forecast offices, has expanded to a total 170 GOES-Taps and more than 200 Weather Service Office Taps.

Satellite Data Service Support. NOAA's Environmental Data and Information Service (EDIS) continued special climatological support to NASA during 1980. EDIS archived and published meteorological rocket observations of wind, temperature, and density for altitudes of 20 to 80 kilometers, obtained from a 30-station worldwide network. The data are used to determine the wind and thermodynamic stresses experienced by spacecraft, including the Space Shuttle, during launch and reentry. In addition, EDIS extracted and digitized hourly peak wind data for Cape Canaveral Air Force Station and digitized and quality-controlled hourly surface weather observations for that station and for Vandenberg Air Force Base, to support space vehicle launches. EDIS also provided serially complete observations of wind speed and direction at 1-kilometer intervals from the surface to 30 kilometers for Vandenberg, for modeling environmental conditions expected during Shuttle recovery.

Satellite Data Uses

Determining Winds and Temperatures. Vertical temperature and humidity measurements of the atmosphere and global-scale sea surface temperatures are obtained from the polar-orbiting satellites, and winds are derived from cloud motions observed in the geostationary satellite pictures. The data are given to the National Weather Service and the Department of Defense for global numerical analysis and forecasting models, providing important information on the state of the atmosphere, particularly in areas such as the oceans and the Southern Hemisphere where conventional meteorological observations are lacking. During 1980, research focused on improving techniques to derive atmospheric temperature and humidity soundings and winds from satellite data. In addition, research is obtaining soundings and wind data in areas associated with developing storms. Advances have been made in applying satellite soundings to mesoscale (local area) analyses. Research has demonstrated that significant information can be derived on small-scale disturbances that produce severe weather such as thunderstorms and tornadoes.

Twice-daily measurements of sea surface temperature (SST) are obtained from satellite infrared data in cloud-free regions of the world's oceans. These measurements are transmitted to the National Weather Service, the U.S. Navy, and worldwide users for applications in meteorology, national defense, fisheries, and oceanographic research. In addition, computer-produced contour charts of satellite-derived SSTs are prepared defining the large-scale, worldwide temperatures as well as small-scale detail for the waters adjacent the United States. SST charts, summarizing periods ranging from one day to one month, are sent to users by mail. During 1980, the accuracy of individual SST measurements was improved by more precise determination of intervening atmospheric effects on the infrared signal from the sea surface. A multichannel approach to calculating corrections for these atmospheric effects has been tested successfully and will be put into use in 1981. SST charts also were made more accurate, more easily interpreted, and more useful for monitoring the quality of the satellite data.

The NOAA Wave Propagation Laboratory contracted for a hardware feasibility study of the *Windsat*, a satellite to be capable of measuring the global winds by an onboard, pulsed, doppler lidar (laser light detection and ranging). The study concluded that there are no hardware or technological barriers to achieving the *Windsat* goal. A ground-based model of a pulsed infrared doppler lidar demonstrated wind-measuring capabilities to ranges greater than 25 kilometers. By scaling the laser energy and optics size to sizes anticipated for the satellite, the analytical results of the hardware feasibility study were experimentally confirmed.

Monitoring Global Radiation. A part of the national climate program is the radiation budget of the earth and related cloud climatology. Data from NASA's *Nimbus 7* earth radiation budget experiment are improving the accuracy of determining radiative heat gains or losses of the earth. This accuracy results from improved instrument design and from advanced models of bidirectional reflection and emission of radiation from earth and cloud surfaces. The models, critical in the interpretation of satellite measurements, will be employed in future operational radiation budget programs using NOAA satellite data. Methods have been developed to determine cloud type and amount with data from another *Nimbus 7* instrument. Research is in progress to determine the suitability of the results for a global cloud climatology, a requirement of the national and international climate programs.

Environmental Warning Services. The eruption of Mount Saint Helens was monitored and tracked by both polar-orbiting and geostationary satellites. Information on movement, density, and spread of the resulting smoke and ash plume was used in routing aircraft, evacuation activities, and clean-up efforts. Estimates of the location and movement of the plume were provided to numerous U.S. and foreign government agencies and television stations.

In 1980, NESS continued to study satellite picture data to improve detection of hurricanes, tornadoes, flash floods, severe thunderstorms, blizzards, and dense fogs. Methods are being developed to obtain quantitative information that can be applied to short-range warnings to the general public and to agricultural, aviation, and marine interests. Recent accomplishments include developing techniques for making quantitative rainfall estimates from satellite infrared imagery with interactive computers. The estimates are used for flash-flood warnings. Methods for processing data and preparing products also are being improved, so that they can be easily understood and used. Temperature measurements for fruit-frost warnings and cloud-top heights for aviation are examples of this work, as is NESS participation in the Prototype Regional Observing and Forecasting Service (PROFS).

To improve satellite support to the National Weather Service's National Flash-Flood Program, NESS is developing methods to provide operational estimates of intense convective rainfall. Estimates will be made by new interactive computer technology. Meteorologists will begin to use a video graphics terminal to analyze rainfall amounts from GOES images. The half-hourly estimates will be summed over the observing period and displayed with county or state grids. First tests were completed using imagery of Hurricane Allen. When the new technology is operational, dissemination of satellite-derived flash-flood products will be faster and additional customers will have access to the information. Interactive computer programs will reduce data handling, increase use of computer resources, and make information more rapidly available. The system also is a step toward eliminating photographic requirements and converting to an all-electronic imagery displaying system.

During 1980, the Scofield-Oliver technique for estimating rainfall from cold-topped convective thunderstorms was refined and became operational. This technique is used in real-time to help meteorologists and hydrologists evaluate or predict flood potential and issue flash-flood warnings. A modification of the technique for estimating rainfall from warm-topped convective storms has been developed and is now being tested. NESS is developing additional techniques for estimating precipitation from large-scale storms.

NOAA's National Hurricane Research Laboratory (NHRL) has continued to use satellite data for its research into hurricanes and convective cloud systems. In cooperation with NESS and NASA, NHRL continued to analyze rapid-scan visible and infrared satellite data to develop and improve techniques for estimating rainfall in hurricanes. Data collected concurrently from the east and west GOES satellite systems for Hurricane Frederic in 1979 were used. The data were collected nearly simultaneously with measurements made by NOAA's research aircraft before and during Frederic's landfall. Stereographic analysis of cloudtop heights was compared with vertically scanning airborne radar estimates of rain-echo heights. Good agreement was found in the eyewall and in convectively active rainbands. Additionally, upper cloud motions determined from satellite data have led to detailed analysis of upper flow features in the vicinity of Hurricane Frederic as it redeveloped over Cuba. Detection of these mesoscale upper flow features, which would have gone undetected by conventional means, is contributing to our understanding of storm development.

NHRL continued to evaluate microwave technology for use in remotely detecting meteorological parameters in hurricanes. Active and passive microwave data in hurricanes from the 1978 *Seasat* satellite experiment have shown that surface-wind fields in all but the inner core of a storm can be determined within 10 percent accuracy after correcting for rainfall attenuation. However, poor spatial resolution near the hurricane's core prevents accurate measurement of the strongest winds. Airborne microwave measurements suggest that if satellite spatial resolution could be improved, hurricane-force winds could be measured.

Seasat passive microwave measurements have shown that area average rainfall rates can be accurately determined from satellites, although spatial resolution is somewhat crude. Sea surface temperature estimates made by *Seasat* are being evaluated in the vicinity of hurricanes, well ahead of and behind the storm. Recent improvements in computer programs are leading to accuracies of $\pm 1°C$.

NOAA's Office of Weather Research and Modification uses digital satellite imagery in convective cloud research, focusing primarily on a satellite rain-estimation technique that uses thermal infrared data from geostationary satellites and a one-dimensional cumulus cloud model. The method permits application of the technique, derived for a semitropical area, to extratropical regions. Success has been obtained for two test locations: the U.S. High Plains and the Sahel region in northwestern Africa. The satellite rain-estimation technique also was used to determine possible outside area effects of cloud seeding in the Florida area cumulus experiment and to estimate attenuation in the *Seasat* scatterometer signals due to precipitation.

NOAA has established the Prototype Regional Observing and Forecasting Service (PROFS) to improve short-range, locally specific weather services. PROFS will coordinate available and emerging observational data, data handling, and information dissemination technologies. It has established communications links with satellite receiving stations at Colorado State University and the University of Wisconsin. In close cooperation with NESS's regional and mesoscale meteorology project at Colorado State, PROFS is developing and testing techniques to combine satellite, radar, surface meteorological network, and ground-based sounding data to produce improved short-term (up to 12-hour), local-scale (metropolitan-area) forecasts. Initial applications will emphasize severe-storm and flash-flood warning services.

Special use of satellite data aided fire fighters and agricultural interests in the western United States. Both fire-weather and agricultural forecasts depend on small-scale weather systems that cannot be identified by analysis of standard reports but are studied by detailed analysis of still and animated satellite photographs. The exact position, dimension, and movement of the moisture fields in the middle or lower layers of the atmosphere, as well as small-scale disturbances within these fields, can be valuable in forecasting fire conditions. Minimum temperature, a critical element for fruit growers, often depends on the length of time a cloud area will cover an orchard at night. NWS forecasters monitor the thickness and height of clouds, which control the rate of heat loss from the ground.

The Anchorage Satellite Field Services Station used real-time GOES animated imagery during the latter half of 1980 to improve its satellite products significantly. Now, wind circulation centers can be identified over the mountainous terrain as far north as the Arctic slope; thunderstorm squall-line development and movement can be monitored and attendant wind shifts and gusts predicted one to two hours in advance. This information is particularly important to aviation and fire-weather programs. Development of specialized satellite image-enhancement methods for assessment of thunderstorm growth and dissipation, Arctic stratus conditions, and the colder, high-latitude conditions of fall and winter have significantly improved the use of the operational data.

Satellite imagery has been used to locate Alaskan waters of 5°C or colder to aid in determining severity of icing. Superstructure icing, a major problem to vessels of all sizes, cost 12 lives in Alaskan waters during 1980. Special ice imagery, provided to NWS forecast offices and to the joint Navy-NOAA Ice Center in Washington, D.C., is used by various agencies in analysis and forecasts and for special operations and rescue efforts. Atlantic Richfield Company used this imagery in 1980 to monitor ice conditions when it was using a drilling ship designed for the Gulf of Mexico for exploratory work in lower Cook Inlet. With these data the company minimized ice damage to the ship, saving $45 000 in insurance premiums.

Time-lapse movies of high-resolution satellite imagery give better understanding of the behavior of sea fog hazardous to offshore drilling operations and to recreational and commercial boating. Increased accuracy in short-range forecasts of sea fog formation and dissipation is expected from relating changes in fog to changes in the surface wind flow and to sea surface temperature patterns observed from geostationary and polar-orbiting satellites.

NASA and NOAA joined in a program in 1980 to demonstrate a centralized storm information system in the operational environment of the National Severe Storms Forecast Center in Kansas City. Ability to analyze, display, and compare data and to apply diagnostic techniques rapidly are fundamental to a more detailed and reliable assessment of the threat from severe weather. Experiments have shown that real-time interactive processing systems incorporating satellite, radar, and conventional data can significantly improve this assessment. A major portion of the interactive computer system developed by the University of Wisconsin is being transferred to the center for extended evaluation. Thereafter, performance specifications and the functional design for an operational interactive system will be developed.

Determining Ocean Conditions. Measurements of ocean color are used to determine the concentration of phytoplankton in coastal regions. This microscopic free-floating plant life forms the basis of the food chain in the ocean. The coastal zone color scanner carried on NASA's *Nimbus 7* satellite measures concentrations of chlorophyll and hence phytoplankton in the oceans. This information, along with such parameters as wind speed and direction and water temperature, indicates the ability of an ocean area to support growth of new fish stocks.

Color scanner data have been used by NOAA's Office of Coastal Zone Management to determine impact zones along our coastlines, caused by the outflow from rivers and estuaries. The data show the path of suspended material in the water as it leaves rivers and estuaries and enters the ocean and indicate the area that would be affected by effluents from factories or populated areas or inadvertent spills. Maps, prepared as guides in planning coastal development, have been completed for the U.S. Atlantic Coast, with the Gulf of Mexico to follow

Scientists from NOAA's Pacific Marine Environmental Laboratory continued to use color scanner data to develop and refine computer programs for measuring particulate matter distributions. In particular, surface-truth data from the Mississippi River plume area and the Grand Banks off Newfoundland are being compared to concurrently collected satellite imagery. When satisfactory atmospheric correction programs are available, other geographic areas will be studied.

During the *Seasat* repeat-orbit period, the short period variability of two western boundary currents—the Gulf Stream in the North Atlantic and the Kuroshio in the North Pacific—was studied by the laboratory's scientists, using multiple orbital passes. *Seasat* altimeter observations showed a significant change in surface topography across these currents, as well as marked displacement of the current axis. In the Gulf Stream region, comparison with coincident infrared images taken by NOAA environmental spacecraft showed the position of stream edge and altimeter readings to be in close agreement.

The *Seasat* synthetic-aperture radar imagery collected during the 1978 Gulf of Alaska *Seasat* experiment has been reexamined by the laboratory's scientists to extract relative surface wind magnitudes and directions. The relative imaging-radar backscatter was compared with surface wind estimates from coincident *Seasat* scatterometer measurements. The analysis indicates that the imaging-radar backscatter is approximately proportional to the square root of the wind speed and may have a rather weak dependence on the wind direction. The importance of this result lies in the excellent spatial resolution of the synthetic-aperture radar; thus, the technique may yield ocean-surface-wind estimates from space on a relatively fine scale grid of one to five kilometers.

Ocean wave research with imaging radar continues. Seven *Seasat* synthetic-aperture radar passes that collected data in the region near the mouth of the Columbia River were identified. These data have been processed to imagery and will now be used in a study of wave transformations as they approach the river entrance and interact with the local bathymetry and strong tidal currents.

A study of bulk microwave properties of first-year sea ice in the Bering Sea was undertaken by Pacific Marine Environmental Laboratory scientists in cooperation with researchers from the University of Washington and NASA's Goddard Space Flight Center. Two years of surface-truth measurements were compared with microwave images of the region taken by the Nimbus electronically scanning microwave radiometer. Results will be used by sea ice forecasters to improve interpretation of real-time microwave images for coastal regions where winter fishing and offshore drilling are intensifying.

In the past, research on the circulation and temperature of the Alaskan coastal waters has been limited. The Anchorage Satellite Field Services Station serves as a resource for water temperature and ice information. Satellite products have been used by the Bureau of Land Management's Outer Continental Shelf office to assess the environment for its leasing areas. NESS and NWS researchers have developed a computer program to forecast freeze-up of the lower Cook Inlet. A study of nearly a year of satellite imagery showed distinct seasonal circulation patterns in the Shelikof Strait-Lower Cook Inlet. This information is important to fishing, energy exploration, oil spill trajectories, and transportation.

Determining Lake Conditions. The Great Lakes Ice Analysis was expanded by NESS in 1980 to include satellite-derived surface water temperatures during the ice-free periods. A combination of the ice and surface temperature analyses provides continuous area coverage of the Great Lakes throughout the year. These analyses are transmitted twice weekly via facsimile and are helpful in making both marine weather and ice forecasts.

Determining Hydrologic Conditions. Use of satellite data for operational snowcover mapping continued into the sixth year. Snowcover during the 1979-1980 winter season was found to be variable throughout Wyoming; above average in the mountains of Arizona, California, Nevada, and Colorado; but below average in Oregon, Idaho, and Montana. The snowcover maps were included for the first time in *Water Supply Outlooks,* issued by the Department of Agriculture's Soil Conservation Service offices in Montana and Nevada.

In February 1980, the U.S. Army Corps of Engineers (Los Angeles District) began receiving NESS satellite snow maps of the central Arizona watersheds; they have requested additional coverage over Utah's Virgin River. The Salt River Project, which generates electricity for the Phoenix area, reported that the 1980 snow maps were successfully incorporated into a new runoff forecasting technique.

The Canadian Atmospheric Environment Service and NESS cooperated to map snowcover in the Saint John basin, a flood-prone watershed in Maine and New Brunswick. The Flood Forecast Centre in Fredericton, New Brunswick, reported that the 1980 spring snow melt estimated from satellite-derived snow maps compared well with computer flow models.

Operational river-ice breakup support was started in 1980 in Alaska. Enhanced infrared imagery delineated frozen, melting, and open water areas. Traditionally, river ice breakup is monitored by aircraft. The NWS River Forecast Office estimates three to five days of aircraft, personnel, and per diem costs were saved by using the satellite data.

Monitoring Agricultural Conditions. Agriculture and Resources Inventory Surveys through Aerospace

Remote Sensing (AgRISTARS), an interagency research program, began in 1979 and will continue for four years. The Departments of Commerce, Agriculture, and Interior, the Agency for International Development, and NASA use advanced remote-sensing data from NOAA and NASA satellites and selected remote-sensing data from aircraft to develop an early warning system. The system detects conditions affecting crop production and quality and provides techniques for more accurate forecasts of domestic and foreign commodity production in the major grain-producing countries of the world. In 1980, NESS began research to develop new satellite products that will provide information on precipitation, daily temperature extremes, solar radiation, and snow cover. Research is under way at several universities and government laboratories to develop and test computer models for deriving these quantities. Starting in July 1980, daily estimates of solar insolation from GOES data were made for the eastern two-thirds of the United States. Also during 1980, the Environmental Data and Information Service reviewed 27 crop yield models and acquired, tested, and evaluated candidate yield models for wheat, sorghum, corn, soybeans, rice, cotton and sunflowers.

Fisheries Monitoring. A highly successful joint effort by the National Marine Fisheries Service and the U.S. Fish and Wildlife Service demonstrated that sea turtles can be tracked by satellite over relatively long distances and periods. An adult female loggerhead turtle was tracked for almost nine months over 1700 kilometers in the northern Gulf of Mexico with a transmitter attached to its shell. The turtle was tracked by the remote-access measurement system on *Nimbus 6*. A similar satellite tracking experiment with a Kemp Ridley turtle off Mexico ended prematurely when the turtle was caught by a Mexican fisherman. The experiments were to determine the feasibility of programs to establish migration routes and behavior patterns of the threatened and endangered sea turtle populations.

In a partially successful satellite tracking investigation, a wild pelagic dolphin in the Pacific was outfitted with a prototype transmitter that relayed signals through the *Nimbus 6* satellite. The surfacing behavior of the animal interfered with transmissions, however; modified transmitters are being developed.

Two major cooperative remote-sensing experiments (Superflux I and II) were conducted in the Chesapeake Bay area by the Fisheries Service, National Ocean Survey, the Coast Guard, NASA, and a number of local universities. The experiments were to evaluate remote-sensing techniques for assessing marine environmental quality, enhance understanding of marine ecosystem processes, and provide a synoptic data base for application to problems of ocean resources and environmental management. They used aircraft-mounted salinity, temperature, chlorophyll, and turbidity sensors, the Landsat multispectral scanner, the *Nimbus 7* coastal zone color scanner, and extensive surface-truth sampling. Indications are that both experiments were successful, although comprehensive analyses of the data are not yet complete.

The Fisheries Service cooperated with NASA and NESS in collecting surface-truth data for the color scanner. Chlorophyll, particulate, and irradiance measurements were taken along the Atlantic and Pacific coasts and in the Gulf of Mexico to assist in developing computer programs for the scanner data and for scanner data bases for ecosystem modeling and assessment.

The Fisheries Service used satellite-acquired thermal and color data of the Pacific Ocean to direct research vessels to likely areas for albacore tuna and provided synoptic charts of sea surface temperature and chlorophyll distribution for studies of anchovy spawning.

Research continued on the use of *Seasat* scatterometer data for estimates of surface-layer transport in the Gulf of Mexico. Shrimp and menhaden appear to depend extensively on surface currents for transport of their eggs and larvae from offshore spawning grounds to the estuarine nursery areas. Satellite-acquired surface-wind-stress data could help develop yield forecasts for these species well in advance of normal fishing seasons. The 1980 effort concentrated on developing a water-current model to be tested in 1981. Historical wind stress data (not from *Seasat*) will be used to determine the accuracy of yield forecasts from satellite data.

A cooperative cost-benefit, technical-option study was completed on use of a satellite-aided communication and data-relay system for observers on board foreign fishing vessels operating in the U.S. Fishery Conservation Zone. The National Marine Fisheries Service, National Weather Service, Coast Guard, and NASA examined law enforcement, fishery management, and research data requirements. A conceptual, optimized communication system was described, in which satellite locationing systems installed on fishing vessels would accept coded data from small, hand-held data loggers operated by the observers.

A research project was begun in the Gulf of Mexico and Atlantic conservation zone using fishery and environmental data collected by observers on Japanese tuna long-line vessels. GOES and NOAA thermal and *Nimbus 7* color data are being examined for correlation with data from the fishing vessels to determine the feasibility of a satellite-aided tactical fishing system for domestic long-liners fishing for tuna and swordfish.

The Northeast Fisheries Center is assisting in developing the New England area remote-sensing system. The system is designed to provide remote-sensing data to two centralized points, one for ocean data, the other for land data. After processing, the data will be made available to a broad range of federal, state, academic, and private users.

The year 1980 marked the first production of Alaskan sea surface temperature charts, used extensively by fisheries. The charts have been excellent for determining the arrival of herring in Bristol Bay. One processor reported savings of nearly $8000 a day in personnel and equipment costs. Commerical fishing for silver salmon around Southeast Alaska was improved by location of the 11°C isotherm. The catch increased from 50 to 200 salmon a day, and trolling costs (fuel, equipment, and time) were significantly reduced. With the onset of winter, the ice edge is also included on the charts and is used extensively by the crab fishery and the Fish and Wildlife Service to inventory marine mammals.

During the summer of 1980 the NESS Satellite Field Services Station at Honolulu coordinated a joint U.S. Navy-Air Force-NOAA program for providing satellite information on sea surface temperatures to the fleet of albacore boats fishing in the North Pacific between Hawaii and Alaska. Sea temperature information acquired by the Air Force from the *Noaa 6* satellite, and pictures from NOAA's *Goes 3* western satellite, were used at the Naval Western Oceanography Center for charts broadcast by radio facsimile three days each week. Ship captains used the charts to help find favorable fishing waters.

Environmental Monitoring Using Data Buoys. The NOAA Data Buoy Office has six buoys in the Northeast Pacific and Gulf of Alaska, three in the Gulf of Mexico, nine in the Atlantic, and five in a new Great Lakes data buoy network. The Great Lakes network will be expanded to eight buoys during the next year. Plans also are under way to incorporate the 12 Coast Guard large navigational buoys at the sites of former lightships into the GOES data collection system. A prototype system now is in operation on the Columbia River Bar Navigational Buoy. Both the data buoys and the navigational buoys provide meteorological data and surface water temperatures. Subsurface water temperatures and wave data are obtained from selected buoys. These data are used by the National Weather Service for forecasting and storm warning, by the Bureau of Land Management for continental shelf assessment, and by scientific programs with specialized marine data requirements. All moored buoys are equipped with position-fixing systems that permit the Nimbus or *Tiros-N* satellites to locate them when they go adrift. Most buoys have been modified to use the *Tiros-N* Argos data-collection system for position fixing.

Other Uses of Satellites and Space

International Cooperation

Sharing Data. More than 120 countries receive images and digital data directly from satellites operated by NOAA. Local governments, academic and scientific institutions, commercial companies, and radio amateurs have bought or built stations to copy these direct readout transmissions. Medium-resolution images from NOAA spacecraft are received in more than 800 locations globally; high-resolution data are obtained in 20 countries. Geostationary satellites provide weather facsimile broadcasts to nearly 30 countries in the Western Hemisphere and to Australia and New Zealand; 3 nations outside the United States also receive high-resolution images.

Applications of these data overseas are primarily for storm detection and aviation forecasting. Special-interest groups also receive and use the data for hydrology (river and flood forecasting, snow accumulation and melt), oceanography (sea ice monitoring, ship routing, pelagic fish migration and harvesting), and other activities. Academic and scientific institutions obtain direct-readout transmissions for research, training, and educational purposes.

Environmental Satellite Assessments. Precipitation estimates from NOAA and GOES satellite images are used by the Environmental Data and Information Service to support the Department of State's Agency for International Development disaster assistance effort. These assessments evaluate the effects of weather on crops in developing nations. During 1980, EDIS expanded its assessments to 50 countries in Africa, to Central and South America, and to Asia.

Domestic Activities

Demographic Studies. The Census Bureau continues to use Landsat data to update its statistics on land and water areas of the United States. An interactive computer system is being developed using digital county-boundary files and Landsat images to distinguish water from land. Area measurements can then be determined for both land and water surfaces.

Investigations were completed on the use of computer-processed Landsat data for showing land-cover changes and urban zones around two sample metropolitan areas under a NASA applications pilot test agreement. Digital registration of Landsat scenes over several different years and related processing show significant land-cover change. The statistical and pictorial results are now being compared with changes interpreted from aircraft photography for the same period. A summary report will document conclusions.

Application of Space Technology to Geodesy and Geodynamics

The National Geodetic Survey, the component of the National Ocean Survey responsible for maintaining a national network of accurately positioned ground stations for geodetic surveying and mapping, continued to work closely with NASA to apply advances in space technology to geodesy and geodynamics. A data-reduction and analysis center and the first of three radio observatories in a new-generation polar motion and universal time-monitoring network became operational during the year. The newly established station, near Fort Davis, Texas, is equipped with the most advanced very-long-baseline-interferometry (VLBI) data-acquisition instrumentation, which was used successfully in several U.S. and international observing programs. Most significant was the Monitoring Earth Rotation and Intercomparison of Techniques (MERIT) project, sponsored by the International Astronomical Union and the International Union of Geodesy and Geophysics. The purpose of MERIT was to evaluate and compare techniques for determining polar motion and earth rotation, including VLBI, satellite doppler, satellite laser, lunar laser, and classical techniques. The VLBI polar motion and universal-time measurements made in MERIT are believed to have the highest resolution, both spatially and temporally, and greatest accuracy ever achieved.

The National Ocean Survey, NASA, the U.S. Geological Survey, and the Defense Mapping Agency have formally agreed to a coordinated approach to developing Global Positioning System geodetic receivers. By late 1982 hardware should be available for testing and evaluation.

The National Geodetic Survey also has worked with NASA on detailed plans for the National Crustal Motion Network, which will be developed over this decade using space geodesy techniques. The network will be used by the geodynamics community for a wide variety of purposes, including studies of intraplate tectonic motion, with possible applications in earthquake predictions, and observing changes in the primary geodetic control network.

Since the radial position of a satellite must be known accurately before satellite altimeter data can be used to measure physical oceanographic conditions, the National Geodetic Survey has developed a method of determining a satellite's radial position more accurately. When the method was tested on *Seasat,* the radial position error was halved. An analysis of altimeter data from the Geodynamics Experimental Ocean Satellite *Geos 3* has also yielded valuable information on time-varying features of the surface of the North Atlantic. Analysis of *Geos 3* and *Seasat* altimeter data over land areas of California and Texas have indicated that accuracies within 20 centimeters are achievable.

The National Bureau of Standards continued to evaluate use of signals from the NAVSTAR Global Positioning System (GPS) satellites for determining geodetic baselines. It was shown theoretically that an accuracy of one to two centimeters can be expected for determining baselines up to 100 kilometers long. The dominant source of error is expected to be uncertainties in the propagation correction for water vapor in the atmosphere, even when water vapor radiometers are used to measure the water vapor content along the line of sight to the satellites. Measurements with GPS signals are expected to play an important role in understanding crustal movements in seismic zones.

Satellite Communications

Public Service Satellites. The National Telecommunications and Information Administration (NTIA) was instructed by the president's National Civil Space Policy to aggregate potential public service users of communications satellite services, stimulate research and development of inexpensive satellite technologies and services, and translate domestic experience in market aggregation and research and development into programs for less developed countries and remote territories.

In pursuing the first mission, NTIA awarded four grants in July 1980 to support management organizations in developing national satellite communications networks through aggregation of the public service market. The four Public Telecommunications Services grantees, while becoming self-supporting businesses over the next four years, will offer distributed video services for educational and other public service uses. An NTIA teleconference in early 1981 was to introduce the grantees to state and local public officials with significant training requirements that may be addressed cost-effectively through telecommunications.

To fulfill its international mission in public service satellites, NTIA planned a three-year educational exchange program to begin in June 1981 for persons from less developed countries. The program—a part of a joint effort with AID begun in 1979—will emphasize the application of satellite communications to the delivery of social services. Also, NTIA and NASA cooperatively fund an examination of the technical, regulatory, and programmatic requirements necessary to enhance communications among the island nations of the Pacific. And NTIA held discussions with the People's Republic of China about that nation's future use of satellite communications. An NTIA delegation visited China in April 1980 to establish closer ties and to explore areas of mutual interest. In particular, talks focused on developments in U.S. technology that might profitably be applied to China's needs.

Technical Support Activity. NTIA's Institute for Telecommunications Sciences supported investigations on existing transponder and ground station availability, satellite service for the Pacific, and requirements for an American Indian Public Radio Network. A frequency-orbit resource study examined the activities of the International Radio Consultative Committee, World Administrative Radio Conferences, and the Federal Communications Commission that affect the rules for using the radio spectrum and for small-antenna ground stations. Technical issues dealt with an assessment of the frequency-orbit capacity available for direct-to-home broadcasting satellite services. In support of AID's Rural Satellite Systems program to test the cost-effectiveness of satellite communications in rural development, the institution was studying demand-assigned multiple-access technology, frequency converter technology, solar power sources, and slow-scan television.

Commercial Satellite Services. A 1980 meeting of the Intergovernmental Maritime Consultative Committee made significant advances in defining a future global distress and safety system. Expected to be in operation by 1990, the system will depend heavily on satellites. The INMARSAT space segment was expected to be a part of the system. The U.S. Maritime Administration and the United Kingdom Department of Trade (Marine Division) were participating with Norway and the Federal Republic of Germany in international trials. This program will develop data to evaluate low-power distress transmitters, which will send signals via commercial satellites to search and rescue centers.

Satellite Time Service. The National Bureau of Standards continued to operate its time-code distribution system via the GOES satellites during 1980. The newly upgraded time-code generation system at the NESS Command and Data Acquisition station, Wallops Island, Virginia, functioned reliably during the entire year. Negotiations were begun with NESS that may lead to significant improvement in NBS satellite position predictions as part of the time-code format. The GOES time code is used by operators of electrial power networks, scientific-data-monitoring systems, and aircraft-borne instrumentation.

NBS has developed a new passive maser (microwave amplification and stimulation with electromagnetic radiation) to be evaluated by Jet Propulsion Laboratory (JPL) for possible use in keeping the deep space navigation network synchronized with a minimum of calibrations. The first prototype of this new hydrogen maser—about five times smaller in size, weight, and cost than comparable active maser designs—was delivered in December 1980.

Space Support Activities

Measurement and Calibration Services

Antenna Calibrations. NBS continued to assist the U.S. Air Force Satellite Control Facility in conducting a measurement assurance program for antenna calibrations. This facility makes acceptance and performance tests on satellites for the Global Positioning System, Defense Satellite Communications System, NATO Communications System, and the Navy and Air Force Tactical Systems. In addition, NBS measured phase and amplitude on the Shuttle imaging radar (SIR) antenna for NASA and determined its far-field patterns, which are critical to evaluation of the antenna's performance for earth-imaging applications.

Space Shuttle Measurements. NBS is investigating two aluminum alloys used in the Space Shuttle to determine how variations in processing influence microstructure and physical properties. Emphasis has been on nondestructive evaluation methods such as eddy-current conductivity, hardness, ultrasonic velocity and attenuation, and positron annihilation. The program has yielded appreciable information about the metallurgy of these alloys.

NBS has completed the new large spectrometer-calibration chamber at the Synchrotron Ultraviolet Radiation Facility for NASA flight instruments. The first calibration customer for this system will be the Space Shuttle instrumentation designed to study solar irradiance. NBS also is making measurements important to designing and interpreting experiments on materials and thermophysical properties in the microgravity environment of space. Two focal points are the role of convection effects and the role of container effects. This work includes measurement of convection effects of simultaneous temperature and composition gradients during alloy solidification, measurement of surface tensions and their temperature dependencies in candidate materials for convection studies in space, development of a free-cooling technique to permit measurement of the specific heat and other thermophysical properties of reactive materials during levitation in space, and measurement of multilayer absorption and phase transitions at interfaces that influence interactions with containers in space.

Atmospheric Measurements. NBS provides spectroscopic data and standards for modeling the earth's atmosphere, other planetary atmospheres, and interstellar matter. These data and standards are the basis of a number of developing NASA techniques to measure concentrations of atmospheric constituents. NBS also provided NASA with spectral frequencies of important stratospheric constituents, line shapes, and line intensity data for these species. The information allows NASA to interpret spectral data from its satellites and to monitor species concentrations.

NBS has developed a unique facility to calibrate secondary standards of spectral irradiance in the vacuum ultraviolet. The facility was used to evaluate and calibrate portable deuterium lamps to be flown on Spacelab 2. Precise knowledge of the lamp characteristics is the key to making highly precise absolute measurements of solar irradiance in the region of the spectrum most sensitive to solar variability. If determination of changes in the ultraviolet radiation from the sun, by periodic inflight calibrations, are precise enough, the measurements will be a sensitive indicator of trends in the solar radiation output. A similar evaluation and calibration were made for Goddard Space Flight Center, for the planned portable krypton lamp for vacuum-ultraviolet radiometric applications on the *Space Telescope*.

Fuel Property Measurements. NBS completed an extensive experimental measurement program that will improve ability to model the transport properties of the oxygen used as the oxidizer in present and future propulsion systems. The measurements, which span the dense liquid region to above room temperature and extend to very high pressures, were made by an automated transient hot-wire technique and laser-light-scattering methods. Results significantly improved the best predictive model for these materials.

Instrument Measurements. NASA's Marshall Space Flight Center and NBS are investigating the science and technology of thin-film Josephson junctions as radiation detectors. Point-contact Josephson junctions have been shown to be extremely sensitive detectors of electromagnetic radiation but will not survive a launch into space.

NBS also completed development and field-tested a high-accuracy spectroradiometer to improve measurements of terrestrial irradiance from direct sunlight over the region of 290 to 320 nanometers. The spectroradiometer has an uncertainty not exceeding five percent and gives three to five times more accurate measurements than previously attainable. The new system will improve the reliability of atmospheric ozone measurements.

To support the *Solar Maximum Mission*, NBS developed methods to calibrate absolute radiometric and diffraction optics for high-resolution x-ray spectrometers used for plasma diagnostics of solar flares. The techniques developed are being applied to analysis of data on high-temperature solar plasmas. An NBS-developed krypton-dimer radio-frequency discharge lamp was chosen as a component of the high-resolution spectrograph being developed at Goddard to fly on the *Space Telescope*.

Solar Activity

Solar Convection. NBS is investigating solar convection properties and the associated transport of mechanical energy, using coordinated satellite and ground-based observations. Measurements of steady flows in the chromosphere, made with the *OSO 8* satellite, were extended to the transition region using the ultraviolet spectrometer and polarimeter experiment on the *Solar Maximum Mission* satellite. Observations were complemented by simultaneous ground-based studies with the diode-array instrument at Sacramento Peak Observatory.

Data Services. Two international scientific programs collecting extensive satellite data are the Solar Maximum Year (1979–1981) and the Middle Atmosphere Program (1982–1985). Both require the archive and data-dissemination services of the Environmental Data and Information Service's World Data Center-A for Solar-Terrestrial Physics and central information exchange services. In addition, future spacecraft missions will require international exchange of information and data. Space and satellite intensive programs require the auroral indices and other synoptic ground-based data. EDIS developed a computer program to identify the equatorward boundary of the auroral oval from *Tiros-N* and *Noaa 6* energetic particle measurements. The results are to be used in testing a new Air Force "over the horizon" radar system known to be affected by ionospheric activity along the radar's viewpath, which cuts through the auroral oval region.

Warnings and Forecasts. The Space Environment Services Center (SESC), operated jointly by NOAA and the U.S. Air Force, is the National and World Warning Agency for disturbances on the sun, in space, in the upper atmosphere, and in the earth's magnetic field. A major portion of the real-time data comes from space environment monitors on NOAA's polar-orbiting and geostationary environmental satellites. A memorandum of agreement has been signed between the Air Force and SESC, defining the support required for Air Force Shuttle operations. SESC will provide warnings and predictions of radiation dangers to personnel and instruments flown by DoD on the Shuttle.

Support for a team of scientists with experiments on the *Solar Maximum Mission*, launched early in 1980, was being provided by a unit of SESC established at Goddard Space Flight Center. This highly successful operation has been supported with real-time data and forecasts from the Boulder facility.

Space and Atmospheric Research

Space and Atmospheric Physics

Magnetospheric Physics. Scientists of the NOAA Space Environment Laboratory continued to analyze and interpret data from the particle detectors carried by the International Sun-Earth Explorer (ISEE) satellites. The remote-sensing data have shown the dayside magnetospheric boundary to be extremely well defined and in almost constant motion, and theoretical studies are being made on particle-transmission properties of this boundary. The ring current comprises the geomagnetically trapped charged particles of the Van Allen Radiation Belts, and its enhancement produces magnetic disturbances at the earth's surface. Laboratory scientists have shown that a significant portion of the ring current enhancement is caused by a redistribution of resident particles rather than an injection of new particles.

Planetary Atmospheres. NBS made laboratory investigations of the rate constants and mechanisms of the self-reactions of sulfur monoxide. These reactions are important in modeling the chemistry of the atmosphere of Venus. Rate constants have been obtained for three important sulfur monoxide reactions, and the groundwork laid for extending chemical kinetic measurements to more complex systems. In addition, NBS is investigating chemical systems in the planetary atmosphere of Jupiter. The studies include mechanistic and gas kinetic investigations. Recently major efforts have been directed toward the acetylene cycle that, in part, controls concentration of several major atmospheric constituents.

NBS is using high-sensitivity stylus techniques to measure the surface microtopography of mirrors for the Advanced X-ray Astrophysics Facility (*AXAF*). *AXAF* is to be a free-flying, national x-ray observatory, launched on the Shuttle. The NBS stylus measurements are being made in collaboration with the Harvard Smithsonian Center for Astrophysics and will be correlated with other measurements from Marshall Space Flight Center, Naval Weapons Center in China Lake, and Lawrence Livermore Laboratory. Eight surface-geometry characterizations will be calculated from NBS measurements using a minicomputer stylus instrument. Characterizations will include the root-mean-square roughness, autocorrelation and amplitude-density functions, and power spectrum.

Stellar Atmospheres. NBS has been developing the absolute radiometric calibration techniques and the spectroscopic analysis methods for reliable measurement of physical properties (temperature, densities, velocities, and magnetic fields) in solar and stellar plasmas. These methods are being applied to analysis of ultraviolet data from the quiescent and flaring chromospheres of single and close binary stars cooler than the sun, obtained with the spectrometers on Skylab and the *International Ultraviolet Explorer* satellite, and will be applied to data from the *Space Telescope* and the solar optical telescope on Space Shuttle. X-ray observations with the High Energy Astrophysical Observatories *Heao 1* and *Heao 2* are being used to model the hot coronas in stars cooler than the sun and to study stellar flares.

Stratospheric Physics. Concern about human impact on the earth's ozone layer has led to more intensive atmospheric monitoring at NBS. Ultraviolet absorption photometry is used from ground-based and flight instruments to determine the ozone content. These measurements depend on accurate knowledge of the absorption cross-sections of ozone at the measurement wavelengths and at the ambient temperatures of the atmosphere. Since previously published values for these cross-sections are discordant and of limited detail, NBS is making new and more accurate measurements over a wide range of temperatures and wavelengths.

Atmospheric Chemistry

The National Bureau of Standards, in programs with NASA and other agencies, is making mechanistic and gas kinetics investigations of atmospheric reactions selected for their importance in modeling catalytic cycles that control stratospheric ozone. In addition, NBS provides evaluated photochemical and kinetic rate data. It also provides an evaluated reaction-rate data base for atmospheric chemistry models. And it is making experimental and theoretical studies as part of the NASA Lewis Research Center's Space Shuttle combustion-research program to determine effects of gravity on flame inhibition and extinguishment by halogens. This work will aid definition of the application of halocarbons as flame inhibitors both in the Space Shuttle and in terrestrial environments.

Aeronautical Programs

Aircraft Support

Instrument Calibration and Materials Research. NBS developed a standard-phase angle meter that can be used for the calibration of very-high-frequency omnirange (VOR) navigation systems. After documentation of the instrumentation and procedures, NBS will offer a calibration service to VOR instrumentation manufacturers, DoD, and major airlines.

In support of NASA's planned National Transonic Facility (NTF), NBS is developing a measurement procedure for characterizing the surface microtopography of models to be used in the NTF. The NTF's wind tunnel will permit high-speed testing of models at mach numbers of 0.1 to 1.2. Surface texture will play a significant role in the testing, since boundary-layer thickness at high speeds will be as small as 0.25 micrometers. The objective of the project is to develop a light-scattering technique to measure surface texture of NTF models during production and final inspection. Reliability will be established by comparing the technique's characterizations with those from scanning-electron-microscope stereoscopy and 3-D stylus profilometry.

Radar Techniques. A new Radar Techniques Development Branch, a unit of the Next Generation Radar Joint System Program Office, was established in Norman, Oklahoma, by NOAA's National Weather Service. This unit, in cooperation with NOAA's National Severe Storms Laboratory, will be developing and testing techniques for acquiring, processing, and displaying weather radar data for use by the operating agencies.

Weather Hazards. NASA and NOAA's National Severe Storms Laboratory are investigating lightning and turbulence hazards to aircraft using instrumented jet fighter aircraft, surface lightning locator systems, and dual-doppler radars. Of concern are lightning hazards to aircraft composite structure and to new-generation airborne electronic equipment and controls.

Aeronautical Charting

The National Ocean Survey developed methods to provide the aviation public with more timely and accurate air navigational information. NOS publishes three series of visual charts used by pilots when they depend on visible landmarks to determine location and direction. NOS regularly conducts flights throughout the contiguous United States to check these charts and has begun a new program in which photogrammetric techniques will certify and verify obstacles to flight. On airport obstruction charts, NOS shows the position and evaluation of possible obstructions at and near commercial airports. Automated data can now provide FAA with accurate, up-to-date information.

During 1980, NOS began including low-level, high-speed military training routes and terminal radar service areas on sectional aeronautical charts, which are designed for visual navigation by slow and medium-speed aircraft; and VFR terminal area charts, which are large-scale charts for visual navigation in highly congested metropolitan areas. These routes also are depicted on low-altitude en route charts and on VFR-IFR wall planning charts. During the year NOS also certified terrain and obstacle data for 20 air-route traffic control centers for the FAA's en route minimum-safe-altitude warning system.

Department of Energy

The Department of Energy (DOE) and its predecessor agencies have supported the United States space program with their specialized skills since the early 1960s. Present activities that were initiated during the early period include the application of radioactive-isotope-decay energy to supply operating power for satellite systems and participation in the U.S. program of surveillance of the atmosphere and space for clandestine and other nuclear explosions. More recently, DOE has studied the use of space for nuclear waste disposal, the solar power satellite concept, and remote sensing from space for energy resource exploration, energy facility siting, and environmental monitoring. DOE contributes to operational programs in some of these areas, and all are the subject of continuing research and development to improve performance, efficiency, safety, and general understanding to meet expanding and new requirements in energy and national security.

Space Applications of Nuclear Power

DOE substantially supports the space program through technology development and production of nuclear-powered electric generators for present and potential NASA and Department of Defense (DoD) missions. The photographs transmitted from NASA's *Voyager 1* and *2* spacecraft, revealing hitherto unknown details of the topography of Jupiter in 1979 and Saturn in November 1980, were made possible by space nuclear power systems. Continuing progress is being made toward compactness, lighter weight, and improved conversion efficiency and safety.

Radioisotope Thermoelectric Generators (RTGs)

Improved heat-source materials and components entered production for the NASA Galileo mission (Jupiter orbiter and probe) scheduled for mid-1980s launch. NASA planned to launch a Galileo spacecraft from the Space Shuttle to explore the planet Jupiter and its environment. The orbiter will provide long-term data on the planet Jupiter and its moons and will release a probe to penetrate the Jovian atmosphere to collect and transmit data on the planetary morphology.

During 1980, in concert with mission requirements, the multihundred-watt, silicon-germanium-unicouple production line was reestablished for the general-purpose heat-source radioisotope thermoelectric generator (GPHS-RTG). In addition, the preliminary design of the GPHS-RTG for the Galileo orbiter and the International Solar Polar Mission was completed. A solar polar spacecraft developed by the European Space Agency (ESA) was planned for launch on the Shuttle in the mid-1980s to observe the sun and the solar wind at high heliographic latitudes.

The technology verification program was completed for the dynamic isotope power system, to improve efficiency of the conversion system and enhance the reliability and performance level of selected components. During fiscal 1980, the ground demonstration system was upgraded with improved components and performed at 17-percent efficiency. Endurance testing was to ensure technology readiness of the system components by the end of 1980, permitting a review of the nuclear option for power requirements in the 1- to 2-kilowatt range for candidate space missions.

Space Reactor Technology

A technology development program for an advanced space reactor was begun in fiscal 1979, after studies by the Advanced Space Power Working Group, a joint DoD-DOE committee to examine late 1980s' mission requirements. The program was to establish the technology base for a high-temperature, compact, nuclear-electric reactor system for use in space, producing power in the 10- to 100-kilowatt range. Development of reactor component technology that will support a future system demonstration, to be scheduled and jointly supported by the user agency, was planned.

The new system was expected to be capable of supplying power for a space-based radar spacecraft, electronic mail systems, advanced television, holographic teleconferencing facilities, and other systems for potential civilian and military assignments.

During 1980, examination of the possible component technologies and test facilities was continued, with particular analytic emphasis on core and radiator heat pipes, and thermoelectric materials and power module technology.

Advances in Supporting Technology

Advances continued to be pursued in fuel preparation, capsule production and welding, process control, quality control, and reliability. Production of ceramic fuel spheres for the multihundred-watt generators for the NASA Galileo spacecraft was completed in 1980 at the Savannah River Plutonium Fuel Fabrication Facility; to increase the specific power for the orbiter and subsequent spacecraft, the assay of the plutonium-238 oxide feed material was increased. Production of the 62.5-thermal-watt, hot-pressed-PuO_2, cylindrical fuel form was begun in fiscal 1980 at the Savannah River facility for the NASA Galileo and International Solar Polar Mission. The 62.5-watt fuel form, its fabrication process, design refinements, and encapsulation technology were originated by the Los Alamos Scientific Laboratory.

Operational and reentry analyses by General Electric and the Battelle Columbus Laboratories assisted in the development of the GPHS module. The Air Force Weapons Laboratory, Naval Nuclear Weapons Center, and Applied Physics Laboratory of the Johns Hopkins University tested and evaluated the module. The Los Alamos Scientific Laboratory tested the composite fibrous graphites and the Teledyne Energy Systems staff also assessed the improved graphites.

Reliability engineering requirements were reviewed by the Sandia Laboratories and DOE and an updated program requirements document was issued. The intent of the increasingly rigorous reliability effort is to outline to contractors and bidders the basic practices which must be pursued to provide continued positive assurance that reliability requirements for space nuclear systems will be met.

Satellite Power System

The Solar Power Satellite (SPS) was early proposed for collecting solar energy in space and beaming it to ground receiving antennas for distribution to utility networks. A broad three-year assessment of the SPS concept was completed in 1980 by DOE and NASA.

A number of system alternatives were evaluated that could affect SPS technical approach and viability, flexibility in selecting power level, land requirements, environmental effects, and cost. Alternative concepts studied included photovoltaic (solar-cell) and solar-thermal (rotating-machinery) energy conversion systems, microwave and laser power-transmission systems, and onshore and offshore receiving antennas. Environmental effects were assessed in the key areas of microwave effects on health and ecosystems; space-worker health and safety; rocket exhaust effluents, reentry products, and microwave energy effects on the atmosphere; electromagnetic compatibility considerations that influence the use of the satellite orbit; and effects on astronomy. The studies were based on existing scientific literature, analysis, and on a number of limited experiments in selected areas. Societal issues assessed were related to resources (materials, energy, and land); institutional concerns (finance and management, regulation, and utility integration); international implications (agreements, military implications, and vulnerability), and public concerns. The economic practicality of the SPS was also assessed and the results compared against other advanced energy technologies. The results of the assessments, as well as suggested areas of additional research, were included in an assessment report.

Nuclear Waste Disposal

In 1980, the status of terrestrial and space components was evaluated in support of the NASA-DOE study of the potential for nuclear waste disposal in space.

Remote Sensing of the Earth

Data from NASA-developed satellites carrying instruments to sense the earth's surface and atmosphere benefit DOE programs: enhancement of exploration technology for uranium, natural gas, and oil; geological characterization of potential nuclear-waste-disposal sites; and survey of other potential energy facility sites for environmental and seismic suitability. Use of data from existing and future satellite platforms in these and other energy-related activities is expected to increase.

During the past year, DOE completed a study of its present and potential use of land remote-sensing systems and participated in the activities of the interagency Interim Policy Group on Land Remote Sensing. The policy group, chaired by the National Oceanic and Atmospheric Administration, produced a document on the issues and options in planning for a civil, operational, land remote-sensing satellite system.

Nuclear Test Detection

The concept of satellite-borne surveillance of worldwide nuclear activity evolved during studies in 1959-1962 when the Limited Test Ban Treaty was being considered. Since that time, DOE and its predecessor organizations have participated in a continuing interagency program for development, operation, and improvement of U.S. satellite systems for surveillance of nuclear explosions in and above the atmosphere and in outer space—regions where the Limited Test Ban Treaty forbids nuclear testing. Because of its specialized knowledge of nuclear explosion characteristics and its capability to detect and measure radiation, the Atomic Energy Commission was assigned the task of designing and developing detector instrumentation for the satellites. DoD managed spacecraft procurement, deployment, operations, and overall schedules. Six pairs of Vela satellites were launched from 1963 to 1970 into approximately circular earth orbits at about 112 000 kilometers. Although the Vela satellites are now quite old, the last four were still in use in 1980.

The nuclear-explosion-surveillance mission of the Vela satellite program is now incorporated into other multimission DoD satellite programs. DOE retains responsibility for design, fabrication, test, calibration, launch, and operational support of the instrumentation subsystems for nuclear explosion detection.

DOE conducts a vigorous research and development program to meet potential new detection requirements, such as might result under a comprehensive test ban treaty, as well as to understand the space environment in which the surveillance systems must function. Theoretical analysis, laboratory development, and flight testing of environmental and prototype instrumentation on NASA and DoD space systems continue to provide important and unique data. This information has led to concepts and continuing development of systems for substantially greater coverage and for better characterization of signals for credible discrimination between natural phenomena and nuclear explosions.

Department of the Interior

The U.S. Department of the Interior serves as steward for more than 2 million square kilometers of nationally owned public lands and natural resources. Before critical management decisions can be made on conservation or use of specific public lands or resources, two things must be done. First, current information on areas of concern must be obtained. Second, informative interpretations of this data must be derived.

To acquire raw data, many bureaus and agencies within Interior have traditionally relied heavily on aircraft for observation, photography, or other methods of remote sensing over federal lands. In attemping to improve the efficiency and timeliness of data collection over vast, often inaccessible land areas, the Department of the Interior has turned more and more in recent years toward the use of earth-observing satellites that can provide broad, repetitive, and uniform coverage of the earth's surface.

Earth Resources Observation Systems Program

Remote-sensing research, training, and data acquisition for the Department of the Interior is coordinated by the Earth Resources Observation System (EROS) Office, within the U.S. Geological Survey (USGS). Most of the satellite and aircraft images of the earth used by Interior scientists and land managers each year are obtained from a central archive and production facility at the Earth Resources Observation Systems Data Center (EDC) in Sioux Falls, South Dakota. Staff scientists and technicians at EDC participate extensively in remote-sensing research, development, and training for Interior programs and personnel. In 1980, some 150 Interior earth scientists and land managers received remote-sensing training at EDC, and the following Interior bureaus or agencies participated in extensive cooperative research or training projects with EROS scientists: Bureau of Land Management, Water and Power Resources Service, U.S. Fish and Wildlife Service, National Park Service, Bureau of Indian Affairs, Office of Surface Mining Reclamation and Enforcement, and several divisions within the U.S. Geological Survey. Other federal units with responsibilities parallel to those of Interior, including the U.S. Forest Service and U.S. Army Corps of Engineers, also worked closely with EROS scientists this year.

Applications and Research

In 1980, substantial progress was made in the practical application of information acquired by remote-sensing devices aboard aircraft and earth-orbiting satellites. This progress was highlighted by recent advances in the ability to combine satellite data with other forms of information for more useful tools for land and resource monitoring and management. Some noteworthy developments in aeronautics and space activities were:

Sea Mapping. A Geological Survey image of the Berry Islands (east of Miami, Florida) containing Landsat data optimized to show underwater detail was prepared for the Defense Mapping Agency, where it was combined with bathymetric data, printed, and distributed for comments. It is considered a landmark product, pointing the way for a more cost-effective way of mapping the shallow seas throughout the world.

Water Use. The Geological Survey is cooperating with NASA in an applications pilot test to use Landsat data for mapping irrigated cropland in a 458 000-sq-km area of the High Plains in support of the Regional Aquifer Study and the National Water-Use Program. Water from the High Plains aquifer irrigates some 65 000 sq km of cropland, about 23 percent of the total irrigated cropland in the United States. The project is designed to provide regional maps of irrigated cropland for estimating ground-water withdrawals and availability of water. Related irrigation inventory studies also are being tested in Idaho, California, Louisiana, Nebraska, and Florida.

Monitoring the Environment

The Geological Survey routinely transmits environmental data by radio from more than 250 water-gauging-station platforms to the Geostationary Operational Environmental Satellite (*Goes 3*) for relay to ground receiving stations linked to a Survey computer network. The data are then available within minutes to water management agencies throughout the United States for operational planning and early warning of extreme events, such as a flood. Most of the platforms relay only hydrologic data, although certain geologic information—such as seismic, strain, and magnetic data—is also available. For example, 20 platforms in the vicinity of Mount Saint Helens, Washington, transmit hydrologic and geologic data.

Land Inventories

The Bureau of Land Management recently concluded a successful demonstration project to evaluate the usefulness of Landsat computer-compatible tapes, aerial photographs, and ground data for mapping and inventorying 10 000 sq km of wildland vegetation in Mohave County, Arizona. With computer processing to combine ground data with Landsat tapes, the overall cost of the project came to about $15 per sq km (6 cents per acre). It appears that the remote sensing technology used in this project can contribute significantly to the bureau's need to acquire vegetation information efficiently.

Park Management. The National Park Service is improving its management ability by use of Landsat data. In 1980, it concluded two experiments proving the effectiveness of satellite data in monitoring and managing national park environments. An investigation of the use of Landsat data to observe water level and flow in the Shark River Slough of Everglades National Park, Florida, revealed that Landsat information can be used to monitor conditions accurately in a freshwater marsh ecosystem, especially in comparing wet and dry season slough margins. The information is invaluable where water control structures determine the entry flow of a marsh. Landsat data were merged with topographic data and related information to classify accurately and map 22 major kinds of vegetation on some 10 000 sq km in and around Olympic National Park, which has declining rainfall levels and therefore vegetation changes from west to east. Vegetation maps are used in day-to-day National Park decision-making, and Landsat technology could produce vegetation maps at a small fraction of the cost of traditional, labor-intensive methods.

Fire Control. Of great concern to the U.S. Forest Service is the knowledge of what kinds of vegetation, or "fuels," are vulnerable to forest fires anywhere they may start. The fire fuels, if mapped, could be included with topographic and weather information to predict the behavior of a fire, thus greatly increasing the potential for making successful fire-control decisions. In 1980, the Forest Service completed a feasibility study in a portion of the Lolo National Forest in western Montana, which demonstrated that Landsat and topographic data can be merged on computers to produce "fuel maps" that, with the aid of wind and weather data, could prove to be useful tools for fire control.

Endangered Species. The U.S. Fish and Wildlife Service used Landsat during 1980 to help assess habitats in Oklahoma for greater and lesser prairie chickens, both endangered species. Traditional field surveys have failed to explain the dramatic decline in prairie chicken populations in recent years. Landsat data analysis provided a cost-effective means of assessing the decline. The relationship between density of male prairie chickens (from field surveys) and land-cover types (from Landsat) closely parallels the relationship determined from field-survey data alone. Because collection of extensive data in the field is expensive and time-consuming, Landsat analysis, combined with limited ground-data collection, may reduce overall costs of assessing habitats.

Wetland Forests. Research is being carried on in the use of radar image data to discriminate between wetland and dryland forest at test sites in the Puget Sound area, in the Rockies of Montana and Idaho, and on the Delmarva Peninsula. *Seasat* synthetic-aperture radar images are being evaluated for geological, hydrological, and land-resource information. These images show initial promise for outlining wetlands.

Water Inventories

Thermal infrared imagery from aircraft is helping to find areas of shallow ground water and springs in the flood plain of the Calamus and North Loup Rivers of Nebraska. Within the Grand Canyon of the Colorado River, aerial color-infrared photography is measuring the impact of high water on the riverine environment in areas where accessibility is very limited. *Seasat* radar altimetry is being evaluated for measuring land subsidence resulting from the withdrawal of ground water in the Tucson-Phoenix area.

Weather Monitoring

The Bureau of Reclamation and the GOES satellite are observing winter storm systems over parts of California and a five-state region of the Rocky Mountains. Analysis of the observations is expected to improve understanding of winter mountain storm systems and their resultant spring runoff effects.

A network of 150 solar-powered, portable, meteorological monitoring stations will soon be in operation. Each station will measure and report wind speed and direction, temperature, relative humidity, barometric pressure, and precipitation every five minutes and transmit measurements hourly by radio to a satellite. The data from each station will be collected via a downlink-computer system, which will receive and record data from as many as 240 stations per hour and disseminate the data to project sites. This system will give Department of Interior project scientists almost real-time information on weather developments.

Sea Ice

Interior personnel have continued to cooperate with NASA and other agencies in studying ice dynamics of the polar regions through interpretation of microwave data from satellites and aircraft. That information, supported by field observations, is being used to develop models to analyze the effects that various conditions may impose on the fragile balance of physical forces in the polar regions.

Nighttime Imaging

Studies of applications of nighttime images of the earth taken by the Defense Meteorological Satellite Program determined that excellent potential exists in these images. If such a system were optimized for studying the earth, practical applications would be found in areas of geophysical phenomena, natural resources, energy conservation, and demography.

Crustal Studies

Conventional geophysical data have suggested that magnetic data acquired by spacecraft may be useful in studying areas where land-based magnetic data are unavailable. Thus *Magsat*, launched into orbit by NASA in 1979, was developed to provide a perspective on the terrestrial magnetic field. Several Geological Survey research projects under way combine ground and airborne geological, geophysical, and mineralogical data with *Magsat* data to improve understanding of the geologic features of specific regions.

Cartography

Continued studies in applications of satellite data to cartography have resulted in the basic specifications for a mapping satellite (*Mapsat*) that could provide three-dimensional and multispectral data. The system as conceived emphasizes simplicity and cost-effectiveness but features improved resolution and geometry. Onboard linear-array detectors would make possible a one-dimensional flow of data that could be processed by a simple computer program. A feasibility study was under way to test this concept.

International Activities

A number of developing countries are actively pursuing the application of remote-sensing technology to environmental and resource problems. Under the U.S. Foreign Assistance Act, the U.S. Geological Survey participates with the Agency for International Development (AID) in a program to aid developing countries in using remote-sensing technology. Most other international efforts supported by the Department of the Interior are at the request of and under the auspices of the United Nations.

EROS scientists twice held a month-long remote-sensing workshop in 1980 at the EROS Data Center, for a total of 40 scientists from 17 countries. Advanced training for international scientists in geologic interpretation, land-use planning, environmental applications, and digital (computer) image processing was conducted at the Survey's Center for Astrogeology in Flagstaff, Arizona. Onsite courses were also held in Greece, Argentina, Hungary, and Kenya.

Cooperative remote-sensing applications projects were conducted in 1980 with China, Iceland, Tunisia, and Saudi Arabia. These projects use Landsat data interpretations for applications such as oil exploration, global mapping of glaciers, monitoring encroachment of deserts, and preparation of Landsat image mosaics.

The Geological Survey is the lead agency for the International Geological Correlation Program's Project 143 on Remote Sensing and Mineralogical Exploration, jointly sponsored by the United Nation's Educational, Scientific, and Cultural Organization and the International Union of Geological Sciences. The project, designed to develop techniques of remote sensing for mineral and energy exploration and inventory, included more than 200 participants from some 80 nations.

Department of Agriculture

The U.S. Department of Agriculture (USDA) uses remotely sensed data from space as a source of information for a wide variety of research and operational programs.

During 1980, most of the primary research and developmental activities of USDA were included in the Agriculture and Resource Surveys through Aerospace Remote Sensing (AgRISTARS) program, which is designed to determine applications of aerospace technology to agriculture and renewable resources. In addition to AgRISTARS, which is essentially a research program, USDA is using space data operationally in conjunction with its ground data forecasting in the Crop Condition Assessment System to provide commodity analysts timely information on foreign crop conditions. Work on applications of space data in forestry research and management is proceeding. Finally, representatives of USDA have participated in interagency programs to support transition of experimental space remote-sensing systems to fully operational status.

Agriculture and Resource Inventories

The Department of Agriculture is participating with other agencies in the broad-based program of research and development AgRISTARS. A formal memorandum of understanding links the Departments of Agriculture, Commerce, the Interior, and NASA in the program. The Agency for International Development (AID) will evaluate possible applications in developing countries.

USDA concentrates on research in crop-yield models and on early warning and crop condition assessment. In addition to acquiring ground data and developing agronomic data bases, USDA has lead responsibility for projects in soil moisture, land cover, renewable resources, crop area estimates in the United States, conservation, and pollution and will also evaluate resulting technology for its utility for agricultural applications. It also participates in areas of research for which other agencies have leadership responsibility.

Specifically, AgRISTARS includes development, testing, and evaluation of procedures for adapting remote-sensing technology to

- improve USDA's capability to provide early warning and timely and reliable assessments of changes in crop conditions;
- provide more objective and reliable crop production forecasts;
- assist in inventory and assessment of the condition of land, water, and renewable resources;
- develop a cost base for assessing the feasibility and desirability of integrating space remote-sensing technology with existing USDA data sources and systems.

A balanced program of remote sensing uses data from Landsat, environmental and communications satellites, and airborne sensors. Research and development will be combined with tests in an operational environment. The program began in fiscal 1980, when USDA invested $10.8 million in AgRISTARS. USDA agencies participating directly are the Economics and Statistics Service, Forest Service, Soil Conservation Service, and Science and Education Administration. The World Food and Agricultural Outlook and Situation Board monitors the program through its leadership of the User Evaluation Team. The Foreign Agricultural Service communicates its requirements for research and monitors the program for operational applicability of new technology. Eight specific projects support USDA's primary information needs, under a joint program management-coordination structure. USDA has leadership responsibility for five AgRISTARS projects, NASA for two, and NOAA for one:

- Early Warning/Crop Assessment will enable USDA to make timely assessments of changes in factors that affect the quality and production of economically important crops. USDA has lead responsibility. The activity is based in Houston.

- Domestic Crops and Land Cover project will develop, test, and evaluate the use of satellite data for more precise, cost-effective, and timely domestic crop and land-cover acreage estimates at the state, crop reporting district, multicounty, and county levels in the United States. USDA has leadership responsibilty. The activity is coordinated from Washington.
- Soil Moisture project will develop, apply, and evaluate technology to estimate soil moisture profiles from integrated data sources including satellite, aircraft, and ground sensors for agricultural and water resource information needs. USDA has leadership responsibility. The activity is coordinated from Washington.
- Renewable Resources Inventory will provide research and development support to the multiresource inventory methods pilot test, an advanced demonstration of Landsat satellite technology to supplement present methods of making recurrent inventories or renewable resources over large land areas. USDA has leadership responsibility.
- Conservation/Pollution project will develop, test, and evaluate an integrated satellite-aircraft-ground data capability to supply accurate information on conservation practices and to assess the effectiveness of agricultural and forestry practices by applying models. USDA has leadership responsibility.
- Foreign Commodity Production Forecasting will develop and evaluate technology for improving production forecasts in foreign areas and determine suitablity for possible integration into USDA crop information systems. NASA has leadership responsibility. The activity is centered in Houston.
- Supporting Research will improve or develop new remote-sensing techniques for production forecasts in foreign areas as well as early warning of changes in crop condition and yield estimates. The techniques and procedures will be tested in other AgRISTARS projects. The project is located in Houston, with NASA in the lead role.
- Yield Model Development will develop mathematical models using environmental and plant measurement characteristics that represent the yield potential of important crops at state, regional, and national levels. USDA's Economics and Statistics Service and the Science and Education Administration are linked to NOAA, the lead agency, to conduct the program.

Crop Condition Assessment

Remote-sensing research also benefits the Crop Condition Assessment System begun by the Foreign Agricultural Service (FAS) in 1979. The system supports commodity analysts with information on crop conditions in major producing areas around the world. It uses advanced computer and communications technology to acquire, process, and analyze Landsat satellite, weather, and related data and aids effective transfer of research on application of aerospace technology to this operational program.

For a number of years, USDA specialists in FAS and other agencies have developed and tested techniques for detecting crop stress through analysis of reflectance patterns in Landsat digital data. These patterns are the basis for vegetative indices, which plot the "greenness" of the vegetation in the Landsat scene and are produced by computer-aided analysis of digital Landsat data. This greenness can be correlated to the stage of growth and health of crops of interest.

In 1979, FAS used vegetative indices and other advances in technology to provide its foreign commodity analysts more timely information on events that might affect the expected production of crops of economic importance to the United States. In 1980, FAS continued to assess important crops in major producing regions of the world. Assessments were used by commodity analysts in conjunction with the existing ground-data forecasting system in making global crop production forecasts for about 20 crops in some 25 countries.

Management of Renewable Resources

Three Forest Service projects used advanced aerospace technology in 1980. The first, completed in 1980, was a forest resource classification of a portion of the Shasta/Trinity National Forest in California. The cooperative program included the Forest Service, Humboldt State University, and NASA's Ames Research Center. Landsat digital data were used to map general forest cover types, with acreage summaries for each Landsat-derived resource category. The experiment showed that Landsat can provide sufficient species stratification to assist in planning timber sales.

The Forest Service is working with the University of California at Santa Barbara to demonstrate the integrated use of Landsat, terrain, and meteorological data in developing a forest-fire fuels data base. Vegetation in a test area in Southern California is being classified using data on physical factors that influence the intensity and spread of forest fires.

The service completed a vegetative cover map for the entire San Juan National Forest in southwest Colorado. Cover types were derived from Landsat data, and the resulting classification "thematic maps" were converted to standard Forest Service map format. The next phase of work, now being planned, will test use of Landsat data in forest management. Although initial expectation for achieving high map accuracies from Landsat data were not achieved, the Forest Service believes it can improve operations with satellite-derived vegetative cover maps.

Federal Communications Commission

Satellite communications services continued to expand in 1980. The global six-satellite system of the International Telecommunications Satellite Organization (INTELSAT) added the first of its new Intelsat V series and is preparing specifications for the Intelsat VI series. Eight domestic commercial communications satellites were in service at the end of the year, 2 others were scheduled for 1981 launch, and the FCC in December approved the launch of 20 others by eight companies, as well as construction of 5 more. Commercial maritime service was developing and expanding. New concepts and international regulations were under study.

Communications Satellites

INTELSAT

The INTELSAT global communications satellite system consisted of three active Intelsat IVA satellites in the Atlantic Ocean region, two Intelsat IVA satellites in the Indian Ocean region, and an Intelsat IV in the Pacific Ocean region. A high-capacity Intelsat V satellite, first of the follow-on generation of spacecraft, was launched by NASA in December and will replace one of the Atlantic region satellites in 1981. It carried communication packages that operate in both 6- to 4-gigahertz (GHz) and 11- to 14-GHz bands along with a "cross-strap" mode of operation (up on 6 GHz and down on 11 GHz; and up on 14 GHz and down on 4 GHz).

Of the nine Intelsat V satellites under procurement, five (the Intelsat VA versions) will be able to provide maritime services, which were expected to be leased to the International Maritime Satellite Organization (INMARSAT). Each of the five satellites can be launched on any one of three launch vehicles: the Atlas-Centaur, NASA's Space Shuttle, and the European Space Agency's Ariane. The Intelsat Vs and VAs will provide communications capacity to handle increasing traffic demands, now growing at a rate in excess of 25 percent a year, and will also provide planned space-segment capacity to satisfy requirements of INTELSAT signatories for regional and domestic satellite services. INTELSAT planned to introduce time-division multiple access in the mid-1980s, which will markedly increase the channel capacity of its satellites. Specifications for Intelsat VI were in preparation and the request for proposals was to be issued early in 1981.

Maritime

Commercial maritime mobile-satellite service continued to develop and expand. Service was being provided through the Marisat system in the Atlantic, Pacific, and Indian Ocean areas to more than 500 ships. Ultimately, up to 8000 ships were expected to be fitted for satellite communications. The INMARSAT Council and Assembly had met, and the organization was to lease satellite capacity to provide satellite telecommunications to ships in all ocean areas. The first leased service was expected to begin operations in early 1982. On 3 November 1980, the Intergovernmental Maritime Consultative Organization (IMCO) approved the requirements for a future global maritime distress and safety system. The new system will become effective about 1990 and will rely heavily on the use of satellites, especially in the INMARSAT system.

Domestic Commercial Communications Satellites

At the end of 1980, eight domestic communications satellites were operating in the 4- to 6-GHz bands. Of the eight, two were part of the RCA American Communications, Inc., Satcom system, three were in the Western Union Telegraph's Westar system, and three were in American Telephone & Telegraph Company's Comstar system. These satellites provided message toll service, television distribution, and both single and multiple channels per carrier for voice, data, television, and digital data. More than 3500 ground stations were licensed for these services by the end of 1980. Many stations used 4.5-meter antennas to receive and distribute video and audio signals. Since the loss of *Satcom 3* in late 1979, RCA Americom was leasing transponders on the Comstar system until it could launch a replacement satellite.

The first Satellite Business Systems (SBS) satellite was launched in November 1980 to begin commercial satellite operations in March 1981. SBS will use the 12-14 GHz bands to provide a wideband, switched, private communications network (using 5- and 7-meter ground stations) to large industrial and government users on a common carrier basis. Voice, data, and image traffic will use time-division multiple access to the satellite's transponder. On 7 March 1980, the commission's decision for construction of the SBS satellite system was affirmed by the U.S. Court of Appeals for the District of Columbia.

The commission had earlier authorized Hughes Communications Services, Inc., to construct a satellite system known at LEASAT, which will replace the existing Fleet Satellite Communications (FLTSATCOM) system and is intended to provide the Navy and other military services with nearly global communications for national defense.

In December 1980, the commission took action to increase the competitive sources of supply of domestic communications satellite services, authorizing construction of 25 new domestic satellites and launch of 20 of these or previously constructed satellites. The new satellites will replace those nearing the end of their operational lifetimes, will provide for new entrants into the domestic market, and will expand the facilities of existing carriers that have demonstrated the need for additional capacity. The commission authorized:

- Hughes Communications to construct three satellites to operate in the 4-6 GHz bands, to launch two of them as scheduled by NASA, and to place the satellites on station at 74° and 135° W. longitude. Launch of the third satellite was deferred until warranted by customer demand.
- Southern Pacific Communications Company to construct three satellites to operate in the 4-6 and 12-14 GHz bands and to launch two of them for stations at 70° and 119° W. Launch of the third and construction of a fourth were deferred.
- Comsat General Corp. to launch its fourth Comstar satellite (*D-4*), for 127-127.5° W.; to reposition *Comstar D-1* to 95° W.; and to operate *Comstar D-1* and *D-2* as a composite satellite.
- American Telephone & Telegraph Company to construct a Telstar satellite system of three 24-transponder satellites in the 4-6 GHz bands, to launch two of them to 95° and 87° W., and to hold the third. The Telstar satellites will replace the Comstar satellites when they expire.
- RCA American Communications, Inc., to construct six additional Satcom satellites to operate in the 4-6 GHz bands and to launch four, for 131° W., 83° W., 139° W. (to replace *Satcom 1*), and 143° W. (to replace *Satcom 2*). The fifth will be deferred until traffic requirements justify the additional orbital location. The sixth will be an on-ground spare.
- The Western Union Telegraph Company to construct and launch two additional Westar satellites (4 and 5), which will each carry 24 transponders in the 4-6 GHz band and will replace the nearly expired *Westar 1* and *2*. Orbital locations of 99° and 123°W. were assigned to them.
- American Satellite Company to acquire a 20-percent undivided ownership interest in the Westar space segment.
- A partnership, Space Communications Company —formed of Western Union (50 percent), Fairchild Industries, Inc. (25 percent), and Continental Telephone Corp. (25 percent)—to take over Western Union Space Communications, Inc., business, the construction and operation of the TDRSS/Advanced Westar system.
- Space Communications Company to construct the Advanced Westar system consisting of the commercial portions of five complete space stations, components for a sixth space station, and parts for a seventh space station in the domestic Fixed Satellite Service. The system is part of a four in-orbit satellite system that also would be used as a Tracking and Data Relay Satellite System (TDRSS) by NASA. Two satellites would be used exclusively for TDRSS service in government frequency bands, one exclusively for commercial domestic satellite services in the 4-6 and 12-14 GHz bands, and the fourth for both TDRSS and commercial services. Spacecom was authorized to place two Advanced Westar Satellites in geostationary orbit at 79° and 91° W. for commercial domestic services and to construct and operate the associated tracking, telemetry, and command ground station at White Sands. Western Union will lease 50 percent of Advanced Westar and American Satellite the other 50 percent. Two additional satellites will be launched for exclusive TDRSS services.
- Satellite Business Systems to launch its second satellite to operate in the 12-14 GHz bands. Launch of a third will be deferred. Orbital locations are to be selected.

Finally, the commission announced its intent to consider early alterations in domestic satellite licensing policy to reduce orbital spacing (from 4° to 3°), provide in-orbit restoral capacity, use more spectrum-efficient transmission techniques, use higher frequency satellites (such as those at 18-30 GHz), and accommodate hybrid satellites.

Experiments and Studies

Small growth continued in the area of emergency communications provided by two Application

Technology Satellites, *ATS 1* and *ATS 3*. These satellites have narrow-band VHF transponders, and experimenters send narrow-band voice and data communications by them to and from fixed and portable stations. Messages deal with medical emergency, state government operation, search and rescue operations, and church administration.

Use of the Geostationary Operational Environmental Satellite to collect environmental data increased. The satellite is operated by the National Environmental Satellite Service of the National Oceanic and Atmospheric Administration. Observations and measurements of physical, chemical, or biological properties of oceans, rivers, lakes, solid earth, and atmosphere are collected by data-collection platforms on the earth, relayed to the satellite, and then distributed to users for fire-weather forecasting, prediction of water runoff, and collection of environmental data near offshore oil drilling platforms.

Communications Studies

The commission continued in 1980 to work in the forum of the International Telecommunication Union (ITU) to achieve an international regulatory framework in which the benefits of satellite communications can best be provided to the public. The commission was preparing for the 1983 Region 2 Regional Administrative Radio Conference (RARC), which will draw up a detailed plan for the Broadcasting-Satellite Service (BSS). Preparation for the World Administrative Radio Conference (Space Telecommunications), with the first of two sessions to be held in 1984, had also begun. The first session will decide which space services and frequency bands should be planned; establish the principles, technical parameters, and criteria for the planning; establish guidelines for regulatory procedures for services and frequency bands not to be planned; and consider other possible approaches to guarantee all countries equitable access to the geostationary-satellite orbit and the frequency bands allocated to space services.

Direct-Broadcast Satellites (DBS)

Direct-broadcast satellites are conceived as communications satellites in geostationary orbit, providing signals, probably television, that can be received by small, inexpensive antennas in individual homes in the United States. Community reception using larger antennas is also contemplated. The proposed downlink frequencies are in the 12-GHz band and uplink frequencies to the satellites are in the 17-GHz band. The range of frequencies is tentative and will be decided at the 1983 regional conference.

The commission began studying direct-broadcast satellites at the end of 1979, motivated by a need to plan the assignment of frequencies in the BSS band. The commission was also preparing for the 1983 regional conference. An application for a BSS system was expected.

The commission study basically consists of two areas of investigation: policy concerning entry of direct-broadcast satellites into the market place and technical issues. A report was written on the first by the Office of Plans and Policy and one on the latter by the Office of Science and Technology. A notice of inquiry invited public comment on the reports. Comments on regulation of interim systems were received in late 1980, and comments on policy issues and the technical report were scheduled for early 1981.

Additionally, the commission issued a separate notice of inquiry into preparations for the 1983 Region 2 conference. The date for filing comments has passed, but additional notices in that proceeding are expected to be released in 1981.

Department of Transportation

The Federal Aviation Administration (FAA), the aviation component of the Department of Transportation, regulates aviation safety, develops and operates a common system of air navigation and air traffic control for both civil and military aviation, fosters the growth of civil aeronautics at home and abroad, contributes to the development of an effective national airport system, promotes aviation security, and ensures as far as possible that all civil aviation activities are conducted in a manner protective of the environment. To carry out these responsibilities, FAA conducts a variety of research, development, and engineering programs. The programs fall into three principal categories: aviation safety, environmental research, and air navigation and air traffic control.

Aviation Safety

Recent Initiatives

The objective of FAA's research, development, and engineering programs in aviation safety is to demonstrate the feasibility—technically, operationally, and economically—of designs, techniques, procedures, and equipment to improve the crashworthiness of aircraft; enhance the performance and safety of propulsion systems; and provide backup for the development of aircraft, airman, and equipment certification requirements, compliance procedures, and regulatory standards for successful integration of man and machine in advanced aircraft systems. In new and ongoing efforts during 1980, FAA

- Investigated the adequacy of passenger seat-restraint systems in transport aircraft accidents. The investigation determined that the problem was not so much in the seat-restraint systems themselves as in the deformation on impact of the airframes and floors. The study was reoriented to determine the best methods of reducing floor and airframe deformation and to introduce energy absorption concepts into seat design.
- Participated with the Army in a helicopter-icing project. The agency contributed to the improvement of an Army inflight icing simulator and also held a nationwide symposium on objectives and requirements for a national helicopter-icing research effort. The research would develop certification standards designed to inhibit icing conditions.
- Joined the Canadian government's National Aeronautics Establishment in the first of a series of longitudinal stability evaluation tests in instrument-flight-rule (IFR) helicopter operations. The tests were expected to be of great value in establishing the operational requirements for certifying helicopters for IFR operations.
- Investigated, with the Department of Defense and NASA, advanced integrated flight systems for future use nationally. The object was to determine what these systems will look like and the safety regulations that will have to be promulgated for their use.
- Began a nationwide effort for organizing research in atmospheric effects on new, advanced aircraft systems.

Fire Safety Research

FAA devoted much effort toward improving an aircraft passenger's chances of surviving a crash that he would be able to escape from were it not for the postcrash rupture of fuel tanks and the spontaneous ignition of released, mistlike fuel particles. Rupturing fuel tanks, igniting fuel, fires, explosions, and toxic gases from burning cabin materials make an occupant's survival all but impossible unless he can get out in time. At least two remedies are obvious. One is to inhibit or slow the spread of postcrash fires and explosions; the other is to establish cabin safety standards that will gain time for evacuation of the plane by its occupants.

Over the years, FAA's fire safety research has searched for an antimisting fuel able to operate efficiently in existing aircraft systems and for a replacement for the highly volatile and flammable fuels in use. It has pioneered a variety of research initiatives in cabin safety research, including burn tests of cabin interior materials to establish their relative toxicity, the investigation of partition geometry to slow the spread of fires, the development of computerized models to simulate cabin fires, and the establishment of a permanent aircraft-fire test facility to make tests that closely simulate actual cabin fires.

Research in these areas continued during 1980. As in 1979, the agency made fire tests using a C-133 fuselage to simulate a full-scale wide-bodied jet. The tests sought to determine the smoke, heat, and toxic gases released by burning commonly used aircraft interior materials. Tests to determine the heat resistance of aircraft evacuation slides showed that adding an aluminized coating to the surface of the slides made passenger evacuation safer. The agency also expanded antimisting fire research and simulation tests of fuel spills from ruptured tanks to determine how to arrest and contain spilling.

FAA established in June 1978 a Special Aviation Fire and Explosion Reduction (SAFER) Advisory Committee to review its fire safety program and to recommend what was most needed to reach its objectives. The 24-member committee—drawn from the airlines, aircraft manufacturers, universities, public and private research organizations, and flight and cabin crews—was asked to "examine the factors affecting the ability of the aircraft cabin occupant to survive in the postcrash environment and the range of solutions available."

Two technical working groups under the committee worked on interior compartment materials and postcrash fire reduction. Special subgroups studied short-term rulemaking possibilities in materials, material system toxicology, materials evaluation and testing, cabin fire safety, and evacuation slide integrity. The working groups also examined devices to make materials inert, explosion suppression devices, crash-resistant fuel-tank technology, and antimisting kerosene fuels. More than 150 of the world's top experts in fire research, accident investigation, materials development, system design, and aircraft fire and occupant safety assisted the committee and working groups.

The final report of the committee was submitted to the FAA administrator in September 1980. Its most important recommendation, the committee emphasized, was for investigating and validating antimisting kerosene. Developing an antimisting technology could prove to be the single most significant safety action the agency could take to reduce postcrash fires. Another recommendation envisaged designing and procuring fuel tanks and fuel-tank systems that resist rupture regardless of the deformation or failure of the surrounding aircraft structure. Other recommendations dealt with fuel-tank vent protection, engine fuel shutoff, available reduced-flash-point kerosene fuels, fire-resistant cabin interior materials, fire-blocking seat-cushion materials, and the possible use in cabin interiors of aluminum panels, epoxy glass panels, or phenolic panels, all of them highly fire resistant.

The FAA administrator set up in-house working groups to examine the recommendations and to translate them when feasible into rulemaking proposals.

Aviation Security Research

Progress was made in 1980 in developing x-ray, thermal-neutron-activation, nuclear-magnetic-resonance, and electronic-vapor-explosive detection devices. These advanced technology devices are meant to supplement the predeparture screening program that has been in place since the 1970s to deter terrorism and sabotage aboard aircraft. Intended to detect, effectively and automatically, bombs and other explosives hidden in lockers, checked baggage, cargo holds, and cargo compartments, they reached the following levels of development in 1980:

- Two units of a new x-ray baggage-inspection device were accepted from the contractor and sent for further testing to FAA's Technical Center and Dulles International Airport. In addition, a modular, automated x-ray device reached the procurement stage, and an experimental x-ray test-target-calibration inspection device completed its development and was undergoing limited field tests at the end of 1980.
- A thermal-neutron-activation device for detecting explosives was tested on baggage and cargo at several airports and was being improved at the end of 1980.
- The model of a nuclear-magnetic-resonance device for the automatic inspection of baggage and air cargo was tested at the Dallas-Fort Worth Airport and was being modified for improved performance.
- The development of an electronic-vapor-detector device for the detection of explosives was completed and its performance evaluated.

FAA also continued to experiment with small animals whose performance in detecting explosives compares favorably with electronic vapor detectors.

Medical Safety Research

FAA's Civil Aeromedical Institute (CAMI), at Oklahoma City, has as part of its mission the preparation of research studies on the medical aspects of aviation safety. Among studies published by CAMI in 1980 were:

- *Boredom and Monotony as a Consequence of Automation: A Consideration of the Evidence*

Relating Boredom and Monotony to Stress. The available data offered no support to the belief that boredom and monotony within the automated environment were per se productive of stress. Reports of boredom could serve most usefully as warnings that some elements in an automated job might be contributing to lowered attentiveness and work dissatisfaction.

- *Cosmic Radiation during Air Travel.* An advisory committee on the radiation biology of supersonic flight described the galactic and solar cosmic-radiation environment, estimated accumulated radiation dosage during high-altitude flight, enumerated risks of genetic and somatic injury, discussed possible radiation protection measures, and gave the status of forecasting and monitoring solar, cosmic events.
- *Postmortem Coronary Atherosclerosis Findings in General Aviation Accident Fatalities: 1975-1977.* The autopsies of 764 pilots who were in fatal general-aviation accidents during the two-year period were examined to determine the prevalence by age of coronary atherosclerosis in the group. The study determined that 51 percent of the autopsied pilots had had some degree of the disease and that, while only about 5 percent had had it in a severe form, the rate per thousand of severe cases increased from 14.5 for ages less than 30 to 89.9 for ages 50 years and above and that the rate nearly tripled from ages 30-39 to 40-49 (22.1 to 63.6 cases).
- *The Current Role of Alcohol in Civil Aviation Accidents.* Alcohol-associated general-aviation accidents have remained at a constant 16-percent level since 1969. An FAA survey of pilot attitudes revealed a lack of appreciation of the adverse effects of alcohol on safe flight among one-third of general-aviation pilots. These pilots believed that it was safe to fly with a positive alcohol level in their blood of 0.015 percent or higher. An intensified pilot-education program warning of the adverse effect on safe flying of even small amounts of alcohol was recommended.

Airport Pavement Development

Research projects on airport pavement in 1980 included:

- *Non-destructive Airport Pavement Testing.* The requirement that airport pavements be tested periodically to determine their load-carrying capabilities has made it necessary in the past to dig large pits in the pavements, make special bearing tests, and sample and test the materials—a method that was costly and time-consuming and required the temporary shutdown of the pavements tested. An FAA-developed, nondestructive testing technique—which applies vibration to the pavement, measures deflection, and calculates strength and load-bearing capability by computer—is now being adopted by airport operators throughout the national airport system.
- *Use of Waste and Recycled Materials in Airport Pavement Construction.* Research funded by FAA—with similar research by the Federal Highway Administration, the U.S. Navy, and the Army Corps of Engineers—established that certain waste and recyclable materials can be used safely and effectively in pavement construction. Old pavements are being crushed and reused as aggregate for new pavements, and fly ash, lime, sulfur, and various tailings and other industrial wastes are being used in new airport pavement construction throughout the country.

Environmental Research

Two principal environmental research projects were pursued in 1980: investigation of an atmospheric health hazard in aircraft cabins at high altitudes and examination of whether aircraft operations in the stratosphere damage the environment.

The first project studied high-altitude ozone contamination of cabins. During the winter of 1976-1977 acute physical discomfort marked by coughing and shortness of breath was noted by passengers and crew members on some long-range, high-altitude flights over the North Pacific. A possible cause was thought to be atmospheric ozone seeping into the cabins through their pressurizing systems. FAA, working closely with NASA and other government agencies, monitored and analyzed the ozone concentration both inside and outside at cruise levels and concluded that grounds existed for this belief. The agency promulgated a rule in 1980 setting limits on the amount of ozone permitted in the cabins.

The second project, FAA's continuing High Altitude Pollution Program (HAPP), was an outgrowth of DOT's earlier (1971-1975) Climatic Impact Assessment Program, the first comprehensive assessment of the effects of stratospheric pollution by aircraft, especially supersonic aircraft. The departmental study concluded that large-scale commercial aircraft operations, including SST operations, could significantly reduce atmospheric ozone. Studies since then by FAA under HAPP have led to a directly opposite conclusion: that foreseeable stratospheric aircraft operations would slightly increase total columnar ozone rather than decrease it. However, there is an element of uncertainty in this conclusion, since some calculations based on plausible parameters lead to an inference of a possible ozone decrease. The objective of HAPP is to resolve this uncertainty.

Air Navigation and Air Traffic Control

Microwave Landing System (MLS)

FAA first began developing a microwave landing system in the early 1970s, using an advanced, time-referenced scanning-beam technique. The MLS was accepted by the International Civil Aviation Organization (ICAO) in April 1978 as the international standard to replace the existing instrument landing system (ILS).

Three versions of the microwave system have been developed: a basic, wide-aperture system for large airports; a basic, narrow-aperture system for medium-size airports; and a small-community system. Test and evaluation of the basic narrow system and the small-community system were completed in 1979; testing of the basic, wide-aperture system, begun in 1979 at NASA's Wallops Flight Center, continued in 1980.

Action was taken during the year to secure ICAO approval of a checklist of standards and recommended practices, setting forth specifications, standards and operational practices of the various telecommunications systems used in international civil aviation. Work proceeded on both implementation and transition plans for the system and on production specifications for the basic narrow and small-community systems and associated technical documentation.

Concurrently FAA had under way in 1980 a so-called Systems Test and Evaluation Program (STEP). Its name to the contrary, STEP was concerned not so much with development, test, and evaluation, which had already been done, as with demonstration of the MLS versions for potential users and the gathering of "live" operational data for use by the operating services in developing operational handbooks, siting standards, and flight inspection procedures.

Discrete-Address Beacon System (DABS)

A spinoff from the primitive World War II identification-friend-or-foe (IFF) radar surveillance system, the present air traffic control radar-beacon system (ATCRBS) came into being in the mid-1960s as a secondary radar system. An airborne transponder automatically transmits an aircraft's identity and altitude when triggered by sensors mounted on ground-based radar interrogator antennas. Processed and digitized, this information and other positional information of the aircraft appears as an electronically written readout on controllers' display screens and radar scopes.

A serious ATCRBS shortcoming became apparent with the increasing traffic densities of the 1970s: the inability to ensure separation of transponder replies from aircraft flying close to one another. Transponders on all the aircraft in a given area reply indiscriminately to ground interrogation signals aimed at perhaps one or two of them, overlapping and garbling the responses. Computers at the ground stations must unscramble them, impeding to that extent the processing and digitizing of information that controllers rely on in making decisions.

FAA is completing development of a discrete-address beacon system (DABS) to overcome this difficulty. The DABS sensors—advanced interrogators mounted on primary radar antennas—will be able to address DABS-transponder-equipped aircraft individually and receive a transponder response from a specific aircraft rather than from all the aircraft in the immediate vicinity. The DABS transponder will respond only to its own aircraft's unique identity code in a ground sensor's interrogation.

DABS also will provide a digital data link between DABS-equipped aircraft and the ground-based air traffic control system, making possible the transmission of a large variety of data that would otherwise require direct controller-pilot communications.

A contract was awarded in early 1976 for 3 engineering-model DABS automatic traffic-advisory-and-resolution system (DABS/ATARS) sensors and 30 DABS transponders. Two models were delivered in mid-1978, and the third in early 1979. The sensors and transponders are being tested and evaluated at three locations centered on the FAA Test Center at Atlantic City.

New Automated Weather Observation Systems

In the mid-1970s, FAA began the development of a completely automated, unmanned weather station capable of weather observation service comparable to that from an on-the-spot, full-time weather observer. It was to be developed for use, at great cost savings, where FAA was responsible for providing manual weather observations. Working with the National Weather Service, which had developed such a station for remote and isolated areas, FAA developed a prototype automated weather observation station of its own, the AV-AWOS.

The AV-AWOS was fairly well developed when the agency in early 1978 began testing it at Patrick Henry International Airport at Newport News, Virginia. Data from standard, off-the-shelf, meteorological sensors were fed into a computer and the result—an on-the-spot, real-time weather service—was broadcast to pilots and others by a computer-generated voice broadcast. After four months of testing at Newport News, the concept was proved successful, but better sensors were needed. Under an interagency agreement the National Weather Service built a wind, altimeter, and voice-equipment (WAVE) system, which FAA tested and successfully demonstrated at Frederick Municipal Airport at Frederick, Maryland, in 1980.

The WAVE system provides the basic means for measuring, processing, and reporting by computer-generated voice (and by other means) surface temperature; dewpoint; wind speed, direction, and gusts; altimeter setting; and density altitude. The primary purpose of the system is to provide current weather and local altimeter services at airports that do not have this capability. Two commercial systems have been certified to provide this service. A number of these systems will be procured during 1981.

The FAA, anticipating the need for more complex systems, enhanced the WAVE system by adding more sensors and appropriate software for sensing and reporting visibility and ceiling, providing present weather information, and computing density altitude. This intermediate system, the automatic low-cost weather observation system (ALWOS), provides all the WAVE functions and will satisfy FAA regulatory requirements. The ALWOS system was successfully evaluated at Dulles International Airport during 1980. Plans are being made to test and demonstrate a more advanced version of ALWOS on an off-shore oil platform in early 1981.

ALWOS tests will also provide the means for a continuing FAA effort to develop and evaluate both hardware and software for a full, automated, surface weather observation system—the automated weather observation system (AWOS)—that will meet all of the present-day requirements of aviation weather observation, including present weather information, thunderstorm detection, etc. Final technical development of the AWOS will be completed by late 1981.

Direct-Access Radar Channel (DARC)

In late 1976, FAA let a contract for 22 direct-access-radar-channel en route air traffic control subsystems. Of the number, 20 were to provide a backup for the radar data processing systems at each of the FAA's 20 semiautomated air-route traffic control centers. The remaining two systems were to serve as backup for the system itself, one at the FAA Technical Center at Atlantic City for systems support, the other at the FAA Academy for the instruction of student controllers.

The DARC was to operate its narrow-band (digitized) radar data processing system when an individual traffic control center's primary IBM 9020 computers either failed or were shut down for maintenance. Using specially designed minicomputers and associated software and hardware computer components, DARC, operating in a "hot standby" mode, would be ready at a moment's notice to operate the processing system, which provides the controller an automatic alphanumeric readout on plan view displays of aircraft identity, position, and altitude, for his decisions for the safe separation of the aircraft under his control.

The existing backup in the NAS en route stage A system—as the automated en route air traffic control system is known—is broadband radar, a manually operated system in effect before the automated system was introduced. The controller prepares by hand a clear plastic marker for each controlled aircraft, with identity and altitude and other essential flight information. In changing from narrow-band to broadband radar operation, he repositions his radar scope from the vertical to the horizontal and pushes each marker manually across the scope to keep it as close as possible to the moving radar blip. DARC will make possible the eventual phaseout of the slow manual system.

By late 1978, DARC was ready for testing. The first unit went to the FAA Academy in November; the second to the FAA Technical Center a month later. The first operational DARC was received at the Salt Lake City Center in July 1979. Minneapolis, Chicago, Washington, and Jacksonville centers received the next subsystems in 1979. The remaining 15 deliveries were completed during 1980. By mid-1981 all 20 centers are expected to have completed the testing and commissioning of their DARC subsystems.

En Route Automated Radar Tracking System (EARTS)

A simpler, less costly, en route, automated radar tracking system—considerably different from the equipment used in the 20 domestic traffic control centers—has been developed for the special needs of the dispersed Anchorage, Honolulu, and San Juan centers. EARTS is essentially an expanded ARTS III modified for en route operations by adding a plan view display component from the en route stage A equipment list.

Deliveries of the new EARTS equipment began in the spring of 1978. Initial operating capability was attained by all three centers by 1979, and Anchorage began operating the equipment in August 1980. Honolulu was scheduled to follow in February 1981; and the San Juan center—which had for some time been using the ARTS III component of its EARTS package for approach control functions of the airports at San Juan, St. Croix, and St. Thomas—was expected to go into full, automated en route operation in March 1981.

New Automated Flight-Data Display Systems

Two principal improvements made progress during 1980, the electronic tabular display subsystem (ETABS) in the en route system and the terminal information display system (TIDS) in the terminal system:

ETABS. The system is designed to eliminate the need for manually updating and posting paper flight-progress strips in controller consoles and manually entering new flight data into center computers. Automatic extraction and display of data will save the controllers time and enhance productivity. An engineering model of the system, near completion in 1980, will be tested and evaluated at FAA's Technical Center at Atlantic City preparatory to procurement.

TIDS. The program is aimed at reducing the manpower required to distribute flight progress data and related information in airport control towers and radar control rooms. Using computer-stored and processed data, the system will provide significantly improved displays of flight data and airport operation data. Devices to display wind, weather, and the status of airport equipment will be consolidated, and existing electromechanical flight strip printers will be replaced by electronic displays. A contract was awarded in 1980 for development of a prototype system consolidating the environmental displays. In a subsequent phase, the flight data displays will be integrated with this system, tested, and evaluated.

New Radars

In addition to the newly developed, solid-state airport surveillance radar (ASR-8), 57 of which were in operation by the end of 1980, development was completed on the airport surface detection radar (ASDE-3) and procurement continued on the ARSR-3, an improved long-range radar.

ASDE-3. The object of this program was to develop an improved surveillance system for airport surface-traffic control, with improved aircraft detection during fog and rain. Testing and evaluation of a prototype ASDE-3, delivered to the FAA Technical Center in August 1979, was complete in May 1980, and implementation is expected to start in 1983.

ARSR-3. This new-generation, long-range, en route air traffic control radar was designed for use in high-density traffic and embodies such advanced features as improved antenna design, solid-state construction, and built-in test equipment. A total of 27 new ARSR-3s, including 4 mobile units, was procured by early 1980; 13 fixed units were in operation at the end of the year.

Next-Generation Weather Radar (NEXRAD) Program

The FAA has entered a joint program with the Department of Defense and Department of Commerce for a new common-use weather radar. The radar will use the doppler technique to detect hazardous weather phenomena and is designed to meet the nation's weather radar data needs in the 1990s and beyond. NEXRAD will replace the National Weather Service's obsolete weather radar network with a solid-state, joint-use, doppler radar network.

A joint NEXRAD Special Program Office staffed by representatives of the participating agencies was established in 1980 and a joint development program plan approved. An operational timetable calls for development by 1981 of the functional specifications and provision of both a validated concept and a prototype of the system by 1984. Full-scale development and limited production will begin in 1985, and full production will be under way and nationwide deployment begun in 1986.

Environmental Protection Agency

The Environmental Protection Agency (EPA) and NASA, working under two memoranda of understanding, have developed measurement systems and used satellite systems to gather data for field studies of hazy air masses and of the transport and transformation of oxidants and other pollutants in the northeast quadrant of the United States.

Energy-Related Environmental Research

The Interagency Energy/Environment Program (IEEP), a program under EPA direction instituted in 1974, draws on the expertise of some 36 research groups from federal departments and agencies, Department of Energy national laboratories, and EPA's own laboratories. The goal of the IEEP is to provide regulatory decision-makers in the federal government and the states with environmental data and assessment methodologies to ensure that national goals of energy development and self-reliance are met with minimal impact on human health and the environment. NASA participates, under the first memorandum of the understanding, providing EPA useful products of space-age technology, including a multispectral scanner and a data-analysis system for remote sensing of pollution and pollution effects. In addition, NASA aircraft have flown numerous missions in support of field study and in gathering data for pollution surveys.

Pollution Monitoring

The second understanding commits EPA and NASA to a cooperative program of research on hazy air masses. These masses are frequently found, especially in the eastern half of the nation, during summer months when meteorological conditions cause thermal inversions (as well as the formation of oxidants through photochemical reactions) in the atmosphere over populous industrial areas. At these times the air is stagnant and any pollution that enters the atmosphere remains in the local area, sometimes for extended periods. The air becomes unhealthy to breathe, especially for persons already suffering from impaired-pulmonary-function diseases. Hospitals treat increased numbers of persons for pulmonary disorders. EPA seeks to understand the causes of these prolonged elevated-pollution episodes (PEPEs) so as to predict when they will occur and to understand their atmospheric chemistry well enough to propose abatement or avoidance measures.

The joint EPA-NASA hazy-air-mass program has four goals:

- To determine if existing satellite systems can be used to help predict and track PEPEs.
- To identify ways in which the satellite systems can be modified to improve their ability to see hazy air masses and to distinguish natural haze from that caused by industrial pollution. Existing satellite sensor systems were designed primarily for planetary studies and thus designed to see through any intervening atmosphere. Accordingly, the wavelengths to which the sensors respond were chosen specifically to miss the haze. Possibly by the simple expedient of choosing other wavelengths, a satellite system far more useful for defining hazy air masses can be developed.
- To accelerate development of remote-sensing systems for atmospheric pollutants. These systems are already under development by NASA for possible use in future satellites and they are being implemented with partial funding from EPA through the IEEP.
- To investigate the feasibility of using satellite-based communication systems in large-scale field studies of air pollution transport and transformation phenomena. These studies require the participation of several research teams and several airborne and mobile ground-based vehicles.

PEPE/NEROS Field Study

In July and August 1980, EPA made a large-scale field study known as PEPE/NEROS (Persistent

Elevated Pollution Episode/North East Regional Oxidant Study). This was the first field study to have the benefit of a UV-DIAL (ultraviolet-differential absorption lidar) system for obtaining range-resolved ozone data from an airplane. Earlier in the year, the UV-DIAL system, mounted in NASA's Electra aircraft, performed well, obtaining ozone data that agreed with in situ data taken simultaneously from another aircraft. The UV-DIAL data taken for the PEPE/NEROS experiment will be analyzed and compared with the rest of the experimental data in fiscal 1981. The performance of the UV-DIAL, considered a minor breakthrough, stimulated the interest of researchers both in this country and in Europe.

The multispectral scanner (MSS), obtained by EPA's Environmental Monitoring Systems Laboratory at Las Vegas from NASA with earlier IEEP funding, also flew missions in the PEPE/NEROS field study. Other measurements of air pollution phenomena were made subsequently over the San Francisco area with NASA's MSS system mounted in its U-2 aircraft, to obtain a data base for deriving recommendations for future satellite systems. Recommendations were expected to be made for specific spectral regions to be sensed and a computer algorithm for analyzing the data to detect boundaries of hazy air masses.

At PEPE/NEROS headquarters in Columbus, Ohio, researchers received via satellite near real-time data on the formation of hazy air masses and their subsequent movement. These data were combined with near real-time meteorological data to predict and identify the air masses. Large numbers of aircraft and surface units stood by at various locations in the East, but the summer proved abnormally free of dangerous inversion conditions. Two PEPEs were observed during the four-week study period, one over the southeastern states and the other over Kentucky and Tennessee.

The satellite data were useful, not only for guiding researchers during the field measurement portion of the PEPE/NEROS study, but also in interpreting the immense volume of atmospheric pollutant data taken by the other units. The McIdas (man-computer interactive data-analysis system) of the University of Wisconsin, which can simultaneously display satellite and meteorological data, was being used to provide a framework for the interpretation of the in situ pollutant data.

NASA's Jet Propulsion Laboratory also participated, deploying its laser absorption spectrometer (an airborne instrument that measures the amount of ozone between the airplane and the ground) and a van-mounted system for measuring the vertical temperature profile and relative humidity. This latter system makes microwave measurements of atmospheric molecular oxygen and water.

UV-DIAL Development

The next phase in the development of the UV-DIAL system will be to modify it to detect sulfur dioxide and to fit it with a more powerful laser, extending its range for daylight operation. Clearly, lidar systems can be used to take data that, because of expense and technology limitations, are not otherwise obtainable. The present UV-DIAL system was designed as a research system; it is massive and requires considerable electric power. The design goal was to determine the absolute limits of lidar capability. One path of research in the future would be to design a lidar system with reduced power requirements and perhaps miniaturized components, so that it can be used in smaller aircraft. Another research path may lead to the development of a ground-based atmospheric observatory that scans the skies over urban areas and maps pollution three-dimensionally and continuously. Such an observatory has already been built in Japan.

The use of present satellite data to locate and track hazy air masses has been demonstrated. If the effort to improve the ability of satellite systems to see the haze succeeds, it may be possible to predict air pollution levels in the same way that changes in the weather are now predicted.

National Science Foundation

The National Science Foundation, charged with advancing basic scientific knowledge, supports research in aeronautics and space sciences. Most of this research is in astronomy and atmospheric sciences, to which staff and visitors at NSF-supported National Research Centers contribute significantly.

Multiple Quasars

Since the discovery of the law of gravitation by Isaac Newton, the behavior of a mass under the influence of gravity has been well understood. Einstein's later insight predicted that a particle of "pure energy" (i.e., light) should also be influenced by gravity—in this case, deflected by the gravitational field of a massive object. One of the key tests of general relativity, in fact, is to compare Einstein's precise prediction of the amount of this deflection (as starlight passes near the sun, for example) with the measured amount, a test which is still occupying the attention of experimental physicists.

A fascinating consequence of the deflection of light was appreciated and investigated by Einstein and many others. Under ordinary circumstances, light travels in a straight line. However, if an intervening massive object at a point along the light path deflects the beam, then the light can take several distinct alternate routes (each being deflected by differing amounts). From the observer's point of view, the beams of light appear to be coming from slightly different directions and therefore give the illusion of several distinct light sources. A slight focusing effect of the deflector will also tend to make some of the images abnormally bright; this phenomenon has come to be known as a "gravitational lens."

Quasars are starlike objects of tremendous luminosity and distance, believed to be centers of violent activity in the nuclei of galaxies. Their starlike appearance and vast distance make them the most likely objects in which a gravitational lens effect might be seen. In the spring of 1979 two British astronomers, Dennis Walsh and Robert Carswell, and an American, Ray Weymann, discovered a close optical pair of quasars whose properties were so nearly identical that it appeared to them inescapable that the images were produced by the same light sources. Subsequent observations seemed to confirm that these twin quasars do indeed represent a gravitational lens in action.

The theory was further advanced by NSF-supported research in the past year. In March 1980 Weymann, with David Turnshek and Richard Green, was studying the spectral properties of a set of quasars. While viewing the image of one of the quasars before recording its spectrum, Turnshek and Weymann noticed that the image actually consisted of a bright image and two very close but much fainter images. Since the likelihood of two ordinary stars appearing by chance so close to the bright image is small, they realized that the two fainter images were likely to be of considerable interest. Further observations were carried out with the multiple-mirror telescope, a joint project of the University of Arizona and the Smithsonian Institution. The critical and difficult observation was to obtain a spectrum of one of the faint companion images. If a gravitational lens was operating, a single source of light would produce both images, and their spectra would be identical. In fact, the spectra they recorded appeared identical to within the accuracy of the observation, thus lending strong support to the existence of another gravitational lens—in this case producing a triple image.

Mount Saint Helens Volcano

When the Mount Saint Helens volcano in southern Washington became active on 27 March 1980, after a long quiescent period, it caused a flurry of interest among scientists across the country.

Volcanic eruptions can have significant effects on the chemical balance of the stratospheric ozone layer, which protects the earth from solar ultraviolet radiation. Sulfur dioxide from eruptions can combine with hydroxyl radicals to form sulfuric acid in the stratosphere. Other chemicals, such as carbonyl sulfide, may also enter the lower atmosphere (troposphere) and work their way upward into the stratosphere, eventually reacting with light to form more sulfuric acid. Local toxic effects might be caused by such gases as mercury vapor.

Evidence is considerable that volcanoes may also have long-term climatic effects. Backscattering of light by very fine ash particles and sulfuric acid can reduce the amount of light reaching the earth, with concomitant changes in precipitation and cooling patterns.

Scientist Richard Cadle flew a specially instrumented aircraft operated by the NSF-supported National Center for Atmospheric Research (NCAR) through the Saint Helens plume in April, gathering particle and gas samples. The aircraft was outfitted with evacuated canisters to gather samples of the gases for chromatographic analysis, special filters for collecting particles, a water sampler developed by the U.S. Geological Survey to determine how much of the water in the volcano's cloud originated from ground water and how much from the earth's mantle, a quartz microbalance impactor (from NASA), for determining the size distribution and composition of particles, and filters (from Michigan Technological University) for collecting larger ash particles. Photos of the plume were also taken.

Although a weak odor of sulfur dioxide and hydrogen sulfide could be detected in the aircraft cabin, only negligible amounts of sulfur compounds were measured. Cadle believes that the volcano's sulfur output was low because its eruptions were phreatic, caused by ground water hitting hot magma, rather than magmatic, characterized by hot gases from molten lava. Magmatic eruptions are more likely to inject sulfur compounds into the atmosphere. At the time of the NCAR flights, the eruptions reached only six kilometers above sea level. Because of the lack of sulfur dioxide in the plume and because the ash particles were too large to rise into the stratosphere, the eruption was not likely to have much impact on weather and climate.

An eruption on 18 May reached stratospheric levels, and preliminary results from samples taken by another NSF-supported research group at the University of Washington indicated the presence of hydrogen sulfide in the plume. Cadle strongly suspects that the presence of a sulfur compound indicates that the 18 May eruption may have been magmatic; it was also a much hotter eruption than would be expected from a typical phreatic event, and particle sizes in the cloud were much smaller than previously. A "bulge" that developed in the mountain before that 18 May eruption was also indicative of a buildup of magma.

The 18 May eruption provided other unique opportunities for research on the impact of volcanic emissions on the atmosphere. David J. Hofmann and J. M. Rosen of the University of Wyoming flew balloon-borne instruments into the volcanic plume over Laramie, Wyoming, and detected condensation nuclei throughout the lower stratosphere up to an altitude of 26 kilometers. This is believed to be the first direct observation of particles of this small size in volcanic injections into the stratosphere. Particles in this size range act as condensation centers and precursors of larger aerosol particles capable of scattering sunlight and affecting the heat balance of the earth. Finding volcanic injection of condensation nuclei directly into the stratosphere provides an important new step toward the understanding of natural versus man-made influences on the earth's climate.

Solar Maximum Year

NSF and NASA jointly supported the Solar Maximum Year, which reached a peak in observational activity corresponding to the maximum in the solar cycle in 1980. NASA is responsible for the spacecraft observations of the sun, most of which are provided by a dedicated satellite—the *Solar Maximum Mission* (*SMM*). NSF is responsible for the ground-based research. As part of that research, the National Center for Atmospheric Research is also participating directly in *SMM*, which carries seven scientific instruments, including the NCAR coronagraph-polarimeter. It was launched into earth orbit on 14 February 1980, to study flares on the sun during the 1979–81 peak of its 11-year sunspot cycle. The NCAR instrument will help to study the evolution of the sun's corona and the transient activity associated with flares.

Like the instrument used on the Apollo telescope mount of the Skylab orbiting solar observatory (which took measurements during the solar activity "minimum" in 1974), the NCAR telescope makes it possible to view the extremely thin corona by using an external occulting technique to create an artificial eclipse. Filters permit observations at various wavelengths of light useful for seeing different facets of solar activity, and polarizing filters permit determination of magnetic fields in the corona. The satellite is complemented by associated observing programs at more than 100 ground-based observatories, including a new telescope system at the NCAR High Altitude Observatory station on Mauna Loa in Hawaii.

The ground-based observatories have already shown significant results. Solar telescope observations at the South Pole dramatically confirmed the existence of solar global oscillations, or pulsations of the surface of the sun, with a period of 5 minutes, and provided information about even longer periods. Preliminary analysis suggested that solar oscillations with a period of 160 minutes may have been observed from the South Pole. While the 5-minute oscillations can be attributed to events in the outer layers of the sun, the 160-minute-period oscillations would have to originate deep within the sun, upsetting the basic notion that the sun's structure is neatly layered.

The South Pole was chosen by NSF as the observation site for several reasons. Most important, during the summer at the South Pole the sun is visible for 24 hours a day at a constant elevation above the horizon, providing uninterrupted observing periods much longer than attainable anywhere else. The high elevation (3000 meters) and the cold, dry air are additional advantages of the South Pole for solar observations.

Iridium and the Cretaceous-Tertiary Boundary

The recent discovery by NSF-supported scientists of unexpectedly high levels of iridium and other platinum-group elements in marine sediments deposited during the transition from the Cretaceous to the Tertiary Periods (65 million years ago) has thrown new light on the mystery of the extinction of the dinosaurs and other Mesozoic organisms. The iridium anomaly was first noted by scientists at the University of California, Berkeley, in sediments collected near Gubbio, in the Italian Apennines, during a collaborative study by U.S. and European scientists on relationships between biostratigraphic and magnetic-reversal correlations.

Iridium concentrations near the Cretaceous-Tertiary boundary at Gubbio are 30 to 160 times those found in ordinary deep-sea sediments. Subsequent work has shown that iridium and other noble metals are also anomalously abundant in a thin layer of clay that marks the boundary in Denmark and that they occur in the relative proportions found in chondritic meteorites. Because iridium and related elements in the earth's crust are depleted below their meteoritic abundances, the high concentrations and chondritic ratios in the boundary sediments are consistent with an extraterrestrial source. The Berkeley group suggests that the source of the extraterrestrial matter might have been a meteorite, as large as 10 kilometers in diameter, which would have thrown up enough pulverized terrestrial debris to cut off solar radiation and suspend photosynthetic processes for several years. This dust, containing the meteoritic component, eventually settled in the oceans to form the thin clay layers found in Italy and Denmark.

Although the impact hypothesis requires further testing, the concept of a brief suspension of photosynthetic processes fits well with the known pattern of Cretaceous extinctions. All dinosaurs, as well as old marine and flying reptiles and many groups of marine plants and invertebrates, perished. The surviving life forms included organisms such as land plants that might have been able to regenerate from root systems, seeds, and spores, as well as primitive mammals, small reptiles, and marine invertebrates that could possibly have survived the disruption of normal food chains by subsisting on insects and decaying vegetation during the period of diminished sunlight.

But before this hypothesis can be accepted major questions must be considered. One of these is to what extent the extinctions occurred in different places at the same time. The marine section at Gubbio is important in this respect because it has been used as the basis for the best detailed correlations between biostratigraphy and the chronology of worldwide magnetic reversals and because it is believed to represent a continuous sedimentary record across the Cretaceous-Tertiary boundary. Another question is the time span. If the impact hypothesis is correct, worldwide extinctions were instantaneous in a geologic sense. Although there are still differences of opinion on the validity of the impact hypothesis, it has given a sharp focus to several other groups working on similar problems under NSF sponsorship.

Smithsonian Institution

The Smithsonian Institution contributes to the national space program through an integrated program of basic research and development in space science and astrophysics at its Smithsonian Astrophysical Observatory (SAO) in Cambridge, Massachusetts, and through the public displays and exhibits of its National Air and Space Museum (NASM) in Washington. The Center for Earth and Planetary Studies at NASM also conducts basic research in support of national goals.

Space Sciences

High Energy Astrophysics

Acquisition and analysis continued in 1980 on the data obtained by the *Heao 2* (*Einstein*) satellite, a spacecraft carrying the first x-ray telescopes capable of providing focused images of x-ray objects in space. For example, the deep x-ray survey studied the nature of the extragalactic x-ray background, distant quasars, x-ray sources in galaxy M31, and x-ray emission from radio galaxies Centaurus A and Cygnus A and from clusters of galaxies.

The studies of clusters of galaxies at cosmological distances included the discovery of apparent evolution in the temperature of these clusters, as well as placing quantitative limits on their luminosity evolution. Nearby rich clusters of galaxies were also observed, and the x-ray observations were compared with optical studies to produce a new, albeit tentative, system for classifying clusters as those dominated by a single central galaxy and those lacking any central condensation.

The study of galaxy clusters and galactic halos also included measuring the mass of M87's halo from the distribution of the x-ray-emitting gas, leading to an estimate of mass equal to about 10^{13} solar masses. In a related study, an extended x-ray source centered in the elliptical galaxy M86 was found to be the result of ram-pressure stripping of the galactic gas by the gas pervading the Virgo cluster. The galaxy itself could retain its internally generated gas during the periods when it is far from the dense cluster core.

Other x-ray astronomy studies made with the *Einstein* observatory satellite included the precise location, and thus further knowlege, of the gravitational masses of the sources within globular clusters; the first x-ray imaging and time-resolved spectral studies of an x-ray burst (from the globular cluster Terzan 2); time-resolution studies of a gama-ray burst; imaging and spectral studies of the unusual optical object known as SS433; a study of emission from flare stars; the analysis of the x-ray emission from supernova remnants and from radio pulsars; and a study of the Crab Nebula and associated pulsar that led to the first measurement of the "off"-state flux from the Crab.

The *Einstein* satellite completed a first survey of 40 square degrees containing the Small Magellanic Cloud. Twenty-four new x-ray sources were discovered, including one very bright supernova remnant in the SMC. In collaboration with the X-ray Astronomy Group at the University of Leicester, England, maps were made showing x-ray emission from supernova remnants 1006, IC443, W44, and 49.

The study of quasars concentrated on finding correlations between x-ray luminosity and optical luminosity, and between x-ray luminosity and redshift. Observations have been interpreted as requiring two mechanisms for x-ray production in quasars. Refined calculations of the contribution of quasars to the diffuse x-ray background have led to the conclusion that quasars are a major source. Further, the limit set by the diffuse x-ray background constrains the number of optically faint quasars and provides support for models in which quasar evolution is predominantly luminosity evolution and not pure density evolution.

Observations of extragalactic x-ray sources by the *SAS 3* satellite continued. And on 22 March a sounding rocket launched from White Sands, New Mexico, carrying a solid-state spectrometer measured the line strengths of C V, VI and O VII, VIII, which are emitted from the hot component of the interstellar medium. Preliminary results confirmed the presence of the hot component at a temperature of about 1 100 000 kelvins.

Balloon Astronomy

In October 1979, the flight of a 102-centimeter balloon-borne telescope carried a high-resolution, far-infrared Michelson interferometer to an altitude of 29 000 meters. For 10 hours at this altitude, it measured the far-infrared spectra of the Orion nebula, the M17 molecular cloud, and the terrestrial stratosphere. Preliminary results included the first detection of a large number of spectral lines from shock-wave-excited carbon monoxide in Orion, as well as the first far-infrared measurement of stratospheric hydrogen chloride and the first detection of stratospheric peroxide, the latter two being important in the chemistry of the ozone layer.

Reduction of data from earlier flights of the balloon-borne telescope continued. The first far-infrared map of a giant molecular cloud and the follow-on observations of radio continuum and molecular line observations have shown that star formation is occurring throughout the cloud, not just at the end of the cloud containing the bright H II region, as previously thought. It is now important to understand what mechanism could have triggered star formation simultaneously over such an extended region. Also, the first far-infrared map of the highly evolved H II region, M16, was produced. This study of M16 is important in understanding the later stages of evolution of star-forming regions. The first measurement of the far-infrared size of the extended dust cloud surrounding the carbon star, IRC + 10216, was acquired, and it was determined that the mass loss from the star had to be considerably larger only 2000 years ago.

Earth's Resources

The SAO Satellite Tracking Network provided laser tracking coverage for geophysical research at SAO and other organizations in the United States and abroad. This year tracking focused on the high earth-orbiting NASA *Lageos* satellite as well as others in near-earth orbits. A total of 5000 passes of decimeter-accuracy data were acquired.

The satellite data were used in investigations of polar motion, earth and ocean tides, and crustal motion and deformation and in determination of the gravity field and its temporal variations. SAO continued as coordinator and U.S. interface for overseas laser tracking participants and acted as a coordinator and computations center for the MERIT Campaign, an International Astronomical Union-International Union of Geodesy and Geophysics program to monitor polar motion and earth rotation.

An accumulation of six years of laser ranging data from three satellites was used to measure global ocean tides by satellite perturbation analysis. This study also measured body tides, and it determined the near-diurnal core-mantle resonance and the semiannual tide for the first time.

Observational data from several satellite experiments—the mass-spectrometer measurements of *ESRO 4*, *Explorer 51*, and the Air Force's *S3 1* satellite, in particular—have provided the base for developing an improved model of the earth's thermosphere and exosphere. While the work encompasses all aspects of the neutral upper atmosphere, the main emphasis is on the geomagnetic variation and the diurnal variation, the two areas most in need of improvement in present models.

Routine calculations of the earth's polar motion with laser ranging measurements by *Lageos* were under way, and pole positions were being provided to the Bureau International de l'Heure in Paris every five days. A successful combination of satellite-to-sea-surface altimetry data, oceanic hydrographic data, and surface-gravity data led to the calculation of a circulation model for the North Atlantic.

Solar and Stellar Physics

Major analysis programs centered on data returned by *Skylab* from both the extreme ultraviolet spectrometer and the Apollo telescope mount (ATM), by the *Heao 2* (*Einstein*) satellite, by the International Ultraviolet Explorer *IUE*, and by the flight of a Lyman-alpha white light coronagraph.

Skylab studies concentrated on magnetically confined plasma structure in the corona: bright points, active region loops, sunspot loops and prominences. For example, analysis of *Skylab*'s extreme ultraviolet data showed quantitatively for the first time that bright points evolve and change in brightness over time-scales as short as 5.5 minutes, the shortest time-scale available from the data. This discovery suggests that coronal heating in bright points is due to an intermittent impulsive heating mechanism, most likely one that releases energy stored in the coronal magnetic field.

A preliminary *Einstein* stellar survey was completed and revealed that stars of virtually all classes are x-ray emitters. Of particular importance, both very early (hot) and very late (cool) stars have x-ray emission substantially greater than predicted by "standard" theories of shock-heated stellar coronas. These new observations, combined with previous (*Skylab*) solar x-ray and extreme-ultraviolet observations, led to theoretical studies of coronas heated by dynamo-generated magnetic fields.

Ultraviolet observations of Cygnus X-1 by the *IUE* satellite were analyzed to produce tighter constraints on estimates of the inclination of the system and the mass of the compact object. Observations of cataclysmic variables led to the conclusion that nuclear burning is the most plausible explanation for the 10- to 40-electron-volt "blackbody" continuum emission components. Study of the Hyades giants showed a surprisingly large difference in transition-region emission for stars of the same age. High-temperature species (C IV and Si IV) have been found to occur mainly, but not necessarily, around hot early stars and, it is thought, may result from photoionization of an H II region close by the star. Surface activity on stars of the RS CVn type has been studied by using both *IUE* and ground-based high-dispersion observations from the Mount Hopkins Observatory.

Gravity Research

The use of maser clocks, which have been demonstrated to have fractional frequency stabilities at the 10^{-16} level in spacecraft, has led to new concepts for testing relativistic gravitation and particularly for detecting gravitational radiation. Under study was the use of a time-correlated multiple-link doppler system for detecting very low frequency (10^{-5} Hertz) pulses of gravitational radiation and for improving the precision of doppler tracking for a close-approach solar-probe mission to measure the mass distribution of the sun.

A cryogenically cooled hydrogen maser was operated at temperatures as low as 26 kelvins. Development and testing were under way, using two separate, newly constructed cryogenic masers. Demonstration experiments of relative stability data below the 1×10^{-16} level for intervals of 600 seconds were in progress.

Final results of the 1976 rocket-probe redshift experiment indicated predictions of general relativity were valid at the 70×10^{-16} level.

Lunar Research

A consortium to carry out a detailed study of the petrology, chemical composition, and age-dating of the *Apollo 16* lunar rock Breccia 67015 was established under the leadership of a Smithsonian scientist. Earlier maps and descriptions of this breccia had been published and distributed by the Lunar Science Institute, Houston.

Planetary Research

A photograph obtained by *Voyager 1* during its March 1979 encounter with Jupiter shows a bright fireball on the Jovian nightside. The phenomenon, believed produced by an infalling meteoroid of 11-kilogram mass, was calculated to be about 10 times more likely to occur on Jupiter than on Earth, from a comparison of elapsed time of the observation (20 minutes) with the total time spent searching for fireballs.

Center for Earth and Planetary Studies (National Air and Space Museum)

The Center for Earth and Planetary Studies continued investigation of lunar photogeology, comparative planetology, and terrestrial and Martian desert features. Comparisons made between ridges in the Caloris basin on Mercury and lunar basins indicated the basins were affected by global-scale compression resulting from early cooling of the moon.

Crater characteristics on Mars shown in Viking images were being examined to determine their distribution on different terrains.

The study of deserts was further expanded during August 1979, when a delegation visited parts of the Gobi, Tengri, and Dzungarian Deserts in North China.

Department of State

International space cooperation efforts in support of U.S. foreign policy objectives and of goals of the National Aeronautics and Space Act were of high priority to the Department of State during 1980. Attention focused both on cooperation with individual countries and on endeavors with multilateral and international organizations. The Department of State coordinated closely with NASA, Department of Defense, Office of Science and Technology Policy, National Oceanic and Atmospheric Administration, and National Security Council in formulating U.S. positions on civilian space issues. Issues ranged from the establishment of additional critical communications support for the Space Shuttle from foreign ground stations to the continuation of U.S. industry support to limited launch vehicle development in Japan.

In 1980 the United Nations, through its Committee on the Peaceful Uses of Outer Space and various working groups, continued to be a prime forum for formalizing multinational viewpoints and programs to advance cooperation in the uses of outer space. The Department of State, NASA, and DoD regularly represent the United States at meetings of the Outer Space Committee and its Legal and Scientific and Technical Subcommittees.

Activities within the United Nations

Outer Space Committee

The United Nations Committee on the Peaceful Uses of Outer Space is a major factor in our international space relations. Through this committee the international community is building a foundation for cooperation on legal and political issues. The United States plays a leading role in the main committee and its two subcommittees, the Scientific and Technical Subcommittee and the Legal Subcommittee. Issues before the committee in 1980, as in the recent past, were the Draft Principles governing direct television broadcasting by satellites, the Draft Principles for remote sensing of the earth, the definition of outer space, the use of nuclear power sources in outer space, the use of the geostationary/geosynchronous orbit, and preparations for the U.N. Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE '82).

Vienna is scheduled to host the UNISPACE '82 Conference from 9 to 21 August 1982. Planning for the conference began in 1980, but basic problems of U.N. and organizational questions remain unresolved.

Moon Treaty

Consideration was given to matters related to signature and ratification of the Treaty Governing the Activities of States on the Moon and Other Celestial Bodies (the Moon Treaty), which was opened for signature by consensus of the U.N. General Assembly on 5 December 1979. The treaty has been under discussion since late 1971, when the General Assembly adopted resolution 2779, in which it took note of a draft treaty submitted by the USSR and requested the Committee on Peaceful Uses of Outer Space and its Legal Subcommittee to consider elaboration of a draft international treaty on the moon.

The Moon Treaty is based to a considerable extent on the 1967 Outer Space Treaty. It defines obligation of both immediate and long-term application to such matters as safeguarding human life on celestial bodies, promoting scientific investigation and exchanging information relative to and derived from activities on celestial bodies, and exploitation of the natural resources of celestial bodies.

Communications Satellites

The International Telecommunications Satellite Organization (INTELSAT) originated as an international joint venture in August 1964 when 11 countries signed agreements to form a single, global, commercial communications satellite system. The definitive agreements establishing INTELSAT entered into force 12 February 1973, and by the end of 1980 it was an international legal entity with owners' equity of more than $550 million, in which 105 countries held investment shares proportional to their use of the satellite system. Communications Satellite Corporation (Comsat Corp.) is the designated U.S. participant in INTELSAT and, with an investment share of about 24 percent, the largest shareholder.

INTELSAT is responsible for designing, developing, constructing, establishing, operating, and maintaining the space segment of its global system. The system consists of high-capacity communications satellites stationed in synchronous orbits over the equator, at an altitude of 35 790 kilometers above the Atlantic, Pacific, and Indian Oceans. From these positions, each of the satellites serves an area larger than one-third of the earth's surface, thus providing global coverage. Ground stations are owned and operated by entities in the countries where they are located.

The satellites in the global system and 283 ground-station antennas operating with them in 1980 provided more than 760 pathways, or direct communication links, among more than 140 countries, territories, and possessions. A growing number of countries are also building stations within their boundaries and are using INTELSAT satellites to improve their domestic communications systems.

In response to widespread recognition that the application of satellite technology to maritime communications offers a vastly improved capability for safety and distress messages, fleet management, and public correspondence, the United States participated in negotiations leading to the creation in 1979 of the International Maritime Satellite Organization (INMARSAT) to establish a global maritime communications satellite system. U.S. participation in INMARSAT was authorized by a 1978 amendment to the Communications Satellite Act, which also designated Comsat Corp. as the entity to undertake the technical, operating, and financial responsibilities of U.S. membership. Patterned closely after INTELSAT in its ownership and management arrangement, INMARSAT in 1980 had 29 members; Comsat Corp. was the largest shareholder with 23 percent, followed by the Soviet Union with 14 percent. In November 1980, INMARSAT approved an operational plan for its first-generation space segment, which will include maritime payloads on board three Intelsat V spacecraft, two dedicated Marecs spacecraft manufactured by the European Space Agency, and one Marisat spacecraft. INMARSAT was expected to begin international maritime communications in 1982 in a transition from the present Marisat system, which was developed by Comsat General Corporation and is owned by a consortium of U.S. companies. The Marisat system has been providing maritime services to the U.S. Navy and to commercial shipping and offshore industries since 1976.

International Communication Agency

The United States International Communication Agency (USICA) followed U.S. space exploits for a worldwide audience in 1980, reporting scientific results that continue to come from discoveries of past planetary explorations, as well as the ongoing journey of the Voyagers to the planet Saturn and the development of the Space Shuttle. Coverage included press articles, Voice of America reports, exhibits, informational materials, and films.

Space Shuttle Coverage

USICA's press service, the "Wireless File" to 193 posts in 125 countries, carried a series of articles on the first orbital Space Shuttle flight, scheduled for 1981. The series highlighted the technological innovations necessary for the development of the new hybrid rocket-airplane, the flexibility and economy the system provides for routine space and earth research, and the men and women being trained to work in the Shuttle and its space laboratory.

The Voice of America gave continuous coverage to preparations for the launch. It broadcast interviews of NASA Administrator Robert Frosch and others working to solve prelaunch technical problems. VOA interviews of mission specialists—a new kind of astronaut in the Shuttle crew—provided information on women and U.S. minority group astronauts. Listener requests for a NASA book on the Shuttle indicated a wide audience awaited the 1981 launch. Throughout the year, the international audience sent in questions about space for VOA's " Question and Answer" programs. The Shuttle was again the lead topic. In late October, USICA prepared the groundwork for a NASA film on the Shuttle that embassies and overseas posts provided to TV stations and screened for audiences in our centers at the time of the 1981 launch.

Unmanned Space Probe Coverage

Most of the agency's 1980 coverage of the space program concerned the scientific results that continued to come out of such flights as the Viking missions to Mars in 1976, the Pioneer probe to Venus in 1978, and the Voyagers' passes by Jupiter in 1979.

The year began with coverage of the maps resulting from the radar probes of the surface of Venus. Scientists interpreting the radar data were interviewed by the USICA press service and VOA. VOA also reported the *Solar Maximum Mission*—a satellite to examine the sun during the height of the sunspot cycle—and the implications of the data for Earth's atmosphere, weather, and climate. VOA's worldwide English service carried information on Jupiter's rings discovered by Voyager missions, as well as information on the Jovian satellites that Voyager spacecraft examined with high-resolution instruments as they flew past the planet. The January 1980 issue of a USICA magazine recapped the spectacular views provided by Voyager in 1979.

Voyager 1's pass near Saturn in November 1980 was given special news service coverage. The accounts highlighted not only the discoveries at Saturn, including three additional satellites, but the significance of the journey in understanding the solar system's second largest planet and its satellite Titan.

General Space-Related Activities

USICA continued a number of other activities supporting the U.S. space effort. VOA reported space community sessions at Woods Hole, Massachusetts, in 1980 that discussed the future of the U.S. space program.

USICA overseas posts were provided a packet of NASA publications to help them answer space-related questions from the press and the public.

Film footage from the NASA film "Lacie," on the large-area crop inventory experiment, was used in a production on computer technology illustrating the spinoff usefulness of space technology.

Agency exhibits overseas in 1980 contained information related to space technology. For example, "Science and Technology: Paths to Progress," a 780-square-meter exhibit in Zambia in August, included satellite models and live demonstrations of online computer searches from a computer bank in California arranged through the National Technical Information Service and RCA Global Satellite Communications. Another display in the exhibit gave information on Landsat earth resources data and technology. The USICA exhibits section filled some 15 field requests for display items on space during the year, including moon rock, spacesuits, models, posters, paper shows, and slides.

Appendixes

APPENDIX A–1

U.S. Spacecraft Record

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

Year	Earth Orbit[a]		Earth Escape[a]	
	Success	Failure	Success	Failure
1957	0	1	0	0
1958	5	8	0	4
1959	9	9	1	2
1960	16	12	1	2
1961	35	12	0	2
1962	55	12	4	1
1963	62	11	0	0
1964	69	8	4	0
1965	93	7	4	1
1966	94	12	7	1[b]
1967	78	4	10	0
1968	61	15	3	0
1969	58	1	8	1
1970	36	1	3	0
1971	45	2	8	1
1972	33	2	8	0
1973	23	2	3	0
1974	27	2	1	0
1975	30	4	4	0
1976	33	0	1	0
1977	27	2	2	0
1978	34	2	7	0
1979	18	0	0	0
1980	13	4	0	0
Total	954	133	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.

APPENDIX A–2

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

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

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
Total	756	1339	10	8	17	8	1	1	1	1

[a] Includes foreign launchings of U.S. spacecraft.

Successful U.S. Launches—1980

Launch Date (GMT), Spacecraft Name, COSPAR Designation, Launch Vehicle	Spacecraft Data	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
18 Jan. *Fltsatcom 3* 4A Atlas-Centaur	Objective: To place spacecraft in synchronous, near-equatorial orbit for USAF narrow-band and wide-band communications and USN fleet-relay and broadcast channels. Spacecraft: Hexagonal, composed of payload module and spacecraft module; 6.7 m high. Provides 1 SHF and 23 UHF communications channels. Weight after apogee motor firing: 1005 kg.	35 662 35 406 1423.1 2.4	Third of five planned satellites, successfully launched by NASA for Navy and Dept. of Defense. Apogee kick motor fired 20 Jan. Spacecraft placed in desired synchronous orbit. All spacecraft systems turned on and operating. Still in orbit.
7 Feb. Defense 10A Titan IIID	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	481 299 92.4 97.0	Still in orbit.
9 Feb. *Navstar 5* 11A Atlas F	Objective: To support Global Positioning System. Spacecraft: Irregular cylinder with 4 extended solar panels and complex of antennas. Weight: 433 kg.	20 165 20 095 715.9 63.7	Still in orbit.
14 Feb. *Solar Maximum Mission* (*SMM*) 14A Delta	Objective: To observe solar flares or other active-sun phenomena simultaneously, using 5 or 6 *SMM* experiments. Secondary objective to measure total radiative output of sun over 6-mo period. Spacecraft: Modular, 4 m long, fits into circular envelope 2.3 m in diameter. Instrument module contains solar payload instruments as well as fine-pointing sun-sensor system for pointing control. Below instrument module and separated by transition adaptor is multimission modular spacecraft (MMS), a triangular framework supporting 3 modules, each 1.2 × 2 × 0.5 m, housing 3 spacecraft subsystems: attitude control, power, and communications and data handling. Two solar paddles affixed to transition adaptor supply up to 3000 watts. Weight: 2315 kg.	562 558 95.9 28.5	Successfully launched by NASA. First solar flare observed 19 Feb. On 21 May, 6 *SMM* instruments measured solar flare covering more than 5.2 billion square km of sun's surface. Fluctuations of 0.1% of sun's radiation output have been measured. Still in orbit.
3 Mar. Defense 19A Atlas F	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	1 151 1 035 107.1 63.5	Triple launch. Still in orbit.
Defense 19C	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	1 165 1 050 107.4 63.4	Triple launch. Still in orbit.
Defense 19D	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	1 167 1 050 107.5 63.5	Triple launch. Still in orbit.
26 Apr. *Navstar 6* 32A Atlas F	Objective: To support Global Positioning System. Spacecraft: Irregular cylinder with 4 extended solar panels and complex of antennas. Weight: 433 kg.	20 231 19 622 707.6 62.9	Still in orbit.

Successful U.S. Launches—1980

Launch Date (GMT), Spacecraft Name, COSPAR Designation, Launch Vehicle	Spacecraft Data	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
29 May *Noaa-B* 43A Atlas F	Objective: To launch spacecraft into sun-synchronous orbit for NOAA for earth scanning, remote observations, solar-particle-radiation measurements, atmospheric soundings, and data dissemination in real-time. Spacecraft: Launch configuration including apogee kick motor, 371 cm high, 188 cm in diameter. Solar panels deploy in orbit. Structure composed of 4 major elements: reaction control equipment support structure (RSS); equipment support module (ESM); instrument monitoring platform (IMP); and solar array. With exception of IMP and transition ring, basic structure identical to DMSP block 5D2. Instruments include advanced very-high-resolution radiometer (AVHRR), data-collection and location system (DCS), space environment monitor (SEM), total energy detector (TED), medium-energy proton electron detector (MEPED), high-energy proton-alpha detector (HEPAD), and Tiros operational vertical sounder (TOVS) composed of 3 instruments: high-resolution infrared sounder (HIRS/2), stratospheric sounding unit (SSU), and microwave sounding unit (MSU). Weight in orbit after apogee-kick-motor firing: 723 kg.	1 028 250 97.5 92.2	Third in series of operational environmental monitoring satellites launched by NASA for National Oceanic and Atmospheric Administration (NOAA). Launch vehicle malfunction placed spacecraft in highly elliptical rather than planned circular orbit. Attempts to correct orbit unsuccessful; spacecraft unable to operate effectively. Replacement planned.
18 June Defense 52A Titan IIID	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	262 164 88.8 96.4	Dual launch. Still in orbit.
Defense 52C	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	1 326 1 326 112.1 96.6	Dual launch. Still in orbit.
9 Sept. *Goes 4* 74A Delta	Objective: To launch spacecraft into earth-synchronous orbit for NOAA, to provide near-continual, high-resolution visual and infrared imaging over North and South America and surrounding oceans, collect environmental data from up to 10 000 remote-observing platforms, measure energetic solar field, and broadcast centrally prepared weather and satellite information. Spacecraft: Cylindrical, 2.15 m in diameter and 4.43 m long from top of S-band omni antenna rod to bottom of apogee boost motor. Apogee boost motor ejected after synchronous orbit reached. Primary structural member is thrust tube in center of cylinder. Visible infrared spin-scan radiometric atmospheric sounder (VAS) extends length of spacecraft, located in and supported by the thrust tube. Scanning mirror looks out through opening in cylindrical solar arrays. Space environment monitor (SEM) system measures magnitude and direction of magnetic field, intensity of solar x-ray radiation, and energy level and quantity of energetic particles. Spin-stabilized. Weight at liftoff: 835 kg. Weight in orbit, after ejection of apogee boost motor: 495 kg.	35 801 35 774 1436.2 0.2	First of three-satellite series to replace initial three operational satellites. Successfully launched by NASA for National Oceanic and Atmospheric Administration. *Goes 4* is fourth in series of operational spacecraft funded by NOAA. Apogee boost motor, fired 11 Sept., placed it in synchronous orbit at 90° west longitude. Turned over to NOAA for operational use on 15 Oct. Will be repositioned to replace an orbiting satellite according to operational needs.

Successful U.S. Launches—1980

Launch Date (GMT), Spacecraft Name, COSPAR Designation, Launch Vehicle	Spacecraft Data	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
31 Oct. *Fltsatcom 4* 87A Atlas-Centaur	Objective: To place spacecraft in synchronous, near-equatorial orbit for USAF narrow-band and wide-band communications and USN fleet-relay and broadcast channels. Spacecraft: Hexagonal, composed of payload module and spacecraft module; 6.7 m high. Provides 1 SHF and 23 UHF communications channels. Weight after apogee motor firing: 1005 kg.	36 035 35 534 1436.0 2.3	Fourth of five planned satellites, successfully launched by NASA for Navy and Dept. of Defense. Apogee kick motor fired 1 Nov. Spacecraft placed in desired synchronous orbit. Satellite systems turned on and operating. Still in orbit.
15 Nov. *SBS 1* 91A Delta	Objective: To provide integrated, all-digital, interference-free transmission of telephone, computer, electronic mail, and video teleconferencing to SBS business and industrial clients. Spacecraft: Cylindrical, 216 cm in diameter, with stowed height at launch of 282 cm; 666 cm high with solar panel and antenna deployed in orbit. Spin-stabilized. Provides up to 480 million bits of data per second, equivalent of more than 10 million words. Two nickel-cadmium batteries provide power during eclipse. First use of payload assist module PAM-D (SSUS-D); flown in place of Delta upper stage. Weight after apogee motor firing: 555 kg.	35 800 35 771 1436.1 0.1	First in series of three communications satellites built for Satellite Business Systems (SBS), successfully launched by NASA. Apogee kick motor fired 17 Nov. After deployment in geosynchronous orbit at 106° west longitude, telescoping solar panel was extended and communications antenna raised to operating position. First U.S. domestic commercial communications satellite to use higher, less congested 12- to 14-gigahertz (K-band) frequencies. Operational control turned over to SBS 20 Nov.
6 Dec. *Intelsat V F-2* 98A Atlas-Centaur	Objective: To place spacecraft in geosynchronous orbit for INTELSAT, provide 12 000 voice circuits plus 2 television channels simultaneously. Spacecraft: Modular main body, 1.66 × 2.01 × 1.77 m, winglike solar arrays span 15.6 m. Height, 6.4 m; width, 6.8 m; 6 communications antennas—2 global coverage horns, 2 hemispherical/zone offset-fed reflectors, and 2 offset-fed spot beam reflectors. Double the capacity of Intelsat IVA series. Weight at launch: 1928 kg.	35 734 35 639 1431.0 0.9	First in new series of nine satellites, successfully launched by NASA for 105-member-nation International Telecommunications Satellite Organization (INTELSAT). Placed in geostationary orbit 8 Dec., after apogee motor firing. Expected to be operational in May 1981 as system's primary Atlantic Ocean spacecraft. First 3-axis-stabilized Intelsat satellite.
13 Dec. Defense 100A Titan IIIB	Objective: Practical applications and uses of space technology such as weather and communications. Spacecraft: Not announced.	356 183 89.8 63.8	Still in orbit.

APPENDIX B–1

U.S.-Launched Applications Satellites 1975–1980

Date	Name	Launch Vehicle	Remarks
		COMMUNICATIONS	
7 May 1975	Anik 3 (Telesat 3)	Thor-Delta (TAT)	Launched for Canada.
22 May 1975	Intelsat IV F-1	Atlas-Centaur	Eighth in high-capacity series. Positioned over Indian Ocean.
27 Aug. 1975	Symphonie 2	Thor-Delta (TAT)	Launched for France and West Germany. Positioned over Atlantic.
26 Sept.1975	Intelsat IVA F-1	Atlas-Centaur	First of new series double the capacity of its predecessors. Positioned over Atlantic.
13 Dec. 1975	RCA-Satcom 1	Thor-Delta (TAT)	Launched for RCA as first of its communications satellite series. Positioned over Pacific.
17 Jan. 1976	CTS 1	Thor-Delta (TAT)	Canadian-U.S., most powerful experimental satellite.
30 Jan. 1976	Intelsat IVA F-2	Thor-Delta (TAT)	Positioned over Atlantic.
19 Feb. 1976	Marisat 1	Thor-Delta (TAT)	For maritime use by Comsat, over Atlantic.
15 Mar. 1976	LES 8, LES 9	Titan IIIC	Experimental satellites with radioisotope power sources.
26 Mar. 1976	RCA-Satcom 2	Thor-Delta (TAT)	Second of three.
22 Apr. 1976	NATO IIIA	Thor-Delta (TAT)	First of new series.
13 May 1976	Comstar 1	Atlas-Centaur	Placed over Pacific for AT&T by Comsat.
10 June 1976	Marisat 2	Thor-Delta (TAT)	For maritime use by Comsat, over Pacific.
8 July 1976	Palapa I	Thor-Delta (TAT)	Indonesian domestic communications.
22 July 1976	Comstar 2	Thor-Delta (TAT)	Placed south of United States for AT&T by Comsat.
14 Oct. 1976	Marisat 3	Thor-Delta (TAT)	Placed over Indian Ocean.
28 Jan. 1977	NATO IIIB	Thor-Delta (TAT)	Second of new series.
10 Mar. 1977	Palapa 2	Thor-Delta (TAT)	Indonesian domestic communications.
12 May 1977	DSCS II-7,8	Titan IIIC	Defense communications (dual launch).
26 May 1977	Intelsat IVA F-4	Atlas-Centaur	Positioned over Atlantic.
25 Aug. 1977	Sirio	Thor-Delta (TAT)	Italian experiment.
15 Dec. 1977	Sakura	Thor-Delta (TAT)	Japanese experiment.
7 Jan. 1978	Intelsat IVA F-3	Atlas-Centaur	Positioned over Indian Ocean.
9 Feb. 1978	Fltsatcom I	Atlas-Centaur	First of new Defense series.
5 Mar. 1978	Oscar 8	Thor-Delta (TAT)	Secondary payload with Landsat 3, replacement for Oscar 6 for amateur radio communications.
31 Mar. 1978	Intelsat IVA F-6	Atlas-Centaur	Positioned over Indian Ocean.
7 Apr. 1978	BSE	Thor-Delta (TAT)	Japanese experimental direct-broadcast satellite for television; named Yuri; domestic satellite.
11 May 1978	OTS 2	Thor-Delta (TAT)	European Space Agency experimental relay satellite; domestic satellite.
29 June 1978	Comstar 3	Atlas-Centaur	Positioned south of U.S. over the equator by Comsat; domestic satellite.
19 Nov. 1978	NATO IIIC	Thor-Delta (TAT)	Final one of this military series.
14 Dec. 1978	DSCS II-11,12	Titan IIIC	Defense communications (dual launch).
16 Dec. 1978	Anik 4 (Telesat D)	Thor-Delta (TAT)	Launched for Canada; domestic satellite.
4 May 1979	Fltsatcom 2	Atlas-Centaur	Second of new DoD series.
9 Aug. 1979	Westar 3	Thor-Delta (TAT)	Launched for Western Union Co. as part of its domestic communications links.
21 Nov. 1979	DSCS II-13,14	Titan IIIC	Defense communications (dual launch).
2 Dec. 1979	RCA-Satcom 3	Thor-Delta (TAT)	Launched for RCA, but contact lost during orbit circularization.
18 Jan. 1980	Fltsatcom 3	Atlas-Centaur	Third of DoD series.
31 Oct. 1980	Fltsatcom 4	Atlas-Centaur	Fourth of DoD series.
15 Nov. 1980	SBS 1	Thor-Delta (TAT)	Launched for Satellite Business Systems as part of its domestic communications links.
6 Dec. 1980	Intelsat V F-2	Atlas-Centaur	First of new series, positioned over Atlantic.
		WEATHER OBSERVATION [a]	
6 Feb. 1975	SMS 2	Thor-Delta (TAT)	Second full-time weather satellite in synchronous orbit.
12 June 1975	Nimbus 6	Thor-Delta (TAT)	To build numerical models for Global Atmospheric Research Program.
16 Oct. 1975	Goes 1	Thor-Delta (TAT)	First fully operational synchronous-orbit weather satellite.
29 July 1976	Noaa 5 (ITOS-H)	Thor-Delta (TAT)	Second-generation operational satellite.
16 June 1977	Goes 2	Thor-Delta (TAT)	Second of this series.
14 July 1977	Himawari	Thor-Delta (TAT)	Japanese geosynchronous satellite.
23 Nov. 1977	Meteosat	Thor-Delta (TAT)	European Space Agency geosynchronous satellite.
1 May 1978	AMS 3	Thor-Burner 2	DoD meteorological satellite.
16 June 1978	Goes 3	Thor-Delta (TAT)	Third of this series for NOAA.
13 Oct. 1978	Tiros-N	Atlas F	First of third-generation for NOAA, also experimental satellite for NASA.
24 Oct. 1978	Nimbus 7	Thor-Delta (TAT)	Last of this experimental series for NASA.
6 June 1979	AMS-4	Atlas F	DoD meteorological satellite.
27 June 1979	Noaa 6	Atlas F	Like current DoD meteorological satellites.
29 May 1980	Noaa-B	Atlas F	Failed to achieve useful orbit.
9 Sept. 1980	Goes 4	Thor-Delta (TAT)	Fourth of this series for NOAA.

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

U.S.-Launched Applications Satellites 1975-1980

Date	Name	Launch Vehicle	Remarks
			EARTH OBSERVATION
22 Jan. 1975	Landsat 2	Thor-Delta (TAT)	Second experimental earth resources technology satellite. Acquired synoptic multispectral repetitive images useful in such disciplines as agriculture and forestry resources, mineral and land resources, land use, water resources, marine resources, mapping and charting, and environment.
5 Mar. 1978	Landsat 3	Thor-Delta (TAT)	Third experimental earth resources satellite.
26 Apr. 1978	HCMM (AEM 1)	Scout	Experimental, low-cost, limited-function heat-capacity mapping mission for earth resources.
27 June 1978	Seasat 1	Atlas F	Proof-of-concept oceanographic-phenomena data-collection satellite.
			GEODESY
9 Apr. 1975	Geos 3	Thor-Delta (TAT)	To measure geometry and topography of ocean surface.
4 May 1976	Lageos	Thor-Delta (TAT)	Laser geodynamic satellite.
			NAVIGATION
12 Oct. 1975	TIP 2	Scout	Transit Improvement Program.
1 Sept. 1976	TIP 3	Scout	Transit Improvement Program.
23 June 1977	NTS 2	Atlas F	Forerunner of Navstar Global Positioning System.
28 Oct. 1977	Transit	Scout	Developmental model.
22 Feb. 1978	Navstar 1	Atlas F	Global Positioning System satellite.
13 May 1978	Navstar 2	Atlas F	Global Positioning System satellite.
7 Oct. 1978	Navstar 3	Atlas F	Global Positioning System satellite.
11 Dec. 1978	Navstar 4	Atlas F	Global Positioning System satellite.
9 Feb. 1980	Navstar 5	Atlas F	Global Positioning System satellite.
26 Apr. 1980	Navstar 6	Atlas F	Global Positioning System satellite.

APPENDIX B-2

U.S.-Launched Scientific Payloads 1975-1980

Date	Name	Launch Vehicle	Remarks
7 May 1975	SAS-C (Explorer 53)	Scout	Measure x-ray emission of discrete extragalactic sources (Italian-launched).
21 June 1975	OSO 8	Thor-Delta (TAT)	To study minimum phase of solar cycle.
9 Aug. 1975	COS-B	Thor-Delta	Extraterrestrial gamma radiation studies (ESA European satellite).
6 Oct. 1975	Atmosphere (Explorer 54)	Thor-Delta	Photochemical processes in absorption of solar energy.
20 Nov. 1975	Atmosphere (Explorer 55)	Thor-Delta	Photochemical processes in absorption of solar energy. Measure spatial distribution of ozone.
15 Mar. 1976	Solrad HiA, HiB	Titan IIIC	Measure radiation and particles at close to 120 000-km circular orbit.
22 May 1976	P-76-5	Scout	Plasma effects on radar and communications.
8 July 1976	SESP 74-2	Titan IIID	Particle measurements up to 8000 km.
20 Apr. 1977	Geos	Thor-Delta (TAT)	European Space Agency, study of magnetic and electric fields from geosynchronous orbit (not attained).
12 Aug. 1977	Heao 1	Atlas-Centaur	X-ray and gamma-ray astronomy.
22 Oct. 1977	ISEE 1,2	Thor-Delta (TAT)	Magnetosphere and solar wind measurements (for NASA and European Space Agency respectively).
26 Jan. 1978	IUE	Thor-Delta (TAT)	Ultraviolet observation of astronomical phenomena, in elliptical geosynchronous orbit.
14 July 1978	Geos 2	Thor-Delta (TAT)	European studies of magnetosphere, in geosynchronous orbit.
12 Aug. 1978	ISEE 3	Thor-Delta (TAT)	International Sun-Earth Explorer, in halo orbit near Earth-Sun libration point.
24 Oct. 1978	Cameo	Thor-Delta (TAT)	Barium and lithium cloud experiments, carried in rocket body of Nimbus 7 launcher.
13 Nov. 1978	Heao 2	Atlas-Centaur	High-resolution observations of astronomical x-ray sources.
30 Jan. 1979	Scatha	Thor-Delta (TAT)	Measurement of sources of electric charge buildup on spacecraft.
18 Feb. 1979	Sage	Scout	Measurement of stratospheric aerosols and ozone.
24 Feb. 1979	Solwind	Atlas F	Measurement of solar wind, electron buildup in polar regions, aerosols, and ozone.
6 June 1979	Ariel 6	Scout	Measurement of cosmic radiation (United Kingdom payload).
20 Sept. 1979	Heao 3	Atlas-Centaur	Gamma and cosmic ray emissions.
30 Oct. 1979	Magsat	Scout	Detailed current description of earth's magnetic field and of sources of variations.
14 Feb. 1980	SMM	Thor-Delta (TAT)	Solar Maximum Mission.

U.S.-Launched Space Probes 1975-1980

Date	Name	Launch Vehicle	Remarks
20 Aug. 1975	Viking 1	Titan IIIE-Centaur	Lander descended, landed safely on Mars on Plains of Chryse, 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.
9 Sept. 1975	Viking 2	Titan IIIE-Centaur	Lander descended, landed safely on Mars on Plains of Utopia, 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.
15 Jan. 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.
20 Aug. 1977	Voyager 2	Titan IIIE-Centaur	Jupiter and Saturn flyby mission. Swung around Jupiter in July 1979 to arrive at Saturn in 1981, possibly going on to Uranus by 1986.
5 Sep. 1977	Voyager I	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.
20 May 1978	Pioneer Venus 1	Atlas-Centaur	Venus orbiter; achieved Venus orbit 4 Dec., returning imagery and data.
8 Aug. 1978	Pioneer Venus 2	Atlas-Centaur	Carried 1 large, 3 small probes plus spacecraft bus; all descended through Venus atmosphere 9 Dec., returned data.

U.S. and Soviet Manned Spaceflights 1961-1980

Spacecraft	Launch Date	Crew	Flight Time	Highlights
Vostok 1	12 Apr. 1961	Yuriy A. Gagarin	1 h 48 min	First manned flight.
Mercury-Redstone 3	5 May 1961	Alan B. Shepard, Jr.	15 min	First U.S. flight; suborbital.
Mercury-Redstone 4	21 July 1961	Virgil I. Grissom	16 min	Suborbital; capsule sank after landing; astronaut safe.
Vostok 2	6 Aug. 1961	German S. Titov	25 h 18 min	First flight exceeding 24 h.
Mercury-Atlas 6	20 Feb. 1962	John H. Glenn, Jr.	4 h 55 min	First American to orbit.
Mercury-Atlas 7	24 May 1962	M. Scott Carpenter	4 h 56 min	Landed 400 km beyond target.
Vostok 3	11 Aug. 1962	Andriyan G. Nikolayev	94 h 25 min	First dual mission (with Vostok 4).
Vostok 4	12 Aug. 1962	Pavel R. Popovich	70 h 59 min	Came within 6 km of Vostok 3.
Mercury-Atlas 8	3 Oct. 1962	Walter M. Schirra, Jr.	9 h 13 min	Landed 8 km from target.
Mercury-Atlas 9	15 May 1963	L. Gordon Cooper, Jr.	34 h 20 min	First U.S. flight exceeding 24 h.
Vostok 5	14 June 1963	Valeriy F. Bykovskiy	119 h 6 min	Second dual mission (with Vostok 6).
Vostok 6	16 June 1963	Valentina V. Tereshkova	70 h 50 min	First woman in space; within 5 km of Vostok 5.
Voskhod 1	12 Oct. 1964	Vladimir M. Komarov Konstantin P. Feoktistov Boris G. Yegorov	24 h 17 min	First 3-man crew.
Voskhod 2	18 Mar. 1965	Pavel I. Belyayev Aleksey A. Leonov	26 h 2 min	First extravehicular activity (Leonov, 10 min).
Gemini 3	23 Mar. 1965	Virgil I. Grissom John W. Young	4 h 53 min	First U.S. 2-man flight; first manual maneuvers in orbit.
Gemini 4	3 June 1965	James A. McDivitt Edward H. White II	97 h 56 min	21-min extravehicular activity (White).
Gemini 5	21 Aug. 1965	L. Gordon Cooper, Jr. Charles Conrad, Jr.	190 h 55 min	Longest-duration manned flight to date.
Gemini 7	4 Dec. 1965	Frank Borman James A. Lovell, Jr.	330 h 35 min	Longest-duration manned flight to date.
Gemini 6-A	15 Dec. 1965	Walter M. Schirra, Jr. Thomas P. Stafford	25 h 51 min	Rendezvous within 30 cm of Gemini 7.
Gemini 8	16 Mar. 1966	Neil A. Armstrong David R. Scott	10 h 41 min	First docking of 2 orbiting spacecraft (Gemini 8 with Agena target rocket).
Gemini 9-A	3 June 1966	Thomas P. Stafford Eugene A. Cernan	72 h 21 min	Extravehicular activity; rendezvous.
Gemini 10	18 July 1966	John W. Young Michael Collins	70 h 47 min	First dual rendezvous (Gemini 10 with Agena 10, then Agena 8).
Gemini 11	12 Sept. 1966	Charles Conrad, Jr. Richard F. Gordon, Jr.	71 h 17 min	First initial-orbit docking; first tethered flight; highest earth-orbit altitude (1372 km).
Gemini 12	11 Nov. 1966	James A. Lovell, Jr. Edwin E. Aldrin, Jr.	94 h 35 min	Longest extravehicular activity to date (Aldrin, 5 h 37 min).
Soyuz 1	23 Apr. 1967	Vladimir M. Komarov	26 h 37 min	Cosmonaut killed in reentry accident.
Apollo 7	11 Oct. 1968	Walter M. Schirra, Jr. Donn F. Eisele R. Walter Cunningham	260 h 9 min	First U.S. 3-man mission.
Soyuz 3	26 Oct. 1968	Georgiy T. Beregovoy	94 h 51 min	Maneuvered near unmanned Soyuz 2.
Apollo 8	21 Dec. 1968	Frank Borman James A. Lovell, Jr. William A. Anders	147 h 1 min	First manned orbit(s) of moon; first manned departure from earth's sphere of influence; highest speed ever attained in manned flight.
Soyuz 4	14 Jan. 1969	Vladimir A. Shatalov	71 h 23 min	Soyuz 4 and 5 docked and transferred 2 cosmonauts from Soyuz 5 to Soyuz 4.
Soyuz 5	15 Jan. 1969	Boris V. Volynov Aleksey S. Yeliseyev Yevgeniy V. Khrunov	72 h 56 min	
Apollo 9	3 Mar. 1969	James A. McDivitt David R. Scott Russell L. Schweickart	241 h 1 min	Successfully simulated in earth orbit operation of lunar module to landing and takeoff from lunar surface and rejoining with command module.
Apollo 10	18 May 1969	Thomas P. Stafford John W. Young Eugene A. Cernan	192 h 3 min	Successfully demonstrated complete system including lunar module descent to 14 300 m from the lunar surface.
Apollo 11	16 July 1969	Neil A. Armstrong Michael Collins Edwin E. Aldrin, Jr.	195 h 9 min	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	11 Oct. 1969	Georgiy Shonin Valeriy N. Kubasov	118 h 42 min	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	12 Oct. 1969	Anatoliy V. Filipchenko Viktor N. Gorbatko Vladislav N. Volkov	118 h 41 min	
Soyuz 8	13 Oct. 1969	Vladimir A. Shatalov Aleksey S. Yeliseyev	118 h 50 min	

U.S. and Soviet Manned Spaceflights 1961-1980

Spacecraft	Launch Date	Crew	Flight Time	Highlights
Apollo 12	14 Nov. 1969	Charles Conrad, Jr. Richard F. Gordon, Jr. Alan L. Bean	244 h 36 min	Second manned lunar landing. Continued manned exploration and retrieved parts of Surveyor 3 spacecraft, which landed in Ocean of Storms on 19 Apr. 1967.
Apollo 13	11 Apr. 1970	James A. Lovell, Jr. Fred W. Haise, Jr. John L. Swigert, Jr.	142 h 55 min	Mission aborted; explosion in service module. Ship circled moon, with crew using LM as "lifeboat" until just before reentry.
Soyuz 9	1 June 1970	Andriyan G. Nikolayev Vitaliy I. Sevastyanov	424 h 59 min	Longest manned spaceflight to date, lasting 17 days 16 h 59 min.
Apollo 14	31 Jan. 1971	Alan B. Shepard, Jr. Stuart A. Roosa Edgar D. Mitchell	216 h 2 min	Third manned lunar landing. Mission demonstrated pinpoint landing capability and continued manned exploration.
Soyuz 10	22 Apr. 1971	Vladimir A. Shatalov Aleksey S. Yeliseyev Nikolay N. Rukavishnikov	47 h 46 min	Docked with Salyut 1, but crew did not board space station launched 19 Apr. Crew recovered 24 Apr. 1971.
Soyuz 11	6 June 1971	Georgiy T. Dobrovolskiy Vladislav N. Volkov Viktor I. Patsayev	570 h 22 min	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 30 June 1971.
Apollo 15	26 July 1971	David R. Scott Alfred M. Worden James B. Irwin	295 h 12 min	Fourth manned lunar landing and first Apollo "J" series mission, which carried Lunar Roving Vehicle. Worden's in-flight EVA of 38 min 12 sec was performed during return trip.
Apollo 16	16 Apr. 1972	John W. Young Charles M. Duke, Jr. Thomas K. Mattingly II	265 h 51 min	Fifth manned lunar landing, with Lunar Roving Vehicle.
Apollo 17	7 Dec. 1972	Eugene A. Cernan Harrison H. Schmitt Ronald E. Evans	301 h 52 min	Sixth and final Apollo manned lunar landing, again with roving vehicle.
Skylab 2	25 May 1973	Charles Conrad, Jr. Joseph P. Kerwin Paul J. Weitz	672 h 50 min	Docked with Skylab 1 for 28 days. Repaired damaged station.
Skylab 3	28 July 1973	Alan L. Bean Jack R. Lousma Owen K. Garriott	1427 h 9 min	Docked with Skylab 1 for more than 59 days.
Soyuz 12	27 Sept. 1973	Vasiliy G. Lazarev Oleg G. Makarov	47 h 16 min	Checkout of improved Soyuz.
Skylab 4	16 Nov. 1973	Gerald P. Carr Edward G. Gibson William R. Pogue	2017 h 16 min	Docked with Skylab 1 in long-duration mission; last of Skylab program.
Soyuz 13	18 Dec. 1973	Petr I. Klimuk Valentin V. Lebedev	188 h 55 min	Astrophysical, biological, and earth resources experiments.
Soyuz 14	3 July 1974	Pavel R. Popovich Yuriy P. Artyukhin	377 h 30 min	Docked with Salyut 3 and Soyuz 14 crew occupied space station for over 14 days.
Soyuz 15	26 Aug. 1974	Gennadiy V. Sarafanov Lev S. Demin	48 h 12 min	Rendezvoused but did not dock with Salyut 3.
Soyuz 16	2 Dec. 1974	Anatoliy V. Filipchenko Nikolay N. Rukavishnikov	142 h 24 min	Test of ASTP configuration.
Soyuz 17	10 Jan. 1975	Aleksey A. Gubarev Georgiy M. Grechko	709 h 20 min	Docked with Salyut 4 and occupied station during 29-day flight.
Anomaly	5 Apr. 1975	Vasiliy G. Lazarev Oleg G. Makarov	20 min	Soyuz stages failed to separate; crew recovered after abort.
Soyuz 18	24 May 1975	Petr I. Klimuk Vitaliy I. Sevastyanov	1511 h 20 min	Docked with Salyut 4 and occupied station during 63-day mission.
Soyuz 19	15 July 1975	Aleksey A. Leonov Valeriy N. Kubasov	142 h 31 min	Target for Apollo in docking and joint experiments of ASTP mission.
Apollo	15 July 1975	Thomas P. Stafford Donald K. Slayton Vance D. Brand	217 h 28 min	Docked with Soyuz 19 in joint experiments of ASTP mission.
Soyuz 21	6 July 1976	Boris V. Volynov Vitaliy M. Zholobov	1153 h 32 min	Docked with Salyut 5 and occupied station during 49-day flight.
Soyuz 22	15 Sept. 1976	Valeriy F. Bykovskiy Vladimir V. Aksenov	189 h 54 min	Earth resources study with multispectral camera system.
Soyuz 23	14 Oct. 1976	Vyacheslav D. Zudov Valeriy I. Rozhdestvenskiy	48 h 6 min	Failed to dock with Salyut 5.
Soyuz 24	7 Feb.1977	Viktor V. Gorbatko Yuriy N. Glazkov	425 h 23 min	Docked with Salyut 5 and occupied station during 18-day flight.
Soyuz 25	9 Oct. 1977	Vladimir V. Kovalenok Valeriy V. Ryumin	48 h 46 min	Failed to achieve hard dock with Salyut 6 station.

U.S. and Soviet Manned Spaceflights 1961-1980

Spacecraft	Launch Date	Crew	Flight Time	Highlights
Soyuz 26	10 Dec. 1977	Yuriy V. Romanenko Georgiy M. Grechko	898 h 6 min	Docked with Salyut 6. Crew returned in Soyuz 27; crew duration 2314 h.
Soyuz 27	10 Jan. 1978	Vladimir A. Dzhanibekov Oleg G. Makarov	1558 h 53 min	Docked with Salyut 6. Crew returned in Soyuz 26; crew duration 142 h 59 min.
Soyuz 28	2 Mar. 1978	Aleksey A. Gubarev Vladimir Remek	190 h 17 min	Docked with Salyut 6. Remek was first Czech cosmonaut to orbit.
Soyuz 29	15 June 1978	Vladimir V. Kovalenok Aleksandr S. Ivanchenkov	1911 h 23 min	Docked with Salyut 6. Crew returned in Soyuz 31; crew duration 3350 h 48 min.
Soyuz 30	27 June 1978	Petr I. Klimuk Miroslaw Hermaszewski	190 h 4 min	Docked with Salyut 6. Hermaszewski was first Polish cosmonaut to orbit.
Soyuz 31	26 Aug. 1978	Valeriy F. Bykovskiy Sigmund Jaehn	1628 h 14 min	Docked with Salyut 6. Crew returned in Soyuz 29; crew duration 188 h 49 min. Jaehn was first German Democratic Republic cosmonaut to orbit.
Soyuz 32	25 Feb. 1979	Vladimir A. Lyakhov Valeriy V. Ryumin	2596 h 24 min	Docked with Salyut 6. Crew returned in Soyuz 34; crew duration 4200 h 36 min, or 175 days.
Soyuz 33	10 Apr. 1979	Nikolay N. Rukavishnikov Georgi I. Ivanov	47 h 1 min	Failed to achieve docking with Salyut 6 station. Ivanov was first Bulgarian cosmonaut to orbit.
Soyuz 34	6 June 1979	(unmanned at launch)	1770 h 17 min	Docked with Salyut 6, later served as ferry for Soyuz 32 crew while Soyuz 32 returned unmanned.
Soyuz 35	9 Apr. 1980	Leonid I. Popov Valeriy V. Ryumin	1321 h 29 min	Docked with Salyut 6. Crew returned in Soyuz 37. Crew duration, 4436 h 12 min.
Soyuz 36	26 May 1980	Valeriy N. Kubasov Bertalan Farkas	1580 h 54 min	Docked with Salyut 6. Crew returned in Soyuz 35. Crew duration 188 h 46 min. Farkas was first Hungarian to orbit.
Soyuz T-2	5 June 1980	Yuriy V. Malyshev Vladimir V. Aksenov	94 h 21 min	Docked with Salyut 6. First manned flight of new-generation ferry.
Soyuz 37	23 July 1980	Viktor V. Gorbatko Pham Tuan	1911 h 17 min	Docked with Salyut 6. Crew returned in Soyuz 36. Crew duration 188 h 42 min. Pham was first Vietnamese to orbit.
Soyuz 38	18 Sept. 1980	Yuriy V. Romanenko Arnaldo Tamayo Mendez	188 h 43 min	Docked with Salyut 6. Tamayo was first Cuban to orbit.
Soyuz T-3	27 Nov. 1980	Leonid D. Kizim Oleg G. Makarov Gennadiy M. Strekalov	307 h 8 min	Docked with Salyut 6. First 3-man flight in Soviet program since 1971.

U.S. Space Launch Vehicles

Vehicle	Stages	Propellant[a]	Thrust (in kilo-newtons)	Max. Dia. (m)	Height (m)	Max. Payload (kg)		First Launch
						555-Km Orbit	Escape	
Scout	1. Algol IIIA	Solid	481.0	1.12	21.95	186[b]	38.6[b]	1972(60)[c]
	2. Castor IIA	Solid	281.0					
	3. Antares III	Solid	83.1					
	4. Altair III	Solid	26.2					
Thor-Delta 2900 series	1. Thor plus 9 TX	LOX/RP-1	911.9	2.44	35.36	1 769[b]	476[b]	1973(60)[c]
	354-5	Solid	440.4[d]					
	2. Delta (DSV-3)	N_2O_4/Aerozine	45.8					
	3. TE 364-4	Solid	66.7					
Atlas F/TE 364-4	1. Atlas booster & sustainer	LOX/RP-1	1 970.6	3.05	25.91	1 497[b]		1977(60)[c]
	2. TE 364-4	Solid	66.7					
Atlas-Agena	1. Atlas booster & (SLV/3A)	LOX/RP-1	2 237.5	3.05	40.54	2 722[b]	454[b]	1968(60)[c]
	2. Agena	IRFNA/UDMH	71.2					
Atlas-Centaur	1. Atlas booster & sustainer	LOX/RP-1	1 912	3.05	40	4 500[b]	1450[e]	1962
	2. Centaur	LOX/LH_2	133.4	3.05				
Titan IIIB-Agena	1. LR-87	N_2O_4/Aerozine	2 353.1	3.05	48.46	3 614	3727[f]	1966
	2. LR-91	N_2O_4/Aerozine	444.8					
	3. Agena	IRFNA/UDMH	71.2					
Titan IIIC	1. Two 5-segment 3.05-m dia.	Solid	10 413.3	3.05	40.54	—	1464[g]	1965
	2. LR-87	N_2O_4/Aerozine	2 353.1	3.05				
	3. LR-91	N_2O_4/Aerozine	444.8					
	4. Transtage	N_2O_4/Aerozine	71.2					
Titan III(23)D	1. Two 5-segment 3.05-m dia.	Solid	10 413.3	3.05	46.94	11 182[h]		1971
	2. LR-87	N_2O_4/Aerozine	2 353.1					
	3. LR-91	N_2O_4/Aerozine	444.8					
Titan III(34)D	1. Two 5½-segment 3.05-m dia.	Solid	11 555.6	3.05	49.13	12 545[j]		1981
	2. LR-87	N_2O_4/Aerozine	2 353.1					
	3. LR-91	N_2O_4/Aerozine	444.8					
Titan III(34)D/IUS	1. Two 5½-segment 3.05-m dia.	Solid	11 555.6	3.05	48.00	1 818[j]	1818[i]	1981
	2. LR-87	N_2O_4/Aerozine	2 353.1					
	3. LR-91	N_2O_4/Aerozine	444.8					
	4. IUS 1st Stage	Solid	191.3					
	5. IUS 2nd Stage	Solid	71.2					
Thor LV-2F	1. Thor	LOX/RP-1	756.2	2.44	23.77	512[k]		1976(66)[c]
	2. TE 364-4	Solid	66.7					
	3. TE 364-15	Solid	44.5					
Thor SLV-2A/Block 5D-2	1. Thor plus 3	LOX/RJ-1	756.2	2.44	24.23	653[k]		1980(63)[c]
	TX 354-5	Solid	689.5[d]					
	2. TE 364-4	Solid	66.7					
	3. TE 364-15	Solid	44.5					

[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.

[b] Due east launch.

[c] The date of first launch applies to this latest modification with a date in parentheses for the initial version.

[d] Set of 3.

[e] With TE-364-4 solid-fueled motor.

[f] Polar launch 185 km.

[g] Synchronous equatorial (nominal).

[h] Polar 185 km (nominal).

[i] Polar 185 km (current estimate).

[j] Synchronous equatorial (current estimate).

[k] Polar 833 km (from WTR).

Space Activities of the U.S. Government

HISTORICAL BUDGET SUMMARY — BUDGET AUTHORITY

(in millions of dollars)

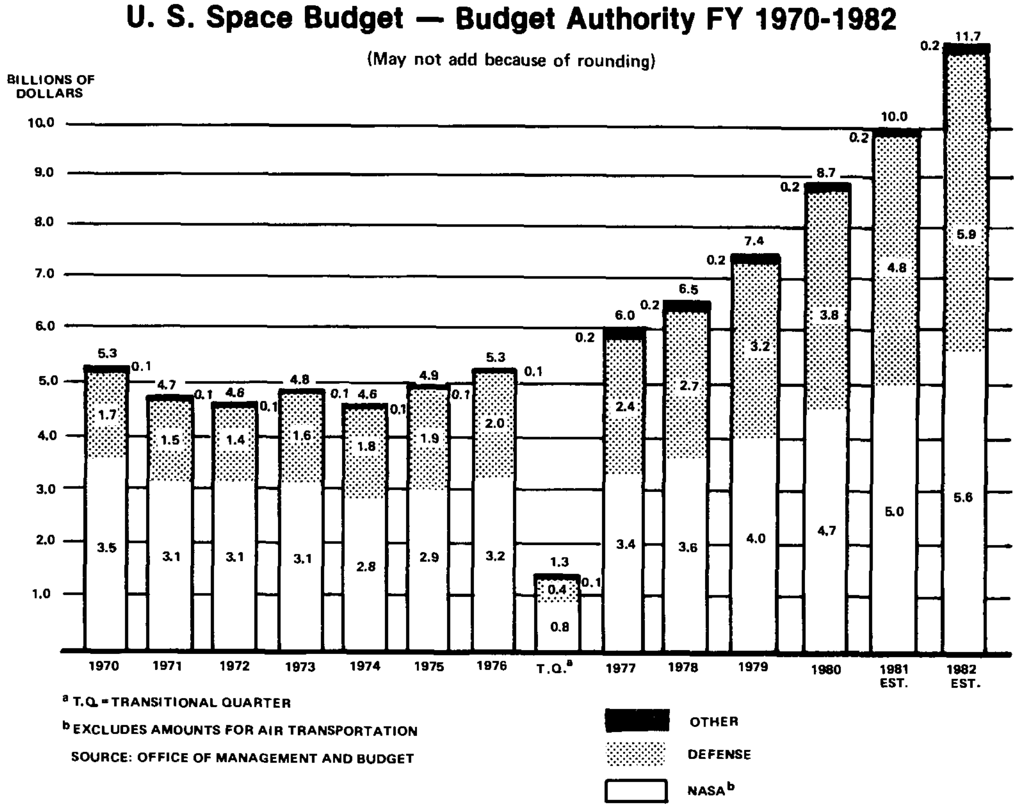
Fiscal Year	NASA		Defense	Energy	Com-merce	Interior	Agricul-ture	NSF	Total Space
	Total	Space[a]							
1959	330.9	260.9	489.5	34.3	...	...	...	...	784.7
1960	523.6	461.5	560.9	43.3	...	...	...	0.1	1065.8
1961	964.0	926.0	813.9	67.7	...	...	...	.6	1808.2
1962	1824.9	1796.8	1298.2	147.8	50.7	...	...	1.3	3294.8
1963	3673.0	3626.0	1549.9	213.9	43.2	...	...	1.5	5434.5
1964	5099.7	5016.3	1599.3	210.0	2.8	...	...	3.0	6831.4
1965	5249.7	5137.6	1573.9	228.6	12.2	...	...	3.2	6955.5
1966	5174.9	5064.5	1688.8	186.8	26.5	...	...	3.2	6969.8
1967	4965.6	4830.2	1663.6	183.6	29.3	...	...	2.8	6709.5
1968	4587.3	4430.0	1921.8	145.1	28.1	0.2	0.5	3.2	6528.9
1969	3990.9	3822.0	2013.0	118.0	20.0	.2	.7	1.9	5975.8
1970	3745.8	3547.0	1678.4	102.8	8.0	1.1	.8	2.4	5340.5
1971	3311.2	3101.3	1512.3	94.8	27.4	1.9	.8	2.4	4740.9
1972	3306.6	3071.0	1407.0	55.2	31.3	5.8	1.6	2.8	4574.7
1973	3406.2	3093.2	1623.0	54.2	39.7	10.3	1.9	2.6	4824.9
1974	3036.9	2758.5	1766.0	41.7	60.2	9.0	3.1	1.8	4640.3
1975	3229.1	2915.3	1892.4	29.6	64.4	8.3	2.3	2.0	4914.3
1976	3550.3	3225.4	1983.3	23.3	71.5	10.4	3.6	2.4	5319.9
T.Q.[b]	931.8	849.2	460.4	4.6	22.2	2.6	.9	.6	1340.5
1977	3817.8	3440.2	2411.9	21.7	90.8	9.5	6.3	2.4	5982.8
1978	4060.1	3622.9	2728.8	34.4	102.8	9.7	7.7	2.4	6508.7
1979	4595.5	4030.4	3211.3	58.6	98.4	9.9	8.2	2.4	7419.2
1980	5240.2	4680.4	3848.4	39.6	92.6	11.7	13.7	2.4	8688.8
1981 Est.	5519.1	4997.2	4789.4	42.0	91.9	12.1	15.5	2.4	9950.5
1982 Est.	6118.3	5617.3	5916.3	38.0	126.3	12.6	17.2	2.0	11729.7

[a] Excludes amounts for air transportation (subfunction 402).
[b] T.Q. = Transitional Quarter.

SOURCE: Office of Management and Budget.

U. S. Space Budget — Budget Authority FY 1970-1982

(May not add because of rounding)



[a] T.Q. = TRANSITIONAL QUARTER
[b] EXCLUDES AMOUNTS FOR AIR TRANSPORTATION
SOURCE: OFFICE OF MANAGEMENT AND BUDGET

APPENDIX E-2

Space Activities Budget

(in millions of dollars)

Federal Space Programs	Budget Authority 1980 Actual	Budget Authority 1981 Est.	Budget Authority 1982 Est.	Outlays 1980 Actual	Outlays 1981 Est.	Outlays 1982 Est.
Federal agencies:						
NASA[a]	4680.4	4997.2	5 617.3	4340.1	4733.3	5 375.6
Defense	3848.4	4789.4	5 916.3	3162.3	3920.1	4 952.8
Energy	39.6	42.0	38.0	48.8	42.9	40.0
Commerce	92.6	91.9	126.3	88.7	75.6	103.2
Interior	11.7	12.1	12.6	11.7	12.1	12.6
NSF	2.4	2.4	2.0	2.4	2.4	2.0
Agriculture	13.7	15.5	17.2	13.7	15.5	17.2
Total	8688.8	9950.5	11 729.7	7667.7	8801.9	10 503.4
NASA:						
Space flight	2819.8	3191.3	3623.0	2593.7	3021.3	3487.0
Space science, applications, and technology	1424.8	1359.4	1471.5	1345.6	1285.3	1425.1
Air transportation	559.8	521.8	501.1	508.5	537.1	515.7
Supporting operations	438.8	450.2	526.6	403.8	430.3	467.4
Less receipts	−3.0	−3.6	−3.9	−3.0	−3.6	−3.9
Total NASA	5240.2	5519.1	6118.3	4848.6	5270.4	5891.3

[a] Excludes amounts for air transportation.

SOURCE: Office of Management and Budget.

APPENDIX E-3

Aeronautics Budget

(in millions of dollars)

Federal Aeronautics Programs	Budget Authority 1980 Actual	Budget Authority 1981 Est.	Budget Authority 1982 Est.
NASA[a]	559.8	521.8	501.1
Department of Defense[b]	2335.9	2533.3	2811.1
Department of Transportation[c]	95.5	106.2	106.5
Total	2991.2	3161.3	3418.7

[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 and Facilities, Engineering and Development.

SOURCE: Office of Management and Budget.

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