

Aeronautics and Space Report of the President

1978 Activities

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Aeronautics and Space Report of the President

1978 Activities



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

President's Message of Transmittal

To the Congress of the United States:

I transmit this report on the Nation's progress in space and aeronautics during 1978. This report is provided in accordance with Section 206 of the National Aeronautics and Space Act of 1958 as amended (42 U.S.C. 2476).

Included in this report are statements of policy designed to maintain American space leadership. This report concentrates on the most significant Federal space and aeronautical activities. These emphases have enabled us to reduce the amount of detail and number of separate agency program descriptions.

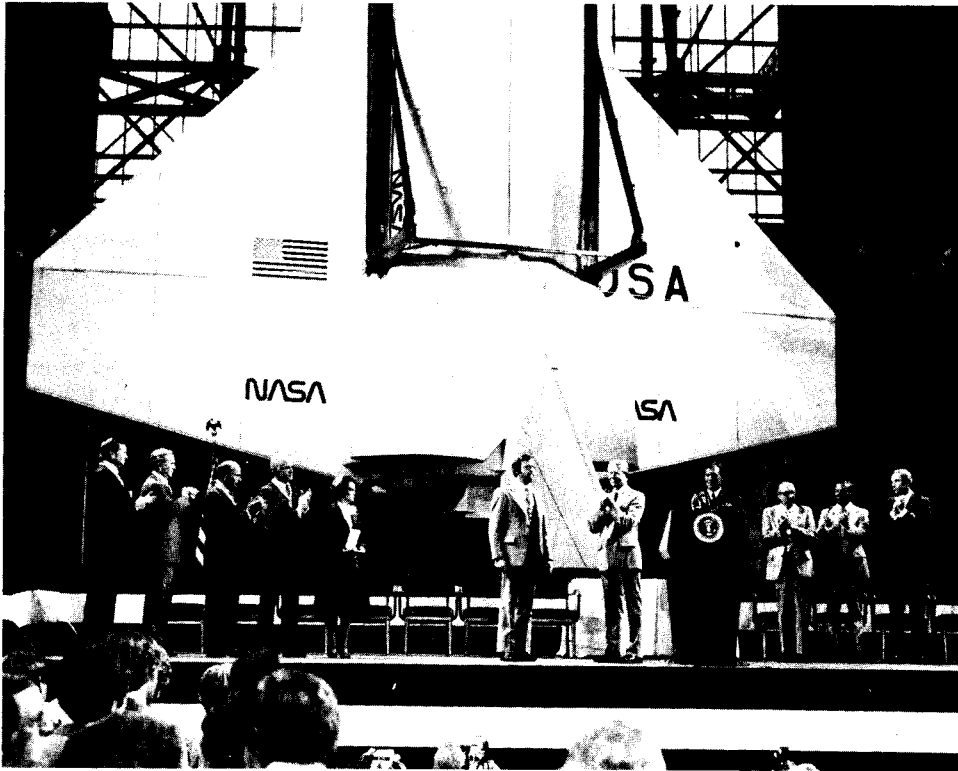
THE WHITE HOUSE

July 1979

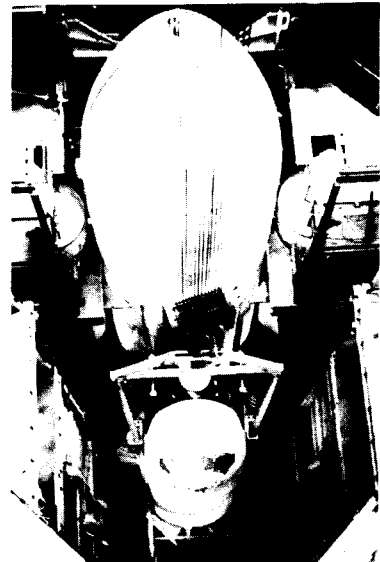
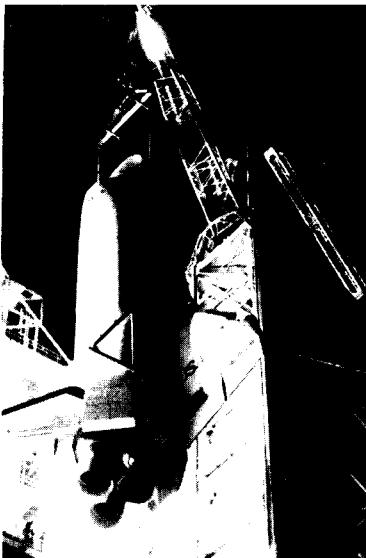
JIMMY CARTER

Aerospace Events of 1978

This twentieth year of the United States space program saw the awarding of the first Congressional Space Medals of Honor, progress of the Space Shuttle toward orbital flight, sensor results from new environmental and planetary spacecraft, and continued research on improvement of aviation.

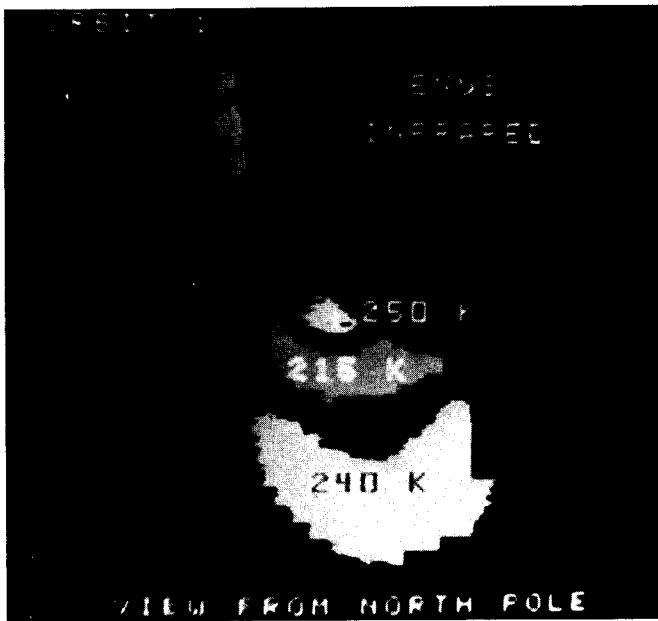


On October 1, 1978, President Carter presented the first six Congressional Space Medals of Honor to Mercury, Gemini, Apollo, and Skylab astronauts (above). In the Space Shuttle program, the orbiter Enterprise, having flown the approach and landing test flights in 1977, was airlifted to the Marshall Space Flight Center. In May 1978 it was hoisted (lower left) into the dynamic test stand and joined (lower right) to the external fuel tank and two solid-rocket boosters for vibration testing of the total Shuttle configuration.

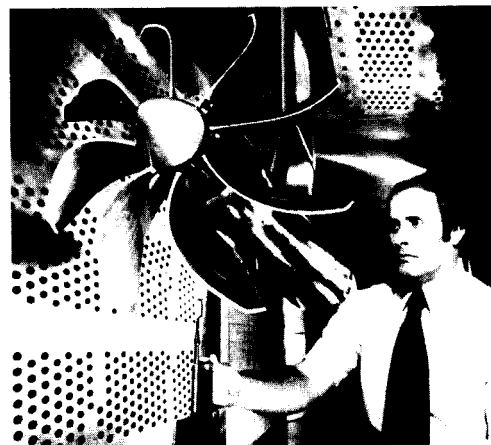




Seasat 1, orbited on June 27, 1978, returned interesting data during its 3½-month reporting lifetime. In views by its synthetic aperture radar, above is a portion of the Beaufort Sea ice pack, some 800 kilometers inside the Arctic Circle. The light area (right) is Banks Island, Canada; the dark strip adjacent is first-year sea ice, 1 to 2 meters thick. To the left of it is open water, and the dark area (left) is the main polar ice pack. The other radar image (right) shows a complex ocean structure northeast of Miami. Striations (upper left) may be related to motion of the Gulf Stream, while the irregular pattern at bottom may show surface wind and rainfall from a local squall (center).



Pioneer Venus orbiter took the image at left in December 1978. An infrared view of the north pole of Venus, it shows the pole (center) with cloud-top temperatures of 250 K (-10°F) and flanked by cooler clouds (215 K, -72°F). At mid latitudes the cloud temperature of 240 K (-28°F) shows a different spectral signature. In aeronautics, the Army-NASA Rotor Systems Aircraft (below, left) began flight testing in 1978. Equipped with auxiliary jet engines and fixed wing, it can safely test a wide variety of rotors and propulsion systems. Below, Lewis Research Center tested small-diameter 8-bladed propellers which offer the same aircraft speeds as current turbofan engines but at 20 to 40 percent better fuel economy.





Summary of United States Aeronautics and Space Activities in 1978

Introduction

For the United States, the year 1978 marked the 20th anniversary of the official beginning of a national program in space. It was in 1958 that President Eisenhower proposed, the Congress enacted, and the Executive Branch began operating under the National Aeronautics and Space Act of 1958.

During this anniversary year, the national programs in aeronautics and space continued to make progress toward their goals. In aeronautics, advances were made in aircraft fuel economy and emission and noise control. In space, the Space Shuttle surmounted several development and test barriers in preparation for its first orbital flight, scheduled for late 1979. Two Pioneer spacecraft arrived at Venus and returned a harvest of information about our shrouded sister planet. United States expendable launch vehicles attempted 33 launches into space, with 32 successes, orbiting a total of 41 spacecraft. NASA's 20 launch attempts—including 2 launches by NASA for the Department of Defense (DoD)—were all successful, placing 25—plus 2 DoD—spacecraft into orbit: 16 were for NASA's own programs, 1 was a "piggyback" Oscar amateur radio satellite, and the remainder were reimbursed launches for governmental, international, and commercial customers. DoD orbited 16 satellites in 14 successful launches out of 15 attempted (including the 2 DoD launches performed by NASA). Among the NASA spacecraft were the second of three big high-energy-astronomy satellites; Tiros-N, prototype of a new generation of high-data-rate weather satellites; and two Pioneer spacecraft headed for Venus.

In October the President issued a statement that constitutes a positive source of policy direction on the future of our country's efforts in space. The text of this statement is reprinted as Appendix F.

In this chapter, highlights of the year in the national aeronautics and space programs are organized topically rather than by agencies responsible for particular activities. The other chapters

enlarge on the activities of the six Federal agencies with the largest programs in aeronautics and space.

Communications

Communications satellites were the earliest, and remain the largest, commercially successful offspring of the United States investment in space.

Operational Space Systems

Intelsat. The International Telecommunications Satellite Organization increased its worldwide membership in 1978 to 102 nations. On March 31, NASA launched for Intelsat the last of the Intelsat IV-A satellites, this one to serve in the Indian Ocean region. Future satellites will be of the Intelsat V series, which will double the communications capability of the IV-A. At the close of 1978, three active Intelsat satellites were serving the Atlantic Ocean region and two were serving the Indian Ocean region.

Marisat. Commercial satellite services to shipping continued to increase. As in 1977, the Marisat system served the U.S. Navy in the Atlantic, Pacific, and Indian Oceans and commercial shipping in the Atlantic and Pacific; service may soon be added for commercial shipping in the Indian Ocean. The Federal Communications Commission (FCC) issued rules under which commercial shipping can be licensed to operate with the Marisat system and has participated in the work of the preparatory committee laying the groundwork for the establishment of the international INMARSAT organization.

Military Navigation Satellites. The existing Navy navigation satellite system is Transit, a two-dimensional position-fixing system primarily in support of ballistic missile submarines. The five satellites permit a user to take position fixes every two hours or less. Thirteen years old in 1978, the system has also been used in offshore oil exploration and measurement of the drift of polar ice. A modified Transit satellite, launched in October 1977, car-

ried two special transponders called translators; these will support tests of Trident I missiles.

The other military navigation satellite system is the NAVSTAR Global Positioning System. It is a joint-service system to provide high-accuracy, global position fixing in three dimensions. When fully operational, it will consist of 24 satellites in three orbital planes at 20,400 kilometers altitude and will serve 25,000 to 35,000 users. Still in the concept-validation phase, NAVSTAR orbited the fourth of its satellites on December 10, 1978; two more will be launched in early 1979.

Domestic Commercial Communications Satellites. In 1978, domestic communications satellites totaled 7, operating in the 4 and 6 gigahertz bands; 2 were in RCA Americom's SATCOM system, 2 in Western Union's WESTAR system, and 3 in AT&T's COMSTAR system. All transmit and distribute voice, television, and digital data. Satellite Business Systems, which has proposed to have 2 satellites in operation by 1981, would operate in the 12 and 14 gigahertz bands to provide integrated digital transmission of voice, data, and image traffic for large industrial and government users. The FCC authorized Satellite Business Systems to use transponders on a domestic satellite for tests of its ground equipment. FCC's authorization to proceed with construction was reversed by the Court of Appeals.

In early 1977, the FCC decided to allow Earth stations with antennas less than 9 meters for cable television. The first large users were the Corporation for Public Broadcasting and the Public Broadcasting Service, which have put into operation 150 Earth stations linking all public television stations in the 50 states plus Puerto Rico and the Virgin Islands. Another 750 applications have been approved for small-antenna, receive-only stations for cable television. In addition, the Corporation for Public Broadcasting has joined National Public Radio in applying for the right to distribute, via satellite, multiple audio programming to their network radio stations. The Mutual Broadcasting Company has filed for authority to construct and operate 500 small receive-only stations operating through domestic satellites. In mid-1978 the FCC authorized the American Satellite Corporation to transmit and receive 132-kilobit digital service with 5-meter antennas. Another 130 Earth stations have been authorized for communications services using satellites and Earth antennas as small as 4.5 meters in remote locations in Alaska, offshore drilling rigs, and drilling ships. The total of all domestic small-antenna Earth stations that the FCC has authorized to date exceeds 1200.

Military Communications Satellites. Three broad categories of space communications are identified for the defense establishment:

- worldwide point-to-point communications for fixed users with high capacity and high data rate
- communications for mobile users, with moderate capacity and low data rate
- command and control of strategic nuclear forces.

Serving the first of these needs, the Defense Communications Satellite Program is configured for four active satellites and two on-orbit spares. By the end of 1978, the four active satellites were in place—two launched in May 1977 and two in December 1978—but the launch of the spares failed in March 1978.

The mobile-user requirement is to be met by the Fleet Satellite Communications System. The first of five spacecraft was launched in February 1978; installation of broadcast receivers in ships of the fleet is almost complete, with nearly 300 ships and 150 submarines now equipped.

Strategic command and control will be provided by the Air Force Satellite Communications System. Deployment of airborne, mobile, and fixed terminals began in 1978 and will continue for another four or five years. The space component presently consists of transponders on several types of host spacecraft.

Space Communications Experiments

Experimental Satellites. NASA's Applications Technology Satellites (ATS) continued to be used for experimental public-service communications. Two of these satellites have narrow-band VHF transponders that are being used by 3 experimenters sending voice communications to 24 receiving stations. Messages deal with medical emergencies, state government operations, and church administration. This year 5 educational experimenters used ATS 6, a high-powered "broadcast" satellite, to relay high-quality video containing college-level courses designed to update teacher training. These signals have gone to 30 small, inexpensive antennas scattered around a sizable part of the U.S. Canada's Communications Technology Satellite (CTS) has been tested in the higher 12–14 gigahertz band. NASA experimented with teleconferencing over CTS; representatives of Indian tribes in Montana and New Mexico talked with Federal officials in Washington, D.C., about tribal problems.

Communications Research. Increasing demands on the world's crowded radio spectrum have led

NASA to investigate means of compressing the bandwidth of digital transmissions, thereby making room for additional transmissions. A development completed this year enables transmission of full-motion, color television in one-tenth of the usual bandwidth. An international program using communication satellites to improve the ability of search and rescue teams to find distressed ships and aircraft progressed toward a demonstration flight in 1982.

Communications Studies. A U.S. delegation participated in the Aeronautical Mobile Conference in February 1978. A worldwide plan was developed for the frequencies used by international airlines. Preparations continued for major U.S. participation in the General World Administrative Conference to be held in the fall of 1979. Meeting once every 20 years to reallocate the use of the radio spectrum, this conference is the first since space communications achieved maturity and is considered crucial to their continued growth.

Planning and coordination of U.S. telecommunications activity were consolidated in a new National Telecommunications and Information Administration, formed in May 1978 in the Department of Commerce by Executive Order. Consolidating the functions of the former White House Office of Telecommunications Policy and Commerce's Office of Telecommunications, the new organization will plan and monitor government aspects of commercial communications satellite systems and will coordinate technical compatibility of the systems with other communications systems in the U.S. and abroad.

Earth's Resources

Spacecraft and aircraft continued in 1978 to operate as platforms for sensors that inventoried and monitored changes on Earth's land surface, on and in its waters, and in its surrounding environment. Some of these sensing systems remained tentative and experimental, others were semi-operational, and a few were fully operational.

Inventorizing and Monitoring

Earth Resources Experiments. Landsat 3 was launched on March 5, 1978, and is producing good data from all sensors except for the thermal band. Landsat 1 had finally ended operations in February, after five and a half years. Landsat 2 continued to function well. On the ground, the new all-digital Landsat data-processing system was being checked out at NASA's Goddard Space Flight Center in Maryland and the Department of Interior's

EROS Data Center in South Dakota. It should reduce the delivery time of Landsat data products to customers by more than 50 percent.

A new kind of experimental sensor joined the NASA family of Earth resources satellites in 1978. The Heat Capacity Mapping Mission (HCMM) satellite was placed in a Sun-synchronous orbit on April 26. From this orbit the spacecraft can take readings of same-day maximum and minimum ground-surface temperature at selected locations. Temperature comparisons may offer a new tool for distinguishing rock types and amounts of soil moisture.

A number of experiments using Landsat data have demonstrated the applicability of space-sensed data for management of land and water resources. The largest single project relating to agriculture was the Department of Agriculture's Large Area Crop Inventory Experiment (LACIE), which completed its three-year analysis in 1978. Results were promising: LACIE's crop predictions were 90 percent accurate for the wheat yield in the U.S. Southern Great Plains and the U.S.S.R. Another demonstration included use of Landsat data by NASA and 13 agencies of the state of Texas to update and maintain a multipurpose inventory of natural resources.

Land use of a different type was the subject of a study by the Department of Commerce's Bureau of the Census; Landsat data were used to update urban-area boundaries for 5 cities. An effort will be made to detect urban change in 5 cities in 1979. Similar studies on an international scale were conducted by the Bureau of the Census and funded by the Agency for International Development. Evaluation of tests in Bolivia and Kenya concluded that Landsat images could help developing nations improve or update maps and boundary locations in preparation for a national census or to interpret physical-cultural land cover.

Several bureaus of the Department of the Interior are using Landsat imagery for planning and land-management purposes. The National Park Service is inventorizing the vegetation of the Lake Mead National Recreation Area, training personnel in planning and management of 25 large recreation areas. The Bureau of Reclamation is using Landsat data to inventory the irrigated lands in the Colorado River basin, detect changes in land use, and map wildlife habitats—part of developing a plan for meeting the future water requirements of the river basin.

Monitoring the Sea State. Seasat 1, NASA's experimental satellite equipped to measure global ocean dynamics and physical characteristics, was launched on June 27, 1978. All sensors returned

excellent data. By mid-July, a wide range of ocean phenomena had been observed and measured, and many of the measurements could be validated by independent ground-truth data gathered by aircraft and ships deployed by NOAA. Then on October 9, the Seasat satellite suffered a total electrical failure from which it never recovered. The data that it returned in its three-and-a-half-month lifetime will be valuable from a scientific standpoint and as an evaluation of the instrumentation carried on the satellite.

In a five-year program to update hydrographic charts, the Defense Mapping Agency began working with NASA and the Department of Interior's EROS Data Center to acquire data from Landsat's multispectral scanner covering 3000 shallow-water areas of the world.

NOAA investigators worked with the University of Alaska on use of satellite and other remotely sensed data to study ice development and sediment density and movement along the coast of Alaska. The university, with funding from NOAA, operates a center for storing, processing, and developing techniques for use of remotely sensed data.

With the launch on October 24, 1978, of NASA's experimental environmental satellite Nimbus 7, NOAA increased its ocean-color research substantially to take advantage of the capabilities of a new sensor aboard the satellite, the Coastal Zone Color Scanner. An experiment conducted in the Gulf of Mexico in October 1977 demonstrated that measurements of ocean radiance varied in proportion to concentrations of both suspended particulate matter and chlorophyll. If such measurements could be corrected for atmospheric influences, the Nimbus 7 Color Scanner should make it possible to estimate six to eight ranges of suspended particulates and chlorophyll. After the Nimbus 7 launch, scientists from NOAA, NASA, Scripps Institution of Oceanography, Texas A&M University, and the University of Southern California made in situ measurements in the Gulf of Mexico to correlate with data from the Color Scanner.

For several years NOAA scientists have been studying charts of monthly sea-surface temperatures that were compiled from satellite data. The study shows a gradual, slight cooling of oceans in the Southern Hemisphere since 1975. In the North Pacific a large cold-water anomaly developed during the 1976-1977 winter, reappeared the following year, and appears to be forming again in the 1978-1979 winter. Evidence continues to indicate the existence of an ocean-to-atmosphere link between this sea-surface temperature anomaly and colder-than-normal winters over much of the U.S. east of the Rocky Mountains.

Monitoring Pollution. The Coastal Zone Color Scanner aboard the Nimbus 7 satellite offers promise of detailed information about oil spills if its data can be properly calibrated. To that end, the Environmental Protection Agency's test facility in Leonardo, New Jersey, measured the optical characteristics of 10 samples of crude oil that were aged over the course of a week in simulated ocean conditions. In the visible region, the tests showed the oil had increased reflectance beyond that of the water; in the infrared range, equivalent blackbody temperatures increased. NOAA scientists will apply these controls to Color Scanner data from actual oil spills.

Another use NOAA plans for data from the Color Scanner is in evaluating water quality in the Great Lakes. When enough surface-truth samples have been gathered, the scanner will be evaluated for the accuracy of its data on algae, suspended sediment, and calcium carbonate.

The "urban plume" problem in air pollution—the aggregate of pollutants emitted from an urban area and then transported through the atmosphere for some distance while its constituents change character under the influence of sunlight and mixing—has been a subject of research by the Environmental Protection Agency and NASA for several years. In 1977, NASA joined with the Virginia State Air Pollution Control Board to measure constituents of the urban plume from the Norfolk-Hampton Roads area. Instrumented aircraft from NASA's nearby Langley Research Center flew sampling flights through the plume during the summer, while the Virginia agency measured ozone concentrations at ground level. Downwind from the urban complex, typical buildups of ozone were as much as double the normal. Two NASA-developed laser systems were brought into the study in July 1978, taking measurements of the total ozone burden in the mixing layer—usually from the surface to two kilometers. One laser system was mounted in an aircraft, the other on the ground. If the accuracy of their measurements compares favorably with those from conventional methods, the NASA lasers may be used as sensors on spacecraft.

Another environmental concern has been the reduction of aircraft noise and emission pollution. In one attempt at noise reduction, EPA joined NASA in research on the design of propellers for general-aviation aircraft, seeking a design for optimum aerodynamic performance at the lowest noise level. Propellers on two different general-aviation aircraft were being redesigned according to new theories on propeller noise. In another study, NASA monitored the vibration response of buildings near Kennedy and Dulles airports during

overflight by jet transport aircraft, including the Concorde. Vibrations were at levels that could be heard by persons within the buildings, though well below levels that would cause structural damage. Vibration levels from Concorde were higher, but only in proportion to its generally higher noise level.

In one approach to reduction of aircraft emissions, NASA has for several years been working on new combustor technology for large turbine engines, aiming particularly to reduce emissions of carbon monoxide and unburned hydrocarbons during engine idle. Three advanced combustors reduce emissions by 20 to 30 percent, and the technology proved effective in reducing emissions from small aircraft during takeoffs and landings.

Environmental Analysis and Protection

One of the early successes of the U.S. space program was the weather satellite. For more than a decade complex systems of weather satellites have been operational in weather forecasting. In the last few years, research has started on the less-discernible trends of world climate and effects on Earth's upper environment caused by man-generated pollutants.

Weather Satellite Operations. During 1978 NOAA operated two polar-orbiting satellites, Noaa 4 and 5, the last of the series of Improved Tiros Operational Satellites (ITOS). The first of the third generation of polar orbiters, NASA's prototype Tiros-N, was launched October 13, 1978; Noaa 4 was deactivated on November 18 and Tiros-N began functioning in the network in December. NOAA's first operational satellite of the new series, Noaa-A, is scheduled for launch in mid-1979. The Tiros-N system will consist of two satellites in near-polar, Sun-synchronous orbit, crossing the equator about 12 hours apart. Each satellite features four primary sensors: a very-high-resolution radiometer, a vertical sounder comprised of three complementary sounding instruments, a data collection and location system, and a space environment monitor. The new series will have improved resolution in both visual and infrared imagery of Earth's cloud cover, will measure moisture and temperature, and will monitor proton and electron flux. To handle the much larger flow of digital data that these satellites will generate, a new ground system was completed in June 1978.

The other system of weather satellites is the Geostationary Operational Environmental Satellites (GOES). The usual configuration of this system is two spacecraft in geosynchronous orbit located over the equator at longitudes approximating the east and west coasts of North America. Throughout

1978, Goes 2 remained in position at 75° west longitude as the eastern operational satellite. Goes 3, launched on June 16, was positioned at 135° west longitude in July, replacing Goes 1 as the western operational satellite. Because of the special circumstance of the Global Weather Experiment, Goes 1 was moved in November to 60° east longitude over the Indian Ocean, where it will be operated by the European Space Agency for the duration of the global program.

The DoD weather satellite system is the Defense Meteorological Satellite Program. It supports military operations with high-quality visual and infrared imagery and other specialized weather data, as well as furnishing supplemental data to NOAA. Two satellites in polar orbit acquire data on the world's weather four times a day, store it, and later transmit it to the Air Force and Navy weather centrals in Nebraska and California respectively. They also transmit the data in real time to mobile read-out stations at key locations around the world to support tactical operations. During 1978, the third Block 5D satellite was launched and became operational. In addition to imagery, these satellites take high-quality profile measurements of vertical temperature and moisture and count precipitating electrons in auroral regions.

Weather Research. In December 1978 the World Meteorological Organization's long-anticipated Global Atmospheric Research Program (GARP) began. Its first phase was the year-long Global Weather Experiment. Several U.S. agencies are contributing equipment and research personnel, with a central role being played by NOAA and NASA environmental satellites. The interconnecting and sometimes overlapping coverage by satellites from several nations, together with the more extensive ground-truth data being collected by observers from many nations, should produce a high-density data bank as well as provide for intercalibration of data and interpretation techniques. NOAA continued research on the use of imagery from geostationary satellites to derive wind speed and direction. Joint experiments with NASA indicated that automatic cloud tracking produced accurate wind vectors under uncomplicated conditions. Computer programs have been written for the first international comparison of winds derived from cloud motions that were in the field of view of neighboring geostationary satellites—namely, those of the U.S., Japan, and the European Space Agency.

Satellite data were used by NOAA to produce operational snowmaps for 30 U.S. and Canadian river basins during the 1977–1978 snow season. Some 600 snowmaps were used by Federal and state

agencies to aid in prediction of water runoff, flood prevention, dam and reservoir regulation, hydroelectric generation, and monitoring of consumption. January 1978 was a record snowcover month for North America, but was quickly exceeded by February. Snowcover in the Northern Hemisphere was about 8 percent above the 10-year average for the 3 winter months.

Atmospheric and Magnetospheric Research. For some years a number of Federal agencies have been making various kinds of measurements of constituent gases and particles in the several layers of the Earth's outer environment. Chronologically the range of interests has grown from concern for charged-particle effects on radio communications, to the pass-through effects on weather, to effects of man-generated pollutants on the ozone layer, and most recently to the effect on Earth's climate.

NOAA and the U.S. Air Force have for some time operated the Space Environment Services Center, which not only collects and analyzes data but is the national and international warning agency for disturbances on the Sun, in space, in the upper atmosphere, and in the Earth's magnetic field. Recently the center has been predicting solar activity so as to estimate the orbital lifetime of the Skylab space station. In addition to the data gathered from its regular satellite and watch-group sources, the center was assisted in the Skylab instance by the Bureau of Standards, which analyzed sunspot variations over the last 30 years.

In stratospheric research, NOAA developed a technique using pulsed Doppler radar to measure wind profiles from the ground up to about 100 kilometers. To make a measurement from the ground through the troposphere and lower stratosphere to about 30 kilometers takes one minute.

NASA has been charged by Congress with defining the effects on stratospheric ozone of man-generated pollutants. There is now a program plan, a measurement strategy, and some 130 funded tasks being worked on by government, universities, and industry. Stratospheric balloons with instruments from the University of Michigan and Canada have simultaneously measured about a dozen constituents of the stratosphere; the data are being used to test photochemical models. The most significant recent advance in theory and data analysis has been the intensified awareness of the close coupling in the stratosphere among the nitrogen, hydrogen, and chlorine families. This principle has been used in a number of models that have helped define the measurement strategy. Data analysis is setting a baseline against which changes in the ozone layer can be measured. NOAA scientists are also researching the chemistry of the stratosphere. With

ground-based long-path optical absorption techniques, they have been able to measure nitrogen trioxide for the first time.

Methane, a compound almost entirely of natural origin, is always present in the stratosphere in trace amounts; its distribution is a key to stratospheric chemistry. NOAA scientists this year measured the concentrations of methane at various latitudes and at altitudes to 30 kilometers.

At the request of the Environmental Protection Agency, the National Academy of Sciences prepared *Response to the Ozone Protection Sections of the Clean Air Act Amendments of 1977: An Interim Report*. It found the danger to stratospheric ozone from release of chlorofluoromethanes to be roughly double that of earlier estimates, while the effect on ozone from exhaust gases of high-flying aircraft, including SSTs, was found so slight as to be of no immediate concern.

As in other areas of space research, the recent advances in sensors for stratospheric research and the increased numbers of users of such sensors have created a need for agreed-upon calibration of instruments and standardized baselines against which measurements can be made and interpreted. From June 2–20, 1978, NASA, NOAA, and the Soviet Union performed a calibration exercise. From NASA's Wallops Flight Center, Wallops Island, Virginia, NASA launched 3 sounding rockets; from their research ship positioned off the island, the Soviets launched 5 of their rockets. NOAA's Wallops Ionosphere Station monitored local ionospheric conditions to provide a common data base for both nations. The results may clear up differences in past interpretation of ionospheric data in the altitude range of 80–120 kilometers.

The two International Sun-Earth Explorer satellites launched in 1977 have been observing the interactions between particles in the solar wind and Earth's magnetosphere. With the improved resolution and spatial coverage of the energetic-particles experiment on board one of the two satellites, it has been possible to describe much more completely the particle environment. Research by NOAA and the Max Planck Institute for Aeronomy has delineated characteristics of the magnetospheric boundary not known before. NOAA scientists have demonstrated that the geomagnetic disturbances called substorms—storms that affect Earth's radio communications, electric power distribution, and long-line telephone systems—can now be predicted.

Earth Dynamics. Investigations of Earth dynamics focus on mineral and energy reserves, earthquake forecasts, and geodetic surveys.

Major earthquake areas mark the zones of contact between tectonic plates—continent-size floating

pieces of the Earth's crust. Measurement of the rate of movement along the fault line between plates also indicates the amount of subsurface stress, which can eventually release itself in an earthquake. This year NASA made the first direct measurement of lateral movement along a fault. Using a technique called Very Long Baseline Interferometry (VLBI), NASA had positioned mobile laser systems in California along the San Andreas Fault—the contact zone between the Pacific and North Atlantic plates—and bounced laser pulses off satellites. Analysis of the triangulation data indicated an observed movement more rapid than that predicted by other methods. More observations began in December 1978, to verify and extend the earlier data.

Experiments continued to try to refine VLBI measurements. NASA made VLBI measurements of radio stars from radio observatories located on the east and west coasts of the U.S.; mobile laser systems were used for the ground-to-satellite signals from both coasts. Repeatable accuracies of 4–6 centimeters seem to have been attained. With improvements in correction for atmospheric distortion, it should be possible to attain the 1–2 centimeter accuracy needed to detect crustal deformation.

Although much is known about average motion of the tectonic plates, we know very little about the mechanisms of the plate motion. Is it episodic? Is the movement smooth—or is it jerky? One set of answers to these questions may come from the use of VLBI. Under the auspices of the National Science Foundation, new wideband recording systems are being installed on antennas in the U.S. and Sweden; these should enable detection of the expected continental drift of about 1.7 centimeters per year between those parts of North America and Europe. This experiment will be the first real-time measurement of plate motion and should provide important clues to the nature and behavior of the driving mechanism.

In studies of the Earth's magnetic field, NASA and the U.S. Geological Survey, Department of the Interior, have agreed to construct a mathematical model of the magnetic field and to analyze magnetic anomalies, using data from Magsat.

Space Science

Looking outward from Earth, space science is considered to begin in the region where interactions occur between the Earth's magnetic field and the incoming solar wind. Beyond that, it encompasses the solar system and the entire detectable Universe.

Sun-Earth Studies

Much remains to be learned about the Sun, the sole source of Earth's light, life, and energy; and about the interactions between solar emissions and the layers of Earth's environmental shell.

The Solar Wind. On August 12, 1978, NASA launched the last of three International Sun-Earth Explorer (ISEE-C) satellites to study the spatial and energy fluctuations of the solar wind and the interactions at the boundary of Earth's magnetosphere. ISEE-C was programmed to orbit much farther out from Earth than the other two ISEE satellites. For the first time a satellite would orbit about the L1 libration point—a spot about 1.5 million kilometers away, where Earth's and Sun's gravitational fields equalize. Solar-wind data from this outpost will arrive at Earth antennas about an hour before the same portion of the solar wind arrives at ISEE-A and B, stationed near the edge of the magnetosphere. In this international project, ISEE-B is furnished by the European Space Agency, the other two by the U.S.

Studies continued of the causes and effects of the spectacular displays in the upper atmosphere known as the aurora borealis in the northern polar region and the aurora australis in the southern polar region. These displays disrupt radio, radar, and satellite communications and cause navigational problems. NASA investigated the measurement of small electric fields operating over large distances in space, thought to be the agent for propelling the kinds of particles visible in the auroral displays. Some scientists feel such fields also affect solar climate relationships and anomalous effects seen in the ionosphere. The National Science Foundation has been supporting research at the University of Alaska, where scientists, building on 20 years of worldwide studies, have succeeded in describing the complex interactions between solar radiation and Earth's environmental shield. With this understanding and the data arriving from ISEE-C, it should be possible to forecast the occurrence and intensity of major auroral activities.

NOAA examined the interactions of various fluid motions within the solar wind. In steady-state conditions, it was found that when non-radial flow occurs in some coronal holes, the ratio of alpha particles to protons near the Sun is reduced by frictional drag on the protons by alpha particles. At Earth distance, alpha particles arrive at higher speeds than protons when heated to much higher temperatures at the Sun.

The Sun. The origins and processes of solar flares continued to be studied. The National Bureau of Standards worked on the development of technology for accurate measurement of the physical prop-

erties—temperatures, density, velocity, and magnetic field—of the atmospheres of the Sun and other stars. Data will be received from such satellites as the Orbiting Solar Observatory, the International Ultraviolet Explorer, and the Solar Maximum Mission.

From April 24–May 8, 1978, a large sunspot group moved across the solar surface. The first major activity since 1976, it peaked on April 28 into the largest flare ever observed, one of four peaks that significantly affected Earth's outer atmosphere. The Department of Commerce's World Data Center A for Solar-Terrestrial Physics is preparing a report documenting these observations.

The Navy and Air Force were also studying solar flares, primarily out of concern for their effect on radio communication. The Navy used Solrad-Hi and Goes satellite data, measuring solar events in real time, to perform R&D on a prediction system. The Naval Research Laboratory continued basic research in solar physics, solar-terrestrial relationships, and plasma processes. The Air Force performed theoretical studies of the processes leading to solar flares. Working closely with the National Science Foundation, Air Force scientists are installing a worldwide radio-solar-telescope network and are developing techniques for forecasting the time-history of high-energy particles that solar flares eject toward Earth.

Study of the Planets

The planets are studied not only for the sake of pure scientific knowledge, but for what other planets and their processes can teach us about Earth and its processes.

Mars. During 1978 all 4 Viking spacecraft at Mars contributed important data. Especially the two orbiters were active, returning data on Martian geology and atmospheric behavior. By the end of the year one orbiter and one lander had gone silent and the other two were expected to end their missions in the spring of 1979. NASA started funding a 5-year program by the U.S. Geological Survey to further analyze data from the two Viking landers, especially some 50,000 photographs. USGS published a geologic map of the surface of Mars, taken from over 2000 photographs from the Mariner 9 orbiter in 1971–1972.

Venus. Early in December 1978, two NASA spacecraft arrived in the vicinity of the planet Venus. Our nearest planetary neighbor and the most like Earth in size and distance from the Sun, Venus is always obscured by massive cloud layers and blanketed in a heavy, hot atmosphere.

The first of the two Pioneer spacecraft to arrive was an orbiter; flying an elliptical orbit, it dipped

into the atmosphere once each orbit and reported on the atmosphere and ionosphere. The second spacecraft was a "bus" from which four probes split into widely separated descents through the atmosphere to the surface; they were not designed to survive impact, though one of them did for a time.

By the end of the year, only the real-time data were available; though only a sampling, these data indicated that the whole group of mission objectives would be well covered. Possible surprises are: three distinct cloud decks, differentiated in particle types; beneath the clouds, very similar pressure and temperature variation with altitude, the presence of water vapor and oxygen just below the clouds, and unexpectedly large amounts of helium, neon, and argon.

Jupiter. NASA's two Voyager spacecraft, launched toward Jupiter in 1977, flew through the asteroid belt and continued toward the planet. The first spacecraft will begin observations of the huge planet and its moons early in 1979, with the nearest encounter on March 5; Voyager 2's encounter will occur on July 9. As they pass Jupiter, both spacecraft will be able to use the planet's gravitational field for acceleration toward Saturn. Meanwhile development continued on the Galileo spacecraft to be launched in 1982—a Jupiter orbiter for intensive study of the planet and its moons, and a Jupiter probe to descend through the atmosphere for in-situ measurements.

Saturn. Saturn is the target for several visits by NASA satellites. In September 1979, Pioneer 11 will arrive from its 1974 flyby of Jupiter, pass just outside the rings of Saturn, and then tilt in close to the planet. Voyagers 1 and 2 are expected to arrive at Saturn in late 1980 and mid-1981 respectively; Voyager 2 will have the option of using Saturn's gravitational field to swing on out past Uranus.

Charon. NASA-sponsored ground-based astronomers discovered this hitherto unknown minor planet in an orbit between those of Saturn and Uranus.

Uranus. One of the major planetary discoveries of 1977 was the existence of 5 faint rings around Uranus, enabling that planet to join Saturn as a select group of known ringed planets. In 1978 this discovery was extended by astronomers sponsored by the National Academy of Sciences, using the 2.5-meter-diameter telescope at the Las Campanas Observatory in Chile. Employing infrared techniques from this excellent observing site, at a time when a faint star passed behind Uranus, the astronomers were able to count the rings as they passed in front of the star, detecting another 3 rings for a total of 8. The orbit of Uranus was crossed by a manmade object for the first time, as Pioneer 10 reached that

point in its journey out of the solar system. Uranus might be visited by Voyager 2 in 1984.

Pluto. Another discovery of NASA's ground-based astronomy program in 1978 was that distant Pluto has a previously unknown moon.

Study of the Universe

Answers to the most profound questions man can ask about physical existence and processes may well be found in study of the complexities of the Universe.

Research with Spacecraft. The second of the big High-Energy Astronomy Satellites (HEAO 2) was placed in orbit in November 1978. The largest automated spacecraft yet launched in the U.S. space program, this series of 3 astronomy satellites is instrumented to inventory and study the high-energy sources of the Universe. HEAO 1, launched in August 1977, has surveyed the sky, identifying x-ray sources in large numbers; by the end of its mission in early 1979 it should have identified as many as four times the number of x-ray sources that were known before. HEAO 2 is the largest x-ray telescope yet placed in space; from the map of x-ray sources made by HEAO 1, HEAO 2 will point at the most interesting sources—some of them two-thirds of the way to the edge of the Universe—for detailed study. HEAO 3, to be launched in 1979, is another mapping satellite, but operates in the gamma-ray and cosmic-ray bands.

Aside from pinpointing further x-ray sources, HEAO 1 also identified a hot plasma which encompasses our galaxy and may exist throughout the Universe. This is of great potential importance to cosmologists; if plasma of similar temperature and density exists throughout the Universe, it would contain half the mass required to close the Universe.

The Explorer class of satellites continued their useful work. Smaller and cheaper than observatory-class satellites, Explorers are instrumented for specialized investigations. This year the Small Astronomy Satellite-C, in its third year of operation, discovered a Quasi-Stellar Object. The IUE (International Ultraviolet Explorer) satellite, launched in January 1978, is a joint project of NASA, the European Space Agency, and the United Kingdom. It records the spectral lines showing atomic radiation in the atmosphere of stars, in the interplanetary medium, and in objects within the solar system. The early observations centered on subluminescent stars, which are the last step in stellar evolution.

The last of the Orbiting Astronomical Observatories, OAO 3, named Copernicus, has been in orbit more than six years. This year it supplied useful information on a possible black hole located in the constellation Scorpius.

One of the two blanks being cast for the primary mirror of the Space Telescope was finished this year on schedule. The Space Telescope will be the first general-purpose astronomical observatory launched into space for an expected lifetime of more than 10 years. To be carried by the Space Shuttle in late 1983, the telescope is designed to be repaired in orbit, have Shuttle crews change experiments, or even be brought back to Earth for rework and relaunch.

Research from Suborbital Vehicles. A NASA sounding rocket acquired a well-calibrated spectrum of the Seyfert (active) galaxy NGC 4151, especially useful because it can help calibrate a spectrum of the same galaxy obtained by the IUE satellite. Three superpressure balloons made complete circuits of the southern hemisphere monitoring ozone. The aircraft-mounted Kuiper Airborne Observatory detected the first infrared "Bok Globule." These globules have appeared as black spots in our galaxy, opaque to any radiation. With this identification, the emissions of a whole new class of objects can be measured directly.

Research from the Ground. Scientists sponsored by the National Academy of Sciences, using recently developed instruments at the Hale observatories and Kitt Peak National Observatory, reported the best evidence yet for the existence of a supermassive black hole. In the center of the galaxy M 87, a dark compact mass has all the characteristics of a black hole, with a mass of about 5 billion times that of the Sun. Since the 1960s scientists have speculated that supermassive black holes may be the hyper-efficient energy sources for the extremely powerful processes in quasars, radio galaxies, Seyfert galaxies, and BL Lac objects, as well as similar but weaker events in more normal galaxies.

The youngest star yet discovered, less than 2000 years old, has been identified by the staff of NSF's Kitt Peak National Observatory. Using the Fourier Transform Spectrometer with the Observatory's 4-meter telescope, observers were able to reclassify an unusual object, Becklin-Neugebauer (BN)—previously thought to be a collapsing pre-stellar object—as a young but full-fledged star.

Observations by the Smithsonian Institution complementing those of the IUE satellite discovered optical counterparts to two more x-ray sources as well as optical bursts from an x-ray burst source.

Study of the Life Sciences

U.S. Experiments on Soviet Spacecraft. In October 1978, the final-results symposium on Cosmos 936, the Soviet Life Sciences mission that flew 7 U.S. experiments, was held in Moscow. The mission fea-

tered the first in-flight use of a centrifuge as a 1-g control.

Studies in Planetary Biology. NASA and the National Science Foundation supported studies that extended our understanding of planetary biology. In an area of Antarctica which had been labeled abiotic, lichen-like organisms were discovered, contributing to our understanding of the distribution of life in the Universe. Another study found amino acids, the building blocks of life, in a clay deposit rich in the heavy metal zinc; this metallized clay rejected certain organic molecules and fostered others, building them into amino acids.

Transportation

The national programs in aeronautics and space include extensive research and development for new transportation systems and for improving the operations and flexibility of existing systems.

Space Transportation System

A fundamentally new way of using the space environment, the Space Transportation System embraces future mission planning, logistics, and flight and ground operations. The flight component is the Space Shuttle, scheduled to make its first orbital flight test in 1979. Its components are: the orbiter, housing the crew of 3 to 7 persons and the payload, and able to reenter from space, land on a runway, and fly again; the two solid-fuel rocket boosters, attached to the orbiter for the launch phase, then parachuted into the ocean for recovery and reuse; and the external tank, carrying liquid oxygen and hydrogen for the orbiter's three main engines during the launch phase. All flight hardware passed critical tests in 1978. Similar progress was made with ground facilities and with planning and booking of missions.

The operational capability of the orbiter will be extended by supplemental systems contributed by a number of sources. The first Spacelab, a set of modules including a shirtsleeve laboratory and pallets exposing instruments directly to the space environment, is being funded, designed, and built by the European Space Agency. The remotely operated loader-unloader arm, being funded and built by Canada, will lift payloads out of and into the cargo bay while in space. The Inertial Upper Stage, a three-configuration set of upper stages to propel heavy orbiter payloads into orbits or planes beyond the reach of the orbiter, is being funded and built by DoD. The Spinning Upper Stages, smaller boosters to put smaller payloads into higher orbits, are being funded and built by U.S. aerospace industries as commercial ventures.

Space Shuttle. Assembly and testing of all flight elements passed through critical phases in 1978.

The first of the four flight orbiters neared completion of its assembly and would be delivered to Kennedy Space Center in 1979. Its high-pressure liquid-hydrogen, liquid-oxygen engines have to be capable of repeated firings in 55 missions. Every new engine system has to be debugged during testing, and as problems came under control, testing time accumulated beyond 35,000 seconds, toward the preflight goal of 80,000.

Another challenging development problem was thermal protection for the orbiter from the searing heat of reentry. The kind of ablative heatshield that protected each Mercury, Gemini, or Apollo spacecraft for one flight had to be supplanted by insulation material that would protect an orbiter for its design 100-flight lifetime. The insulation project included a search for new materials, new computer-controlled machining techniques, and new means of cementing thousands of tiles to the skin of the orbiter. The problems gradually yielded and were under control by the end of the year.

The orbiter test vehicle, which in 1977 had flown the series of approach and landing tests, spent most of 1978 at NASA's Marshall Space Flight Center for vibration testing. The orbiter that will make the first orbital test flight was being outfitted with its flight systems at the end of the year and will be delivered to Kennedy Space Center in 1979 for preparation for launch. Another orbiter was finished this year and is in structural testing. When refurbished and fitted with flight equipment, it will join the flight program in 1981. Fabrication of the third orbiter began, and long-lead-time components were ordered for the third and fourth; they will join the fleet in FY 1983 and 1984 respectively; an option exists for a fifth orbiter if demand warrants it.

The solid-rocket boosters got their second and third firing tests in 1978. Subsystem tests, including 6 parachute drops, were completed. Boosters for the first flight were being fabricated at the end of the year.

Three external tanks were fabricated and delivered in 1978 for use in testing; fabrication began on the first three flight versions.

Ground Equipment. At NASA's Kennedy Space Center in Florida and Dryden Flight Research Center in California, the facilities and instrumentation for checkout, launch, and recovery were being installed on schedule in 1978. Installation of computerized equipment for the launch processing system—connecting the control center with the orbiter processing facility, the launch pad, and the fuel facility—was on schedule.

Planning for Operations. Up to six orbital flight tests of the Space Transportation System are planned, with the operational system beginning early in 1981. The first few years of operational flights are fully booked, partially by NASA, DoD, and other U.S. Government agencies, partially by foreign agencies and commercial customers. After intensive selection competition, 35 astronauts—6 of them women—were selected and began training. A program begun by NASA in 1977 for inclusion of small, partial payloads proved to be very successful. By the end of 1978, more than 250 advance payments for such payloads had been received. Universities have been accorded special priorities on payloads to encourage students to develop such packages.

DoD completed most of the design for Shuttle launch facilities at Vandenberg AFB, California, from which launches into polar orbit will be conducted for both military and commercial customers. Operational status is scheduled for mid-1983.

Spacelab. Early in 1978 the European Space Agency's Spacelab passed its critical design review; this was followed by fabrication of many components and their delivery to Bremen, Germany, where assembly of the flight unit was begun. The first Spacelab flight is scheduled for mid-1981.

Inertial Upper Stage. DoD's development of the Inertial Upper Stage continued in 1978. The two-stage configuration will be used by NASA mostly for delivery of heavier Shuttle payloads to geosynchronous orbits; the first such use will be to launch the Tracking and Data Satellite into geosynchronous orbit in 1981. The three-stage version will be used by NASA for planetary flights, the first being the orbiting of the Galileo mission in Jupiter in 1982.

Spinning Solid Upper Stages. These smaller, solid-propulsion upper stages will for the most part replace Delta and Centaur launch vehicles for boost of payloads from Shuttle orbit to geosynchronous orbit. Flight hardware is being manufactured; NASA has already placed orders in behalf of Comsat's Intelsat V missions and for NOAA's GOES satellites.

Skylab

Skylab, the first U.S. orbiting laboratory, has been in orbit since May 1973; after housing 3 successive crews in 1973–1974, it was expected to stay in orbit until about 1983. More sunspot activity than forecast increased the density of the upper atmosphere and shortened Skylab's orbital lifetime to 1979–1980. Concern about the uncontrolled reentry of such a large object led to an early attempt to gain the means to boost or deboost Skylab. Ground

controllers reactivated the dormant Skylab and manipulated its controls to align it in the least-resistance attitude, extending its orbital lifetime by a few months; also work was begun in October 1977 on a Teleoperator Retrieval System, a booster rocket that could be orbited on an early Shuttle flight and used to adjust Skylab's orbit. A reassessment in November 1978 found irreconcilable difficulties with continued high levels of sunspot activity, deterioration of Skylab onboard systems, and delays in the Shuttle flights. In December the effort to adjust Skylab's orbit was discontinued.

Expendable Launch Vehicles

The United States space program had a total of 33 launches in 1978; 32 were successful in launching 41 payloads. Two lost payloads in the one launch failure were DoD's DSCS communications satellites on a Titan III. Titan III, Scout, Delta, Thor, and Atlas F vehicles were used for space launches this year.

Research for Spacecraft Improvement

A number of research projects in materials and structures, electronics, and propulsion were conducted in 1978.

Materials and Structures. NASA developed a new iron-based alloy for walls of cryogenic-fuel tanks that is 100 percent stronger than stainless steel and 400 percent tougher than commercial cryogenic steel. Also, a new surface insulation proved to be 3 times as strong and 5 times as strain-resistant as material planned for use on the Space Shuttle. Graphite-polyimide structures, which promise major reductions in structural weight for spacecraft, were studied to develop techniques for processing and fabricating that will be consistent in quality and be reliable.

Electronics. Research was completed in 1978 on a long-life attitude-control system for spacecraft. Designed to function for more than 8 years, it also attained a pointing accuracy of 0.01 degrees. To improve spacecraft-derived imagery for terrestrial, astronomical, and planetary missions, NASA has been developing charge-coupled solid-state micro-electronic devices to replace vidicon tubes. In 1978 an 800 × 800-element array was built on a single silicon chip 1.2 centimeters square; in tests it provided TV-quality imagery. It will be used on the Space Telescope and Galileo missions. Another failure problem in space electronics has been microwave tubes, plagued by burnouts in the filaments of their heaters. An advanced cathode under development produces electrons by field emission, requiring no heater. Successfully fabricated this year, it holds

promise of increasing the lifetime of microwave amplifiers to over 20 years. As spacecraft have increased in capacity to collect and return larger volumes of data, a growing bottleneck has developed on Earth in the processing of raw data through a general-purpose computer, NASA has completed design of a specialized, multispectral-image processor that can reduce by a factor of 100 the time required for processing data.

DoD continued a broad range of developments in electro-optics, microwave, and computers for use in spacecraft and aeronautics. Electro-optics are being used to improve such devices as range finders and trackers, navigational systems, target designators, and miniature solid-state TV cameras. Microwave technology continues to improve the generating of microwave power and miniaturization of electronics with solid-state components. Computer improvements in mass memory are fostering computer correlation of terrain features with stored maps for precise navigation over long distance.

Space Propulsion. In rocket propulsion, NASA tested a long-duration chemical rocket burning liquid hydrogen and liquid oxygen, this year with both high-pressure turbopumps operating at rated speeds. In solar electric propulsion, NASA completed the baseline processor and operated it with an ion thruster; this is technology for a 3-kilowatt, 3000-second specific-impulse thrust subsystem for orbital control of spacecraft. Fabrication was begun on NASA's one-millipound auxiliary thruster, to be test-flown on an Air Force satellite in 1981.

Aeronautical Transportation

Aeronautical transportation, like space transportation, comprises military as well as civil systems and those already operational as well as those in development.

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

FIGHTER AIRCRAFT. The F-15 continued to be deployed to tactical units, totaling 360 production aircraft by the end of the year. Improvements added in 1978 were an increased fuel capacity and improved radar capability. The F-16 multinational fighter completed most of its developmental test program in 1978 and will enter the Air Force operational inventory early in 1979. The F/A-18 carrier-based fighter flew for the first time in November and has been approved for full-scale development; it will replace Navy and Marine F-4 Phantom fighters. The A-10 close-support aircraft is being delivered to tactical units in the U.S. and Europe, 175 of them by the end of the year. The AV-8B, the improved light attack vertical/short

takeoff and landing aircraft for the Marine Corps, completed the first phase of wind-tunnel testing at NASA's Ames Research Center. NASA data confirm superior V/STOL characteristics that will enable it to double the range or payload of the AV-8A. The first flight of one prototype aircraft took place in November.

BOMBER AIRCRAFT. The B-1 bomber, though canceled for production and deployment, continued a 3-aircraft development and test program at Edwards AFB, California, to measure performance and structural airloads, complete development of the F101X engine, and evaluate the offensive avionics.

TRANSPORT AIRCRAFT. The E-3A Airborne Warning and Control System (AWACS) aircraft, activated into an operational wing in April, were evaluated during the Brave Shield XVII exercise in the Pacific Northwest. Two aircraft were operationally deployed to Iceland in October to replace aging EC-121s for airborne surveillance and control over the North Atlantic. The advanced E-4 concept (E-4B), intended for command and control of strategic nuclear forces, was in an extensive test program to determine final systems and configuration.

HELICOPTERS. The CH-47 helicopter program completed the modernization of 7 major systems in 2 of 3 prototypes. When testing is completed, the modernized systems are to be installed in all A, B, and C models, greatly simplifying logistics and maintenance. The Advanced Attack Helicopter was in test and evaluation of design modifications on 2 flight prototypes. Fabrication began on 3 more prototypes. Initial actions were taken on the H-X helicopter, a concept for an advanced replacement of the "Jolly Green" search and rescue helicopters that performed so well in Vietnam. This version would be capable of long-range penetration of enemy territory at night and in bad weather.

CRUISE MISSILES. Flight tests continued with the Tomahawk, a high-subsonic-speed, turbofan, long-range cruise missile. Designed for launch from submarines or surface vessels and to carry conventional armament, it can also be a land-attack missile with a nuclear warhead. In full-scale development were three other configurations of cruise missile: the Air-Launched Cruise Missile will fly a competition of prototypes in the second half of 1979; the Sea-Launched Anti-Ship Cruise Missile is planned for offensive or defensive use from submarines, cruisers, and Spruance-class destroyers; the Ground-Launched Cruise Missile, planned for a theater-of-operations role, could, by providing more nuclear firepower, relieve aircraft for use in conventional missions.

Operational Airway Systems. The Federal Aviation Administration (FAA) of the Department of Transportation is responsible for operating the National Aviation System. NASA assists with R&D for the airborne portions of the system.

AIR SAFETY. FAA continued to improve aircraft equipment and to study safety-related problems for aircraft on the ground, in takeoff, and in landing. As a result of research into the problems of controlling aircraft traffic on the surface areas of airports—runways, taxiways, etc.—particularly in bad weather, a new radar has been developed. The ASDE-3 (Airport Surface Detection Equipment) is better able to detect and track stationary and taxiing aircraft in all weather conditions. A development model will be evaluated.

To provide warning of potential wind-shear problems during takeoffs or landings, the FAA has developed and tested the Low-Level Wind Shear Alert System. Remoted anemometers are mounted 6 to 12 meters above the ground in the approach and departure corridors at busy airports. When a wind vector difference of as much as 28 kilometers per hour develops between any of the remoted anemometers and the centerfield anemometer, the air traffic controllers relay the information to all arriving or departing aircraft.

A machine-generated wind problem of increasing concern has been the wake vortices—strong rotational wind gusts—that trail behind large jet aircraft as they approach and land; following aircraft, especially smaller ones, are endangered and must be protected by enlarging the separation distance between aircraft, which reduces the airport's traffic capacity. A prototype of a Vortex Advisory System is being tested at Chicago's O'Hare International Airport. A network of anemometers in the runway approach zones assesses wind conditions, determining when aircraft separation can be set at 5 kilometers.

AIR TRAFFIC CONTROL. Since 1971 the Departments of Defense and Transportation and NASA have jointly worked on R&D for a Microwave Landing System (MLS). There are both operational and economic advantages to equipping the national air network with a universal system that can handle civil and military air traffic for the remainder of this century.

The same deficiencies in the existing Instrument Landing System (ILS) that motivated the U.S. to develop a new landing system also affect the international aviation community and generated wide support for a new international standard. The International Civil Aviation Organization (ICAO) set out to select and standardize an international system. There were several competing sys-

tems and a series of demonstrations narrowed the field. In April 1978 the U.S. entry, the Time Reference Scanning Beam, was selected by the ICAO as the international standardized system. Concurrently the development of MLS prototypes continued; the Basic (Wide Aperture) System will be tested in 1979. Test and evaluation of the Basic (Narrow Aperture) and Small Community Systems were completed.

Another system entering evaluation is the Discrete Address Beacon System; the first of 3 models began evaluation in mid-1978, another in October. The beacon system provides discrete identification of individual aircraft by use of code-numbered transponders in the aircraft. In the increasingly automated environment of the airways system, this automatic identification factor is important.

Airway Modernization. The airway system is moving toward greater automation and conversion to digital operations. An all-digital terminal automation system was demonstrated in the Tampa-Sarasota area in December 1978. In this system, satellite control towers as far as 32 kilometers from an air traffic control center can be fed radar data for safe separation and control of aircraft.

To increase the productivity of the air traffic controller, FAA began development of TIPS (Terminal Information Processing System) to relieve the controller of manual duties by providing an improved system for processing and distributing flight and other operational data. The system may be installed in as many as 60 high- and medium-density terminals and 70 low-density terminals.

Research for Aeronautics Improvement

An essential element in a competitive national aviation establishment is a continuing flow of innovations and refinements. NASA and DoD research improvements in present and future aircraft, while FAA develops improvements in the National Aviation System. (Research on environmental effects of aircraft will be found in the *Earth's Resources* section of this chapter.)

Engines. For current transport aircraft, NASA research concentrated on improving the technology of individual components in engines to make them more efficient in fuel conservation and to improve the durability of engine systems. For future turbofan engines for transport aircraft, NASA began research in 1978 on component technology with the goal of reducing fuel consumption by 12 percent. DoD operated two programs: one assessed core components of engines under realistic test conditions, seeking to improve reliability and reduce costs in manufacturing and maintenance; the other program studied the interaction of high-pressure engine

components, such as turbine engine cores, with low-pressure fans and compressors to evaluate the total engine system as an installation problem.

Aerodynamics. NASA wind tunnels tested a series of high-lift devices, winglets, and extended wing tips. High-lift flaps and slats showed greater lift coefficients with the supercritical wing than with the current transport-aircraft wing. Winglets and wing extensions, when applied to current transport aircraft, recorded drag reductions of 3 to 5 percent. A joint NASA-Air Force flight-test program will evaluate winglets mounted on KC-135 aircraft in 1979.

A problem in design of modern fighter aircraft has been that the high power levels of modern engines generate so much turbulence that it distorts the basic aerodynamics of the airframe, thereby compromising the overall performance of the aircraft. NASA has test-flown the F-15 aircraft and subjected it to wind-tunnel testing; the combined data have improved our ability to predict interactions between propulsion aerodynamics and airframe aerodynamics.

Structures. DoD and NASA research on aircraft structures is mostly concentrated on development of composite structures that can substitute for conventional aircraft structures, with reductions in weight and fatigue problems. Conservative in approach, the testing thus far has involved relatively small components of larger structures, building up a design data base in static, fatigue, and sonic experience. The largest parts now in flight test are a 3-meter section of the B727 elevator and a 2.5-meter segment of a spar for the L1011 vertical fin.

DoD continued research and test of a number of applications of composite materials to aeronautical structures, helicopter blades, etc., to reduce weight and cost. Another area of exploration is adhesive bonding of structures in large cargo aircraft, with the intent of reducing assembly demands from hundreds of pieces to a few large bonded modules.

Improvement of Long/Short-Haul Aircraft. NASA's research on technology for future long-haul supersonic aircraft centered on flight tests of systems and components on the YF-12 aircraft. Extensive flight tests were completed using a cooperative flight control system that successfully integrated engine and engine inlet control systems. Attempts to lower costs and lengthen the life span of supersonic aircraft focused on concepts for advanced superplastically formed/diffusion bonding of structural elements.

Research on quiet short-haul aircraft reached a high point in 1978 with delivery of NASA's Quiet Short-Haul Research Aircraft. In August it began a year-long proof-of-concept flight test program. So far the aircraft has demonstrated 3 times as much

approach lift coefficient as conventional jet transports, making possible very low approach speeds at extremely low noise levels.

Aircraft Fire Safety. FAA intensified its research into post-crash cabin fires in several parallel programs. One set of tests examining the hazards to cabin occupants from burning fuel spills showed that for 5 minutes after the crash, stratified heat and smoke were major barriers to escape, but that the lightest winds could blow combustion gases into the cabin and increase the dangers. Another continued the examination of various cabin materials to identify those that gave occupants the best chance of escape. An agreement was signed with the United Kingdom to do enough research on antimisting kerosene to determine whether preliminary tests justified a full test program on this approach to minimizing the fireball that often accompanies crashes that otherwise would be survivable.

Aviation Security. This year the FAA focused its R&D for deterring air-travel terrorism and sabotage on improved techniques for the detection of explosives in luggage. Investigations included a testing of a bomb-detector system based on nuclear magnetic resonance; examination of computer-aided dual-energy x-rays, used in medicine for "cross section" x-ray pictures, for possible application to bomb detection; and development of computer software that substantially increases the contrast in an automated radiation system for detecting bombs.

Space Energy

The standard means of producing or storing electrical energy in space have been solar cells, batteries, fuel cells, and radioisotope thermoelectric generators. Future space missions now being planned by NASA and DoD will require dynamic power systems to provide notably higher voltages over a mission profile lasting several years. Attention is also being given to the possibility of capturing large quantities of solar energy in space and beaming it to Earth as a supplemental power source.

Energy for Use in Space

Solar Cells and Arrays. NASA's work on improving the efficiency of solar cells broke through a long-standing barrier in 1978. The voltage limitation that had existed for silicon solar cells since 1954 was finally exceeded. Since higher voltage means increased cell efficiency, future solar arrays can be 20 percent lighter, smaller, and cheaper. In a separate development, lightweight solar arrays were success-

fully tested at full scale—32 meters long and producing 66 watts of electricity per kilogram of weight.

Batteries. Batteries have limited the effective life of Earth-orbiting satellites. The most limiting factor in battery life has been the separators, used to deny contact between the active ingredients. NASA research has produced a new separator that can double the life of batteries; the separator is now being tested in nickel-cadmium batteries. In another approach, DoD is working on development of a nickel-hydrogen battery, intended to replace current nickel-cadmium batteries.

Radioisotope Thermoelectric Generators. The Department of Energy (DOE) is developing a new form of radioisotope thermoelectric generator (RTG) for NASA's Galileo mission. Scheduled for launch in January 1982, Galileo will require two 200-electrical watt RTGs for reliable power sources lasting 5 or 6 years. DOE chose a power source new to the space program, a selenide isotope, as the power generator. Conversion efficiency should run 8–9 percent as opposed to the 6–7 percent of previous silicon germanium generators.

A further improvement in the efficiency of this system is called for by the International Solar Polar Mission, operated jointly by NASA and the European Space Agency. Two spacecraft are to be launched early in 1983; each will need a power supply of 275 watts two years after launch. DOE's work this year was in concepts for the design of the selenide generator to a new conversion-efficiency standard of 10–11 percent.

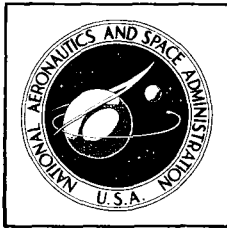
Dynamic Power Systems. At space power levels

greater than 500 watts, dynamic power systems are expected to take over from the static selenide conversion systems because of improved efficiency, endurance, reliability, and weight ratio. In the Kilowatt Isotope Power System (KIPS) program, an Organic Rankine Cycle was selected during 1978 to be further developed for use in missions in the 1980s. The goal of the KIPS program is 1000–2000 watts at an efficiency of 18 percent.

Reactor Power Systems. Potential DoD missions in the 1980s foresee electrical power requirements in the range of 10 to 100 kilowatts. DOE is continuing studies of several possible reactor concepts, fuel forms, and conversion systems.

Energy from Space for Use on Earth

The concept of a Satellite Power System in geostationary orbit, spreading massive collectors to capture solar energy, concentrate it, and beam it to Earth antennas, has been studied since 1968. Several years ago NASA operated a modest investigation of the concept; in 1976 responsibility was transferred to DOE, with NASA continuing to provide baseline technology. In 1978 DOE and NASA published a joint plan for concept development and evaluation. Under this plan NASA will identify the concepts that are most attractive from technical and economic standpoints. DOE will assess the possible consequences in terms of environmental, health, and safety effects. Also DOE is doing a comparative study of solar power systems versus other advanced energy systems.



National Aeronautics and Space Administration

Introduction

The National Aeronautics and Space Administration (NASA) is charged with the planning, direction, and conduct of research and development in space and aeronautics for civil purposes. Activities are shared or joined by a number of other civilian agencies of governments—foreign, Federal, state, and local—with research or operational interests in these fields. The Department of Defense (DoD) conducts the portion of the space program that is peculiarly military; in aeronautics, NASA supports DoD with research data which may be of use with current and future military aircraft.

In space, NASA's long-standing goals have been the development of technology and techniques for more effective space operations; development and demonstration of an increasing range of practical applications of space technology and data; and scientific investigations of the Earth and its immediate environment, of the bodies comprising our solar system, and of the origins, entities, and physical processes of the Universe. In aeronautics, the goals have been improvement in the aerodynamics, structures, engines, and overall performance of aircraft, to make them safer, more efficient, and more compatible with our environment.

Applications to Earth

NASA's programs for applying space research and technology to specific needs of the nation made substantial progress in 1978. The emphases continued to center on space observations of Earth's environment and resources, experimenting in space to acquire new knowledge about materials, and improving technology for space communications.

Environment

In environmental observation, NASA applies space technology to information systems so that we may better understand and forecast environmental behavior. There are five major research areas;

weather, climate, severe storms, ocean processes, and environmental quality.

Weather. Weather research focuses on techniques and instruments that can significantly improve forecasting. Much of the work is carried out jointly with teams from the National Oceanic and Atmospheric Administration (NOAA) of the Department of Commerce, and is largely developmental support of NOAA's operational National Environmental Satellite System.

Both NASA and NOAA have been preparing major support for the international project called GARP, the Global Atmospheric Research Program. In 1978 GARP moved from the planning stage into the Global Weather Experiment (GWE). Beginning on December 1, 1978, the one-year experiment will study worldwide atmospheric patterns essential to understanding the transient behavior of weather (both near- and medium-term) and to learning about the physical processes involved. Work in NASA concentrated on the collection and processing of satellite-sensed data, preparation of data sets derived from Nimbus and Seasat satellite observations, and analysis and applications of such data. NASA supported NOAA in updating its operational system—a system crucial to the first GARP effort—by orbiting the Goes 3 spacecraft and by completing the experimental Tiros-N spacecraft and launching it on October 13, 1978. Tiros-N incorporates technology developed in NASA's R&D programs as well as two major instruments contributed by France and the United Kingdom. Designed to requirements stated by NOAA, it emphasizes the acquisition of quantitative data from Earth's atmosphere and surface. When used in numerical models of the atmosphere, these data should significantly enhance NOAA's ability to make extended (1–2 week) forecasts. To this end, Tiros-N will be a primary data source for the GWE.

Goes 3, launched June 16, 1978, completes a series of Geostationary Operational Environmental Satellites (GOES). Currently the mainstay of NOAA's operational system, the GOES satellites

were derived from NASA's experimental synchronous meteorological satellites. Goes 3 is stationed at 135 degrees west longitude, from which position it constantly monitors weather conditions over the Pacific Ocean and the western U.S.

As the time drew near for the beginning of the GWE, a void in the global data collection system seemed likely when the Soviet Union informed the participants that it would not be able to launch its synchronous meteorological satellite in time for the experiment. NASA, NOAA, the National Science Foundation, and the European Space Agency (ESA) jointly decided that the gap should be filled by moving one of the GOES satellites. NOAA relocated Goes 1; it started operating from its new position over the Indian Ocean in December 1978 under control of an ESA ground station near Madrid, Spain.

After 5 years of development, Nimbus 7 was launched into polar orbit in October 1978. The nation's first research satellite dedicated primarily to measurement of environmental quality, the 8 sensors on Nimbus 7 will monitor pollution (measuring stratospheric constituents such as ozone, aerosols, and other trace gases); observe ocean conditions (measuring water color in the coastal zones to determine chlorophyll and sediment distribution, sea-ice distribution, and sea-surface winds, temperatures, precipitation, etc.); and will monitor Earth's radiation budget, a key climatic factor.

Climate. In 1978 NASA defined its goals and objectives for a broad research program in support of the evolving National Climate Program. They included development of space capability for global observations of those parameters that will contribute to understanding the processes that influence climate and climate change. NASA's climate research program will include

- the use of space-derived data sets for climate applications and studies
- development of a global climate observation system
- special studies of important climate processes.

Also in 1978, a major sensor system was defined that will make significant contributions to the climate program—the Earth Radiation Budget Experiment. It will be designed to provide long-term, continuous measurements of energy arriving at and leaving from the Earth. Detailed scientific and technical requirements were coordinated with NOAA and other users, agreed upon, and procurement of flight hardware was begun in late 1978. Also NASA began measuring the solar constant using Earth-radiation-budget data collected by Nimbus 6 and 7. The value of the solar constant

during the last two years was found to have remained stable within 0.2 percent.

A major study begun in 1978 is analyzing the effects of atmospheric aerosols on Earth's climate. Key scientific areas being investigated are the contribution of volcanic aerosols to climate changes, human contributions to stratospheric aerosol layers, influences of human-generated tropospheric aerosols on the heating or cooling of Earth, and regional climatic effects related to all these factors. In situ measurements and the remotely sensed data from the Nimbus and SAGE satellites will be used in this investigation.

Severe Storms. NASA's goals for severe storms research are to reduce the geographic size of early warning areas for these violent events and to identify meteorological indicators that enable early diagnosis of individual storms as they develop. Subject of investigation include indicators of storm severity, development of storm prediction models, improvement of understanding of the atmospheric dynamics involved, and development of ground-truth requirements.

Another effort in severe storms research is the Atmospheric Cloud Physics Laboratory. Planned for launch on Spacelab 3, this laboratory is expected to provide new information on precipitation and warm-cloud formation, factors essential to improvement of rain forecasts. The project is progressing satisfactorily. After experiment design was reviewed in detail in May, hardware development was begun.

An instrument that looms very important in local-storm research continued its progress toward flight readiness. The VISSR (for Visible and Infrared Spin-Scan Radiometer) Atmospheric Sounders (VAS) will operate from geosynchronous orbit, providing highly dense and continuous measurements of factors vital to storm generation. The VAS demonstration will be conducted in cooperation with NOAA. The NASA-funded first instrument is to be provided for the Goes-D spacecraft, to be launched in mid-1980.

Ocean Processes. NASA conducts ocean-processes research in several areas: use of remotely sensed data for understanding and forecasting the marine environment, demonstration and validation of advanced ocean-sensing techniques, development of marine geophysical models; and evaluation of the benefits from satellite-derived ocean data.

Launched in 1975, Geos 3 continues to provide useful information. Altimeter data have been used to define ocean geoids for many parts of the world. Of particular importance was the completion of the detailed western North Atlantic geoid. Users of GEOS data include the Defense Mapping Agency, NOAA, and the Department of the Interior.

Seasat 1 was successfully launched on June 26, 1978. The objectives of the Seasat mission were to measure the global ocean dynamics and physical characteristics, to determine the key features of an operational system, to improve the body of scientific knowledge about oceans, and to demonstrate the utility of the data to the user communities. All sensors were turned on by July 7.

By mid-July, measurements had been made of the open ocean, the Gulf Stream, Beaufort Sea ice, and Hurricane Fico. This range of targets provided initial data on all the principal objectives for the Synthetic Aperture Radar. Ocean features observable in the data included waves, air-sea interactions marked by natural slicks, Gulf Stream shear, surface winds, sea ice, storm seas, and orographic steering of on-shore winds by terrain features. The pass over the hurricane also produced quantitative wind speed and direction data, supplemented by NOAA's surface-truth data from aircraft and ships. It is fortunate that such a range of data types was acquired early in the mission, for on October 9 Seasat had a massive electrical failure; all attempts to receive or communicate with the satellite since then have been unsuccessful. The categories of data that had been acquired were being analyzed to determine their productivity and potential for future applications.

On Nimbus 7 the Coastal Zone Scanner is measuring patterns of reflected sunlight associated with water-quality indicators such as sediments, chlorophyll, and certain pollutants. A Scanning Multi Channel Microwave Spectrometer, identical to the one on Seasat 1, is measuring sea-surface temperature, atmospheric water vapor, and winds.

Environmental Quality. In NASA's research on environmental quality there are three broad areas of investigation: the quality of the surface waters of lakes, rivers, and ocean coastlines; the quality of the lower atmosphere, or troposphere, with its regional air pollution problems; and the problems of the upper atmosphere, or stratosphere, especially of ozone variability and the interacting constituents which influence ozone.

In a study of air quality, an investigation was begun on applying remote sensing technology to studies of pollutant chemistry and the transport of pollutants downwind from urban centers—the "urban plume" problem. To determine the design parameters of mature remote sensing instruments that could measure urban-plume constituents such as carbon monoxide (CO), methane (CH₄), ozone (O₃), sulfur dioxide (SO₂), and particulates, NASA joined with the Virginia State Air Pollution Control Board in a measurement program to characterize the urban plume from the Norfolk-Hamp-

ton Roads area of Virginia. From its nearby Langley Research Center, NASA flew instrumented aircraft to sample the plume during the summer of 1977, while the Virginia agency measured the ground-level concentrations of ozone. The studies showed that typical buildups of ozone downwind from the urban complex were as much as double the concentrations nearby. In July 1978 two NASA-developed laser systems were used to take measurements of the total ozone burden in the mixing layer—normally from the surface to two kilometers—with one laser flown in an aircraft and the other operating from the ground. The results are now being compared with other measurements made at the same time by more conventional techniques. If their accuracy is confirmed, the NASA instruments may become prototypes for advanced sensors in future space missions.

Long-term monitoring of stratospheric ozone is essential for the years ahead not only because the ozone layer filters out much of the harmful solar ultraviolet radiation which would otherwise reach Earth's surface, but because of the role that ozone and other stratospheric gases and aerosols play in the environment's energy balance and in the world's climate. In the last year considerable progress was made in reducing the backlog of ozone data collected earlier by Nimbus spacecraft and awaiting analysis. Refined methods of analysis have produced more effective data products for use in further scientific studies. Color-coded images clearly show geographical variations in ozone; a sequence of such images can show temporal variability and transport phenomena.

NASA has been an active participant in international groups interested in ozone monitoring. The World Meteorological Organization (WMO), for example, supplements satellite observations by data collection from balloons, sounding rockets, and ground-based measurements. In April, an International Intercomparison of Ozonesondes met in the Federal Republic of Germany. Ozonesonde balloons were launched during a two-week period by East and West Germany, Japan, and the U.S. Intercomparisons help to ensure the compatibility of the data these countries contribute to WMO's Global Ozone Research and Monitoring Project.

Resource Observations

Space observations are developed and their application demonstrated to meet national and international needs for improved management of agricultural production, water, and land resources; for improved exploration of mineral and energy resources; and for better understanding of the dynamic characteristics of Earth.

For the decade of the 1970s, the principal instrument for gathering the remotely sensed data needed for such purposes has been the Landsat series of Earth observation satellites. For five and one-half years Landsat 1 had provided data; its operations were finally terminated in February 1978 because of mounting instrument and system problems. Landsat 2, launched in January 1975, is operating nearly flawlessly. The remaining onboard tape recorder has now logged more than 1150 hours of use, exceeding all lifetime expectations based on ground tests and orbital experience with Landsat 1. Landsat 2's orbit was adjusted to counteract its natural degradation and to lag Landsat 3 by 9 days for better spacing of Earth coverage. Landsat 3, launched on March 5, 1978, is producing good data from the 4 reflective bands on the Multispectral Scanner. Excellent data, with improved resolution, are coming from the upgraded Return Beam Vidicon system. The only anomaly is the malfunction of the thermal band. One of the two detectors in this band has failed, decreasing the resolution along the orbital path by a factor of two.

In addition to Landsat receiving stations in the U.S., receiving stations also operated in Brazil, Canada, Iran, Italy, Japan, and Sweden. These stations function under agreements between NASA and their sponsoring agencies. More stations are in process in Argentina, Australia, and India, and others are under discussion.

The new all-digital Landsat data processing system has been installed at NASA's Goddard Space Flight Center and the Department of Interior's EROS Data Center and at year's end was in the final phases of checkout. It will significantly improve the delivery time for requested Landsat photographic products and computer-compatible tapes. Previous delivery times of 30-60 days should decrease to 15-25 days with the new system. When a communications-satellite data link is established between the ground receiving stations and these two data-processing facilities in early 1979, delivery times should be reduced another 5 days.

RENEWABLE RESOURCES. During 1978, NASA researched, developed, and tested techniques for extracting from space-acquired data the information that is important to the management of agriculture, forestry, range land, water, and land resources.

AGRICULTURE. Over the last several years, most of the R&D effort on applying space-derived data to agricultural needs has been in support of the Department of Agriculture's Large Area Crop Inventory Experiment (LACIE). Extending over three crop-years, the experiment was completed in the summer of 1978. On the whole, the results were very promising. LACIE met the "at harvest" ac-

curacy goal of 90 percent prediction of wheat production in the U.S. Southern Great Plains and did as well in the U.S.S.R.

The major technical accomplishments have been:

- Techniques and procedures were developed for using remotely sensed data to forecast wheat production in foreign areas on a timely and objective basis.
- Acceptable accuracies were achieved for prediction of wheat production in the U.S.S.R., although the repeatability of this accuracy over a longer time frame has yet to be demonstrated.
- In foreign and domestic situations where current crop information is inadequate, Landsat data were studied to develop improved sampling techniques and to obtain better understanding of farming techniques.
- Analysis techniques that were developed made digital data more cost effective; analyst time was reduced from 12 hours per segment early in the LACIE program to 3 hours, while improving accuracy.

LAND AND WATER RESOURCES. During 1978, NASA operated in a number of geographical locations demonstrating Landsat's capability to provide meaningful, repetitive data for such diverse problems as land-use change, forest clear-cutting practices, the status of irrigated lands, and population growth on the urban fringe.

Three Application System Verification and Transfer (ASVT) projects continued this year with the Pacific Northwest states of Oregon, Idaho, and Washington in a Land Research Inventory Demonstration; the Army Corps of Engineers in a Water Management and Control project using Landsat data for delineation of hydrologic land use; and with several states (California, Colorado, and Arizona) and Federal agencies (Departments of Agriculture, Interior, Energy, and Army Corps of Engineers) using Landsat data for improved snow-mapping and water-runoff predictions. Measurements of snowcover areas have been correlated to snowmelt runoff in California and Colorado. Year-to-year comparison of snowcover measured by Landsat provided data that were closer to actual flow than forecasts using conventional techniques, which ran 8-11 percent higher. Planning is under way to make this technology available for routine use in western states.

Two new ASVT projects were started in 1978: one was a demonstration of the capability of Landsat data to assist the Navajo Nation to assess and better plan for development of their lands; the other was a demonstration in conjunction with a consortium of 13 Texas state agencies using Land-

sat data to update and maintain a multipurpose natural resources inventory.

Four Applications Pilot Test (APT) projects continued in 1978: one with the Department of Interior in a Wildland Vegetation Inventory demonstration and another in a Land Use and Change Detection demonstration; one with the St. Regis Paper Company demonstrating a Forest Resource Information System; and one with the Bureau of the Census for an Urban Area Boundary Delineation study. Five cities have been classified—Boston, Orlando, Houston, Seattle, and Richmond—as to land use and the outer boundary of the urban-area fringe zone delineated by means of remotely sensed data. The next phase will begin in FY 1979; 5 cities will be studied to determine the capability of remotely sensed data to detect urban change.

In 1978 major emphasis was placed on transfer of resource observations technology to state and local governments. A cooperative effort was initiated with the National Governors Association to make state agencies more aware of potential uses of remote sensing. In combination with a parallel arrangement with the National Conference of State Legislatures, this effort provides a basis for continued assessment of state needs for NASA technology and for development of long-term programs for meeting those needs.

The Regional Remote Sensing Applications Program assists state and local government agencies in developing a capability to use Landsat data for meeting resource and environmental management information needs in response to Federal and state legislation. Since early 1977, over 250 state personnel have been trained in the use of Landsat digital data processing techniques. Multi-discipline technology demonstration projects were underway or completed in 17 states during 1978. Transfer programs resulted in development of a Georgia Natural Resources Inventory System operated by the state's Department of Natural Resources. Demonstrations of land-cover inventory from Landsat data were begun in Maryland, Montana, and North Carolina and are under way in seven other states. North Carolina has acquired a data processing system for utilizing geo-based information and is rapidly integrating Landsat data into land-cover analysis. In agricultural applications, a project demonstrating Landsat use in cotton-crop inventory was completed in California. Similar agricultural land-use demonstrations were begun in Florida and Montana and are under way in three other states. Other demonstration projects included inventories of water resources (6 states), forests and rangeland (7 states), environmental management (10 states), and wildlife habitat management (6 states).

Non-Renewable Resources. Earth-observation data are obtained from a family of specially instrumented satellites applied to land-form analysis.

OBSERVATION AND DATA SYSTEMS. A new tool, the Heat Capacity Mapping Mission (HCMM) spacecraft, was launched on April 26, 1978, into a Sun-synchronous orbit. The 620-kilometer-high track of the spacecraft enables its instruments to obtain maximum and minimum ground-surface temperatures at selected locations within a 24-hour period. Comparison of these two temperatures may provide a new way of identifying rock types and deriving soil moisture. The first data products were provided to investigators in early August.

An ASVT was started this year with 7 Appalachian states—New York, Pennsylvania, Ohio, West Virginia, Virginia, Kentucky, and Tennessee—to demonstrate the use of Landsat data in identifying and locating geological lineaments associated with natural gas found in Devonian shale.

Several instruments are being developed for flight on the Shuttle in experiments to define their value to geological prospecting:

- The Shuttle Imaging Radar-A. This synthetic aperture radar, developed from residual Seasat hardware, will be used to evaluate the applicability of L-band imaging radar for analysis of geological land forms and structure. It is scheduled for an Orbital Flight Test mission.
- The Shuttle Multispectral Infrared Radiometer. This 10-channel instrument should help determine the most useful region of the spectrum for discriminating among rock types and different surface compositions. It too will fly on an early Shuttle mission.
- The Large Format Camera. To be available for flight in late 1980, this camera will provide high-resolution stereo photography with several base-to-height ratios. A single picture from an altitude of 190 kilometers will cover 26,000 square kilometers on Earth, an area equal to that of the Florida peninsula from Miami to Orlando, with a resolution of 10–15 meters.

GEODYNAMICS. Research in geodynamics contributes to understanding of earthquake mechanisms, to the processes leading to the formation of mineral and energy resources, and to a general improvement in scientific knowledge of Earth.

Very Long Baseline Interferometry (VLBI), using signals from radio stars or laser-ranging to satellites and the Moon, provide a basis for ultra-precise geodetic measurements that are theoretically capable of accuracies to within centimeters over continental distances. These techniques can be used to measure the motion and rotational rate of

Earth's polar axis, tectonic plate motion, or crustal deformation at plate boundaries.

NASA made VLBI measurements using large fixed antennas at radio observatories on the U.S. east and west coasts and mobile systems in California. For ground-to-satellite signals, mobile laser systems made measurements in Massachusetts and California and these were compared with ground geodometer systems. While the laser results are still being analyzed, the VLBI experiments demonstrated a repeatable accuracy of 4–6 centimeters for both continental and local-scale distances. Improvements in atmospheric correction techniques are now being made which should provide the precision (1–2 centimeters) required for detection of crustal deformation.

Using satellite laser ranging, NASA succeeded in detecting the relative motion of the North American and Pacific plates across the San Andreas Fault in California—the first direct measurement of plate motions ever made. These results were derived from distance measurements made in 1972 and 1974 and again in 1976 as part of the San Andreas Fault Experiment. More observations started in December 1978, using improved Mobile Laser Stations and the Laser Geodynamics Satellite (Lageos), to verify and extend the earlier results. Eight mobile ground laser stations are now being readied for global deployment in mid-1979 to acquire data for the Lageos investigations.

Improved models of the Earth's gravity field are being developed. These will contribute to understanding of Earth's interior composition, structure, and density distribution, all of which relate to the location and formation of natural resources; to understanding of the forces that product tectonic plate motions; and to analysis of satellite altimetric data for studies of ocean current systems and ocean circulation. The latest Goddard Earth Model (GEM-10) accounts for features as small as 750 kilometers in size. The gravimetric geoid derived from this model clearly delineates gravity variations associated with tectonic features, such as the subduction occurring at deep trenches. Gravity models currently being developed will make it possible to define features that are about 500 kilometers in size. In addition to using conventional satellite tracking data, these new models will contain satellite altimetry data from Geos 3 and Seasat 1, as well as additional surface gravimetry measurements that are now becoming available.

Materials Processing in Space

At present NASA's work in materials processing in space concentrates on developing methods of experimenting so as to learn more about materials

behavior and developing space processes to produce materials.

The unique physical effect in space that cannot be duplicated on Earth is, of course, weightlessness. It interests materials processors because it voids two of the effects of the law of gravity that have limited materials processing on Earth: one is the convective motions that gravity compels in fluids; unstable and uncontrolled, these motions cause variations in temperature and composition of the forming material. The other is the contamination suffered by chemically reactive materials when they come in contact with their container while processing. Experiments have verified that weightlessness could mitigate these problems. The work done in space thus far has developed some of the basic techniques that will be needed for more sophisticated investigations.

For several years NASA had worked to draw together a combination of scientific interests and space capabilities to take advantage of the routine access to space that will be afforded by the Shuttle. The past year has seen major progress in seeking participation from the materials R&D community, beginning with a National Academy of Sciences study which endorsed the scientific investigations of materials and recommended a research strategy leading to private and non-NASA government support of such investigations after an initial phase of technology development and demonstration. NASA worked closely in 1978 with an advisory committee from the materials community, making detailed technical and management plans to implement the strategy recommended in the NAS study. Candidate subjects found to be attractive for early experiments include detector materials, inertial confinement fusion targets, containerless processing, floating zone experiments, heat-pipe technology, space vacuum research, and bioprocessing studies.

Concurrently NASA has proceeded with development of the experiments proposed by the scientific community and selected in 1977 for flight on early Space Shuttle missions. A contractor was selected in 1978 and has been working with the experimenters to arrive at design requirements.

In preparation for the transition to private research, NASA has established a Commercial Space Processing Development Office at the Marshall Space Flight Center in Huntsville, Alabama. It studies institutional, legal, and economic issues involved in private space processing, operates an information program for industry, and negotiates with U.S. companies interested in long-range joint undertakings with NASA. Two proposals for joint projects leading to commercial manufacturing operations in orbit have been received from industrial sources and are being evaluated.

Space processing experimentation continued in 1978 with the September 11 flight of the Space Processing Applications Rocket (SPAR). All experiments performed well. Four films and some 20 experiments were recovered and are being analyzed by the experiments.

Much of the SPAR equipment is readily adaptable for use on the Shuttle as a "piggyback" payload, since it can operate nearly autonomously. NASA has begun development of a package of interface hardware that will support SPAR payload apparatus on the Shuttle. The Materials Experiment Assembly includes mounting hardware, power supply, heat rejection and command subsystems, data recording equipment, and acceleration measuring instrumentation. To be flight-ready by 1980, this inexpensive rental equipment, when combined with the SPAR equipment, will provide the capability for space-processing investigations in crystal growth, alloy solidification, formation of particle dispersions in solid electrolytes, containerless processing of glasses, and growth of large polymer particles.

Communications

NASA continued research in communications technology aimed at alleviating problems in use and allocation of the increasingly crowded geosynchronous orbit and the radio spectrum. These are finite resources that must be used with maximum efficiency.

Bandwidth Compression. One improvement now in design and development is a spaceborne antenna that, on command, can quickly form, shape, and point its transmit and receive beams in response to the needs of users on the ground, while avoiding interference. Based on technology used by DoD, the agile beams of this Adaptive Multi-beam Phased Array can greatly increase the effective capacity within any frequency band. The new antenna will be tested in orbit in a Shuttle/Spacelab flight.

With the coming of the digital era to space communications, the designated frequency allocations require the use of special systems for transmitting digital television signals within a minimum bandwidth. NASA has developed a bandwidth compression technique, demonstrating full-motion color television transmission on only one-tenth the bandwidth otherwise required for digital transmission.

Low-Cost Data Collection. Several agencies have encountered problems in low-cost data collection from remote areas. Commonly, low-rate data from the user's sensors are relayed by a small, standardized ground terminal through a NOAA satellite to a central analysis point.

NASA in the past year completed a joint pilot project with the California Division of Forestry us-

ing satellite systems to demonstrate forest fire protection. Local weather and ground moisture data were sent from remote regions through a NOAA satellite's repeater to meteorologists in Sacramento who can interpret from the data the probability of a forest fire's occurring in a specific region.

Also in 1978 NASA concluded arrangements with the U.S. Coast Guard to demonstrate the use of satellite communications technology for identifying and locating fishing vessels and controlling tanker traffic within our 370-kilometer offshore conservation zone. In the planned experimental system, ships to be monitored would be required to carry a receiver/transmitter that would receive navigation data derived from the Coast Guard's Loran-C system and automatically send it through an existing geostationary satellite to a ground computation center. The shipborne equipment is now in design; experiments with the equipment aboard Coast Guard ships are planned for 1980.

Land-mobile communications via terrestrial radio links have grown explosively in the last 10 years, a trend that is expected to continue. By 1990 there may be 200,000 mobile telephone subscribers, 1 million private dispatch users, and over 3 million subscribers to radio paging services, comprising a \$10-billion market in the U.S. alone. The Federal Communications Commission recently allocated more bandwidth for domestic land-mobile use to permit the growth anticipated in metropolitan-area communications. In 1978, NASA began studying how a satellite system could be integrated with this growing terrestrial "cellular" system to make operations possible in medium- and small-sized towns and in rural areas, which cannot be economically served by a terrestrial system. This has generated a U.S. position in support of allocation of a primary frequency (806-890 megahertz band) for land-mobile satellite service for North, South, and Central America. NASA has also sought allocations of multiple primary international frequencies for active and passive space sensors of Earth resources satellites.

Public Service Communications. The international space research program to significantly improve the capability of search and rescue forces to locate aircraft and ships in distress is progressing toward its first demonstration flight in 1982. NASA and NOAA are providing design modifications for the NOAA-E, F, and G spacecraft to accommodate a Canadian-built transponder package and a French-built distress-signal processor. As a part of the demonstration, the U.S.S.R. plans to equip Soviet spacecraft similarly so as to interoperate with the U.S.-Canadian-French system. An operational lifesaving network such as this is expected to improve the speed and success rate of search and

rescue while substantially reducing operational costs.

Public service communications experiments continued through use of the joint U.S.-Canadian CTS spacecraft and on the NASA ATS satellites. More than 300 such experiments and demonstrations have now been conducted. In the Appalachian region, college-level courses are being transmitted via ATS 6 from the University of Kentucky to teachers throughout the region, exploring a potential satellite role in upgrading teacher skills. The West Indies was the scene of another ATS project; a joint NASA/Agency for International Development experiment, completed in March 1978, transmitted live course lectures among the islands.

CTS was used in cooperation with several large industrial corporations to test the utility of state-of-the-art communications and terminal equipment in transmitting high-speed digital data and videoconferencing. Another CTS experiment is the College Curriculum Sharing Experiment, between Carleton College in Canada and Stanford University in California. It is demonstrating the use of communications satellites for extending curricula by video sharing of classes among universities and countries. CTS also demonstrated delivery of public-service telecommunications useful to Indian communities. Indian tribes in Montana and New Mexico talked via CTS with Federal officials in Washington, D.C., about health, agriculture, education, and other tribal concerns.

Science

Study of Earth's Upper Atmosphere

When the NASA Upper Atmospheric Research program began several years ago, the emphasis was on assessing the effect of man-generated perturbations of the stratospheric ozone. By 1978 the program had matured into an extensive scenario of field measurements, theory and data analysis, and laboratory studies centering on understanding the mechanisms of Earth's stratosphere and mesosphere. With the active participation of the NASA Stratospheric Research Advisory Committee and other Federal agencies, NASA has developed both a program plan and a measurement strategy. These are being implemented through approximately 130 funded tasks participated in by government agencies, universities, and industrial research communities, plus international efforts.

During the past year, NASA-sponsored field measurements provided significant new data. In a pair of joint flights of the University of Michigan and the Canadian Stratoprobe balloon payloads,

simultaneous measurements were obtained of ozone (O_3), water (H_2O), methane (CH_4), nitric acid (HNO_3), nitrogen dioxide (NO_2), nitric oxide (NO), nitrogen pentoxide (N_2O_5), hydroxyl radical (OH), HO_2 radical, ClO radical, and hydrogen chloride (HCl). The data are being used to test photochemical models and examine the hypothesized steady-state relationships among the HO_x , NO_x , ClO_x , and O_x families. The ClO radical has been independently measured in the stratosphere by resonance fluorescence, laser heterodyne, and microwave radiometric techniques. Seasonal and day-to-day changes in HNO_3 column density and the steady increase with time in Freon 11 ($CFCl_3$) concentration have been noted from ground-based infrared measurements. Altitude profiles of HCl , hydrogen fluoride (HF), CH_4 , nitrous oxide (N_2O), H_2O , carbon monoxide (CO), and O_3 have been obtained with a balloon-borne infrared interferometer. New mass-spectrometric measurements indicate that carbon dioxide (CO_2) mixing ratios may not be constant at altitudes of 30–38 kilometers as had been generally assumed. Further advances in stratospheric measurements are expected from several techniques now under development for measuring trace species, radiation levels, photolysis rates, and atmospheric dynamics.

In theory and data analysis, the most significant recent advance has been in increased appreciation of the close coupling among the nitrogen, hydrogen, and chlorine families of species. A variety of 1-, 2-, and 3-dimensional models have aided understanding of stratospheric observations and helped define the future measurement strategy. Analysis of satellite and ground-based data is establishing a baseline from which perturbations in the ozone layer can be measured. For example, calculations on production and loss rates of hypochlorous acid $HOCl$, and N_2O_5 in the infrared region; and ClO reservoir for atmospheric chlorine (Cl).

Laboratory studies are using conventional and new laser-related techniques to measure reaction rates among key atmospheric species. Extension of existing rate measurements to stratospheric temperatures and pressures is continuing. Kinetic studies of the formation of $ClNO$ radical, chlorine nitrite ($ClNO_2$), chlorine nitrate ($ClONO_2$), and $HOCl$ in the stratosphere have been performed. A Reaction Rate Panel has been formed to analyze research priorities and provide up-to-date kinetic data for use by atmospheric modelers.

In laboratory spectroscopy, the emphasis on high-resolution measurements reinforces related field measurements. Recent results include spectra of ClO , HCl , hydrogen bromide (HBr), NO , oxygen (O_2), and sulfur dioxide (SO_2) in the ultraviolet region; of CH_4 , methyl chloride (CH_3Cl), fluo-

romethane (CH_3F), ClO , ClONO_2 , Freon 22, HCl , formaldehyde (H_2CO), hydrogen peroxide (H_2O_2), HOCl , and N_2O_5 in the infrared region; and ClO in the microwave region.

Study of the Sun and its Earth Relationships

Research and exploration in this field is centered on understanding the basic characteristics of the Sun and the solar, interplanetary, and terrestrial phenomena which occur during transmission of solar energy.

Study of the Sun. In collecting data on the quiet solar atmosphere, OSO 8 (Orbiting Solar Observatory 8) concluded a successful mission in September 1978. Reduction of the more than three years of data will continue for another year, but the results are already being put to good use. For example, the observations by the high-resolution spectrometers have allowed derivation of a refined temperature model of the solar atmosphere from the region of minimum temperature just above the Sun's visible surface all the way up to the overlying solar corona. This model is of critical importance for interpreting changes in this region caused by solar flares.

The study of solar flares will become more detailed (buildup, release, and decay of energy) with the launch of the Solar Maximum Mission, scheduled for October 1979. Instrumentation, the first of which NASA received in November, included a gamma-ray spectrometer, hard- and soft-x-ray detectors, a versatile ultraviolet spectrometer/polarimeter, a coronagraph to observe flare-related disturbances in the outer solar corona, and a radiometer to measure the total solar flux to an accuracy of 0.1 percent. A major development was the start of a Guest Investigator Program; there were 43 proposals, 16 of them from foreign countries.

Another future solar mission is the International Solar Polar Mission, for which a tentative payload was selected this year. A joint venture with the European Space Agency, this mission will send an ESA and a NASA spacecraft over the poles of the Sun, the first time manmade objects have flown a solar trajectory in so far different a plane from the one of Earth and the other planets. One of the main purposes of the mission is to gather data on the origins of the high-speed solar wind that fans out from the Sun to the edges of the solar system and whose surges are known to cause geomagnetic storms and aurorae in Earth's upper atmosphere. Detailed definition of experiments and spacecraft design were in progress by the end of the year.

Research tools other than satellites also made important contributions to solar research in 1978. Using sounding rockets, the Joint American-Soviet

Particle Intercalibration project operated from NASA's Wallops Flight Center in June 1978 to investigate sources of ionization in the upper atmosphere and compare particle-measuring instrumentation. Another sounding rocket, taking ultraviolet high-resolution spectra of the Sun, found small jets of hot gas moving outward from the lower atmosphere into the solar corona. These jets may help explain the very high (in excess of 1 million kelvins) temperatures of the corona. This mission will be reflown to confirm the evidence of the abundance of these features.

Study of Solar Effects Near Earth. The third International Sun-Earth Explorer (ISEE-C) was launched on August 12, 1978, as the last leg of a three-spacecraft program investigating how fluctuations in the solar wind affect magnetospheric boundaries near Earth. ISEE-C is heading toward a unique orbit around the L1 libration point, where the Earth's and Sun's gravity interact in such a way that L1 appears stationary on the Earth-Sun line about 1.5 million kilometers out from Earth. To prevent the tracking antennas on Earth from being blinded by interference from the Sun, a small propulsion unit will propel the satellite on a halo orbit about the libration point, circling far enough out so that the Sun is not directly behind it in the antennas' line of sight from Earth. ISEE-C, the first spacecraft ever to make use of a libration point in space, will transmit its data on the state of the solar wind to Earth antennas about an hour before the effects of the same portion of the solar wind come near enough Earth to be observed by ISEE-A and -B. ISEE is an international cooperative project, with the European Space Agency providing ISEE-B.

Data from the low-orbit satellites, Atmospheric Explorers C, D, and E, were combined with data from sounding rockets and backscatter radar to form a new model of the upper atmosphere. It makes possible much better predictions than before of how the atmosphere will respond to changes in solar ultraviolet activity during the solar cycle. For example, study of the data showed that ultraviolet activity in the present cycle has not followed the old pattern, which depended on ground-based indicators keyed to 10.7-centimeter radio measurements. The latter predicted a much slower rise in atmospheric density than occurred with the observed decay in Skylab's orbit, while the new model agreed well with it. This marks a significant improvement in our understanding of solar control of the upper atmosphere and has immediate application in more accurate predictions on the reentry of space objects.

A difficult problem with which progress was made is the one of measuring electric fields in space. Small electric fields acting over large distances are believed to be responsible for accelerating the kinds of particles that are seen in auroral displays at high latitudes. They have other influences that are more subtle: they may be responsible for effects on the neutral atmosphere through interactions with moving plasma; some scientists believe they also hold the key to solar-climate relationships and to anomalous effects seen in the ionosphere. Techniques that are being used for measurement of electric fields include the release of chemical tracers, the deployment of very long conductors, and the use of conductivity probes on sounding rockets.

Study of the Planets

Through the last decade and a half of systematic exploration of the planets and other bodies within the solar system, the NASA planetary program has grown in capability from simple flyby spacecraft with very basic instrumentation to much more capable planetary spacecraft. Outfitted with extensive complements of instruments, these spacecraft can measure a great variety of planetary characteristics.

Pioneer Venus. Two Pioneer-class spacecraft with entirely different payloads were launched from the Kennedy Space Center in the summer of 1978, to study the planet Venus. Our nearest neighbor among the planets, Venus is almost a twin of Earth in size and distance from the Sun, yet some fundamental dissimilarity has led to a major difference in the evolutions of the two planets. Venus has a heavy, thick, hot atmosphere. Its surface is entirely hidden by massive clouds thought to be composed of sulphuric acid. One of the two Pioneer spacecraft, an orbiter, arrived at the planet in December. Once in orbit about Venus, it was largely dedicated to investigating the atmosphere and ionosphere, both by remote sensing techniques and by direct sampling as it dipped into the atmosphere to within a couple of hundred kilometers of the surface once on each revolution. It was also to measure the magnetic field of Venus, if there is one, and report on the interactions between the solar wind and the planet's ionosphere. The radar altimeter was to measure the figure of Venus, sketching a relatively crude surface map and allowing some inferences to be made about the internal composition and structure of the planet.

The second Pioneer Venus spacecraft was a "bus," carrying four highly instrumented probes that were released in November, three weeks before planetary encounter on December 9. Each probe was targeted to a different point on the

planet; after a high-speed entry into the atmosphere behind a special heat shield, each probe made a variety of measurements of the composition and physical state of the gases and clouds making up the hostile atmospheric environment. The probes descended slowly to the surface, radioing measurements back to the orbiter until they crashed (although the probes were not designed to survive impact, one of them did briefly). Sophisticated radio tracking from Earth translated probe motions into readings of wind direction and speed. The bus spacecraft also had a science role, taking measurements in the upper atmosphere before it burned up in its descent.

Only the real-time data, which represented a small sampling of the total return, were available by the end of the year. From these data, it appeared that excellent information had been obtained on all mission objectives. Several surprises to standard scientific conceptions of the environment of Venus were suggested in the early data: three distinct cloud decks were penetrated, the upper containing particles of a single size, the middle being sharply bimodal, and the lowest distinctly trimodal, with cloud compositions and levels very similar at all locations where probes descended; just below the clouds oxygen and water vapor were detected, and unexpectedly large amounts of argon, neon, and helium were observed in the atmosphere; as the probes descended, as much as 50 percent of the absorbed sunlight was seen to be absorbed above 55 kilometers, and very similar variations of pressure and temperature with altitude were seen on the day and night sides of the planet.

Voyager. The two Voyager spacecraft were launched toward the planet Jupiter in 1977. The first spacecraft is to encounter that planet on March 5, 1979. Observations will be taken for the previous two months, including detailed study of not only Jupiter but its large satellites in the last few days before encounter. Voyager 2 begins science observations in April, with closest approach on July 9. Jupiter's gravitational influence will be used to redirect the trajectories of both spacecraft toward Saturn; arrival there is targeted for the end of 1980 and the middle of 1981, respectively. Depending on the condition of the spacecraft at that time, there is an option for Voyager 2 to use the gravitational field of Saturn to deflect itself on to an encounter with Uranus.

Viking. The Mars missions of the Viking landers and orbiters are now almost complete. During 1978 all the vehicles conducted important science operations, with the two orbiters being particularly active. Major acquisitions of data were returned on planetary geology and the dynamical behavior of

the Martian atmosphere. At the end of the year, Lander 1 was operating at a reduced level, with end of its mission set for March 1, 1979—although there is still a possibility of continuing minimal automatic reporting (principally meteorology). Lander 2's science operations were terminated in November 1978 and Viking Orbiter 2 ran out of attitude-control gas in July. Viking Orbiter 1 was still in excellent health but its control gas is expected to run out in the spring of 1979.

Pioneer 10 and 11. After five years of reconnoitering the solar system, these two veteran spacecraft are still carrying out their assignments. Pioneer 10, picked to be the first man-made object to fly beyond the solar system into interplanetary space, has traveled almost out to the orbit of Uranus. Some interpretations of its cosmic-ray data suggest that the spacecraft is nearing the outer edge of the Sun's influence. Pioneer 11 has headed back across the solar system after its encounter with Jupiter and is heading toward a flyby of Saturn. In September 1979 the spacecraft will pass just outside the famous rings of Saturn, then dip in close to the planet, telemetering back to Earth the first close-look information about the environment there.

Galileo. This planetary mission will feature two payloads: an advanced orbiter will circle Jupiter making a prolonged study of that planet and its bevy of satellites; a probe will detach and plunge down through Jupiter's atmosphere for unique in situ measurements. The project, which involves substantial cooperation with West Germany, is on schedule for launch in January 1982.

Research and Analysis. Work continued on interpretation of data sent back from previous missions and on acquiring new information about the solar system by means of ground-based telescopes. A new program was begun for more thorough interpretation of Viking data from Mars. Over the next few years this mass of data will be analyzed in depth to extract the greatest possible benefit from these outstanding missions. From ground-based astronomy came two discoveries of note in 1978: a new minor planet, named Chiron, was found in an orbit lying between those of Saturn and Uranus. And the planet Pluto was found to have a close-by moon, which has been given the name of Charon.

Studies of the Universe

NASA's study of astrophysics is directed toward answering some of the most fundamental questions that human beings have ever posed: what is the origin of the Universe? What is the origin of the chemical elements from which Earth, our bodies, and everything we know are constructed? What is

the nature of the exotic high-energy processes occurring in space?

High Energy Astronomy Observatories. A major event in the astrophysics program was the successful launch on November 13, 1978, of HEAO 2 (High Energy Astronomy Satellite-2). The low-altitude, low-inclination orbit (537 kilometers at an inclination of 23.50 degrees) was selected to provide a low radiation background to the view of the experiments.

The HEAO program is composed of the three largest Earth-orbiting automated spacecraft yet launched. They are intended to investigate some of the most recently discovered and most mysterious objects in the Universe—including pulsars, quasars, and possibly black holes. HEAO 1 and 3 are mapping satellites, rotating slowly and plotting sources throughout the sky in their spectral band—HEAO 1 in the x-ray band, HEAO 3 to follow in 1979 for the gamma-ray and cosmic-ray bands. HEAO 2 is a pointing satellite, focusing its large x-ray telescope on the sources pinpointed by HEAO 1.

HEAO 1, which celebrated its first year in orbit in August 1978, has been a success. By the time its second sky survey is completed in the spring of 1979, 1100 or more x-ray sources should have been catalogued, four times as many as were known before. Another major result from HEAO 1 was the identification of a hot plasma—apparently about half a billion degrees—extending beyond our galaxy and possibly throughout the entire Universe. If a plasma of this temperature and density were distributed uniformly throughout the entire Universe, it would contain about half the total mass required to close the Universe. This new concept is of such importance for cosmologists that fresh data are being analyzed as soon as they come from the spacecraft. Other data from HEAO 1 have identified a new black-hole candidate in the Constellation Ara. This brings the total number of candidates thus far to four.

HEAO 2 is functioning well, with all experiments performing. The large size of its x-ray telescope should enable it to see two-thirds of the way to the edge of the Universe, recording events that occurred as much as 10 billion years ago. Experimenters feel that the first photos reconstructed from HEAO 2 data have brought x-ray astronomy up to the same state of maturity that has been enjoyed by other specialties.

Space Telescope. The Space Telescope, designed as the first general-purpose astronomical observatory in space with an anticipated lifetime of more than a decade, is to be launched by the Space Shuttle in late 1983. Availability of the Space Shuttle will allow in-orbit repair of the observatory, ex-

change of experiments by the Shuttle crew, and, if necessary, return of the entire system to Earth for refurbishment and relaunch.

The body of the Space Telescope is a cylinder some 14 meters in length and 4.3 meters in diameter, with an equipped weight of about 9000 kilograms. The primary mirror will be 2.4 meters in diameter, comparable to those in the larger Earth-based telescopes. Contractors are working on the two major hardware elements, the Support Systems Module and the Optical Telescope Assembly, confirming and refining the requirements. Preliminary design is well under way. Because of the long lead time involved, fabrication of the blanks for the telescope's primary mirror was begun as soon as the project started. The casting of the first of two such blanks was completed this year on schedule.

Five versatile scientific instruments (four American and one European) have been selected for flight at the focal plane of the telescope, where they will carry out a wide range of observations. Their preliminary design is being developed by participating scientists and their subcontractors. Final evaluation and confirmation of the payload will occur early in 1979. The European Space Agency is funding and providing one of the scientific instruments at the focal plane, the solar array portion of the electrical power subsystem, and a number of personnel for support of science operations.

Explorer Satellites. More modest than the observer class of satellites, Explorers have relatively low-cost payloads designed to explore new fields of scientific research. The SAS-C (Small Astronomy Satellite-C), for example, in this its third year of operation continued to provide outstanding astronomy data, including the discovery of a Quasi-Stellar Object.

The IUE (International Ultraviolet Explorer) satellite was launched on January 26, 1978, into an eccentric geosynchronous orbit. A joint undertaking of NASA, the United Kingdom's Science Research Council, and the European Space Agency, IUE can study the spectral lines marking the transmission and absorption of atomic radiation in the atmosphere of stars, in the interplanetary medium, and in objects within the solar system. Early observations concentrated on subluminescent stars, at the end point of star evolution. IUE can also study hot stars at ultraviolet wavelengths. The IUE spectrum of the star HZ 43 appears to confirm this star as a white dwarf. Early observations of active galaxies have proved particularly interesting and will keep astrophysicists busy for some time to come. In fact, there have been over 200 proposals for observing time on IUE during the year 1979, while only 40 to 50 observing programs can be accommodated.

Another international Explorer, the IRAS (Infrared Astronomical Satellite), will be the first satellite designed to study the cold infrared in the Universe. A cooperative project of NASA, the Netherlands, and the United Kingdom, IRAS is scheduled to go into orbit in 1981 with a "first of its kind" cryogenically cooled telescope system. The primary objective is to produce an unbiased all-sky survey of discrete sources, identifying the locations and kinds of objects radiating in the infrared. The U.S. portion of the project, which includes the telescope system, is managed by the Jet Propulsion Laboratory and the Ames Research Center. The project is on schedule, with the detectors for the focal plane being selected in September 1978.

Detailed study continues on two future Explorers. The Cosmic Background Explorer will measure the residual three-degree background radiation believed to be left over from the "big bang" origin of the Universe. The Extreme Ultraviolet Explorer will perform a sky survey of very hot objects such as white dwarf stars, one of the last unexplored regions of the electromagnetic spectrum.

Orbiting Astronomical Observatories. OAO 3, named Copernicus, is still operating after more than six years in orbit; it recently furnished valuable information on an apparent black hole detected in the Constellation Scorpius.

Suborbital Vehicles. Sounding rockets, balloons, and aircraft continued their contributions to the development of technology and advancement of science. A NASA sounding rocket obtained a well-calibrated spectrum of the Seyfert (active) galaxy NGC 4151. This was not only important in its own right but served to calibrate the spectrum obtained later with the newly launched IUE satellite. The usefulness of months-long balloon flights was demonstrated early this year when three superpressure balloons "orbited" the southern hemisphere in support of long-duration ozone monitoring. These superpressure flights also showed initial evidence of large-magnitude atmospheric motions. In the aircraft science program, the Kuiper Airborne Observatory detected the first infrared "Bok Globule." These globules are very small dark clouds in our galaxy which appear on photographs as black spots and up to now have been opaque to any radiation. This identification opens up a whole new class of objects whose emissions can now be measured directly.

Physics and Astronomy Spacelab Payloads. Planning for use of the Shuttle/Spacelab system for scientific investigation continued in its third year. Investigations were solicited from the scientific community for three missions: Orbital Flight Test-4, and Spacelab 1 and 2. The science payload of the Orbital Flight Test mission (OFT-4) will be from

the astronomy and life sciences disciplines, including an instrument to measure the Orbiter's flight environment. The flight is scheduled for 1980. Work on both Spacelab missions is on schedule. All investigations have been confirmed and investigators are contracted to develop their instrumentation. Initial design evaluation has been completed. The payload specialists have been selected.

A Multi-User Instrument program has been approved, in which very large instruments can be "used" by several investigators. The concept is similar to procedures at ground-based astronomy observatories.

Life Sciences

Flight Experiments on Spacelab. An Announcement of Opportunity was issued in February 1978 to the Life Sciences community. It solicited proposals for experiments for the first three Spacelab missions dedicated to Life Sciences (one per year). A gratifying response of 370 proposals was received and evaluation is proceeding.

Space Shuttle Life Sciences. As a follow-on to the Class I, II, and III medical standards published in 1977 for Astronaut Pilots, Mission Specialists, and the non-retention category of Payload Specialists, Retention Medical Standards were published for the career categories of Astronaut Pilots and Mission Specialists.

U.S. Experiments on Soviet Spacecraft. The final-results symposium for the Soviet Life Sciences flight Cosmos 936, which flew seven U.S. Life Sciences experiments, was held in Moscow in October 1978. The flight marked the first inflight use of a centrifuge as a 1-g control. It was a significant contribution and aided in the interpretation of the results of the experiments. Soviet acceptance of 13 U.S. experiments proposed for the U.S.S.R. biosatellite scheduled for launch in late 1979 seems to ensure continuation of this form of international cooperation.

Soviet Experiments on U.S. Spacecraft. At the joint U.S./U.S.S.R. Space Medicine and Biology Working Group meetings held in the U.S.S.R. from October 10-18, 1978, the U.S. invited the Soviet Union to submit proposals for experiments to fly on the Spacelab mission, dedicated to Life Sciences, in 1982.

Studies in Planetary Biology. The discovery, in what had been designated an abiotic area of Antarctica, of lichen-like living organisms has contributed to our understanding of the distribution of life in the Universe. Also the origin of life as we know it may have been illuminated by the finding of a clay deposit that was rich in the heavy metal zinc. It acts as a sort of template, rejecting certain

organic molecules and accepting others and building them into amino acids essential for life. These areas of research were supported by grants from NASA and the National Science Foundation.

Space Transportation

Space Transportation is responsible for placing payloads into their proper orbits and trajectories in space. For the past 20 years, and for at least part of the workload over the next several years, the means used for this purpose has been expendable rockets. But now, after seven years of planning, designing, fabricating, integrating, and testing, the versatile, economical Space Transportation System is being readied for its first space flight. This will mark a major improvement in the way man travels to, in, and from space.

The Space Transportation System embraces not only the flight hardware but the planning and scheduling of payloads and the ground facilities and logistics for launch, recovery, and refurbishment of the flight hardware. The launch-to-orbit carrier is the Space Shuttle. At launch the Shuttle has several separate but mated components: the aircraft-like orbiter, housing the cockpit area for the crew of up to seven men and women, the cargo bay in which payloads are stored, and the three-engine main propulsion system; mated to the orbiter are the external tank—a large cigar-shaped tank carrying the launch-phase fuel supply of liquid oxygen and liquid hydrogen—the only portion of the Shuttle that is expendable; and the two big solid rocket boosters that supplement the power of the main engines during launch and then fall away into the ocean, to be recovered and reused.

Extending the capability and flexibility of the Space Shuttle, systems are being developed by other organizations: Spacelab, being developed by the European Space Agency, will outfit the Shuttle cargo bay with adjustable combinations of a pressurized, shirtsleeve-environment scientific laboratory and various pallets that will mount scientific instruments for direct exposure to space; the Remote Manipulator System, from Canada, a long, remotely operated mechanical arm that while in orbit will move payloads out of and into the cargo bay; the Inertial Upper Stage, being developed by DoD, that, deployed in low Earth orbit from the cargo bay, will propel payloads to orbits beyond the capability of the Shuttle; and Spinning Solid Upper Stages, being developed by U.S. industry as a commercial venture for economical transportation of smaller payloads from the Shuttle orbit to geosynchronous orbit.

Space Shuttle

The Space Shuttle, scheduled to begin orbital flight tests in 1979, is designed to provide frequent, comfortable, efficient access to the space environment in future decades. The national fleet of four Shuttle orbiter vehicles (a fifth is an option if traffic by NASA, DoD, and other domestic and international users justifies its use) offers a greater range of capabilities compared to previous systems—a transition to reliable, reusable space transportation.

These advances include:

- flight into orbit and deorbit, yet subjecting the flight crew and payload to only mild accelerations
- from 3 to 7 persons can live and work in a comfortable, shirtsleeve environment; payload specialists do not require lengthy astronaut-type training
- cost effectiveness markedly improved by use of recoverable, reusable systems.
- major reduction in the difficulty and cost of transporting payloads and people to and from Earth orbit
- placement, servicing, and recovery of spacecraft
- deorbit to routine landing on a runway.

All principal elements of the Space Shuttle have been in development for some time and moved nearer their final form in 1978. Development milestones of the year included the delivery of the structural test article, later to be converted to become the second flight orbiter; accumulation of almost 50 percent of the firing time planned for the main engine tests; delivery of three external tanks for use in various kinds of testing; and installation on schedule of launch equipment and facilities at Kennedy Space Center. Some crucial tests have been completed on major systems. A considerable amount of testing still lies ahead to verify reliability and durability, but flight hardware of all elements will be readied for shipment to KSC early in 1979 for the first manned orbital test flight, now scheduled for near the end of 1979.

Shuttle Orbiter. After completing the approach and landing tests in late 1977, the orbiter test vehicle was delivered to Marshall Space Flight Center for full-scale ground vibration testing with other elements of the Shuttle system. The orbiter scheduled for the first orbital flight is nearing the end of assembly at the Rockwell International Space Division in Palmdale, California. After installation of the last systems and checkout, this orbiter (No. 102) will be delivered to KSC. The orbital flight test program will involve up to six flights.

The structural test article was completed this year and is now being tested in the structural test facility at the Lockheed Corporation. Following

these tests, it will be refurbished and equipped as the second flight vehicle, with delivery scheduled for 1981.

The main propulsion systems testing began in 1978 at the National Space Technology Laboratories in Mississippi. The assembled hardware includes an orbiter aft fuselage, an external tank, and three main engines.

Main Engine. The main engine represents one of the largest advances in the state of the art, principally in the requirement for long life and the much higher thrust-to-weight ratio achieved by operating at high pressure. As has been true in the development history of all new rocket engines, the main engine experienced a number of problems in development and testing. A comprehensive component and system test program in 1978 identified and resolved most operational problems. Although some difficulties remain, the main engine has been tested a number of times at the rated power level and full-duration runs. Over 35,000 seconds of test time have been accumulated, which is well on the way to the 80,000-second requirement prior to the first orbital flight.

External Tank. The external tank combines tanks for liquid oxygen and liquid hydrogen and an inter-tank structure. Three development external tanks were manufactured and delivered in 1978. They are being used for structural testing, system ground vibration testing at MSFC, and testing of the main propulsion system at National Space Technology Laboratories. Also in 1978, fabrication was started on the first three flight tanks, to be delivered to KSC in 1979.

Solid Rocket Booster. The second and third motor firing tests were completed successfully in 1978, with one more to come. Qualification tests have also been completed on a number of subsystems such as the recovery package, the electrical subsystem, and the instrumentation subsystem. Parachute tests were completed, with six successful drop tests showing that the boosters can be brought down from altitude to the ocean surface and recovered for reuse. The boosters for the first orbital flight are now being fabricated and will be delivered to KSC in 1979.

Launch and Landing. The ground equipment for launch and landing of the Space Shuttle comprises both instrumentation and facilities at KSC and the Dryden Flight Research Center in California for use in checkout, processing, launch, and recovery. Installation of the computerized equipment of the launch processing system is on schedule. The stations of this system connect the launch control center with the orbiter processing facility, the launch pad, and the hypergolic maintenance facility. Other ground-support equipment was installed

in the vehicle assembly building, the solid rocket booster disassembly facility, the parachute refurbishment station, and at the orbiter landing facilities.

Follow-On Production. Looking beyond the orbital test flights, NASA continued in 1978 the production of Space Shuttle equipment that will be needed for the operational Space Transportation System. Fabrication began on major structural parts of the third flight orbiter, as well as procurement of long-lead-time raw materials and components for the third and fourth flight orbiters; delivery of these orbiters is scheduled for FY 1983 and 1984, respectively.

Operation of the Space Transportation System

When the Space Transportation System becomes operational early in 1981, a greatly expanded range of space activities will be possible. A wide variety of users have already made firm commitments to use the system—civilian and military components of the U.S. government, several categories of domestic and foreign customers, and others will be able to place a wide variety of payloads and experiments into Earth orbit. Payloads can be refurbished in orbit or returned to Earth for repair and relaunch; space laboratories can be launched, operated, and returned to Earth for examination; scientists can fly along to operate their experiments; geosynchronous or planetary orbits are available with the use of supplemental upper stages. With the art of the possible expanding so rapidly, and with flight hardware coming off the production line, NASA has placed major emphasis in 1978 on planning and preparing for operations.

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. User handbooks and pricing guides, which describe types and costs of standard and optional services, will be published in 1979. A reimbursement formula for DoD use of the Shuttle was negotiated and incorporated in a memorandum of agreement.

As a product of extensive negotiations during the past year, nine commercial and foreign users, including Comsat, Western Union, RCA, Telesat/Canada, and the governments of India, Iran, Indonesia, and the Federal German Republic have made payments or deposits on STS flight reservations. Together with NASA's own payloads, plus firm commitments from DoD and other U.S. government agencies, all flights planned for the first few years of STS operations are guaranteed to have payloads.

A program to provide for small, self-contained payloads was begun by NASA 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 U.S. and abroad, this program has been extremely successful in attracting new users; by the end of 1978, advance payments had been received for more than 270 individual payloads, with a wide variety of ideas and experiments. The response from educational institutions has been particularly gratifying, since it indicates renewed interest from young people in space research and exploration. Several universities are offering science scholarships or grants for students to develop payloads.

DoD has received approval to install STS launch and recovery facilities at Vandenberg AFB, California, to handle high-inclination missions. NASA has been negotiating for maximum commonality of ground equipment at KSC and Vandenberg. Agreement was reached this year and procurement initiated of common equipment, reducing both acquisition and operating costs.

Flight Crew. In anticipation of STS operations, 35 new astronaut candidates, including six women, were selected in 1978 and began training at NASA's Johnson Space Center in Houston, Texas. The training includes classroom sessions, survival training, and familiarization with the flight environment of space.

Spacelab

When the concept of the Space Shuttle was taking form some years ago, many discussions were held between NASA and European agencies in pursuit of a mutual goal—that Europe participate from the outset in the Space Shuttle and in a form that was, first, a major contribution, and, second, a discrete and readily identifiable element. The result was Spacelab, a science laboratory housed in the cargo bay of the orbiter and used for a variety of experiments in one or many science disciplines, and that can be reused for as many as 50 flights. Under the 1973 agreement between the European Space Agency and NASA, ESA is responsible for the design, development, manufacture, and delivery to NASA of the first Spacelab flight unit, an engineering model, two sets of ground-support equipment, and spares to support the first two missions. Total cost of Spacelab development to Europe is estimated at \$600 million. On the other side, NASA agreed to be responsible for operations with Spacelab and for secondary equipment such as the crew tunnel joining the orbiter cabin and Spacelab. In addition, NASA plans to begin in 1979 the pur-

chase of additional Spacelab production items from ESA.

In 1978, a major development milestone for Spacelab was achieved when it passed the overall-system critical design review. Many components for the first flight unit were fabricated and delivered to the integration site in Bremen, Germany.

Testing of systems and components accelerated in 1978. All testing of electrical system integration was completed. Subsystem qualification is past the halfway point at subcontractor facilities. The first set of electrical ground-support equipment passed the acceptance test, is now supporting testing of the engineering model, and will be delivered to NASA. Deliveries are on schedule to support the first Shuttle/Spacelab mission planned for August 1981. NASA expects to complete modification of the operations and checkout building at KSC in February 1979. This is the building in which the Spacelab will be prepared for launch.

Inertial Upper Stages

The Inertial Upper Stage (IUS) system is being designed and developed by DoD to extend the capability of the Space Shuttle into orbits that are beyond the capability of the Space Shuttle alone. The solid-propellant IUS and its payload will be carried to low Earth orbit in the cargo bay of the orbiter, where the IUS will be deployed to reboost its payload. NASA will use a two-stage configuration of the IUS primarily to achieve geosynchronous orbit, a three-stage version for planetary orbit. The first NASA use of the two-stage version will be for the launch of the Tracking and Data Relay Satellite System into geosynchronous orbit in early 1981; the first planetary mission will be Galileo, scheduled for launch in January 1982.

Spinning Solid Upper Stages

Two sizes of Spinning Solid Upper Stages (SSUS) are being developed by industry at its own expense for launch of smaller spacecraft to geosynchronous orbit. The SSUS-D is configured for satellites that have been using the Delta expendable launch vehicle, the SSUS-A for those using the Atlas-Centaur. Both versions use spin stabilization and solid motors for simple, reliable, economical systems that provide easy transition to the Space Shuttle. Designs are nearing completion and flight hardware is being manufactured. NASA has ordered SSUS-As for Comsat's Intelsat V communications satellite missions and for NOAA's Geostationary Operational Environmental Satellite missions. Commercial users are buying SSUS-Ds directly from the developer.

Skylab Reboost/Deorbit

Skylab was the first U.S. orbiting laboratory; launched in May 1973, it was operated by three successive crews for a total of 171 days and was left dormant in February 1974 with an orbital life projected to extend to about 1983. Since that time, sunspot activity has been higher than predicted, making the upper atmosphere more dense and accelerating Skylab's rate of orbital decay. NASA made studies of how Skylab might best be boosted into a higher orbit or, alternatively, powered into a controlled, safe reentry. In October 1977 the Teleoperator Retrieval System was approved; to have been carried into orbit by an early flight of the Space Shuttle, it would have had the capability to adjust Skylab's orbit.

In late November 1978, NASA reassessed the entire concept of altering Skylab's orbit. In December the effort was discontinued because of its limited chance of success. The reasons:

- a general deterioration of systems onboard Skylab made it unlikely that spacecraft responses could be counted on through April 1980
- sunspot activity in recent months was at a high level, further accelerating the decay of Skylab's orbit
- the mission for Skylab, intended for the second Space Shuttle orbital flight, would have been difficult to execute before April 1980, whereas Skylab was now predicted to reenter the atmosphere sometime between mid- and late-1979.

Studies will continue on possible applications of the Teleoperator Retrieval System to other payload delivery and retrieval requirements in the 1982-1983 time period.

Advanced Programs

Advanced studies continued in 1978 to look at future options for improved space concepts and more advanced hardware.

One group of studies centered around the Shuttle, particularly concepts for new stages and systems that would augment Shuttle capabilities. One continuing series of studies examined the electrical power extension module, for use with Spacelab missions, and lower-power and high-power modules for future missions. Evaluation of the concept for the low-power module (25 kilowatts) was completed; consideration of the high-power module (250 kilowatts) began. In concepts for Shuttle-associated stages, studies continued of orbit-transfer vehicles with liquid-fueled engines for propulsion to geosynchronous orbit and of solar electric propulsion stages for orbital transfer and planetary

missions. Design of the latter was brought to the point where project development could begin.

Another set of studies concentrated on the development of and uses for large platforms and structures in space. The studies ranged from ground-fabricated structures that can be deployed in space as integral units, to systems that can be assembled in space from prefabricated components, to systems that can be constructed in space, using fabrication equipment such as beam builders. Applications of these systems range from high-powered radars, radiometers, and multibeam communications systems to very large assemblies for large power modules. Of special interest is the concept of a geosynchronous platform to house a large, advanced communications system. Here studies have investigated both the design and construction of the platform and the communications applications and economics. Work begun in 1977 on techniques for fabricating and assembling large structures in space, as well as for deploying large antennas, was continued. Ground tests of a beam builder demonstrated the capability to fabricate virtually endless aluminum beams in space, working out of the orbiter cargo bay. These concepts are basic to construction of a variety of large structures in space—not only to support power plants to energize scientific and applications missions but also to support very large solar power arrays that might harness the energy of the Sun and beam it back by microwave to Earth. Promising studies in the latter category are partially sponsored by the Department of Energy.

Expendable Launch Vehicles

During 1978, NASA conducted a total of 20 launches for itself and a variety of other users including 2 launches for DoD. Launch vehicles included the Scout, Delta, Atlas-Centaur, and Atlas F.

Scout. The single launch by this vehicle system was of the NASA Heat Capacity Mapping Mission in April from the Western Test Range.

Delta. Still the most popular of the expendable launch vehicle family, Delta had 10 launches in 1978; 2 NASA scientific satellites, the IUE and the ISEE-C; 2 NASA applications satellites, Landsat-C and Nimbus-G; the 6 reimbursable launches were a communications satellite for Japan, an experimental communications satellite for the European Space Agency, a synchronous weather satellite for NOAA, a scientific satellite for the European Space Agency, and a communications satellite each for NATO and for Canada. By the end of 1978, Delta had a career total of 147 launches.

Atlas-Centaur. This system had 7 launches: 2 NASA Pioneer-Venus planetary satellites, a NASA

scientific satellite HEAO; the reimbursables were 2 international commercial satellites, a domestic communications satellite for Comsat, and a communications satellite for DoD.

Atlas F. Developed and managed by DoD, this system was used in 1978 for 2 launches: Seasat-A and the Tiros-N weather satellite.

Launch success rate for the year was 100 percent.

Space Research and Technology

Expanding our capability for space exploration depends on improvements in equipment through space research and technology. The areas of technology that NASA has emphasized are materials and structures; guidance, control, and information; space propulsion systems; and space energy systems. Much of this research could also be described as applied science, and many of its products have potential applications on Earth.

Materials and Structures

Considerations such as weight, strength, and durability in a hostile environment are always important elements in development of advanced launch vehicles, efficient orbiting spacecraft, and planetary entry probes. Use of improved materials or new lightweight structures can significantly reduce the cost and increase the payloads of future space missions.

Materials. A new iron-based alloy was developed for use in cryogenic fuel tanks; it has the highest combination of toughness and strength at low temperatures of any known material. Made by adding small amounts of copper and aluminum to a commercial iron-nickel alloy, the new alloy is 100 percent stronger than commonly used stainless steel and 400 percent tougher than commercial cryogenic steel.

A new surface insulation material developed in 1978 is about three times as strong as the highest strength material currently planned for use as reusable surface insulation on the Shuttle, to withstand the high temperatures of reentry. Of equal promise is its strain resistance: it is five times more resistant to strain than present materials, making it a prime candidate for use with composite structures of graphite-polyimide that are being developed for advanced space transportation systems.

Structures. Development of graphite-polyimide structures for use in advanced space transportation systems offers promise of dramatic reduction in structural weight by making possible a substantial reduction in the thickness of thermal insulation. This year processing and fabricating methods have

been identified that will repetitively produce high-quality structural components. The effort in the coming year will center on fully characterizing the usable properties of the material so that test components can be designed and developed.

It is likely that the next decade or two will see the need for spacecraft that are too large to fit in the cargo bay of the Space Shuttle. Concepts were further defined in 1978 for spacecraft that could be constructed in elements and modules, to be packed in the cargo bay and then assembled in space. The intent for the coming year is to develop many of these concepts into experimental hardware and test them to derive operational design characteristics.

Guidance, Control, and Information

NASA's work in guidance, control, and information in 1978 continued to focus on developing a technology base that would enable a 1000-times increase in flow of space-derived information at one-tenth the cost of mission operations.

Guidance and Control. Completed this year was an extended-life attitude control system for spacecraft, designed to improve reliability, accuracy, and flexibility over previous systems. It consists of an advanced solid-state star tracker, magnetic-bearing reaction wheels, a long-life inertial reference system, and fault-tolerant programmable microprocessor electronics. In tests the system met design goals of 0.01 degrees pointing accuracy and a lifetime longer than eight years.

Sensing and Detection. Seeking to improve the effectiveness of photographic imaging for terrestrial, astronomical, and planetary missions, NASA has emphasized the development of solid-state devices to improve performance and reliability of sensors. Charge-coupled devices—two-dimensional arrays of solid-state devices—have been tested as replacements for the bulkier, more complex vidicon tubes. In 1978 the first 800×800 -element array was built and has been evaluated for use in advanced planetary and astronomical cameras. Contained on a single silicon chip 1.2 centimeters square with a spacing of 15 microns between elements, the array provides television-quality imagery over the complete visible spectrum and into the near infrared bands. Its first use will be in high-resolution cameras to be flown on the Space Telescope and the Galileo missions.

Data Reduction and Distribution. Microwave tubes are a key component in space communications but have been limited in lifespan because of failures in their filament heaters. An advanced cathode that emits electrons by field emission, thereby eliminating the need for a heater, has shown promise of extending the life of microwave amplifiers by a

factor of five, upping amplifier lifetime to over 20 years. This year the first field-emitting cathodes were successfully fabricated; they exhibited current densities of 20 amperes per square centimeter, 10 times the capacity of heated cathodes.

Space-Derived Data Processing. A major bottleneck in converting raw data from spacecraft into useful information is the time and expense involved in processing millions of bits of information in a general-purpose computer. In an attack on one aspect of this problem, NASA has been developing a specialized multispectral image classifier which can reduce data-processing time to 1/100th the present rate. Functional design of the processor has been completed; special analog-to-digital charge-transfer-device classifiers have been designed and tested. A laboratory model of the processor is being readied for verification tests of system performance.

Space Propulsion Systems

Another way in which NASA seeks to reduce cost and increase capability of future exploitation of space is by research on space propulsion technology. Work in both chemical and electric propulsion is aimed at three kinds of space operations: Earth-to-orbit and return, orbit-to-orbit transfer, and interplanetary transfer.

Chemical Propulsion. Technology development for a long-duration rocket engine of 92,000 newtons (20,000 pounds) of thrust, burning liquid hydrogen and liquid oxygen, continued. All engine components have operated at design performance levels. In 1978 for the first time both the high-pressure liquid-hydrogen and liquid-oxygen turbopumps were operated at the rated speeds. The next step will be to demonstrate that the components can meet the requirements of 10 hours of operation and 300 restarts.

For future launch vehicles, this year saw the beginning of combustion studies involving the main combustor and preburner. Studies on potential high-density fuels and the heat transfer of supercritical liquid oxygen have been completed. In the use of new materials in propulsion research, a key accomplishment was the successful operation of a carbon-carbon composite thrust chamber at 2250°C (4000°F).

Electric Propulsion. In solar electric propulsion, NASA is progressing toward a demonstration in 1980 that the technology is available to build a 3-kilowatt, 3000-second specific-impulse thrust subsystem which could increase the flexibility of orbital control. This year the baseline power processor has been completed and operated successfully with an ion thruster. Final assembly began of a

dual-mode thrust subsystem (two thrusters, power processors, and heat rejection system). Fabrication of the solar array was completed, with extension-retraction tests scheduled for early 1979.

The one-millipound auxiliary thruster developed under the NASA technology program is to be flight-tested on an Air Force satellite in 1981. NASA began fabrication for the flight hardware and diagnostic instruments.

Space Energy Systems

NASA's research in space energy seeks to develop high-power, low-cost energy systems and to improve their efficiency and lifespan.

Energy Generation. A major achievement in 1978 was exceeding the voltage limitation for silicon solar cells that had existed since 1954. With high voltage comes increased cell efficiency, meaning a 20 percent reduction in the size, weight, and cost of future solar arrays. In development of lightweight solar arrays, ground testing was successful on a full-scale, 66-watt-per-kilogram solar array wing 32 meters in length; with a full complement of solar cells, it will produce 12,500 watts.

Radioisotope generators employ thermoelectric materials for generating electricity. A new thermoelectric material has been developed by the addition of gallium phosphide to silicon germanium alloys. Efficiency is 30 percent higher than that of material planned for use in the Galileo mission.

Energy Storage. Batteries often limit the effective life of Earth-orbiting satellites. The weak link in battery life has been the separators used to prevent contact between active materials. Now a new separator has been developed that can double the life of batteries. Nickel-cadmium batteries incorporating this material are now being tested to verify the extension of battery life.

Energy Management and Distribution. Using a new process, the highest power, fast-switching transistor ever made has been fabricated. Prototypes have been tested on spacecraft power controllers and a DC motor controller. Proposed applications include power regulators, linear amplifiers, induction heaters used in kitchen stoves, and in the drives of electric vehicles.

Space Data Services

Linking the investigator on the ground with the spacecraft above are information systems operating through the facilities of two worldwide tracking networks, a cluster of mission control centers, a large-scale data processing complex, and a unifying global communications system. From manned flights and planetary expeditions to simpler bal-

loon, rocket, and research aircraft flights nearer to Earth, flight programs are provided tracking, telemetry reception, command, and voice communications as well as real-time data processing for mission control, computational support for determination of orbit and trajectory, plus data processing of engineering and science telemetry data.

Operational Activities

Data services were provided to some 50 Earth-orbital missions in 1978. Some of them were new missions that were indicative of future data-handling requirements: Landsat 3, the Heat Capacity Mapping Mission, and Seasat I required the delivery of high-rate telemetry—exceeding all previous rates—and rapid processing for the production of image products. In deep space, 15 missions received support.

International Tracking Activities

During the year many foreign space missions were provided data services on a reimbursable basis, mostly tracking and telemetry during the launch phase. Two missions of the European Space Agency, GEOS and OTS, and the Canadian Telesat-D received such support while being launched on U.S. rockets. Four Japanese missions were provided launch support even though they used their own launch vehicles. Two French missions, Signe II and Starlette, received support under a reciprocal agreement under which France provided support to some U.S. missions. These were in addition to the many cooperative projects that used tracking and data services supplied by NASA.

One of the most important international activities during the year was the intensive preparation for the General World Administrative Radio Conference to be held in 1979. Every 20 years such a conference convenes to revise the international regulations and frequency allocations that govern the use of the entire radio spectrum. NASA assists other bodies, both national and international, in developing papers and coordinating technical information.

Network Progress

Data Processing Improvements. The Image Processing Facility at Goddard Space Flight Center was improved in 1978. New master data processing units were delivered; they are the heart of an all-digital image processing system. Special pre-processor equipment was also procured to convert HCMM and Nimbus 7 data into a form suitable for use in the new master processors. When fully operational, this new system will produce more accurate and higher resolution images from these missions as

well as Landsat. Images will be corrected for distortion and delivered to the user within 24 to 48 hours. The end product is a high-density digital tape rather than an expensive, slow-to-produce photograph. Rapid delivery of data is especially important to missions that investigate transient phenomena such as the weather.

Deep Space Network Improvement. Conversion of the first 26-meter-diameter antenna to a dual-frequency (S- and X-band) 34-meter antenna has been completed at Goldstone, California. This improved facility will be ready to support the Voyager missions in their Jupiter encounters early in 1979. The addition of the X-band will allow higher rates of data return from interplanetary distances and reflects the general trend toward higher frequencies to improve the science return. Similar conversions were begun on antennas located in Spain and Australia.

NASA Energy Programs

NASA supports work in the field of energy to ensure the effective use of NASA experience and technology in support of national energy needs. The majority of NASA activity in energy is in direct, reimbursable support for the programs of the Department of Energy (DOE).

NASA investigates in 14 energy technology areas; the largest are wind, solar heating and cooling, photovoltaics, and advanced ground transportation. Energy work in NASA totaled almost \$150 million in 1978 and used the expertise of more than 500 scientists and engineers.

Wind Energy

During 1978 NASA's Lewis Research Center made major advances in the technology for large wind turbines. Two systems, each capable of supplying power for approximately 100 homes, are now in place—one in Clayton, New Mexico, the other in Culebra, Puerto Rico. A larger system, intended to supply power for about 250 homes, is in fabrication and scheduled for installation at Boone, North Carolina, in 1979.

Solar Heating

Development of solar heating hardware, begun at NASA's Marshall Space Flight Center in 1976, is now in its final phase. Thirty-five heating systems have been installed at various locations throughout the country with on-site data feeding into a systems evaluation.

Photovoltaic Conversion (Solar Cells)

Photovoltaic research and development is under way at several NASA laboratories, with the Jet Propulsion Laboratory in the lead role. The goal is to achieve a cost for electricity generated by silicon solar cells of \$0.50 per peak watt in 1986. Since the program began in 1974, the cost has been reduced from an average of \$50 per peak watt to a range of \$7 to \$10, and the prospects lead to optimism that the \$0.50 goal will be met. Techniques for automated production and new production technology will be required, but the requisite processes appear to have been identified.

Since today's cost of electric power supplied by solar cells is high compared to conventional power sources, cost-effective applications are largely restricted to remote sites where power is unavailable or is available only at a substantial premium. This situation exists in some of the less developed countries. To gain experience in this kind of environment, NASA recently joined with the Agency for International Development (AID) in a project to provide solar cell power for grinding grain and pumping water in Upper Volta. System development is now complete. Lewis Research Center and AID personnel are working together to develop the operational and maintenance procedures that will enable the equipment to be operated and maintained by local personnel.

Aeronautical Research and Development

NASA's aeronautical research seeks improvements in performance and safety of the current aircraft fleet and a base of high technology that designers can use to improve aircraft of the next generation. These objectives focus research onto

- reducing energy consumption of aircraft
- reducing undesirable environmental effects of aircraft noise and pollution
- improving aircraft terminal-area operations and safety
- advancing the concepts for future long-haul and short-haul air transportation
- solving problems in support of development of military aircraft.

Improving the Energy Efficiency of Aircraft

NASA made progress in 1978 toward its goal of developing the technology that would reduce fuel consumption by derivative and future aircraft engines by as much as 50 percent.

Engine Systems. For derivative engines some 130 potential improvements were identified in component technology for the JT8D, JT9D, and CF6

engines. The 17 selected for development should reduce fuel consumption by as much as 5 percent; as an example, flight tests with a B-52 aircraft verified a 1.3 percent reduction in fuel consumption by use of turbofan blades with a 3.8 aspect ratio in a JT9D engine. For the CF6 engine, an engine mount was tested to investigate reduced blade-to-case clearance in the compressor; this could lead to reducing fuel consumption and direct operating costs.

Studies of performance deterioration in revenue service engines showed that deterioration in performance is more dependent on the number of engine cycles than on length of service. Diagnostic data from ground and flight evaluations, plus historical engine and parts data, confirmed that the core of the engine accounted for about two-thirds of performance loss, with compressor deterioration predominating at higher cycles. Further analysis will improve understanding of deterioration and means of recovering losses.

For new turbofan engines, research was begun in 1978 on longer-range component technology intended to reduce fuel consumption by 12 percent. Each of the following components will be studied: the fan, compressor, combustor, turbine and exhaust nozzle, and seals and clearance control.

New propeller configurations, designed to increase efficiency and reduce noise, were tested. Models (62 centimeters in diameter) of three new designs for eight-bladed propellers achieved maximum efficiencies of up to 79 percent at design conditions of mach 0.8 and 10,500 meters altitude. One of the three was 10 times quieter than the other two.

Aerodynamic and Active Controls. Through a series of wind-tunnel tests, substantial progress was made in study of the effects of high-lift devices, winglets, and wing-tip extensions. Several high-lift designs using flaps and slats achieved greater lift coefficients with the supercritical wing than those obtained on current transport aircraft. Winglets designed to improve efficiency of current transports were verified to reduce drag by 3 to 5 percent. Similar wind-tunnel studies of wing-tip extensions showed drag reductions of as much as 3 percent.

The joint NASA/Air Force experimentation with winglets mounted on a KC135 aircraft completed checkout of instrumentation and calibration flights in preparation for flight-verification tests in 1979. The previously instrumented L1011 was modified with wing-tip extensions to verify in flight the wind-tunnel predictions. Also there was to be flight evaluation of an active control system for wing maneuver and gust load control. Since system reliability is the key to the use of active controls, two redundancy concepts were selected for further

development of the central computer. One design uses software to obtain fault tolerance in the control system; the other uses hardware redundancy.

Research in control of laminar flow is seeking a practical, reliable system that will reduce drag by 20 to 40 percent. Theoretical and wind-tunnel investigations have produced computer programs that enable prediction of the flow parameters and suction requirements needed to maintain laminar flow. These predictions will be used in developing three structural concepts that, for the least increase in weight, will provide the needed surface smoothness and amount of suction.

Structures. Structures research is presently concentrated on advanced composite structures and demonstrating their practical application in flight with six components now flying on transport aircraft. A design data base is being built from static, fatigue, and sonic test data from materials coupons and structural elements. For the DC10 rudder components made of composites and installed on aircraft, their test continued this year; periodic inspections showed no degradation after three years of flight. The manufacturing concept for these components was validated with the production of a batch of 10 of them. Testing of the first full-scale parts, such as a 3-meter section of the B727 elevator and a 2.5-meter segment of the spar for the L1011 vertical fin, is leading up to test verification of full-scale subcomponents.

Reducing Undesirable Environmental Effects

NASA made gains in 1978 in its research to reduce the undesirable noise and exhaust pollution from aircraft.

Aircraft Noise Reduction. This year a computer program that predicts noise sources and propagation effects for individual aircraft became operational. Validation studies compared predictions to measured aircraft noise for six types of aircraft ranging from the Learjet to the Concorde. The predictions were consistently good. Further validation is applying the predictions to high-bypass-ratio engines, and modules are being added for prediction of noise from helicopters and propeller-driven aircraft.

Work was begun on accurate ground simulation of inlet noise from inflight turbomachinery. Neither static ground tests nor wind-tunnel tests had been able to produce data that could be extrapolated with confidence to flight conditions. Preliminary data indicate that the information can be produced in ground tests if a turbulence control structure is placed in front of the engines.

Together with the Environmental Protection Agency, NASA began research on a design for gen-

eral-aviation propellers that optimizes aerodynamic performance at the lowest noise level. New theories on propeller noise are being applied to redesign of propellers on two different general-aviation aircraft.

Two noise studies were conducted in cooperation with the Federal Aviation Administration. In one study that was part of an international study on noise certification requirements for helicopters, ground observers at NASA's Wallops Flight Center evaluated the annoyance level of the blade-slapping noise associated with some overflying helicopters. Results showed no significant increase in individual annoyance; the certification scale does not need modification to be applied to helicopters. In the other study, NASA monitored the vibration response of buildings affected by Concorde and other aircraft flying over communities near Dulles and Kennedy Airports. Though well below levels that could cause damage to the buildings, vibration levels were high enough to be detected by people within the buildings. Vibration levels from Concorde noise were generally higher, but in accord with the amount that Concorde noise exceeded the noise of other jet transports rather than being a unique feature of the Concorde's noise spectrum.

Emissions Reduction. For several years NASA has been experimenting with new combustor technology for large turbine engines in an effort to reduce undesirable emissions. Three advanced combustor concepts designed for significant reductions in emissions of carbon monoxide and unburned hydrocarbons during engine idle tested very well. Carbon monoxide emissions were reduced by a factor of 20 to 30 less than current combustors and a factor of 10 less than previous low-emission designs. In 1978 the new combustor technology was successfully applied to reduction of emissions from small aircraft during takeoff and landing.

Work was begun to develop and evaluate concepts for ultra-low emission combustors. Fundamental investigations of the combustion process have indicated that further substantial reductions in emissions of oxides of nitrogen may be possible. This would be especially useful in minimizing the environmental effects of high-altitude flight. Studies on further reducing emissions during takeoff and landing have explored lean fuel/air burning through premixed/prevaporized and catalytic combustion techniques.

Improving Terminal-Area Operations and Safety

Since terminal-area operations are very demanding on facilities, personnel, and money and since a high percentage of aircraft accidents are associated with takeoffs and landings, concern for improvement in these areas is unremitant.

Terminal-Area Operations. NASA and FAA have a continuing cooperative effort to develop technology for advanced airborne systems and flight procedures that will provide more efficient operations in terminal areas. In one joint program, a NASA B737 aircraft with advanced digital display, navigation, and flight control systems demonstrated coupled, curved approaches and automatic landings and roll-out at Montreal's Dorval Airport using the U.S. Time Reference Scanning Beam Microwave Landing System (MLS). These flights demonstrated the U.S. system to representatives of the International Civil Aviation Organization. This group subsequently selected the U.S. system as the new international precision-guidance landing system, supplanting the 35-year-old Instrument Landing System.

To encourage industry to develop low-cost MLS airborne equipment for use by general aviation and small communities, NASA is demonstrating the flight performance of an MLS receiver designed to an installed cost of less than \$1500.

Safety. As part of its concern for air-transportation safety, NASA has operated a continuing research program to improve runway traction, braking effectiveness, and directional control of aircraft under adverse conditions such as slippery runways, strong crosswinds, or landing-gear problems. During 1978 a three-year flight investigation of the limitations of crosswind landing was completed. The research vehicle used in this investigation was a Twin Otter aircraft. It was evaluated with both a conventional tricycle landing gear and with an experimental crosswind gear. The most critical problem was control of the aircraft during landing roll-out. With the conventional gear, maximum tolerable crosswind was 25–35 kilometers per hour (15–20 knots); with the crosswind gear, satisfactory landings were made with crosswinds between 45 and 55 kilometers per hour (25–30 knots), about half the stall speed of the aircraft. The experimental gear also eliminated the demands on the pilot and the need for large control movements to decrab or slip the aircraft prior to touchdown. This allowed the controls to be near their neutral position at the start of the landing roll, leaving the full control range available for additional correction. This technology is available to commuter-class aircraft serving small airports offering little choice of runway or orientation.

NASA continued the Aviation Safety Reporting System (ASRS) which receives, processes, and transmits processed data to the Federal Aviation Administration on reports of unsafe events that are submitted by persons in the aviation community. The aviation community continues to submit about 100 reports per week; a data bank of more than 9000 safety reports can now be studied.

Advancing Long-Haul and Short-Haul Aircraft

Efforts continued to develop and prove the technology for supersonic aircraft more efficient and much quieter than today's version. And considerable progress has been made on demonstrating the feasibility of future very high-lift, very quiet short-haul aircraft that operate at very low approach speeds.

Long Haul. Research continued on technology for supersonic aircraft that could be economically attractive and environmentally acceptable. Aeroacoustic tests of models with small-scale nozzles verified noise predictions, including forward-velocity effects. Engine nozzle concepts for both double bypass and variable stream control were investigated. Predictions of jet noise were found to correlate very well with the experimental acoustical data. In addition, significant reductions in shock noise were verified for annular plug nozzles with inverted velocity profiles. Construction was completed for large-scale testing of a plug nozzle that would be mated with a core engine as part of the research on variable-cycle-engine components.

Flight tests of components for supersonic aircraft research continued to use the high-speed YF-12 aircraft. Extensive flight tests of a cooperative control system were completed, successfully demonstrating in high-supersonic-speed flight the integration of aircraft inlet and engine controls. Recently inlet control aspects of the system were being refined. To investigate YF-12 structural dynamics, a shaker vane system was installed and initial testing was completed. In airframe research on the ground, investigations were started of structural concepts for advanced superplastically formed/diffusion bonding in long-life, low-cost supersonic cruise aircraft. Fabrication of various structural elements was begun.

Quiet Propulsive-Lift Technology. In early 1978 NASA's Quiet Short-Haul Research Airplane rolled out of the Boeing factory in Seattle, Washington. This was a major step in NASA's research program to obtain data for the design and certification of short-haul, powered-lift transports.

After flight acceptance tests, the airplane was delivered to NASA's Ames Research Center, where in August it began its year-long proof-of-concept flight test program. Results thus far indicate that actual performance meets the design goals and predictions. The airplane has demonstrated a wide range of research capability, including a very high approach-lift coefficient—about three times that of conventional jet transports—and very high control power which makes possible terminal-area operations at very low approach speeds—about 100 kilometers per hour (55 knots). And it is extremely

quiet. During its test phase, the airplane will be used to investigate control requirements, handling qualities at low approach speeds, steep approach and takeoff flight paths, and operational procedures and techniques with one engine inoperative.

Technical Support of the Military

NASA aeronautical programs include broad-based research in support of military aeronautics. The emphasis is on advances in technology that offer opportunities for significant improvements in capability. These can then be considered by DoD in planning and developing the next generation of military aircraft.

Stall-Spin Research. For several years NASA, in cooperation with DoD, has conducted an intensive series of investigations into the undesirable stall-spin characteristics of modern fighter aircraft. In 1978 the program continued to yield valuable data, this time in determining the influence of aircraft nose shape on spin characteristics. Out of the study have come several design approaches for control systems that would inhibit the high-angle-of-attack departures that lead to stalls and spins.

Airframe/Propulsion Interactions. Another problem with modern, very high-powered aircraft has been that the large interactions generated by the powerful propulsion system have distorted the aerodynamic design of the airframe and thus degraded the overall performance. Flight data from the USAF F-15 and wind-tunnel data have provided the correlations needed to improve our ability to predict interactions between propulsion aerodynamics and airframe aerodynamics.

NASA-Military Flight Research. The long tradition of NASA and the military services using military-funded research aircraft to gather design and operating data continued in 1978. The two NASA/Army Rotor Systems Research Aircraft are being flown, one in the pure helicopter configuration, the other in the compound configuration using wing and auxiliary engines.

The NASA/Army Tilt Rotor Research Aircraft has been successfully tested in the full-scale wind tunnel at speeds up to 335 kilometers per hour (180 knots). The first of the two prototypes is now entering its NASA flight-research phase.

The two NASA/Air Force Highly Maneuverable Aircraft Technology remotely powered vehicles have been delivered to NASA and are in integration and checkout prior to flight testing.

Cargo Aircraft Studies. In cooperation with the Air Force, NASA completed this year a series of studies defining the advanced technology needed to support the eventual development of cargo aircraft that would meet the future needs for both military strategic airlift and commercial air cargo.



Introduction

The Department of Defense's activities in space and aeronautics are fundamental to the national security. These activities range from scientific research and development, which support a strong technological base, to implementation of new concepts and systems, which provide better and more efficient ways of satisfying requirements in such areas as communications, command and control, environmental forecasting, navigation, surveillance, and experimentation. Although those activities are military in nature, close cooperation between the DoD and other governmental agencies continues to produce benefits for the civilian sector. 1978 witnessed a broad spectrum of advances in space activities, including continued progress in the DoD program to use the Space Shuttle, while aeronautical efforts were highlighted by new technological applications which promise improved aircraft operating efficiencies and navigational aids. The year also witnessed continued activity in developing concepts, designs, and technology for implementation of new spaceborne space surveillance systems. This report summarizes the major space and aeronautics activities for 1978.

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: near-global coverage, service to isolated areas, wide transmission bandwidths, contingency operations, and mobile platform connectivity. The DoD uses leased satellite service in support of its communications needs, but it cannot depend upon commercial satellites alone for satellite communications for worldwide command and control of U.S. military forces.

Defense requirements for satellite communications call for three categories of capability: (1) high-capacity, high-data-rate, long-haul, point-to-point communications for fixed users; (2) mod-

erate-capacity, low-data-rate communications for mobile users; and (3) command and control of strategic nuclear forces. Military satellite communications systems which satisfy these mission capabilities must be hardened against nuclear effects; have jamming and cryptographic protection; and, in the near future, include antisatellite protection. These additional design requirements and high-capacity communication links are unique to DoD, enhancing communications and command/control continuity in a hostile or crisis environment. Currently these three categories of capability are 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 (Gapfiller I); 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 existing systems will be replaced in an evolutionary manner by (1) DSCS III, (2) Leased Satellite (LEASAT) System, and (3) Strategic Satellite System (SSS).

Defense Satellite Communications System (DSCS). The mission of the DSCS is to provide secure voice and high-data-rate transmissions in support of unique, vital national security requirements for worldwide military command and control and crises management. The DSCS supports critical, globally distributed communication requirements of the National Command Authorities, the Worldwide Military Command and Control System (WWMCCS), the Ground Mobile Forces (GMF), the Defense Communications System, the Diplomatic Telecommunications Service, the White House Communications Agency, selected allies, and other U.S. agencies. When fully operational, the DSCS space segment will consist of four active satellites and two on-orbit spares and will provide global (less polar) coverage with near 100 percent availability through the 1980s. To ensure continuity of essential communications and enhance survivability during crises situations and a potential hostile communications environment,

evolving DSCS satellites will include an improved anti-jam capability in addition to nuclear-effects hardening.

The initial research and development phase of the Defense Communications Satellite Program provided a limited operational system from 1966 through 1974. The space subsystem currently consists of four operational spacecraft: two DSCS II satellites (numbers 7 and 8) launched in May 1977 and DSCS II satellites (numbers 11 and 12) launched in December 1978. DSCS II satellites (numbers 9 and 10) failed to achieve orbit in March 1978 due to a launch vehicle failure. A successful December 1978 launch of satellites 11 and 12 will permit the return to NATO of the NATO IIIB satellite which was obtained on loan for temporary use. DSCS II satellites (numbers 13 and 14) will be available for dual launch in May 1979 to achieve the desired six-satellite configuration, while satellites (numbers 15 and 16) will become available for replenishment in late 1979 and 1980.

The next generation of DSCS satellites will be DSCS III models, with improved performance capabilities and protective devices to enhance survivability. During 1978, development of a qualification-model satellite, two R&D flight satellites, and ground command and control equipment continued. The qualification model is scheduled for completion, test, and evaluation in 1979.

The DSCS III satellite will have multiple, independent transponders to efficiently handle both small and large terminals. Its communications channels will have improved anti-jam protection through the use of multiple-beam antennas capable of nulling or minimizing uplink jamming signals. In addition to the normal S-band tracking, telemetry, and command functions operated by the Air Force SCF, the DSCS III satellite will have a super-high-frequency (SHF) command capability, controlled operationally by the Defense Communications Agency. This capability will improve response time for reconfiguration of antenna systems. The satellite will conform to nuclear survivability guidelines and will have a mean mission duration of about ten years. Since the Space Shuttle will become operationally available during the life of the DSCS III program, the new 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.

Fleet Satellite Communications System (FLTSATCOM). Moderate-capacity, mobile-user service will be provided by the FLTSATCOM. Its objective is to implement 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 have been awarded and the first spacecraft was launched in February 1978. Installation of fleet broadcast receivers is virtually complete, with systems installed in nearly 300 ships and 150 submarines. Additionally, over 120 ships are now equipped for reliable, long-range, secure voice operation. Shipboard terminal equipment is now operating through both the MARISAT and FLTSATCOM systems.

Air Force Satellite Communications System (AFSATCOM). AFSATCOM will provide command and control communications for strategic forces. The terminal segment will consist of airborne, mobile, and fixed terminals. Terminal deployment began in 1978 and will continue for the next four to five years. The space segment consists of three phases. Phase I, the current system, employs transponders on several types of spacecraft, including FLTSATCOM and the Satellite Data System (SDS). Phase II will employ single channel transponders on host satellites and an upgraded SDS. Planning for phase III, the Strategic Satellite System (SSS), is underway. It could include further upgrades to the phase II system or a new satellite system.

Satellite Communications Ground Support. The Army Satellite Communications Agency is responsible for the development and acquisition of strategic and tactical satellite communications ground terminals for use by all services. Two major projects in this program element are the DSCS II and the Ground Mobile Forces Tactical Satellite Communications Program. A third and smaller project in this program is devoted to the exploratory development required to support the two major projects.

During 1978, the last of 18 fixed DSCS terminals (AN/FSC-78) were certified and put into operational use. Also 23 Digital Communication Subsystems, which convert the existing analog system to digital operation, were shipped to DSCS terminals, making a total of 30 such shipments to the field. Activity continued on six transportable DSCS terminals (AN/TSC-86) scheduled for delivery commencing in late 1979. A production contract was awarded in 1978 for 21 AN/GSC-39 DSCS terminals which will have two deployment configurations: fixed and van mounted.

Tactical Satellite Communications. Several small SHF terminals have been under test since June 1975. These small terminals are now under contract for low-rate initial production. When fully

deployed, they will provide mobile, multi-channel communications for the ground mobile forces transmitting through the DSCS satellites from the field. A contract for 200 UHF vehicular terminals was awarded in September 1978. Deployment of these terminals will commence in 1980 in support of NATO. A UHF manpack terminal is presently scheduled for procurement in 1979. The interim operational capability provided by the test models continues to support various contingencies and field exercises. Operational testing through the year has refined concepts for use of this significant transmission medium in support of combat readiness.

International Cooperation in Space. In April 1978 the U.S. and United Kingdom implemented an arrangement whereby the U.S. provides capacity on DSCS II satellites to the U.K., in exchange for which the U.K. provides an equivalent amount of telecommunications services to the U.S. Earth terminals of the U.S. and U.K. continued to interoperate in mutual support of each other's operations.

The U.S., U.K., and NATO continued in agreement for a post-1975 communications satellite arrangement. The parties exchange satellite capacity during specified contingency conditions and allocate channels temporarily on a day-to-day basis when difficulties are experienced.

As a result of an agreement signed in September 1976 between the U.S. and NATO, and two extensions signed in 1978, the U.S. has had exclusive use of the NATO IIIB satellite during 1977 and 1978. In return, the U.S. will provide NATO with equivalent DSCS satellite capacity at a time to be designated by NATO and agreed to by the U.S.

By agreement with the Soviet Union, the new Direct Communications Link between the U.S. and U.S.S.R. was officially activated for use on 16 January 1978. This communications link utilizes the Soviet Molniya and the commercial Intelsat satellite systems. The occasion was marked by simultaneous press releases and the transmission of an inaugural message by working level personnel. With this new capability, it was possible to cancel one of the terrestrial "hotline" circuits, designated TGP-2, on 1 July 1978.

Navigation Satellite Activity

Navy Navigation Satellite System (Transit). The Transit system had its thirteenth year of operation in 1978. The purpose of developing Transit was to provide a worldwide, two-dimensional system for position fixing, primarily in support of strategic

ballistic missile submarines. Transit usage has been expanding, both militarily and commercially. It has been adapted to such diverse activities as off-shore oil exploration and measurement of the drift of ice over the poles. The five satellites provide an opportunity for a user to take a position fix every two hours or less, depending upon the latitude. In October 1977, a modified Transit satellite was placed in orbit carrying two specially instrumented transponders, or radio relays, called translators. These translators will test a Trident Missile Tracking System (SATRACK) and check out and calibrate range safety ground stations and equipment, in support of Trident I missile testing.

Since the early 1970s, a Transit improvement program has been under way. The improved satellites will provide greater survivability, as well as a compensation system to adjust for orbital disturbances caused by solar radiation pressure and atmospheric drag. The first of these satellites is planned to be launched in the fall of 1979, the second in the spring of 1980.

The NAVSTAR Global Positioning System (GPS). GPS is a joint service program to provide an increased capability for three-dimensional, high-accuracy, continuous, worldwide navigation. The operational NAVSTAR GPS will consist of 24 satellites at 20,400 kilometers altitude in three orbital planes, a ground segment for calibration and control of the satellites, and 25,000 to 35,000 user equipments of various classes. The GPS will provide all-weather coverage using a common grid, enabling users to passively determine position to within 10 meters and velocity to within .03 meter per second. A lower cost receiver will provide less accurate information (100-200 meters) suitable for most navigational purposes. The system may also be used to provide precise worldwide time transfer.

NAVSTAR GPS is in the concept-validation phase. The fourth GPS satellite was launched into orbit on December 10, 1978. Two additional satellites will be put into orbit in 1979 to form a constellation of six satellites. Development models of all classes of user equipment, including high-accuracy, low-cost, and man-pack models, are being extensively field tested. Initial test results confirm expectations for this system.

Navigation Technology Satellite 2 (NTS 2), developed by the Naval Research Laboratory, was launched in 1977. The NTS 2 allowed (1) evaluation of cesium frequency standards, (2) initial checkout of the NAVSTAR GPS launch vehicle, and (3) evaluation of NAVSTAR GPS orbits. Secondary experiments aboard NTS 2 include various solar cells, dosimeters, and a laser retroreflector.

Meteorological Activities

Defense Meteorological Satellite Program (DMSP). DMSP continued to provide high-quality visual and infrared imagery and other specialized meteorological data to support military operations. The DMSP obtains weather data for the entire Earth four times a day, using two satellites in polar orbits. These weather data are stored aboard the satellites and later transmitted to Air Force Global Weather Central in Nebraska and the Fleet Numerical Weather Central in California. The imagery is also transmitted in real time to transportable read-out stations at key locations worldwide to support tactical operations. DMSP weather data are also provided to the National Oceanic and Atmospheric Administration for its weather prediction activities. During 1978, the third Block 5D satellite became operational. In addition to imagery, these satellites provide high-quality vertical temperature and moisture profile data for the entire globe and provide precipitating electron counts from the auroral regions. The second of these satellites also provides data on the state of the ionosphere.

A joint Air Force/Navy program was initiated in FY 1977 to develop and procure a four-channel (19 MHz–94 MHz) passive microwave imager for DMSP. The sensors will provide data on precipitation location, rate, and type; soil moisture; and on sea surface/atmosphere interface. Four of the sensors are planned for deployment on DMSP satellites in 1980–1984. Conceptual design studies for the Shuttle-optimized meteorological satellite were begun in 1978.

Surveillance Activities

Early Warning Satellites. Early warning capabilities are provided by an intricate system of ground-based sensors and a constellation of three geostationary satellites which provide the earliest indication of a hostile ballistic missile launch against the U.S. During 1978, activities continued for the development of modifications to ensure compatibility of early warning satellite payloads with the Titan IIID and Shuttle Inertial Upper Stages (IUS) as well as development of improvements to the satellite communications elements. The development of improved sensors and on-board processing systems was also completed in 1978. These developments will be incorporated into satellite procurements and retrofitted into existing spare satellites with promise to improve system accuracy as well as increase on-orbit operational life.

Space Surveillance. The current capability for locating, tracking, and identifying objects in space

is provided by a network consisting primarily of ground-based radar sensors that are deployed for purposes other than space surveillance (e.g., missile warning). This sensor network has a limited capability to detect objects above 5500 kilometers altitude and has gaps in the coverage below this altitude. The DoD is currently procuring a Ground-Based Electro-Optical Deep Space Surveillance (GEODSS) system to enhance detection and tracking of satellites at high altitudes.

A viable approach, in the long-term, for providing responsive surveillance up to geosynchronous altitudes appears to lie in spaceborne sensors. Several research and development activities to develop technology supporting this concept have been initiated.

The first of a series of Air Force Multi-Spectral Measurement Program (MSMP) probe launches to collect ultraviolet and infrared data on small rocket engines in space failed in September 1978. After corrective actions are completed, these launches are to resume in January 1979. The first series of three launches is scheduled for completion in September 1979 after which a determination will be made to launch two additional but higher probe flights.

The Defense Advanced Research Projects Agency (DARPA) continued to develop concepts, designs, and technology for advanced strategic surveillance from space during 1978. New concepts in optics, detector arrays, signal processing, cryogenic cooling, and control systems providing a wider range of future missions reached a degree of maturity which justifies demonstration in space. The DARPA 301 gamma-ray spectroscopy project, to be launched in early 1979, employs state-of-the-art intrinsic germanium sensors and newly developed long-lived mechanical cryogenic coolers for remote location and characterization of radiation sources in the upper atmosphere and near space. Responsibility for this project will be transferred to the Air Force at the end of FY 1979. Progress in focal-plane technology allowed DARPA to initiate the Teal Ruby experiment scheduled for Shuttle launch in May 1981 to demonstrate detection of strategic air vehicles from space, to collect spectral and spatial infrared scene data, and to provide a demonstration of advanced focal-plane technology. The DARPA Mini-Halo experiment is scheduled to be launched in 1984 to validate the readiness of technology for advanced early warning and multi-mission surveillance. In 1978, DARPA also initiated the Talon Gold Experiment to develop and demonstrate technology to support space applications which require precision acquisition, tracking, and pointing at long range.

Space Shuttle Activities

Inertial Upper Stage (IUS). The IUS is under development by the Air Force to enable higher energy missions than the Shuttle can perform directly. The Defense Systems Acquisition Review Council conducted a review of the IUS program in March 1978. As a result, the Air Force was authorized to proceed with full-scale development of the IUS. The first use of IUS with Shuttle is planned to deploy the NASA Tracking and Data Relay Satellite. The IUS will support both NASA and DoD needs throughout the Shuttle era.

Classified Shuttle Operations. Present planning for Shuttle operations is predicated on use of NASA's Johnson Mission Control Center (MCC) for simulation, training, and flight control for DoD Shuttle missions. During 1978, a low-cost approach was defined for modification to the MCC which will protect classified payload launches on Shuttle with minimum disruption to civil users.

Vandenberg Air Force Base (VAFB) Shuttle Facilities. Efforts continued during 1978 to acquire Shuttle launch and landing capabilities at Vandenberg Air Force Base (VAFB), California. Vandenberg facilities are required by both civil and DoD users to support polar launches and hence complement Kennedy Space Center (KSC) capabilities which will support launch to low-inclination orbits such as geosynchronous equatorial deployments. Commonality of equipment and procedures between KSC and VAFB will minimize acquisition costs and operations complexity.

The requirements definition contract for VAFB was completed in mid-1978 and follow-on effort, such as design of unique support equipment, development and acquisition of the launch processing and computer applications software, preparation of installation designs, has begun. Facility construction is planned to start in early 1979 after a review of the program by the Defense Systems Acquisition Review Council. The initial capability for Shuttle operations from VAFB is planned for 1983.

Space Boosters

The DoD family of space boosters is comprised of the Atlas and Titan III standard launch vehicles and the surplus IRBM SM-75 Thor and ICBM Atlas E/F vehicles. These boosters launched 15 DoD space missions during 1978: 7 Titan IIIs, 1 SM-75 Thor, 6 Atlas, and 1 Delta (2 DoD launches were conducted by NASA). One launch failure occurred on 25 March 1978, when a Titan IIIC failed to orbit two Defense Satellite Communications System satellites.

Space Test Program

The space test program provides spaceflight test and evaluation for DoD R&D experiments and certain operational spacecraft not authorized their own means for space flight. Two payloads were launched in 1978 on host vehicles: one, a Navigational Package (NAV PAC), was the second of three such geodetic satellites placed in orbit; the second payload was a Host Vehicle Pallet (HVP) carrying four experiments for learning more about the space environment. The last NAV PAC is scheduled for launch in 1979.

Three new spacecraft missions were initiated in 1978: Satellite Infrared Experiment (SIRE), Teal Ruby, and Long Duration Exposure Facility (LDEF). The SIRE spacecraft, to be launched on an Atlas-F, carries seven experiments; the primary experiment tests a new Air Force long-wavelength infrared sensor for the detection of satellites. The Teal Ruby and LDEF missions will be placed in orbit by the Shuttle. The Teal Ruby spacecraft carries three experiments; the primary experiment tests a new DARPA infrared sensor for the detection of aircraft. The LDEF mission consists of four experiments to study the effects on materials and will be flown on NASA's free-flyer, reusable spacecraft.

A new policy was established which specifies that the Space Test Program is to become DoD's pathfinder for exploiting the Shuttle as a manned laboratory in space.

Space Research and Technology

Space-related research and technology by the Department of Defense includes efforts defining the space environment and assessing its effect on the performance of DoD systems operating within it.

Solar Radiation Monitoring Program. The Navy solar monitoring program in 1978 consisted primarily of developing additional applications for operational predictions of propagation phenomena affecting HF and VLF radio systems. Solrad Hi and Goes satellite data provided significant real-time solar measurements for the research and development of a prediction system under evaluation at the Naval Communication Station, Stockton, California. The Naval Research Laboratory continues to explore basic research studies in solar physics, solar terrestrial relationships, and plasma processes to determine these solar effects on Navy systems and operations.

As part of the continuing Air Force technology program in prediction of propagation environment, solar processes are being investigated and solar emissions are measured. The programs in

solar emissions include the theoretical study of the processes leading to solar flares. The Air Force Geophysics Laboratory works closely with the National Science Foundation's Sacramento Peak Observatory. Air Force scientists are developing techniques to forecast the time-history of high-energy solar particles that may impact the Earth following a major solar flare. The Air Force is installing a worldwide radio-solar-telescope network for use with the Solar Optical Observing Network.

Air Force scientists are also participating in rocket and satellite observations of solar ultraviolet (UV) emissions. Working closely with NASA scientists, Air Force personnel are studying the variations in solar UV observed by spectrophotometers on Atmosphere Explorer C, D, and E satellites. Rocket flights designed to measure solar UV flares between 230 and 3500 Angstroms continue to be flown and, in conjunction with satellite measurements, used to develop models of the solar UV emission spectrum.

Environmental Remote Sensing. Navy accomplishments in 1978 included the initial operation of the Satellite Data Processing Center at the Fleet Numerical Weather Central, Monterey, California. This center processes real-time DMSP data and had planned to receive and process the real-time data from NASA's Seasat 1 satellite launched in June 1978. Data from the DMSP satellites provide limited global ocean data for inputs to atmospheric and oceanographic operational analyses and forecasts supporting fleet operations and special DoD operations. Because of the early failure of Seasat 1, real-time processing of the data was not possible. An after-the-fact evaluation of the utility of the available data will be performed. Continued progress has been made in developing applications of satellite-derived infrared imagery in observing sea-surface thermal structures and locating oceanic fronts, eddies, and water masses. The Navy research community, interfacing with fleet exercises conducted during the year, demonstrated the potential of using satellite-collected sea-surface temperatures for tactical applications in antisubmarine warfare and undersea warfare. The sea-surface temperature measurements and analysis also support the National Climate Program.

Spacecraft Charging Technology. The Air Force Geophysics Laboratory (AFGL) is actively involved in the Joint USAF/NASA Spacecraft Charging Technology Program. In addition to developing theoretical and empirical models of the natural environment leading to spacecraft electrical charging at synchronous altitude, AFGL continued preparation of a handbook that will document the full range of variability of charged particles and

fields that can be expected at this altitude. Data from the Air Force Scatha satellite, to be launched in 1979, will be included in a future supplement to the handbook. Scatha satellite instrumentation, supplied by the Air Force, will include electrostatic analyzers, charged particle flux spectrometers, and electron and ion beam systems to assess the feasibility of actively controlling satellite charging and discharging. Close coordination between the interdependent activities of the Air Force and NASA continue through the joint USAF/NASA Spacecraft Charging Technology Program. Models of the energetic electron flux at satellite altitudes will be implemented to measure energetic electrons in the 110-megavolt range. These measurements are needed to determine the dosage rates that satellite microcomponents will be subjected to under operational scenarios.

Advanced Space Communications. The Advanced Space Communications Program has as its goal the development and demonstration of advanced spacecraft and airborne/ground terminal technologies to meet future DoD needs for Military Satellite Communications (MILSATCOM) systems. During 1978, the space technology portion of the program concentrated on null steering antennas and on-board processors to provide the means for future jam-resistant MILSATCOM systems. Space-qualified solid-state amplifiers at 40 and 60 gigahertz were also pursued to provide a reliable alternative to travelling-wave-tubes. During the same period, the terminal technology portion of the program consisted of a dual-frequency (SHF/EHF) terminal, a lightweight SHF terminal, a solid-state UHF transmitter, and a command post processor for interfacing with multiple MILSATCOM systems. In addition, the Laser Communications Program completed its laboratory test program and moved to the White Sands Test Range for initial field tests prior to a flight test program in an EC-135 aircraft.

Other Technological Activities. Significant efforts in on-board satellite data processing and navigation continued. Major emphasis is being placed on solid-state mass memories which will be more reliable and less vulnerable than current systems and on a high-accuracy, autonomous-navigation, and self-test-and-repair computer.

In missile surveillance technology, the Air Force has developed detector modules for a mosaic staring sensor which may lead to a follow-on missile surveillance system having improved survivability in laser and nuclear environments.

In satellite space power systems development, efforts continued on a nickel-hydrogen battery intended to replace current nickel-cadmium units. In

cryogenic cooling for payloads, a broad complementary program was established between DoD and NASA organizations.

Space Ground Support

DoD space activities are principally supported by the Air Force's Eastern and Western Test Ranges, Satellite Control Facility, and Arnold Engineering Development Center; the Navy's Pacific Missile Test Center; and the Army's White Sands and Kwajalein Missile Ranges. These facilities are available for use by Federal agencies, industry, and other nations and support a wide variety of test and evaluation activities.

Eastern Test Range (SAMTEC/ETR). The objective of the Air Force's ETR is to support a variety of DoD space and ballistic missile operations, NASA space programs, and commercial or international satellite launches under the sponsorship of NASA. Current improvement emphasizes the enhancement of telemetry, radar tracking, and range safety. During FY 1978, ETR provided support to Navy testing of Poseidon and Trident Fleet Ballistic Missiles. Launch and data-acquisition support were provided to NASA's Viking program, satellites for commercial organizations and foreign governments, and operational space payloads for the Air Force and NASA. ETR was also actively engaged in conducting planning and analyses in support of the Space Shuttle, which will be launched for orbital test flights from the Kennedy Space Center in 1979.

Western Test Range (SAMTEC/WTR). WTR is a national range providing range tracking, data acquisition, and flight safety support for all ballistic missile and space launches, as well as aeronautical tests. Approximately 45 ballistic missile and space launches were conducted in 1978, along with 20 aeronautical flights. Major aeronautical programs include the F-15 and E-3A. WTR is actively engaged in planning for the Space Shuttle launches from Vandenberg AFB, which involves extensive construction of launch, logistic, and maintenance facilities.

Satellite Control Facility (SCF). Fifteen launches (DoD, NASA, and ballistic), 72,103 satellite contacts, and 63,732 network hours were supported by the SCF during FY 1978. The Guam Tracking Station restoration was completed. The network initiated support to the NAVSTAR Global Positioning Phase I satellites and to the Navy's FLT-SATCOM satellites. Actions were initiated for the data systems modernization/upgrade. This will reduce data processing at remote stations and replace the aging (early 1960s vintage) flight-support computers. This four-year program will centralize data

processing at the Satellite Test Center and, by eliminating unnecessary equipment and associated manpower, produce significant network savings by 1982. Modification of the network with Timed Division Multiplex telemetry equipment was initiated. Expansion of the Thule Tracking Station to a dual antenna configuration was begun. Studies were continued of SCF support requirements generated by DoD's transition to the Space Transportation System.

Pacific Missile Test Center. The Pacific Missile Test Center operates an extensively instrumented Sea Test Range off the coast of southern California. In addition, the Center has radar and telemetry capabilities at the Pacific Missile Range facility on the island of Kauai, Hawaii. These facilities in 1978 supported NASA launch operations of the Delta/Landsat-C, Scout/HCMM, and Atlas/Seasat. Support included radar tracking, telemetry, and command destruct systems. The Pacific Missile Test Center provided EC-121 telemetry aircraft for recording telemetry data and real-time retransmitting of telemetry to the NASA ATS 6 satellite for data relay. The Center was also engaged in planning support of the NASA Space Shuttle Orbiter.

White Sands Missile Range (WSMR). The Army's WSMR continued to provide support to DoD and NASA aeronautics and space programs. A full spectrum of launch, flight, and recovery services was provided, including ground and flight safety, surveillance, command and control, data acquisition, and analyses. Army, Navy, and Air Force programs include Nike launches, Aries and Astrobee sounding rockets, Aerospace Sounding Rocket Vehicle (ASROV), and the Atmospheric Measurement Balloon Program. NASA program support included the Space Shuttle, the calibration rocket program, upper atmospheric sounding using Aerobee and Astrobee-F rockets, Nike-series rocket firings, Black Brant research vehicles, as well as numerous smaller rocket systems and a variety of astronomical test programs. Two ground sites for calibration of meteorological satellites were also maintained for use by NASA.

Kwajalein Missile Range (KMR). The Kwajalein Missile Range (KMR) is operated by the Army as the major test range for our strategic missile forces, both offensive and defensive. It has the sole U.S. 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. KMR instruments have also provided backup support to NASA space programs.

Arnold Engineering Development Center (AEDC). AEDC is the Free World's most compre-

hensive complex of technical and support facilities designed to simulate flight environments on the ground. AEDC's work ranges from basic R&D associated with environmental testing to full-scale flight-hardware testing. In 1978, AEDC provided over 45,000 test hours in support of programs such as Space Shuttle, B-1, and F-16 aircraft; Air Launched Cruise Missile; and support to the Department of Energy. Acquisition of the Aero Propulsion Systems Test Facility (ASTF) will permit simulating the severe flight environments experienced by present and future aircraft of larger sizes and higher speeds. With it, AEDC will be able to fully test air-breathing propulsion systems on the ground prior to flight, thus minimizing extensive flight tests and avoiding costly modifications to completed systems.

Aeronautical Activities

Aircraft and Airborne Systems

F-16 Multinational Fighter. The development test program progressed exceptionally well during 1978 and the operational application of a number of technologies was proven. The flight-by-wire flight control system, when integrated with the flight control computers, provides optimum control throughout the aircraft envelope. Aircraft performance has been significantly improved by the use of aerodynamic design as well as of advanced engine technologies. The extensive use of aluminum structure to reduce cost has been tested to twice the expected airframe life of 8000 hours. The F-16, the first of which was delivered in August 1978, is meeting requirements and will be officially introduced into the Air Force inventory with activation at Hill AFB in January 1979.

B-1 Bomber Program. Plans for production and deployment of the B-1 were halted, but development and testing have continued so that the technical base will be available should alternate strategic systems run into difficulty.

Three aircraft have been flying in the test program at Edwards AFB, California, to measure overall performance, gather data on structural air loads, complete development of the F101X engine, and evaluate the offensive avionics subsystem. The fourth and last B-1 aircraft is nearing completion and will be used to provide further data on the effectiveness of a modern, high-speed, low-altitude penetrating bomber. The program is a vital steppingstone to future strategic penetrating aircraft.

A-10 Close-Air-Support Aircraft. The Air Force plans to procure 733 A-10s to provide a specialized close-air-support aircraft. Research and development is complete, except for new systems being

added to improve effectiveness. Of the 483 aircraft approved for production, over 175 have been delivered to tactical air forces in the U.S. and Europe. The first operational wing has three combat-ready squadrons. The second operational wing, which is being located in USAFE, is currently receiving the first of 108 aircraft. Favorable reliability and maintainability factors have continued, so the anticipated low operating costs should be realized.

F-15 Air Superiority Fighter. Deployment of F-15s to tactical units continued in 1978 with the equipping of a wing at Holloman AFB, New Mexico, and a separate squadron at Camp New Amsterdam, the Netherlands. More than 360 production aircraft were delivered by the year's end, nearly half of the total planned buy of 729 aircraft.

Two significant improvements were incorporated into the F-15 design in 1978. The first increases internal fuel supply, strengthens the landing gear, and adds provisions for carrying conformal fuel tanks. The second replaces the current radar signal processor with a Programmable Signal Processor (PSP) to enhance both the current and growth capability of the radar system. Deliveries of the 325 F-15s configured with these improvements will start in June 1979.

F/A-18 Carrier-Based Strike Fighter. The Navy's F/A-18 aircraft is the replacement for the remaining Navy and Marine F-4 Phantom fighters as they reach the end of their service life. It will also replace the aging A-7 light attack aircraft in the mid-1980s. Introduction of this aircraft into the fleet will provide the tactical commander at sea with a high-performance, agile strike fighter, capable of surviving in hostile territory. The Secretary of Defense has approved full-scale development of this aircraft. First flight was in November 1978.

AV-8B. The success of the AV-8A aircraft in satisfying the light attack vertical/short takeoff and landing (V/STOL) requirement of the Marine Corps has led to the development of the more capable AV-8B. The airplane incorporates a supercritical composite wing, redesigned inlets, and lift improvement devices and will be equipped with angle-rate bombing systems for improved accuracy in weapon delivery.

The AV-8B program completed the initial phase of full-scale wind tunnel testing in 1978 at NASA's Ames Research Center. The NASA data confirm that the AV-8B aircraft will have superior V/STOL characteristics with approximately double the range or payload of the AV-8A. Two YAV-8B (AV-8B prototype) aircraft are under contract; the first flight occurred in November 1978.

H-X. The Air Force is taking initial actions to provide a replacement for the aging H-3 "Jolly

Green" helicopter used by the Military Airlift Command's Aerospace Rescue and Recovery Service. The Jolly Green helicopters served as the vehicle for countless heroic rescue efforts during the Southeast Asia conflict but are faced with problems of age. The replacement aircraft, initially dubbed "H-X," is envisioned as a highly sophisticated and highly survivable vehicle, perhaps a derivative of the U.S. Army Black Hawk. Equipped with the latest state-of-the-art avionics, the helicopter will be capable of long-range penetration of enemy territory under the cover of adverse weather conditions and/or darkness.

Advanced Attack Helicopter (AAH). The Advanced Attack Helicopter program continued in full-scale engineering development during 1978. Major activities during the year consisted of test and evaluation of design modifications on two flight prototypes. Fabrication of three additional prototype aircraft was started. Bench testing of the target acquisition and designation system as well as the pilot night vision system was initiated.

CH-47 Modernization. The CH-47 Modernization Program is designed to increase the life of the older CH-47A, B, and C model aircraft and improve the performance of the A and B models. The development effort is to modify three prototypes and subsequently the current CH-47 fleet with seven modernized systems: rotor, drive, hydraulic, electrical, advanced flight control, cargo handling, and auxiliary power unit. Integration of these changes will result in one standard CH-47 configuration which facilitates logistical support and simplifies maintenance.

Structural modification of the first two prototypes was completed in 1978. More than three ship sets of fiberglass rotor blades were completed and over 120 hours of flight testing were accumulated. Fabrication of a flight controls integration test rig to check out the complete flight control and hydraulic systems is nearing completion.

E-3A Airborne Warning and Control System (AWACS). The E-3A Wing at Tinker AFB, Oklahoma, reached operational status in April 1978. To evaluate this initial operational capability for airborne surveillance, the Air Force Test and Evaluation Center analyzed the E-3A "Sentry" for supportability during deployment and mission effectiveness during orbit coverage. These tests took place during the Brave Shield XVII exercise over the Pacific Northwest.

The first operational deployment of the Sentry occurred in October 1978. Two E-3As were deployed to Iceland to replace aging EC-121s and provide airborne surveillance and operations control over the North Atlantic.

Development is continuing to incorporate into the E-3A the Joint Tactical Information Distribution System (JTIDS) and a maritime surveillance radar mode. These improvements will provide the E-3A with the latest state-of-the-art command and control communications net and enable the E-3A to track maritime targets in high sea states.

E-4 Advanced Airborne Command Post. Airborne command and control of strategic forces is vital to ensuring survivability of connections between the National Command Authorities and strategic nuclear forces. The E-4 program concept offer prospects for survival under severely degraded conditions.

The E-4B aircraft will have an advanced communications capability that will not be operationally limited to air-to-air or air-to-ground line of sight communications. This advanced capability includes the new SHF and UHF airborne satellite communications terminals, high powered LF-VLF terminal, and secure voice and improved communications processing systems. These systems provide the voice and data connectivity, with anti-jam features, that will support operations in a nuclear environment over extended distances. Together with the electromagnetic pulse-resistant E-4B airframe and expanded operation teams and battle staff, these improvements will provide an improved command and control capability with a substantial reduction in the currently operational airborne assets. Further, the increased operational flexibility provided by the E-4B will allow random flight patterns and evasive flight profiles without concern for loss of communications. An extensive test program now under way will form the basis for the final E-4B configuration.

Tomahawk Cruise Missile. Tomahawk is a high-subsonic-speed, turbofan-powered, long-range cruise missile sized to be fired from a submarine torpedo tube, but also capable of being launched from surface ships, aircraft, and mobile ground platforms. This missile is being developed in two forms, a conventionally armed anti-ship version and a nuclear-armed land attack version.

The anti-ship Tomahawk is essential to Navy general-purpose forces in offensive or defensive sea-control operations. Tomahawk will provide an important complement to carrier-based aircraft in extending the Navy's anti-ship capability over a broad ocean area. If they are to have flexible control of the sea, Navy forces must be able to challenge the enemy at sea when neither side has air support. Tomahawk is designed to provide this capability through deployment of long-range offensive power from a variety of platforms. The stand-off capability afforded by Tomahawk will pose a

credible threat to enemy surface forces at minimum risk to our launch platforms.

The primary need for the land-attack Tomahawk is in the theater role, where its single-warhead, high-accuracy penetrativity and its survivability make it particularly suitable for use in limited nuclear attacks.

Tomahawk is planned for installation on nuclear attack submarines and cruisers. A ground-launched version of Tomahawk is being developed for the Air Force. It is also being considered as one candidate for the air-launched cruise missile.

Air-Launched, Sea-Launched, and Ground-Launched Cruise Missiles. All three versions are currently in full-scale development. The Air Launched Cruise Missile (ALCM) represents a major new weapon for the strategic bomber force. The ALCM program is in competitive full-scale engineering development. Missile rollouts are expected in February 1979 and the first competitive flights should occur in June and continue through November 1979. A source selection process will pick a winner prior to the major production decision in February 1980.

The Sea Launched Anti-Ship Cruise Missile (SLCM) is essential to Navy general-purpose forces in offensive or defensive sea-control operations. SLCM will provide an important complement to carrier-based aircraft in extending the Navy's anti-ship capability over a broad ocean area. SLCM is planned for installation on attack submarines, cruisers, and Spruance-class destroyers.

The Ground Launched Cruise Missile (GLCM) is planned for use in the theater role. The Air Force's GLCM provides increased nuclear firepower and could relieve dual-capable aircraft for conventional missions, thereby raising the nuclear threshold.

Pave Low III. Operational evaluation of the Aerospace Rescue and Recovery Service's Pave Low III Combat Rescue System is underway at Military Airlift Command's Kirtland AFB, New Mexico. Pave Low III, integrated into an H-53 helicopter, provides the USAF with a highly sophisticated, advance rescue system that will permit recovery of downed airmen in hostile territory under conditions of total darkness and in adverse weather. Such a system has been necessitated by an increasingly lethal enemy threat that will outdate current rescue tactics. Production has commenced on the first of several systems which are to be delivered within the next few years. These systems will include forward-looking infrared devices, terrain avoidance/following radar, and inertial/Doppler navigation.

Joint Tactical Information Distribution System (JTIDS). The JTIDS program is developing a

highly jam-resistant, crypto-secure, high-capacity digital information distribution system for use by tactical elements of all U.S. forces. Using spread spectrum and time-division multiple-access technology, JTIDS will be capable of interconnecting all participants in an area of 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). During 1978, in-plant and flight testing of the E-3A terminal was completed. All performance requirements were met or exceeded. Also in 1978, initial advance development models of a fighter-aircraft version of the JTIDS terminal were delivered for government test and evaluation. Concept definition studies for a lightweight, low-cost, man-pack version were also completed.

Aeronautical Research and Development

Aircraft Structures and Materials Technology. Each of the services has research and development programs directed toward improved structures and materials for aeronautical and space applications. An example is the Navy's engineering development program to develop a fiberglass composite rotor blade as a replacement for the CH-46 metal rotor blade. This fiberglass blade is designed to be corrosion resistant, have no environmental degradation, be insensitive to small defects, have slow failure propagation with a stiffness warning, and require only visual preflight inspections.

The Air Force is determining the suitability of cast aluminum for primary aircraft structures, offering a minimum 30 percent cost saving with no weight penalty. A large bulkhead from a cargo aircraft was redesigned from over 400 parts and 2500 fasteners to a one-piece cast aluminum structure with no fasteners. Testing is continuing to validate structural integrity.

The Air Force is conducting an advanced development program to demonstrate improvements of advanced technology titanium structures for airframe applications. This program applies recently developed fabrication technologies to airframe structures with a goal of reducing acquisition costs of conventional titanium structures by 50 percent and reducing weight by 30 percent.

Primary Adhesively Bonded Structure Technology is also being developed by the Air Force. Through the use of adhesive bonding, fabrication of large cargo aircraft structures such as fuselages can be reduced from the labor-intensive assembly of thousands of parts to the assembly of a few large

bonded modules. Program objectives are to demonstrate improved structural durability while achieving a 25 percent reduction in acquisition cost and a 15 percent weight reduction. A four-year program, initiated in February 1975, is composed of four phases: preliminary design, detail design, fabrication, and fatigue testing of an adhesive-bonded representative fuselage section 13 meters long and 6 meters in diameter. The first three phases and the limited proof pressure test have been completed. Full-scale fatigue testing is now underway. Two equivalent lifetimes (38,000 pressure cycles) of a goal of four lifetimes were successfully reached on 12 September 1978.

Control Configured Vehicles. In the Control Configured Vehicles program, the Air Force flew military airplanes with unique maneuvering motions that enhance performance. A YF-16 fighter was specially modified with a flight control system that permits the aircraft to move sideways or up and down without changing its attitude in pitch or bank. It can also be controlled to turn or point to potential targets without changing the overall flight path.

Experienced combat pilots have confirmed the potential for significantly increasing the effectiveness of air-to-air combat and weapon delivery, or increasing combat survivability, and for reducing the fuel needs of a mission. Work now is in progress to objectively assess this potential for transition to fighter, bomber, and missile applications of the future.

Remotely Piloted Vehicles (RPV). The Army completed a system technology program which demonstrated that an airborne RPV can obtain reconnaissance and target acquisition information beyond the forward edge of the battle area, where probability of survival of manned systems in a high threat environment is unacceptably low. The full-scale RPV, including a TV sensor and laser range-finder/designator, has a wingspan of 3.6 meters and weighs 66 kilograms. It flies at speeds under 183 kilometers per hour. Plans are now being formulated for full-scale engineering development.

Helicopter Avionics. The AN/ASN-28 Doppler navigation subsystem continues in production, providing Army helicopters a self-contained tactical navigation capability. In addition to present position, range and bearing to ten checkpoints are provided to the crew.

Design-to-cost engineering development contracts continued for the Integrated Avionics Control System (IACS). The IACS will provide an integrated panel for the control of up to ten avionics "black boxes" (radios, transponder, automatic direction finder, etc.), saving cockpit space and improving

the man-machine interface. Prototypes were delivered during FY 1978.

The Army completed concept formulation for a system to improve communications during nap-of-the-earth operations. Using field test data and propagation models in detailed mission analyses, various system alternatives were examined with regard to operational effectiveness. User-desired hardware features and costs also were carefully considered.

Advanced Environmental Control System. The Air Force completed development of an Advanced Environmental Control System which will make aircraft avionic equipment more reliable and improve aircraft performance. Current aircraft environmental control systems provide poor control of dust, humidity, and thermal environments. They are relatively inefficient, require significant amounts of aircraft-developed energy, and are costly in terms of avionic equipment reliability and aircraft performance. Avionic equipment requires more maintenance manhours per flight hour than any other aircraft system; for fighter and bomber aircraft, it uses over half of the total logistic support costs. Improvement in avionic equipment reliability through future utilization of this system will decrease life-cycle costs significantly.

Synthetic Flight Training Systems (SFTS). Following Army testing, the flight simulator for the CH-47 became standard in June 1978. This simulator uses a closed-circuit television system in conjunction with a three-dimensional terrain model to provide a realistic visual display. The first production article of the CH-47 simulator will be placed on contract in early FY 1979. The prototype is now being used in an aviator training program at Fort Rucker, Alabama.

The AH-1 Flight and Weapons Simulator (FWS) is the first to incorporate weapons engagement along with other flight maneuvers. The evolution will continue with the development of the UH-60 Black Hawk Flight Simulator which will use a camera model board for one cockpit and a computer-generated-imagery visual system for the other cockpit. Testing, to be conducted in 1979, will evaluate the training benefits of these two technologies. Concept formulation is underway for the AH-64 Flight and Weapons Simulator which will have the capability to produce the sound and fury of the battlefield.

Research in Aircraft Propulsion Systems. The Advanced Turbine Engine Gas Generator (AT-EGG) program is the main Air Force propulsion program assessing core engine components under realistic test conditions. The program has traditionally assessed performance and has been increasing in scope to include life-cycle costing and structural

testing earlier in the engine development cycle. Accomplishments in 1978 include several successful durability demonstrations of variable-area turbines, lower cost design concepts and manufacturing methods, and testing of a generator core unit. Realistic structural test methodologies are being studied by all participating contractors.

The Aircraft Propulsion Subsystems Integration (APSI) program is another joint Air Force/Navy program. High-pressure turbine engine cores from ATEGG are combined with low-pressure components (fans, compressors, and fan turbines) and inlets, exhaust nozzles, afterburners, and control systems to assess full-scale engines from the standpoint of installation considerations. The Joint Technology Demonstrator Engine (JTDE) program is part of APSI. Accomplishments include demonstrations of variable-cycle-engine concepts and verifying installed performance increases while reducing fuel consumptions by matching the engine cycle to changing flight conditions. The first demonstration was completed in FY 1978.

Advanced Technology Concepts. The DoD Research, Development, Test and Evaluation (RDT&E) program continued to sponsor a myriad of activities for the national defense. Under the RDT&E program, the DoD Science and Technology Program sponsors activities in research, exploratory development, and advanced technology demonstrations. Technological areas covered by this program extend from propulsion for aircraft, missiles, and space systems, to guidance and control, communications and electronics, through materials, structures, information processing, and through environmental sciences to the vital areas of safety and life sciences. Technological applications in aeronautics and space are developed to meet more sophisticated requirements of current and projected programs. During 1978, efforts in advanced electronics—electro-optics, microwave, and computers—continued to provide technological improvements for aeronautic and space systems.

Electro-optics technology is being incorporated in many devices, such as infrared and charge-coupled imagers, signal processors, ring laser gyros, fiber optics, and displays. These devices are finding their way into improved aeronautical systems such as target designators, range finders and trackers, optical search and tracking devices, miniature solid-state TV cameras, and navigational systems.

Advances in microwave technology continue to provide applications permitting improvements in microwave-power-generating efficiencies and electronic package miniaturization by using recently developed solid-state components.

Emphasis continues to be placed upon computer science technology as computer processing require-

ments become more integral with the total aeronautical system. Present aircraft contain as many as a dozen mini-computers, handling functions such as navigation, altimetry, fire control, weapon delivery, search, and flight control. Recent developments in mass memory capabilities are allowing development of computer correlation of terrain features, sensed by radar or passive radiometers, with previously stored mapping information for precise navigation over long distances.

Relationship with NASA

Aeronautics and Astronautics Coordinating Board

The Aeronautics and Astronautics Coordinating Board (AACB) is the primary mechanism for addressing major policy issues of interest to DoD and NASA in space and aeronautics. During the past year the Board placed special emphasis on status of the Shuttle program and schedules, and problems which could impact DoD plans for Shuttle use.

Space Shuttle Activity. On July 20, 1977, the AACB established the Ad Hoc Shuttle Security Group to select a low-cost approach to using NASA facilities at Johnson Space Center for launching DoD classified payloads on the Shuttle. At that time it was recognized that a long-term permanent solution might require a DoD Control Center.

On October 12, 1977, at the 75th AACB meeting, the Group recommended a "controlled mode" approach to using the Johnson Mission Control Center (JMCC). The Board directed the Group to initiate an engineering and management validation study for controlled mode operation at JMCC.

NASA Johnson Space Center (JSC) and the Air Force Space and Missile Systems Organization (SAMSO) both participated extensively in this validation phase. JSC defined changes required at MCC to provide secure data and voice links, separate classified/unclassified data streams, hardware switching, secure areas, a dedicated flight control room, separate secure lines, disconnected remote terminals, and procedural changes (estimated cost \$37 million in FY 1978 dollars). SAMSO reviewed the JSC proposal and added items associated with Tempest considerations, software validation and verification, and automated data processing implementation and certification requirements (estimated cost \$44 million). Thus the total estimated projected cost was \$78 million.

The Ad Hoc Shuttle Security Group recommended to the Board the following:

Pursue controlled mode at JSC for operational use in 1982 which is properly phased and funded at minimum levels, and meets following criteria:

- a. Supports classified launches in mission model.
- b. Is independent of initial availability of any DoD dedicated facility, i.e., does not drive that decision.

The Co-Chairmen agreed to initiate action within their respective agencies to implement the controlled mode approach at JMCC to meet the need for classified payload launches beginning in 1982.

On 30 September 1978 the Deputy Secretary of Defense directed the Air Force to acquire the controlled mode capability at Johnson Space Center in time to support the first DoD classified launch on the Shuttle in 1982. Investment for that purpose will be held to a minimum consistent with essential security needs and projected classified launches on the Shuttle through the mid-1980s.

During the year the AACB closely reviewed the Space Shuttle orbiter's projected payload budget for selected missions along with weight reduction measures, performance enhancement, and uprated propulsion gains to provide a 1350-kilogram positive payload margin for polar launches. Shuttle main engine development progress, the Air Force Inertial Upper Stage development status, and progress on the design of the Air Force Shuttle launch and landing facility at Vandenberg AFB were also examined.

The Board agreed that the revised NASA schedules for Shuttle First Manned Orbital Flight, initial operations at Kennedy Space Center, and orbiter deliveries do not require overall changes in DoD planning for Shuttle use.

National Aeronautic Facilities Program. In its final form as defined by DoD and NASA, the National Aeronautic Facilities Program (NAFP) contained three large facilities necessary to continue the efficient development of aeronautical technology and systems through the end of this century. The facilities contained in the NAFP are:

- *Aeropropulsion Systems Test Facility (ASTF)*—sponsored by the Air Force to support the economical development of advanced engines for fighter, large strategic transport, and bomber aircraft.
- *National Transonic Facility (NTF)*—sponsored by NASA to permit research and development testing at high Reynolds number in the transonic mach-number range (combines the requirements of the earlier High Reynolds Number Tunnel, sponsored by the Air Force, and the Transonic Research Tunnel sponsored by NASA).
- *40 × 80 Foot Subsonic Tunnel Modification*—sponsored by NASA to meet subsonic research

needs for the study of rotor craft and large powered lift vehicles.

Significant progress was made on all three facilities during 1978.

Cooperative Programs/Efforts

DoD continued to actively participate in joint activities with NASA and other agencies during 1978. Efforts already described are the Solar Radiation Monitoring Program, Spacecraft Charging Technology, and activities associated with the Space Shuttle. Other areas of interest:

Space Launch. The major space launch vehicles used by NASA have characteristically been direct applications or derivatives of Air Force ballistic missile systems (Thor, Atlas, and Titan). The Air Force continued to provide Atlas E/F launch vehicles to NASA in support of Seasat I, Tiros-N, and the NOAA environmental satellites; the Air Force 6595th Space Test Group manages the prelaunch checkout and launch of these systems. Air Force personnel at both the eastern and western launch sites provide support to NASA for range operations, range safety, tests, and procurement on a continuing basis.

Orbital Control. The Air Force Satellite Control Facility (SCF) provides prelaunch, launch, and on-orbit telemetry, tracking, and commanding support for most DoD satellites. Currently, as in the past, the SCF provides support to various NASA satellite programs as an augmentation to the NASA STDN network. Support has been in the form of telemetry gathering and tracking information. With the advent of the Space Transportation System, the SCF will continue to provide support to NASA through STDN augmentation.

Tiros-N. As previously described, a new DMSP Block 5D satellite has been put into service. Development of this satellite series was extended to include the basic spacecraft bus for the Tiros-N civil system as agreed between NASA and DoD in 1975, a considerable saving of developmental costs to the government. In addition, there was a joint DoD/NASA buy of the long-lead items from the spacecraft contractor at a lower per-unit cost than if procured independently. This continuing cooperative effort is being coordinated by the joint DoD/DOC/NASA meteorological satellite coordinating board.

Multi-Mission Modular Spacecraft (MMS). The Air Force is supporting NASA's development of a standard satellite called the MMS. The Air Force is requiring that all new DoD Space Test Program missions needing a free-flyer spacecraft give first consideration to using the MMS.

Seasat 1. In June 1978 the Navy began its cooperative effort with NASA for Seasat 1 satellite data processing. This support was short-lived as the satellite stopped transmitting in October 1978. Under the support agreement, NASA was to deliver all Seasat 1 data collected at Fairbanks, Alaska, to the Navy's Fleet Numerical Weather Central (FNWC), at Monterey, California, within six hours of sensing. FNWC was to process these data into Earth-located geophysical units (wave heights, sea surface temperatures, surface winds, etc.). Although real-time data processing was not possible, after-the-fact evaluations of the data and the program should prove the experiment's importance in several areas: (a) demonstrating the advantages of a joint user system, (b) demonstrating the usefulness of oceanographic satellite data in naval operations, (c) providing useful information on the performance and capabilities of Seasat 1 sensors, (d) determining methods needed to fully employ these data in weather and ocean forecasting. Surface temperature measurement and analysis capabilities support the objectives of the National Climate Program.

Standard Atmosphere. The joint effort between National Oceanic and Atmospheric Administration (NOAA), NASA, and USAF which produced the U.S. Standard Atmosphere (1976) continues. The joint publication has disseminated the wealth of knowledge on the upper atmosphere obtained during the past solar cycle. Extensive rocket and satellite data acquired over more than one complete solar cycle are incorporated. This stratospheric measurement capability will provide important spin-off benefits to the National Plans for Stratospheric Research and Monitoring which are now being prepared at the Federal level as a result of the growing concern over ozone depletion and environmental deterioration.

Transonic Aircraft Technology. In a successful joint USAF/NASA program, significant improvements in airplane performance at transonic speeds have been demonstrated through the use of an advanced "supercritical" airfoil on a full-scale flight-test vehicle. Results have been transmitted to the aerodynamic community by symposia and technical reports.

Supercritical airfoil technology is a major aerodynamic breakthrough. The TACT program flight-demonstrated a 36-percent decrease in wing drag and a 14-percent increase in mach number before drag rise begins. The program has established sufficient confidence in this new technology to permit its use on the next generation of military and commercial airplanes.

KC-135 Winglets. The joint USAF/NASA KC-135 Winglet Demonstration Program is an advanced development program with the objective of

proving, through flight testing, that total aircraft drag reduction can be achieved with winglets. Winglets are small airfoils of optimum shape located at the wing tip in a near-vertical position. Drag reduction translates into a fuel saving which is dependent on aircraft fleet utilization rates. Based on recent rates, an 8-percent drag reduction on the KC-135 tanker aircraft could save 164 million liters of fuel annually. Winglets also increase the tanker off-load capability because less fuel is used to transit to and from the refueling point.

The final design has been completed and fabrication has started on the test winglets. Flight testing is scheduled for March to October 1979. This development will have application to both commercial and military transports.

Rotor Systems Research Aircraft (RSRA). A joint Army/NASA contract will provide two rotor-systems aircraft to serve as "flying wind-tunnels" for helicopter research. The aircraft design will permit the in-flight testing of full-scale main rotor systems having from two to six blades. The design also allows the addition of fixed wings and thrusting engines that will permit rotor testing at flight speeds up to 550 kilometers per hour. These two aircraft will provide data on aerodynamic problems that are currently mathematically intractable and cannot be solved without the aid of precise flight research results. The research aircraft, with its first set of rotor blades, completed its first phase of flight testing in 1978 as a pure helicopter, as a compound with thrusting engines, and as an all-up compound with thrusting engines and augmenting wings.

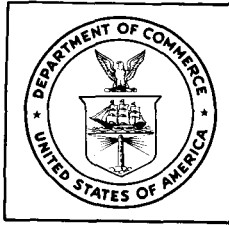
Tilt Rotor Research Aircraft (XV-15). Under a joint Army/NASA contract awarded in 1973, two tilt-rotor research aircraft, the XV-15, were built. The first of the two aircraft completed full-scale tests in mid-1978. The second XV-15 is being ground-tested prior to entering contractor flight tests to establish the basic flight characteristics for both helicopter and airplane modes of operation.

Alternate Fuels Program. The alternate fuels program is part of a long-term coordinated effort among the services, NASA, and the Department of Energy to ensure that liquid fuels obtained from domestic resources such as oil shale, tar sands, and coal will be acceptable in high-performance engines. The initial DoD effort is an experimental program to produce aviation turbine fuels from shale oil and coal. Results to date provide encouraging evidence that the aviation industry can use fuel produced from the vast U.S. resources of oil shale.

Technical Development Support. DoD has detailed a number of technically trained persons to NASA to assist in programs of mutual interest. The technological transfer back to DoD in unique

functional areas is important. The detailees are working in a variety of operational and R&D programs but most are associated with the Space Transportation System. The latter activities include space mission planning, avionics and communications security, crew procedures, payloads software, logistics, and facilities construction.

Astronaut Program. DoD continued to support this program by providing astronaut candidates for the Space Shuttle program. Of 35 new candidates chosen by NASA in 1977, 21 were from DoD. These new astronaut selectees started their training program on 1 July 1978. A call for additional candidates is being considered for 1979.



Introduction

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

The long-range goal of NOAA is to improve the safety and quality of life through greater comprehension of the Earth's environment and through more efficient use of its resources. To meet this mission, NOAA operates, manages, and improves the nation's operational environmental satellite systems; provides satellite data to assess the impact of natural factors and human activities on global food and fuel supplies and on environmental quality; 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; and improves weather services by automating forecast and observation stations, by installing better radar systems, and by continued atmospheric research.

A goal of the NBS is to improve the standards and related services for uniform and reliable measurements. The NBS provides engineering data for the design and construction of complex aeronautics and space equipment.

MARAD strives to improve ship safety, operations, and management. Satellites are used to increase the efficiency of commercial ship communication, navigation, and surveillance of operations.

The NTIA provides Federal agencies with engineering, management, and advisory assistance on national telecommunications issues. The NTIA analyzes telecommunications and information policies and conducts navigation, telecommunications, and remote sensing studies to support communication services.

An aim of the BOC is to improve information on population trends, urban growth, and the internal structure of national land areas. Satellite data are

used for demographic studies and population estimates.

Space Systems

Satellite Operations

The National Environmental Satellite Service (NESS) of NOAA operates two satellite systems: the polar-orbiting system and the geostationary system.

Polar-Orbiting Satellites. During 1978 NESS operated two polar-orbiting satellites. They were NOAA 4 and NOAA 5, the last of the Improved Tiros Operational Satellite (ITOS) series. NOAA 4 was deactivated November 18, 1978. NOAA's third generation of polar-orbiters, the Tiros-N series, began to replace the ITOS series in December 1978. Tiros-N, the NASA prototype and the first of this series, was launched October 13, 1978. NOAA A, NOAA's first operational satellite of this series, is scheduled for launch early in 1979. The Tiros-N system will overlap the ITOS system for a short time to ensure uninterrupted service. The Tiros-N system consists of two satellites in orbit, so there will not be instrumental redundancy on either satellite. Tiros-N was launched into a near-polar, Sun-synchronous 833-kilometer orbit crossing the equator in a northward direction at 1500 local time. NOAA A will orbit at 870 kilometers, crossing the equator in a southward direction at 0730 local time.

The Tiros-N series satellites carry four primary instruments: An Advanced Very High Resolution Radiometer; a Tiros Operational Vertical Sounder, consisting of three complementary sounding instruments, one of which is provided by the United Kingdom; an Argos Data Collection and Platform Location System, which is furnished by France; and a Space Environment Monitor.

Because of the extremely large volume of digital data being delivered by these satellites, it was necessary to install a new ground system. This installation was completed in June 1978. The system is functionally divided into two subsystems called the Data Acquisition and Control Subsystem (DACS)

and the Data Processing and Services Subsystem (DPSS). The DACS equipment is located at Wallops, Virginia; Gilmore Creek, Alaska; San Francisco, California; Suitland, Maryland; and Lannion, France. Satellite data acquired at the Wallops and Gilmore Creek sites are relayed to the NESS Suitland Facility via a domestic commercial communications satellite. The DPSS, located in Suitland, preprocesses and conditions the data for archiving and storage and directs it to the NOAA Central Computer Facility. Products are then developed and distributed to the users. The data are archived in a mass storage system and retained by NOAA's Environmental Data and Information Service.

Geostationary Satellites. NOAA's designation for its Geostationary Operational Environmental Satellites is GOES. Goes 3 was launched June 16, 1978. On July 13, 1978, it was positioned over the equator at 135° west longitude and replaced Goes 1 as the western operational satellite. Goes 1 was moved to 59° east longitude over the Indian Ocean on November 29, 1978, where it will be operated by the European Space Agency throughout 1979 to support the Global Weather Experiment. Goes 2 remained at 75° west longitude as the eastern operational satellite.

Equipment to improve the gridding and registration accuracy of the images produced by Goes satellites was delivered to NESS and will become operational in early 1979. This equipment improves the placing of grids on satellite images and permits registration of sequential images to an accuracy which allows animation of these images automatically.

Satellite Data Uses

Determining Winds and Temperatures. During 1978 research continued on the derivation of winds by tracking cloud motions from geostationary satellite images. NESS and NASA joined in experiments with a man-computer interactive system. Results indicated that automatic cloud tracking yields accurate vectors in all but complex situations. Experiments also were performed in error characteristics of satellite-derived winds. NESS developed computer programs to determine error in wind data provided by the University of Wisconsin and by NESS operations. These error statistics are required by data users for the Global Weather Experiment.

NESS researchers have implemented plans and written computer programs for the first international comparison of winds determined from cloud motions common to the fields of view of neighboring geostationary satellites. The derived winds to be examined are those from the geostationary satel-

lites operated by the U.S., the Japanese Meteorological Agency, and the European Space Agency. These comparisons were proposed to study the global compatibility of geostationary winds prior to the Global Weather Experiment.

The NOAA Wave Propagation Laboratory completed the first phase of a systems analysis on the feasibility of measuring the global winds with a satellite-borne Lidar. Assuming available infrared detector technology and the laser pointing accuracies attainable with current platforms, it was found feasible to measure the average winds through a one-kilometer thickness of the atmosphere to accuracies greater than one meter per second from a satellite in a 300-kilometer orbit.

The Earth's background radiation has an unknown influence on atmospheric temperatures derived from satellite radiometer data. A joint study between NESS and the Wave Propagation Laboratory has been initiated to determine how temperature data obtained from ground-based radiometers can be used to correct for this radiation effect on satellite systems.

Numerous case studies were conducted in 1978 using Nimbus 6 infrared and microwave sounding data. This research contributed to modification of the computer programs used to process Tiros-N radiance data, with the goal of improving temperature and water vapor measurements.

As part of a joint effort with NASA, and the University of Wisconsin's Space Science and Engineering Center, NESS scientists have developed and tested computer programs for manually interacting with the computer to process satellite temperature sounding data. This approach allows the meteorologists, through instant video presentation, to judge the quality of the soundings and edit the data. The technique was successfully tested using research satellite data, and the processing system is being applied to direct read-out Tiros-N sounding data for experimental application to short-term weather forecasting. The technique also will be used to edit and enhance global sounding data obtained during the Global Weather Experiment.

Monitoring Global Radiation. Radiation budget data derived from the NOAA 5 Scanning Radiometer continued to be compiled through February 1978. Mapping of monthly, seasonally, and annually averaged data, and seasonal and annual differences was completed. This effort began in June 1974, and these maps are an important climate diagnostic tool for examining seasonal and annual global patterns of various heat budget components.

Maps showing the annual differences in outgoing longwave radiation and albedo were used to examine major strengthening in clouds over the central tropical Pacific Ocean from June 1976 to

February 1978. Longwave radiation decreases for two consecutive winters were 40 to 70 watts per meter along the equator from 170 E to 150 W.

A display of satellite-derived quantities, used to monitor current climate-scale fluctuations on the Earth, was established. The display shows radiation budget data, sea surface temperatures, tropical winds, Northern Hemisphere snowcover, and the solar constant.

The Earth Radiation Budget (ERB) experiment on Nimbus 6 continued to monitor the solar constant. Preliminary analysis of the observations from July 1975 to May 1978 showed a decrease of 0.35 percent. Nimbus 7, launched October 24, 1978, carried a second ERB experiment. During the past year many studies were conducted to develop and improve the data processing. Much of the work centered on sensor calibration and computer program development, especially for angular models and data validation.

Environmental Warning Services. The GOES Data Collection System (DCS) has a total of 30 national and international users that operate more than 600 Data Collection Platforms (DCP). During 1978, there were eight new users and about 200 DCPs added to the program. The frequency assignment program was refined for the GOES DCS by assigning all odd-numbered reply channels to the eastern satellite and even-numbered reply channels to the western satellite. This allows a larger frequency spread on each channel and lessens the chance of interference between adjacent channels. Another change to the system included the addition of a higher speed transmission line between the NOAA processing center and the users so that data can be extracted more rapidly from the system for the users. A multiple-dissemination capability is now being installed in the GOES DCS. This feature will allow the same data to go to a maximum of four separate users. This capability is being installed in response to hydrology requirements of the National Weather Service, U.S. Army Corps of Engineers, and the Department of Interior's Geological Survey.

The GOES-Tap system, begun in 1975 to provide for the dissemination of weather images by geographic sectors from GOES, was expanded in 1978. By year's end there were more than 90 Federal and 25 civil users of the system. Also, more than 165 other Federal and non-Federal offices received limited amounts of GOES data through connections to the National Weather Service Forecast Offices.

A Customer Controlled Switching System was implemented at the Washington, Kansas City, and San Francisco Satellite Field Services Stations (SFSS). This system allows GOES-Tap users to

select sectors of interest merely by tapping several buttons on a touch-tone telephone. Formerly, each GOES-Tap user had to make a long-distance telephone call to the SFSS, and SFSS personnel had to make the switching change manually. The procedure now is completely automatic.

Meteorologists at NOAA's National Hurricane and Experimental Laboratory and the Miami Satellite Field Services Station used digitally enhanced GOES visible and infrared images to estimate rainfall from tropical storms. The National Hurricane Center used these estimates when issuing severe weather warnings. This technique is experimental and is under evaluation. In addition, satellite-derived rainfall estimates were provided to NWS Weather Service Forecast Offices to aid them in issuing flash flood warnings.

During the past several winters, NWS and NESS have been using GOES enhanced infrared images to determine ground temperatures critical to freeze situations. This forecasting technique has been tested in support of the Florida citrus industry. During the 1978-1979 winter, the satellite-derived temperature data will be displayed in digital rather than image form. These digital thermal patterns will be color enhanced and shown on television when frost conditions are expected.

A "heat island" is a city or major industrial area where human activities are sufficient to warm the area significantly with respect to the undisturbed environment. These local "hot spots" increase convection above them and distort local weather patterns, which influence pollution levels, cloud cover, temperatures, and precipitation. Enhanced infrared images from NOAA satellites have been used experimentally to quantitatively monitor these "heat islands." One example was seen in a NOAA 5 satellite image of the Washington-Baltimore area where the central parts of both cities were 6°C warmer than the surrounding rural areas.

Determining Ocean Conditions. Seasat 1, the NASA oceanographic satellite, was launched June 27, 1978. Circling the Earth 14 times a day in a near-circular, 850-kilometer polar orbit, the satellite covered most of the ocean area every 36 hours. The microwave sensors aboard the satellite have demonstrated the capability to measure oceanic features. On October 9, 1978, Seasat 1 experienced a massive short-circuit which permanently shut down the satellite. More than 90 days of data had been obtained from the microwave instruments. NOAA mounted a comprehensive surface-truth experiment in the Gulf of Alaska during September 1978 to assess the application of Seasat data to its oceanic and atmospheric monitoring responsibilities. This experiment involved U.S. and Canadian

ships and aircraft and NOAA buoys. The surface and airborne measurements obtained during this experiment will be correlated with the Seasat data to determine oceanographic parameters, such as waves, winds, currents, circulation dynamics, surface temperatures, geodesy, and sea ice. Studies of the relationship of these factors to living marine resources are in progress and demonstrations of their applicability are planned.

NOAA's Wave Propagation Laboratory developed computer programs for estimating significant wave heights using Geodynamics Experimental Ocean Satellite (GEOS) radar altimeter data. Wind speed and wave height in hurricanes, observed by satellites, were compared with measurements of the same parameters from aircraft. A mathematical model was completed on the effects of wave motion using measurements made by Seasat's Synthetic Aperture Radar.

Ocean color research increased substantially in support of the October 24, 1978, launch of Nimbus 7, which carried the Coastal Zone Color Scanner. Results of an experiment conducted in the Gulf of Mexico in October 1977 demonstrated that ocean radiance measurements vary systematically with increasing concentrations of both suspended particulate matter and chlorophyll. If sea surface radiance measurements can be corrected for atmospheric influences, it should be possible to estimate six to eight concentration ranges of chlorophyll and suspended particulates using the Nimbus 7 Color Scanner. A post-launch experiment was carried out in the Gulf of Mexico during October and November 1978 by scientists from NOAA, NASA, Scripps Institution of Oceanography, Texas A&M University, and the University of Southern California. The objectives were to gather *in-situ* measurements of chlorophyll and total suspended particulate matter to correlate with data obtained from the Color Scanner.

To evaluate oil spill detection capability from the Nimbus 7 Color Scanner, measurements were made of the optical characteristics of 10 samples of crude oil at the Environmental Protection Agency test facility in Leonardo, New Jersey. Visible and thermal infrared measurements were made for a one-week period as the oil was aged under conditions simulating those found in the ocean. The measurements showed increased reflectance, above background water, in the visible region, and increased equivalent blackbody temperatures over surrounding waters in the infrared.

Continued research by NESS scientists, using monthly mean sea-surface-temperature fields derived from satellite data, has revealed a slight, gradual cooling of the oceans in the Southern

Hemisphere since 1975. The large cold water anomaly in the North Pacific that developed over the 1976-1977 winter reappeared last winter and appears to be occurring again this year. There is continuing evidence that an ocean-atmosphere link exists that will favor a colder-than-normal winter over much of the United States east of the Rocky Mountains when such a sea surface temperature anomaly occurs.

A large iceberg from Antarctica, nearly the size of Delaware, finally drifted clear of the ice fields of the Weddell Sea in January 1978 and moved across the Drake Passage into the South Atlantic near South Georgia Island during March. Since March it has been monitored daily using Goes visible images, and it has lost over 50 percent of its original mass. By December it is expected to be about 800 kilometers south of Tristan da Cunha moving toward South Africa, its remnants possibly encroaching on the more heavily traveled shipping lanes during 1979.

Investigators of NOAA's Outer Continental Shelf Environmental Assessment Program (OCSEAP) used satellite and other remote sensing data to assess the development and decay of fast ice, coastal geomorphology and ecology, sediment plumes, and offshore suspended sediments along the Alaskan coast. Supported by OCSEAP, a fully operational facility has been established by the University of Alaska to provide remote sensing data to scientists involved in Alaskan studies. The university operates a library to acquire, catalog, and disseminate satellite and aircraft remote sensing data; operates and maintains data processing facilities; develops photographic and computer techniques for data storage and retrieval; and consults with and assists investigators in processing and interpreting these data.

In other studies, NOAA and Landsat satellite images of observed ice conditions were used to correlate seismic data with major episodes of ice movement in Kotzebue Sound and ice mapping in the Beaufort and Chukchi Seas. Remote sensing data were used to determine sediment transport in the Bering Sea and to evaluate the hazards of volcanic eruptions in the Alaskan Peninsula. Also, efforts are underway to relate side-looking radar images of sea ice to seal distribution in the Beaufort Sea, and to map bird habitats by digital analysis of Landsat data.

During 1978, a Gulf Stream Analysis was generated weekly from the NOAA and Goes high resolution infrared images. This is a composite map of qualitative seasurface boundaries which shows location and direction of the Gulf Stream, the warm and cold eddies in the Gulf Stream, the thermal interface between the slope and shelf

waters, and the Gulf of Mexico Loop Current. Since fish congregate at thermal boundaries, fishermen use these maps to go directly to productive fishing grounds, thus increasing their yield and reducing fuel costs. Even participants in the Newport-to-Bermuda boat race in June 1978 benefited from knowing the latest position of the Gulf Stream and eddies.

The Gulf Stream Wall Bulletin, also generated from satellite images, describes only the north or west boundary of the Gulf Stream. Updated three times a week and broadcast twice daily over Coast Guard radio, this bulletin gives a sequence of points that represent the west wall of the Gulf Stream. The maximum current lies 7 to 9 kilometers seaward at this line. Coastal shipping interests used this information to route their ships to take advantage of the ocean currents. The mariners were able to reduce their operational costs of both time and fuel.

Determining Lake Conditions. The accuracy of the satellite derived Great Lakes Surface Temperature Analyses, used by the NWS to predict the onset of ice on the Great Lakes, was greatly improved in 1978 with the adoption of a new atmospheric attenuation correction. This new technique integrates observed atmospheric temperatures and corrects for absorption and terrestrial radiation.

The NOAA Great Lakes Environmental Research Laboratory joined others of the Great Lakes Experiment Team to test the feasibility of using satellite data to monitor water quality in the Great Lakes. Scientists will be using data from the Nimbus 7 Coastal Zone Color Scanner (CZCS). The objectives are to acquire enough standardized surface-truth samples to evaluate the potential of the scanner for obtaining accurate observations of algae, suspended sediment, and calcium carbonate; to develop, test, and evaluate scanner water-quality computer programs; and to develop products using the scanner data.

Determining Hydrological Conditions. NESS produced operational snowmaps from satellite data for thirty critical United States and Canadian river basins during the 1977–1978 snow season. Six hundred snowmaps were compiled and used by Federal and state agencies to aid in water runoff prediction, flood prevention, dam and reservoir regulation, hydroelectric power generation, and monitoring of irrigation and human consumption. Snowcover throughout the western United States was generally more extensive and persisted longer into the spring months than during the previous year. Heavy rainfall in California, combined with an above-normal snowpack in the Sierra Nevada Mountains, signified the end of that state's two-year drought.

On a global basis, NESS continued the annual monitoring of Northern Hemisphere snowcover using satellite data. January 1978 proved to be a record snowcover month for North America. This record was promptly exceeded in February 1978. From December 1977 through March 1978, the average snowcover for Eurasia was 51.4 percent and for North America 67.2 percent. For North America, January had 7.4 percent, February had 12.1 percent, and March had 9.1 percent more snowcover than the 10-year average for each of these months. For the entire winter, the Northern Hemisphere snowcover, overall, was about 8 percent above the 10-year average for each month.

In 1978 a research effort was started to estimate rainfall from geostationary satellite data for operational input to the National Weather Service's (NWS) Office of Hydrology riverflow models. The specific need is to determine six-hour mean rainfall amounts over individual river basins. Case studies are being investigated to compare satellite-measured cloud brightness and infrared temperatures with recorded rainfall. Initial results show good correlation between cold, bright clouds and heavy rainfall.

The Environmental Data and Information Service is working with NASA, the University of Wisconsin, and the Environmental Research Laboratories to evaluate and calibrate techniques for using visible, infrared, and microwave satellite data to estimate rainfall over the tropical oceans. The program is using very accurate precipitation estimates derived from shipboard digital radar data for a 125,000-square-kilometer area over the eastern tropical Atlantic.

Monitoring Agricultural Conditions. In 1978, NESS joined with the Department of Agriculture, the Environmental Data and Information Service, and the National Weather Service to establish a Joint Agricultural Weather Facility to increase the use of satellite data for agricultural interests. This facility was designed to provide up-to-date global weather information to Agriculture's decision makers. Specifically, satellite images are used to monitor rain-producing clouds and temperature trends for worldwide agricultural areas. Satellite data are used exclusively in the tropics and Southern Hemisphere to forecast movements of weather systems.

From March to June 1978, NESS furnished satellite-derived ground temperatures to the Water Conservation Laboratory in Phoenix, Arizona. These data were compared with surface measurements of solar, thermal, and moisture conditions to assist in stress analysis of crops in central California. There is increased stress on vegetation when plant temperatures increase and the moisture is low. The

Department of Agriculture is presently evaluating this technique.

Fisheries Monitoring. The National Fisheries Engineering Laboratory joined with NASA, U.S. Fish and Wildlife Service, and Bureau of Land Management to investigate the feasibility of mapping submerged seagrasses, using Landsat and aircraft measurements. Results demonstrate that grass beds in shallow coastal waters can be mapped, and work is continuing to determine how well the technique differentiates common species.

The National Marine Fisheries Service (NMFS) demonstrated the feasibility of tracking marine turtles using remote sensing techniques. Loggerhead turtles were hatched and fitted with small radio transmitters and tracked in the Gulf of Mexico by aircraft for periods up to three weeks. This research was conducted in advance of a larger tracking effort to be carried out in 1979 to see if endangered species, like the Atlantic Ridley turtle, can be tracked using the Tiros-N Argos Data Collection System. The object of these experiments is to see if adult turtles return to the same nesting areas they departed as hatchlings in a manner similar to the behavior of salmon.

The final design of a transmitter for tracking porpoises in the eastern tropical Pacific, using the Nimbus 6 Remote Access Management System, was completed in 1978. Three transmitters will be available for testing and evaluation on captive and wild animals in 1979. The transmitters are designed for operation for periods of up to one year from anywhere on Earth.

Plans to evaluate the feasibility of using Seasat 1 scatterometer data to measure ocean surface circulation patterns were completed. These plans involve a field study to determine the relationship between water circulation and shrimp yield in the northern Gulf of Mexico. If this concept proves feasible, it may be possible to forecast potential yields of shrimp and certain other estuarine dependent species significantly in advance of the fishing seasons. Enough data were collected from Seasat 1 to conduct this experiment.

A theoretical investigation to establish the capabilities of airborne laser systems for assessment of pelagic fish schools was completed. The investigation indicated that laser systems have significant potential for detection and quantification of schooling fishes. Plans for a cooperative program with NASA and segments of the fishing industry were developed to demonstrate this potential in 1979 with an existing airborne laser system.

NMFS, NASA, and the Coast Guard have demonstrated that satellite and aircraft synthetic aperture radar systems have significant potential for

fishery surveillance and management applications. Analysis of radar data collected over concentrations of foreign fishing vessels off Georges Bank show that the vessels can be detected and located, and their speed and direction extracted from digitally processed data. In 1979, research will be directed toward vessel classification.

Environmental Monitoring Using Data Buoys. At the beginning of 1978, the NOAA Data Buoy Office was operating 19 moored data buoys—9 in the Northeast Pacific and Gulf of Alaska, 7 in the Western Atlantic, and 3 in the Gulf of Mexico. Three additional buoys were stationed in the Atlantic in late 1978. Sixteen of these buoys transmit environmental data through the Goes satellite, and in 1979, all buoys will use Goes. The buoys provide meteorological, surface and subsurface water temperature, and wave data to the National Weather Service for forecasting and storm warning activities, to the Bureau of Land Management for continental shelf assessment activities, and to various scientific programs with specialized marine data requirements. All moored buoys are equipped with position-fixing systems which permit the Nimbus satellite to locate buoys that have gone adrift. Buoys soon will be modified to use the Tiros-N Argos Data Collection System for position fixing.

Other Uses of Satellites and Space

International Cooperation

Global Weather Experiment. This is a planned international effort scheduled from December 1, 1978, to November 30, 1979, to provide a coordinated intensive analysis of the world's weather. It was organized by the World Meteorological Organization and the International Council of Scientific Unions. A major source of wind data for the experiment is a network of five geostationary satellites, positioned to provide contiguous weather coverage around the globe in tropical and mid latitudes. Two of these satellites were to be provided by the United States and one each by Japan, the European Space Agency (ESA), and the Soviet Union.

In late 1977, the U.S. was informed that Russia could not provide the fifth geostationary satellite which was to be located over the Indian Ocean. Since the loss of this satellite would have produced a gap in data coverage, the U.S. and ESA were asked to work together to provide for a replacement satellite. In less than a year, Goes 1 was moved to 59° east longitude to fill the void. A data acquisition station was constructed at Villafranca, Spain; the European Space Agency's Control Center at Darmstadt, Germany was modified to accept GOES

data; personnel were provided and trained to operate and maintain the GOES system; and a data processing facility was established at the University of Wisconsin.

By the end of 1978, the fifth satellite system was fully installed, tested, and turned over to ESA for operation. During 1979, Goes 1 data will be processed at the University of Wisconsin to obtain wind fields over the Indian Ocean to support the Global Weather Experiment.

Sharing Data. During the year, the National Weather Service, under the Voluntary Assistance Program of the World Meteorological Organization, established ground stations capable of receiving direct broadcasts from U.S. environmental satellites in about a dozen countries in the Caribbean area, South America, Asia, and Africa. NESS assisted with the assembly and installation of this equipment.

Demographic Studies. Since 1973, the Census Bureau has been exploring two potential uses of satellite images. The first provided assistance to developing countries in using this technology for demographic programs, such as determination of settlement patterns and production of population estimates. This effort was supported by funds from the Agency for International Development (AID). The second was to aid in the Bureau's domestic program for defining statistical areas, particularly those based on population density.

The international studies were carried out in Bolivia and Kenya, and final reports were completed in 1978. The conclusions were that census planners in developing countries could improve their programs by using Landsat images to interpret physical-cultural land cover. Landsat images also could be used in developing countries to update major map features and locate boundaries in preparation for a national census. In addition, settlement patterns, observed by satellites, could aid in planning enumerator assignments.

The study of Landsat data for domestic programs, under the terms of a NASA Applications System Verification and Transfer (ASVT) agreement, continued in 1978. The Census Bureau investigated the utility of using computer-processed Landsat data for delineating developing urban zones around five metropolitan areas, and compared this process with traditional techniques of using standard aerial photographs and map sources to monitor urban expansion. The urban zone boundaries defined from Landsat images were similar to those derived from traditional procedures. In 1979, the work under the ASVT will be directed toward determining the most cost-effective means of using Landsat.

Rocket Experiment. The Environmental Data and Information Service participated in a joint American-Soviet Particle Inter-Calibration Project scheduled from June 2 to 20, 1978. Two Nike-Apache rockets and one Nike-Tomahawk rocket were launched from NASA's Wallops Flight Center, and five Soviet rockets were launched from a Russian research ship, located off the Virginia coast. Ground-based measurements at the Service's Wallops Ionosphere Station were used to monitor local ionospheric conditions for selecting specific launch times. The ionosphere station prepared special analyses of observations for daily briefings to participating scientists and relay to the Soviet vessel. Because of unfavorable ionospheric conditions, the final launch was delayed until September 27, 1978. Results from these measurements may answer differences in past interpretation of ionospheric data in the 80- to 120-kilometer-height range.

Numerical Weather Forecasting

During 1978, the National Weather Service made some important advances in using satellite data as input to their numerical weather forecasting models. For the large-scale computerized analyses and guidance forecasts, atmospheric temperature and moisture soundings and cloud-motion-derived winds from satellite data were used to supplement the classical observational data for rapid global coverage. The number of satellite-derived measurements was increased over the northern hemisphere and measurements in the stratosphere were extended to cover the entire globe. Detailed knowledge of stratospheric conditions is important for ozone monitoring and for supporting Space Shuttle and satellite experiments.

Determination of the Earth's Shape and Gravity Field

The National Ocean Survey worked with NASA to evaluate applications of space systems to geodesy and geodynamics. A network of accurately positioned ground stations is fundamental to all surveying and mapping. Major areas of study included the application of space observation systems to polar motion and Earth rotation, making extensive ground position and gravity measurements to compare with results from laser ranging to satellites and the Moon, Doppler tracking of satellites, and Very Long Base Line Interferometry. Interferometry data were analyzed to extract polar motion, Earth rotation, and baseline vector information. Polar motion values obtained by interferometry agreed to ± 10 milliseconds of arc with Doppler values. Baselines computed at 13 different times

over a 20-month period were accurate to within 15 centimeters for lines as long as 4000 kilometers. Methods are being analyzed or developed to determine accurate positions and densify geodetic control networks with the Defense Global Positioning System. Precise positioning involves making observations on an array of 24 Defense satellites to be launched between 1978 and 1985. Simulation studies indicate that relative geodetic accuracies of 10 centimeters or less can be obtained over distances of 10 to 100 kilometers when the requisite ground receiving equipment is developed.

Altimeter data obtained from the Geodynamics Experimental Ocean Satellite (GEOS) 3 were used to track ocean eddies and currents, independent of surface observations. Correlations of Geos 3 data with NOAA 5 infrared data showed good results. A continuous record of Geos 3 orbits is being computed for accurate referencing of altimeter data.

Satellite Communications

Communications Studies. In March 1978, the National Telecommunications and Information Administration (NTIA) was formed within the Department of Commerce, combining the functions of the Office of Telecommunications and Office of Telecommunications Policy. In its first year, NTIA was active in a broad range of telecommunications issues involving space technology. The Administration formed an Interagency Committee on Satellite Telecommunications Applications, consisting of 16 Federal agencies, to provide for cooperative development of public service satellite applications by Federal and public interest groups. A report was published reassessing the basic issues concerning public service telecommunication needs and satellite networks. The report identifies various issues which arise in connection with potential cost benefits, proposed demonstration, and apparent barriers to the use of satellite telecommunications for the public service sector.

The Administration has the responsibility to monitor, coordinate, and control the overall U.S. Government use of the radio-frequency spectrum. Under these provisions, over 20 satellite networks were reviewed in the first half of 1978 including NASA's Space Shuttle, Landsat-D, and the Tracking and Data Relay Satellite System; portions of the Defense Global Positioning System; and the Defense Satellite Communications System. An assessment was made of the international advance publication, coordination, and registration of these systems under the Radio Regulations of the International Telecommunication Union and actions taken to comply with them.

In 1978, the Administration prepared a report on current activities concerning the technical, regulatory, and economic aspects of direct broadcast satellites using small Earth stations. The report discusses the current and planned activities in domestic satellite communications in the United States. The application of small Earth stations is emphasized, and the general technical characteristics of domestic satellites, presently in service, are discussed. The impact of the antenna size and pre-amplifier noise temperature on overall Earth station cost is included, and tariff cost information for domestic satellite and terrestrial telecommunications services is presented.

The International Telecommunications Satellite (INTELSAT) Organization was created to achieve a single global commercial telecommunications satellite system. The organization now has 102 member nations. In March 1978, the last of the INTELSAT satellites in the IV-A series was launched. In addition to providing international telecommunications services, INTELSAT now is providing domestic services for about 16 countries.

Direct Broadcast Satellites (DBS), planned for future use, will send signals directly into the home. Active debate on these satellites began in the United Nations in 1966. The basic issue is the conflict between the view of those nations that DBS cannot be allowed to operate without permission of the receiving state and the view of those nations, including the U.S., which advocate free and unlimited operation, subject to technical limitations. The Administration participated in deliberations of the issue during 1978 and will continue to contribute to the formulation of U.S. policy views.

Commercial Satellite Service. The maritime community continued to add Maritime Satellite (MARISAT) communications equipment to U.S. commercial vessels to improve their operations. The number of vessels equipped nearly doubled again in 1978. The Maritime Administration (MARAD) continued to provide Maritime Coordination Center services through the General Electric time-shared computer network. This is a prototype service that provides MARISAT communications to the corporate offices of shipping companies. MARAD participated in final International Maritime Satellite (INMARSAT) Preparatory Committee meetings. When implemented, INMARSAT will assure continuity of satellite service to U.S. flag vessels and will expand the offer of service globally for all nations.

The National Bureau of Standards was a consultant for the Defense Global Positioning System and facilitated flux density measurements from these satellites. The measurement techniques are based on work employing a radio star as a standard. The

Bureau of Standards has aided the development of the Navigational Signal Calibration Test Set which evaluates in real time eleven of the measurands critical to the proper performance of the Satellite Navigation System.

Space Support Activities

Launching Activities. The Environmental Data and Information Service prepared a climatological study for NASA's Marshall Space Flight Center. The study provides probabilities for flying weather conditions for "piggy backing" the Space Shuttle orbiter on a Boeing 747 jumbo jet during test periods. Weather conditions will determine the precise time schedule for the ferry flights because unfavorable weather could cause unscheduled landings or diversions. Favorable terminal weather is desirable for safe ground transfer of the orbiter to and from the 747. During 1978, the National Weather Service assigned meteorologists to the Marshall facility to provide operational weather support to the Shuttle testing program.

Solar Activity

The NOAA Space Environment Services Center, 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. Predicted and real-time solar geophysical data were provided to agencies for planning and executing scientific experiments and for operational activities being conducted in the same environment. In particular, the Center provided predictions of solar sunspot activity used to calculate the predicted lifetime of Skylab. The National Bureau of Standards assisted the Center in the Skylab lifetime prediction by documenting an analysis of sunspot variations for the period of January 1848 to February 1978 and the 13-month averaged values. The Center obtains its data from Space Environment Monitors on NOAA and GOES satellites, the global solar flare patrol, and data collected from the International Ursigrams and World Days Service.

Measurement and Calibration Services

The National Bureau of Standards provided NASA with the basic thermodynamic data for the liquid hydrogen and liquid oxygen used in the Gemini and Apollo projects as propellants and life support expendables. The Space Shuttle also uses these for the same purpose. Since the Shuttle's main engines operate at higher pressures, more data are needed. New measurements have been made at pressures to 80 megapascals and the results have been

extrapolated to 100 megapascals. The Bureau also provides calibrations for satellite ultraviolet instruments measuring the solar constant and monitoring ozone concentrations. A special deuterium calibration source for inflight calibrations has been developed.

Space and Atmospheric Research

Space Physics

Interplanetary Physics. The effect of a multi-fluid composition in the solar wind was examined by NOAA's Space Environment Laboratory. For steady state conditions, frictional drag on protons by alpha particles produced a reduction in the alpha-to-proton abundance ratio near the Sun when non-radial flow occurs within some coronal holes. At the Earth's orbit, the alpha particles achieved a velocity higher than the protons when their temperatures at the Sun were very much higher than the protons. For unsteady conditions, the anomalous observations of variable electron to proton temperatures, obtained by numerical simulations, were a result of the high thermal conductivity of the electrons and their frictional coupling to the protons.

Planetary and Stellar Atmospheres. The National Bureau of Standards played a major role in developing the radiative transfer theory needed to interpret the ultraviolet radiation of very hot, bright stars, which lose substantial amounts of mass in high-velocity stellar winds. This theory is currently being used to help analyze spectra obtained from the Copernicus and International Ultraviolet Explorer satellites.

The Bureau also has been developing technology for reliable measurement of physical properties of solar and stellar atmospheres using data from the Orbiting Solar Observatory, the International Ultraviolet Explorer, and the Solar Maximum Mission satellites. The properties being measured are temperature, density, velocity, and magnetic field. These programs are designed to study the evolution and causes of solar flare activity.

Atmospheric Physics

Magnetospheric Physics. The enhanced resolution and spatial coverage of the instruments comprising the energetic particles experiment on board one of the two International Sun-Earth Explorer satellites permit a much more complete description of the particle environment. This is very important to the understanding of the dynamical processes occurring in the magnetosphere. Initial published research by NOAA's Space Environment Laboratory and the Max Planck Institute for Aeronomy

has revealed some characteristics of the magnetospheric boundary not known from earlier, less sophisticated measurements. Availability of data of this quality will significantly enhance our understanding of the magnetosphere. The Space Environment Laboratory scientists demonstrated that the geomagnetic disturbances called substorms can be predicted. Magnetic disturbances have an important impact on radio communications, power distribution, and long-line telephone systems. Laboratory scientists used the NOAA satellite data and observations from the 25 ground observatories of the North American International Magnetospheric Study network to analyze space and time characteristics of magnetic substorms and the associated magnetospheric currents.

Ionospheric Physics. A new generation of high-frequency ionospheric sounders were constructed and tested. The design took full advantage of the latest electronics and minicomputer technology. These instruments will provide major improvements in ionospheric measurements of the ionization as a function of altitude and time. A field station is under construction near Fairbanks, Alaska.

Stratospheric Physics. NOAA's Aeronomy Laboratory developed a new technique to measure wind profiles through the atmosphere from the ground up to about 100 kilometers using pulsed Doppler radar. A single measurement through the troposphere and lower stratosphere up to about 30 kilometers takes about one minute.

Atmospheric Chemistry

Photochemistry. The Aeronomy Laboratory has made some notable contributions toward understanding the chemistry of the stratosphere. Nitrogen trioxide has been measured for the first time using ground-based long-path optical absorption techniques. The stratospheric nitrogen dioxide measurements have been extended to the southern hemisphere and show the winter behavior there to resemble that in the Arctic winter. Methane is a compound almost entirely of natural origin, which is present as a trace gas in the stratosphere. Understanding the disposition of methane in the stratosphere is an important key to understanding stratospheric chemistry. During the past year, the concentration of methane has been measured at various latitudes up to altitudes of 30 kilometers.

The National Bureau of Standards is participating in an interagency program to improve atmospheric measurements of halocarbons and nitrous oxide to permit more accurate predictions of the effect of these species on the ozone concentration in the stratosphere. In the first phase of this program

the Bureau conducted international, interlaboratory tests to assess current measurement accuracy. The results of these measurements by 16 laboratories on a set of common samples showed significant systematic differences among laboratories.

Data Programs

Environmental Data

The Environmental Data and Information Service archives about 2000 metrocket observations each year. The rocket obtains primarily temperature and wind data at altitudes of 20 to 90 kilometers. The data are gathered by 30 stations in the worldwide Cooperative Meteorological Rocketsonde Network. The metrocket has been an important data source in determining wind and thermodynamic stresses which manned and unmanned spacecraft must be designed to withstand during launch and reentry operations. These same data now are being used in the design, test, and operational phases of the Space Shuttle. In addition, they will be important in determining design and loading factors for vehicles used in the establishment and operation of the proposed orbiting space station. Periodic metrocket ozone measurements now are being made to determine the effects of aerosols and supersonic aircraft exhausts on the ozone layer.

The Service operates the World Data Center A for Solar-Terrestrial Physics. It is preparing a report documenting observations of the first significant solar flare activity since 1976. Between April 24 and May 8, 1978, solar rotation carried a large and magnetically complex sunspot group across the solar disk that flared four times at intensities great enough to significantly affect the Earth's dayside and polar ionospheres and the planet's magnetic field. The largest flare ever observed occurred on April 28.

Aeronautical Programs

Aeronautical Publications

Charts and Manuals. The National Ocean Survey delivered to the Federal Aviation Administration (FAA) certified obstacle and terrain data for 36 of 72 air terminals in the United States which were initially targeted to receive this information. The data are used in support of FAA's Minimum Safe Altitude Warning System which alerts air traffic controllers when an aircraft descends below a safe flight altitude within a 120-kilometer radius of an air terminal facility. The FAA plans to expand this system to include 72 additional airports.

The Survey has implemented the Aeronautical Chart Automation Project. A contract soon will be

awarded to develop, design, and process an operational aeronautical chart production system. The proposed system is predicated on several subsystems integrated into a total system for automation of the predominantly manual chart production methods. This will yield higher efficiencies and enhance chart updating and maintenance schedules.

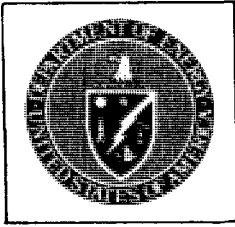
Aircraft Support

Safety Services. The National Bureau of Standards aided the FAA in a reassessment of aircraft separation rules and analysis of data on height-keeping performance of aircraft. The Bureau analyzed the sensitivity of a model used internationally to assess the risk of collision as a function of the separation rules, traffic levels, equipment, and height-keeping performance. The Bureau pro-

vides FAA field inspectors with a portable pressure standard for on-the-spot checks of altimeter setting indicators and aircraft altimeters, and for verifying the accuracy of calibrations.

National Weather Service meteorologists, now assigned to FAA Air Route Traffic Control Centers, are using GOES satellite pictures to help them rapidly detect weather changes that pose a hazard to aviation or impede traffic flow.

NOAA's Aeronomy Laboratory developed a new pulsed Doppler radar technique to measure vertical profiles of turbulence. This has led to the development of a new turbulence model. This model can be used to calculate profiles of turbulence intensity from routine radiosonde measurements. This model shows considerable promise for the prediction of clear-air turbulence.



Department of Energy

Introduction

In the twenty years of the Space Age, the Department of Energy (DOE) and its predecessors, the Energy Research and Development Administration and the Atomic Energy Commission, have had a growing role in our country's exploration and exploitation of space. From a few early Earth-orbital missions through lunar landings to long-term outer-planetary journeys, the compactness, reliability, and lifetime of nuclear isotope power supplies have been essential to mission success. A continuing primary goal of the isotope-power-supply development activity is to support the nation's civilian and military space efforts, with particular orientation toward missions which depend upon delivery of adequate electrical power while operating in a remote, hostile, or specialized environment.

In addition to the space applications of nuclear power, the practicability of using space for applications that bear directly on the nation's energy problems is being investigated. One such application is the potential use of the Space Shuttle to aid in the disposition of nuclear wastes; another is the possible use of a Satellite Power System (SPS) in geostationary orbit to collect solar energy and beam it to Earth where it would be used as a terrestrial energy source. A further role for the DOE involves sensor development in support of DoD programs using spacecraft for nuclear test detection.

Space Applications of Nuclear Power

DOE performs a significant role in the nation's space program through the development and production of nuclear powered electric generators for current NASA and potential DoD space missions. During 1978, active projects included:

- Initiation of flight system development to design, fabricate, and test various components of the static selenide radioisotope generator system for the NASA Galileo mission (Jupiter Orbiter/Probe) scheduled for launch in January 1982.
- Preliminary ground testing of two dynamic radioisotope power systems, which ended in

selection of one system for further technology verification testing in FY 1979–1980.

- Development of a modular heat source termed the General Purpose Heat Source (GPHS).

These new power systems will provide the unique characteristics of relatively low weight, high performance, compact size, high reliability and long life required for sensing, analytical, or communication systems on board spacecraft, satellites, or other remotely located devices operable for long time periods without reliance on external sources of energy.

Government-owned, contractor operated laboratories provide valuable support of these activities. The new plutonium-238 fuel fabrication laboratories and plant facilities at Savannah River have been the site of preproduction studies of the Multi-Hundred Watt fuel form for the Galileo mission; supporting research in fuel studies and advanced heat source design was conducted at the Los Alamos Scientific Laboratory's new Plutonium Facility; and continuing research and improvement in containment capsule materials is pursued at the Oak Ridge National Laboratory and at the Mound Facility, where the heat source is assembled.

Additional activity pursued in 1978 included periodic monitoring of power being supplied to on-going missions, plus data reduction and analyses related to the Viking and Voyager space programs. Support of the nation's civilian space exploration efforts continues as a primary goal of DOE, with particular orientation toward NASA missions which depend upon safe delivery of adequate electrical power while operating in remote, hostile, or specialized environment; of equal significance is a commitment to support the interests of DoD in its deployment of satellite systems for navigation, communication, or surveillance in Earth orbit.

Space Programs

Pioneer

Pioneer 10 and 11 were launched in March 1972 and April 1973, respectively, on missions to the outer planet Jupiter and beyond. Each spacecraft

was supplied electrical power from four Snap-19 radioisotope thermoelectric generators (RTGs). Following more than 6 years of flight time for Pioneer 10 and well over 5 years of flight time for Pioneer 11, the power stability of both systems (presently about 120 watts) remained essentially as predicted. Since Pioneer 10 is well over 2.4 billion kilometers from Earth and is continuing on its planned solar-system escape trajectory, major attention is now focused on Pioneer 11 and the associated Snap-19 generator. This spacecraft is now approximately 1.1 billion kilometers from Earth and 180 million kilometers from Saturn. Extrapolation of Pioneer 11 RTG power curves from the existing 5-year data firmly supports the predicted availability of adequate power at the Saturn encounter in 1979.

Viking

The two Viking Landers were successfully positioned at selected sites on the planet Mars on July 20 and September 3, 1976, after launch on August 20 and September 9, 1975, respectively. Each lander was powered by two Snap-19 RTGs designed to supply a minimum of 70 watts during mission operations. Transmission of scientific data to Earth was dependent on these RTGs for a continuing power supply. Monitoring the power characteristics for each of the Viking generators was continued in 1978. Latest telemetry reports, as of June 1978, indicate stable performance at predictable power output levels, after approximately two years on the Martian surface. Telemetry data reduction analyses will be continued into 1979.

Voyager

The Voyager spacecraft (formerly designated Mariner Jupiter/Saturn) were launched from the Kennedy Space Center on August 20 and September 5, 1977. After slightly more than one year, Voyager 1 and Voyager 2 are presently 600 and 550 million kilometers from Earth, respectively. Each spacecraft is powered by three multi-hundred watt (MHW) radioisotope thermoelectric generators providing a combined power output of approximately 475 watts. Telemetry from the Voyagers during 1978 indicate stable operation of the MHW generators, providing power in accordance with design predictions for data retrieval at Jupiter encounter, March 5, 1979, and July 9, 1979, and for the subsequent Saturn encounter in 1980-1981. The generator lifetime is projected to be adequate to return information from the approach to Uranus in 1986 and possibly from Neptune in 1989.

Galileo

The objective of the NASA Galileo mission is to place a spacecraft in orbit around Jupiter and drop a probe into its atmosphere to pursue a two-year program of imaging the Jupiter satellites and mapping its electromagnetic fields and particle environment. In support of this project, the DOE will provide two 200-electrical-watt RTGs as long-term, durable power sources for the scientific functions of the spacecraft. Jupiter encounter will take place three years after launch in January 1982. In support of this schedule, DOE activity during 1978 has included efforts essential to flight system design, fabrication, assembly, and testing of components for the Selenide Isotope Generator to be used on this mission. Selenide thermoelectrics, new to the space program, indicate a potential for power conversion at the 8-9 percent level as compared to previous MHW generators which used silicon germanium thermoelectrics and operated at 6-7 percent efficiency. Contractors for systems integration and fabrication of components have been selected. Additional technical support is provided by several national laboratories. Plutonium-238 oxide fuel to power the generators will be processed at the new Savannah River Plant. Several modifications designed to improve launch and operational safety aspects of the MHW heat source to be used with the selenide generator were completed in 1978. Qualification testing of the flight design RTG is scheduled to be completed during FY 1980.

Solar Polar Mission

The Solar Polar Mission (formerly termed Out-of-the-Ecliptic) is sponsored jointly by NASA and the European Space Agency. The NASA objective is to conduct science measurements of electric and magnetic fields and to measure the Sun's corona and its magnetic characteristics. Two spacecraft are planned to be launched in early 1983, each requiring a power unit supplying peak power of 275 watts two years after launch. In support of this program DOE initiated preliminary studies in 1978 for a conceptual flight system generator design. Because of mission requirements, the performance goal of this radioisotope generator is targeted for three electrical watts per pound, at about 10-11 percent system efficiency. A modular heat source termed the General Purpose Heat Source is currently under development at the Los Alamos laboratory; coupled with a further improved selenide converter subsystem, it is to provide a generator of improved power density, performance, and safety.

Generator Technology

The demand for nuclear electric power aboard spacecraft or satellites has increased dramatically from 2.7 electrical watts on the first Transit in 1961 to 475 watts on each Voyager in 1977. Missions contemplated by NASA and DOD indicate the need for advanced higher power systems with reduced weight, increased endurance, and reliability at lower cost. To meet this challenge the DOE technology activities for 1978 have been mainly directed toward the development of the new selenide generators, as described for the Galileo and Solar Polar missions, development of a dynamic power system, and the previously described modular General Purpose Heat Source fueled with plutonium-238 oxide to provide the required thermal energy to the evolving future generator systems. This modular heat source is scheduled for future production at the Savannah River Plant.

Competition begun in 1975 between the Isotope Brayton and the Organic Rankine Cycle dynamic power systems culminated with simultaneous ground demonstration unit tests in mid-1978, system evaluation, and selection of the Organic Rankine Cycle (Kilowatt Isotope Power System) for continued technology development. Static selenide radioisotope conversion systems are planned to provide space and system power requirements ranging up to 500 electrical watts; by contrast, the dynamic KIPS system is programmed to provide power in the range of 1000–2000 watts at approximately 18 percent efficiency for foreseeable space missions in the 1980s. In conjunction with dynamic isotope power systems, a study was initiated in mid-1978 to improve definition of the attributes and mission applicability of the KIPS power system. This study is examining various missions and system integration concepts and performing life-cycle cost analyses, with results to be available in late 1979.

Materials technology and development studies pursued in 1978 were directed toward providing improved system performance and safety. A new iridium alloy developed at the Oak Ridge laboratory and designated DOP-26, and three-dimensional woven graphite composites have been subjected to system and safety testing to enhance the structural strength and containment capability for the Multi-Hundred Watt heat source. An alternate platinum-rhodium-tungsten alloy, PT-3008, also has been subjected to similar system testing for use with the General Purpose Heat Source (GPHS). The design, associated analyses, and component and assembly testing for the GPHS, leading to technology readiness status, were completed in 1978. Composite

graphites are intended for use as aeroshell materials on both the improved MHW and GPHS heat sources for future space systems launched on Space Shuttle. The improved MHW heat source is presently scheduled for use on the Galileo program. The flexibility of the modular GPHS should permit its use on most subsequent space electric power generator systems, beginning with the Solar Polar mission.

Space Reactor

Recognizing the ever increasing potential of space electric power systems, DOE is currently examining the available technology base for a 10- to 100-electrical-kilowatt reactor power system for potential DoD applications in the 1980s and early 1990s. In 1978 several fuel forms and conversion systems were studied and fundamental questions concerning development of a space reactor were identified. This technology development will continue efforts toward answering these basic questions to the extent required to permit construction of a ground demonstration system, and to minimize associated risk areas.

Satellite Power System

A Satellite Power System (SPS) in geostationary orbit was suggested in 1968 as a way to convert solar energy in space to microwave energy for transmission to Earth for use as a terrestrial energy source. Initially NASA undertook study of this system. In 1976, the lead management responsibility for the SPS endeavor was transferred from NASA to DOE, with NASA continuing to provide baseline technology inputs to DOE's broad system feasibility studies.

DOE and NASA jointly published an SPS concept development and evaluation program plan in February 1978. This plan evolved from a task group study conducted by DOE in late 1976 and early 1977. The objective of the program plan is to develop an initial understanding of the technical feasibility, economic practicality, and the social and environmental acceptability of the SPS concept. Based upon the detail assessments, recommendations are to be made during FY 1980 as to possible future directions.

NASA is identifying and defining the most attractive SPS concepts from economic and technical considerations. The system definition efforts have produced a reference system. Future system study efforts will refine the definitions of the reference system. DOE is assessing the potential of any adverse environmental, health, and safety effects.

Key environmental issues have been identified and DOE has initiated specific studies to resolve some of the issues in 1978 and 1979.

Studies by DOE are to address issues of resource utilization, institutional factors, international matters, and the societal effects of SPS. Current studies are surveying existing work in all four areas as it applies to the SPS and will define additional efforts required for societal assessment.

Before a commitment to SPS can be considered, DOE is performing a comparative assessment of the SPS and other advanced energy systems to determine if the implementation of the SPS would offer a distinct advantage to the American people. A methodology is being formed to compare different energy systems on a common basis.

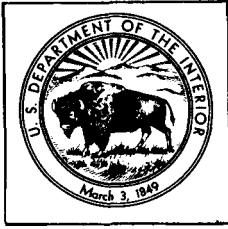
Nuclear Waste Disposal

In support of a NASA-DOE study of the potential for nuclear waste disposal in space, a baseline operational scenario was selected during FY 1978, using the Space Shuttle to place waste into a long-term stable solar orbit between Earth and Venus. A concept definition and evaluation study is tentatively planned through FY 1981. At that time a joint NASA-DOE recommendation would be submitted as a basis for decision on continuing the program.

Nuclear Test Detection

Development of satellite-borne nuclear surveillance began in the early 1960s and led to the Vela Hotel program. Because of its specialized knowledge of nuclear explosion characteristics and capability to detect and measure output radiations, the Atomic Energy Commission, one forerunner of the DOE, was tasked to design and develop the detector instrumentation for the proposed satellites while DoD held responsibility for overall management of program activities and schedules. The Vela satellites were launched into Earth orbits of about 112,000 kilometers—far enough out so that one satellite could view nearly half the Earth's surface and most of outer space. Six pairs of Vela satellites were placed into orbit between 1963 and 1970. Successive satellites carried improved instrumentation for nuclear-explosion surveillance.

The nuclear surveillance mission of the Vela satellite program is now incorporated into other multi-mission DoD spacecraft while DOE continues to retain responsibility for design, fabrication, test, calibration, and launch and operational support of the nuclear test detection instrumentation subsystems. In support of this responsibility, DOE conducts a vigorous research and development program to meet changing detection requirements as well as to develop a detailed understanding of the radiation environment of space.



Department of the Interior

Introduction

The Department of the Interior is responsible for the nation's public lands and for maintaining a balance between the use and conservation of natural resources on these lands. Effective resource management and research require accurate and timely data, whether collected on the ground, from high- or low-altitude aircraft, or from satellites. In some investigations data from various sensors such as multispectral scanners, cameras, and radars are useful. To collect data, the department relies on aircraft for acquiring aerial photographs, carrying experimental airborne instruments, and executing programs such as selection of utility corridors, cadastral surveys, and resource inventories.

The need for surveying and repetitive monitoring of vast and often inaccessible areas has also created a growing interest in satellite data, primarily from the experimental Landsat system because of its synoptic, repetitive, and uniform coverage. Digital Landsat data have made possible the extraction of information by computerized techniques. Because of the flexibility that digital data offer in collecting and managing large volumes of information, resource managers in seven bureaus of the department are incorporating this new technology into their activities to varying degrees.

Earth Resources Observation Systems Program

The Earth Resources Observation Systems (EROS) program is administered for the Interior Department by the U.S. Geological Survey (USGS). The purpose of the EROS program is to develop, demonstrate, and encourage applications of remotely sensed data and aerospace technology which are relevant to functional responsibilities of the department. Efforts of EROS personnel toward these goals have been instrumental in bringing about approximately 25 routine or nearly routine applications of remote sensing and aerospace technology already within the department and approximately 20 applications that are in the experimental stage.

The key facility of the EROS program is the EROS Data Center (EDC) in Sioux Falls, South

Dakota, the principal archive for remotely sensed data collected by U.S. Geological Survey (USGS) and NASA aircraft, and by Landsat, Skylab, Apollo, and Gemini spacecraft. EDC now serves as the national distributor of Landsat products to all agencies of the Federal government and the public. Sales for FY 1978 amounted to about \$3.2 million, about 60 percent of which was for Landsat data.

Improvements in Image Processing and Delivery

Several long-planned improvements to the quality of Landsat products and the efficiency of the delivery system were achieved this year. A digital image system for pre-processing Landsat imagery was installed at NASA's Goddard Space Flight Center; a companion system at EDC provides for volume production and distribution of Landsat data. These new systems will permit a fourfold increase in information content of Landsat image products as compared to conventional processing systems previously used. NASA and USGS have agreed to an arrangement wherein a commercial communications satellite carrier, RCA Americom, will provide a telemetry link for Landsat data from Goddard to EDC. This link, together with telemetry links from Landsat reception stations at Fairbanks, Alaska, and Goldstone, California, will be implemented during spring of 1979 and will reduce the time required to deliver Landsat imagery to the user from 4-6 weeks to 7-10 days. On an emergency basis, it will be possible to examine within 24-48 hours imagery of floods, extent of ice or snow pack, or other time-dependent phenomena such as vigor of range grass.

To make more foreign coverage available, EDC is participating in arrangements with other countries who receive and process Landsat data—Canada, Brazil, and Italy—in establishing an international exchange of data base information.

Imagery of the Shallow Seas

In a 5-year program to update hydrographic charts, the Defense Mapping Agency (DMA) entered into an agreement with NASA and the EROS Data Center to acquire Landsat multispectral

scanner data over certain shallow water areas of the world. Data within the range of foreign receiving stations may be available through the exchange of international data. Special arrangements with NASA are necessary to turn on the satellites' tape recorders to acquire data out of range of a ground receiving station and to operate bands 4 and 5 of the multispectral scanner in a high-gain mode to enhance shallow bottom features. A total of from 9000 to 12,000 data acquisitions will probably be needed to ensure cloud-free coverage of the 3000 required areas. EDC will expedite the necessary processing of the data and provide facilities and consultation for its interpretation. Methods of analyzing imagery of the Trust Territories of the Pacific, developed in an earlier EROS study, were refined, verified, and adopted for use in the DMA program.

Training Programs

The EROS Data Center has achieved a worldwide reputation of excellence for its training programs in the uses of remote sensing data. Seven hundred seventy four participants, representing Federal and other government agencies, private industry, and educational institutions, attended 30 training courses during FY 1978. Since 1973, 119 courses have been given for 2572 students including 620 foreign participants from 84 countries.

Applications and Research

In addition to data distribution and training, EROS activities include technical assistance and research in the applications of remote sensing data to Earth resources investigations. Computer-assisted image analysis techniques are developed, demonstrated, and documented in the Data Analysis Laboratory at EDC in response to the particular needs of user agencies. Cooperative demonstrations and research projects often result in the development of techniques feasible for routine use. Some examples of promising new cooperative projects with potential for routine use in the department are:

- *Integrated geophysical and remote sensing data.* Experimental merging of gravity and magnetic data and data from Landsat, the Heat Capacity Mapping Mission satellite, and Seasat's radar is being tested at sites in 8 states by scientists from EROS and Geologic Division of USGS.
- *Composite mapping and topographic analysis.* The Topographic Division, the National Cartographic Information Center, the Geography

Program, and the Center for Astrogeology of USGS are cooperating with EDC's Data Analysis Laboratory in an experiment to combine Landsat digital data with data from other sources, such as digital maps, terrain tapes, and census data. The techniques developed will be used to generate enhanced imagery and to produce an improved classification of types of land cover. In another cooperative project, with the Bureau of Land Management, digital topographic data are being combined with Landsat imagery to produce stereoscopic images. The technique is used to aid in classification of vegetation in Arizona.

- *Targeting, inventorying, and monitoring ground water resources.* Water Resources Division of USGS is cooperating with EDC in a comprehensive program to use remote sensing technology in locating new sources of ground water and monitoring its use for irrigation. Standards for prediction of ground water occurrence in particular geologic terrains are being developed by evaluating existing remotely sensed data. A study of the Ogallala aquifer in Texas, Oklahoma, and Kansas, and a demonstration project to monitor irrigated cropland in the Suwanee River Water Management District in Florida, are contributing to the development of a methodology to assess the environmental impact of agricultural irrigation.
- *Monitoring desertification.* EROS and the Center for Astrogeology of USGS have developed a precision method for measuring the albedo (brightness) of Landsat images of arid regions in Utah and Nevada in an experiment to monitor desertification. The United Nations Conference on Desertification in 1977 gave high priority to the development of arid region monitoring.
- *Fraunhofer Line Discriminator.* Research cooperatively supported by USGS and NASA has led to the development of an airborne electro-optical device for detecting luminescence which cannot be seen by the human eye. The device, called a Fraunhofer Line Discriminator, has been successfully tested on geochemically stressed vegetation, drought stressed agricultural crops, phosphate rock, oil spills and marine seeps, paper mill and phosphate processing effluents, and uranium-bearing sandstone. The Environmental Protection Agency and the Agricultural Research Service of the Department of Agriculture have contributed support for recent test flights.

Monitoring The Environment

Land Inventories

A Natural Resources Information System, primarily based on aerial photographs and orthophotographs, and updated with Landsat data, has been in use for several years for the Indian lands. A National Wetlands Inventory conducted by Fish and Wildlife Service became operational last year, relying on Landsat data in Alaska and aerial photographs in the lower 48 states.

The National Park Service is cooperating with NASA in an Applications System Verification Test of remote sensing techniques and with EDC in a vegetation inventory of the Lake Mead National Recreation Area. The goal is to train Park personnel in techniques to be used in planning and management of 25 large recreational areas.

The Bureau of Reclamation and Land Management have also participated in cooperative demonstration projects at EDC, where their resource managers were trained to extract information from Landsat data on the interactive digital image analysis system. Mandated by recent legislation to administer large areas, both bureaus have found it cost-effective to procure similar systems, each representing an investment of about \$1,000,000, to conduct inventories in their own facilities on an operational basis.

The Bureau of Reclamation is required by Public Law 90-537 to develop a plan to meet the future water requirements of the Colorado River basin. The newly produced interactive analysis system will be used to inventory the irrigated lands of the area, detect changes in land use, and map wildlife habitat. A continuing cooperative project with EDC is to investigate the potential of data from an airborne multispectral scanner and from the Thematic Mapper planned for Landsat-D.

The Federal Land Management Act of 1976 requires the Bureau of Land Management to keep current an inventory of the resources of public lands to ensure protection of the environment and that optimum use of the land will be made for the long-range public good. To inventory and monitor the 1,910,000 square kilometers of public lands in the 11 western states and Alaska for which it has responsibility, the bureau has devised a comprehensive information system combining data from many sources. The wildland vegetation inventory maintained with the Landsat image analysis system is a vital component of the information system.

Environmental Impact of Fuels Exploration

Interest in the potential for monitoring surface mining operations with Landsat data resulted in a memorandum of understanding between the newly

created Office of Surface Mining and the Bureau of Mines. Financial support to examine the potential was provided by the EROS Program, Office of Surface Mining, the Bureau of Mines, and the state of New Mexico. The feasibility of using Landsat data was demonstrated at the Navajo Coal Mine in New Mexico by the Technology Application Center of the University of New Mexico, using data analysis techniques developed by Stanford University. Similar projects are under way in Florida and South Carolina.

Conservation Division of USGS has contracted with the University of California at Santa Barbara for an analysis of Seasat radar data for the detection of oil or gas on the ocean surface in the Santa Barbara Channel. Data from overflights by Coast Guard aircraft and surface sampling will also contribute to the study.

The Bureau of Land Management and USGS are responsible for regularly supplying the affected states with information about the environmental impact of offshore fuel exploration on coastal areas. Aerial photographs and satellite imagery are used routinely in environmental impact statements.

USGS used airborne multispectral scanners to identify surface alteration associated with uranium mining and also to locate underground coal mine fires. Computer-processed Landsat data are combined with other remotely sensed data collected by USGS to aid in locating potential sites for radioactive waste storage.

Data Acquisition Through Satellite Relay

USGS is the largest single user in the department of the data collection system, with about 100 platforms routinely relaying water data through Landsat, the Geostationary Operational Environmental Satellite (GOES), or a commercial satellite to the USGS computer. Satellite data relay is also used in USGS experiments to monitor volcanoes and earthquakes and to collect magnetic data.

The Bureau of Reclamation Sierra Cooperative Pilot Project combines hydrometeorological data relayed from remote ground stations via GOES with National Weather Service data to determine the best opportunities for cloud seeding.

The Bureau of Land Management uses relay stations in an automatic lightning detection system for remote areas. Bonneville Power Authority tested the system successfully in retrieving hydro-meteorological data from inaccessible sites.

Geology

Geologic Processes

The USGS Center for Astrogeology began a 5-year program, funded by NASA, to analyze data

from the two Viking landers on Mars, including about 50,000 photographs. The origin of deep alluvial channels, the history of Martian volcanism, the possibility of radical climate changes, and the lack of plate tectonic activity similar to that on Earth will be investigated.

USGS published a geologic map of the entire surface of Mars made from over 2000 photographs taken by Mariner 9 in 1971–1972. The map shows landforms and structures and differentiates 23 rock types.

Earth data from the Heat Capacity Mapping Mission satellite are used to identify rock type on the basis of thermal inertia properties.

USGS and NASA have agreed to cooperate in the construction of a mathematical model of the Earth's magnetic field and to analyze magnetic anomalies, using data from Magsat.

The National Oceanic and Atmospheric Administration, Water Resources Division of USGS, and several foreign organizations are cooperating with EROS to publish an atlas of glaciers from satellite imagery.

Mineral Exploration

Imagery from Landsat and aircraft is used routinely by the department as a tool for mineral exploration and to improve the quality and speed of major mineral resource mapping programs. In addition, USGS contracted for approximately 225,000 line-kilometers of aeromagnetic and aeroradioactivity surveys.

Using an airborne multispectral scanner, a USGS research investigation determined that the optimum spectral band for identification of rock type was 2.2 micrometers. As a result, this spectral band has been added to the Thematic Mapper being planned for Landsat-D.

Cartography

High-altitude aerial photography is the principal source of data in the National Mapping program and the Land Use Data and Analysis mapping program of USGS, complemented by the use of Landsat imagery for specialized applications in select areas. For example, Landsat digital imagery was used to locate small water-filled potholes in North Dakota, important as an indicator of a wild-fowl migration route, and to make an interim map of land cover in the National Petroleum Reserve of Alaska.

Landsat Image Maps

A color mosaic of mainland Alaska was prepared by the Alaskan Geology Branch of USGS. The

mosaic consists of 128 Landsat images, and is a photographic product available to the public from EDC.

Two mosaics of the Yemen Arab Republic were made by the USGS in cooperation with the Yemen Arab Republic, under the auspices of the Agency for International Development. The mosaics were made from 12 Landsat images at a scale of 1:500,000 in lithographic format. One is a geographic map annotated in English and Arabic with cultural features, and the other is a geologic map superimposed on band 7 imagery.

A Landsat image map was produced by Topographic Division of USGS of the Chesapeake Bay depicting the most severe ice conditions on record (February 1977), in an experiment to map a temporal phenomenon.

Geodetic Control

To establish geodetic control for mapping in remote areas, such as Alaska, USGS and BLM use portable Doppler receivers to track the Navy Navigational Satellite. Position is computed from frequency shift information from many passes and satellite ephemeris data from permanent tracking stations. The NAVSTAR Global Positioning System, expected in the mid-1980s, will shorten the time required for accurate positioning from the present few weeks to only a day or two.

Space Oblique Mercator Projection

A significant development this year in the application of satellite imagery to cartography concerned the Space Oblique Mercator (SOM) map projection. A map projection is the display of a curved surface of Earth on a flat surface, and the SOM was devised in 1974 to show the satellite ground track continually true to scale for an orbiting satellite combined with the rotating Earth. This year the equations necessary to incorporate the projection into the image processing of Landsat were developed and programmed on the USGS computer. The projection will significantly increase the geometric fidelity of Landsat imagery.

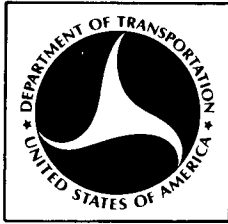
International Activities

Under the U.S. Foreign Assistance Act, USGS participates with the Agency for International Development in a technical assistance program to aid developing countries in Earth science and engineering. These countries frequently request assistance in remote sensing as the most feasible way of addressing some of their environmental and resource problems.

Four-week international remote sensing workshops are given at EDC twice a year as part of this program. In FY 1978, EDC also conducted courses for a group of resource managers from Central America (sponsored by the Inter-American Development Bank), the national mapping agency of Mexico, and the national space agency of Iran. An advanced remote sensing workshop for foreign participants was held at the USGS Center for Astrogeology. In addition, USGS scientists participate in many assistance programs and consultations in the developing countries.

Another international activity of USGS is scien-

tific cooperation providing for joint research and exchange of information. For example, last year EDC conducted a workshop in remote sensing at the Circum-Pacific Energy and Mineral Resources Conference sponsored by the United Nations Coordinating Committee for Offshore Prospecting—East Asia. The workshop was attended by 44 geoscientists from 11 foreign countries. A remote sensing project, led by USGS, is part of the International Geologic Correlations Program, jointly sponsored by United Nations Educational, Scientific, and Cultural Organization (UNESCO) and the International Union of Geological Sciences.



Introduction

The Department of Transportation, through its aviation component, the Federal Aviation Administration (FAA), manages extensive aeronautical research, development, test, and evaluation programs. These activities support FAA in the proper discharge of its mission to promote air safety, assure the safe and efficient use of the national airspace, foster civil aeronautics and air commerce both at home and abroad, develop and operate a common system of air navigation and air traffic control for both military and civil aviation, promote the development of a secure and effective national airport system, and ensure the compatibility of civil aviation with the environment.

These research, development, test, and evaluation efforts help provide solutions to operational problems encountered by FAA in such areas as air navigation and air traffic control, aviation communications, aviation weather, aviation medicine, aircraft noise and air pollution abatement, energy conservation, and aviation safety.

Air Traffic Control and Air Navigation

Microwave Landing System (MLS)

A national program to develop a Microwave Landing System (MLS) was begun in 1971 as a joint effort among the Departments of Defense and Transportation and the National Aeronautics and Space Administration. Program management and funding responsibilities for development of the system were vested in the Federal Aviation Administration.

This new landing system is expected to overcome limitations restricting the usefulness of the Instrument Landing System (ILS), the existing standard, and to provide the operational and economic benefits associated with a universal system capable of meeting the needs of civil and military aviation into the year 2000 and beyond. The deficiencies which led the United States to establish a national MLS development program were also recognized in the international aviation commu-

nity. The result was a series of actions within the International Civil Aviation Organization (ICAO) to select and standardize worldwide a new international system.

A major milestone was achieved in April 1978 when, after nearly four years of preparation and detailed evaluation of candidate microwave landing systems, the ICAO Worldwide All Weather Operations Panel selected the Time Reference Scanning Beam system, developed by the U.S., for international standardization. As a result of the ICAO decision, initial steps were taken to prepare the necessary international standards and specifications for the system.

Action was also taken to complete the development of selected MLS prototypes with the procurement of a Basic (Wide Aperture) System which will be delivered for testing in 1979. The test and evaluation of Basic (Narrow Aperture) and Small Community Systems were completed.

Discrete Address Beacon System (DABS)

The existing Air Traffic Control Radar Beacon System (ATCRBS), a spinoff from the World War II Identification Friend or Foe (IFF), is currently used as the primary tracking and surveillance vehicle in air traffic control (ATC) automation operations. In this system an airborne transponder signals an aircraft's identity and altitude when triggered by ground interrogators mounted on FAA radar antennas. Its shortcoming is its limited ability to separate transponder replies from aircraft in the same immediate vicinity. This leads to the overlapping and garbling of transponder replies and seriously limits the system's ability to meet the demands of the highly automated air traffic control system.

The Discrete Address Beacon System (DABS), in effect an improved ATCRBS, overcomes this difficulty by assigning an individual address code to each aircraft. If an interrogation contains this code, the DABS transponder will respond; if it does not contain the code, DABS will remain silent. Because of this discrete interrogation capability, DABS is a

natural vehicle for a digital data link between the ground-based air traffic control system and the aircraft. It also provides an automatic ground-derived traffic advisory and separation assurance capability not available with the present ATCRBS.

The transition from ATCRBS to DABS will be a gradual, evolutionary process, and will probably be completed over a 10-year period. This will allow amortization of FAA's investment in ATCRBS while at the same time provide sufficient service for current aviation needs.

In mid-1978 the FAA accepted delivery of the first of three engineering models of DABS. This engineering model is now undergoing test at the National Aviation Facilities Experimental Center, in Atlantic City, New Jersey. The second DABS, delivered in October 1978, contained the ground-based separation assurance capability previously described.

Electronic Tabular Display System

Although a significant degree of automation has been introduced in the 20 air route traffic control centers located in the contiguous 48 states, many routine functions are still being performed by air traffic controllers. These functions, usually associated with the processing of flight-plan data, entail manual and other labor-intensive activities, including the updating and posting of flight progress strips in controller consoles and the manual entry of new flight data into the en route computers through time-consuming manual devices.

During the past decade, FAA has been experimenting with electronic tabular displays and touch entry devices as a means of eliminating flight progress strips and improving flight data updating techniques. Based on numerous cost-benefit studies, development of the Electronic Tabular Display System (ETABS) has great potential for increasing control-team productivity and capacity. The benefits and potential productivity increases of the controller through the introduction of ETABS in air route traffic control centers should improve operations, enhance system capacity, and reduce staffing requirements.

During 1978, competitive proposals for the introduction of ETABS were received and evaluated, and a contract was awarded for an ETABS engineering model.

Terminal Information Processing System

The Terminal Information Processing System (TIPS), initiated in FY 1978, is an air traffic control terminal automation program that has the potential for increasing the productivity of the terminal controller. Through the automated fea-

tures of the TIPS computer and associated electronic displays, terminal controllers will be provided with an improved system for processing and distributing flight data and other essential operational information. Today these tasks are performed manually at the terminals; flight data are distributed by means of paper flight progress strips that are cumbersome to handle and require manual updating.

TIPS interfaces with Automated Radar Terminal Systems and computers at host air route traffic control centers; flight and control data can be interchanged automatically between air traffic control personnel, thereby providing more, and more timely, access to essential air traffic control information. The system could be installed in as many as 60 high- and medium-density terminals and at 70 low-density terminal control facilities.

All-Digital Operation For Air Traffic Control Terminal Areas

As part of a continuing plan for improving the automation capabilities of terminal air traffic control services, the first developmental model of a full-digital data processing and display system was delivered to the Tampa-Sarasota terminal areas in early 1978. By digitizing radar data at the radar site and remoting that data to the terminal control facility over a standard telephone communication channel, this system will facilitate expansion and improvement and provide air traffic service at much lower cost. The all-digital design eliminates the normal constraints imposed on the use of analog data and permits limited-distance radar data to be transmitted over landlines.

Another and perhaps more significant improvement from an all-digital operation is the remoting of radar data to satellite control towers that are within the operational radius of radars feeding surveillance data to terminal automation facilities. Through this digital technique, satellite control towers up to 32 kilometers from an ARTS-III facility can be provided digital radar data for the safe separation and control of aircraft within their operation area.

The all-digital terminal automation system was operationally demonstrated in the Tampa-Sarasota area in December 1978. The evaluation will include the remoting of radar data to four satellite tower cabs and the displaying of aircraft positional data on a bright, all-digital display.

Airport Surface Traffic Control

The goal of this research and development program is to develop automation and surveillance aids for airport surface traffic control. Such a devel-

opment would minimize surface traffic delays and provide safer airport operations under all weather conditions. The key to this development is a new radar—Airport Surface Detection Equipment (ASDE-3)—which has improved aircraft detection during fog and rain. Procurement was initiated to obtain a development model of ASDE-3.

Low-Level Wind Shear Alert System

As part of FAA's program to mitigate the effects of low-level wind shear on aircraft terminal operations, the agency has developed and tested the Low-Level Wind Shear Alert System (LLWSAS). The system consists of remotely mounted anemometers mounted between 6 and 12 meters above the ground in the approach and departure corridors of a number of the nation's busiest airports. Wind data from the remotely mounted anemometers are linked by radio to a central airport location (normally the air traffic control tower) for processing and comparison with data sensed by the centerfield anemometer.

When a wind vector difference of 28 kilometers per hour is detected between any one of the remote anemometers and the centerfield anemometer, the difference is displayed in the air traffic control tower cab. The air traffic controllers then relay the centerfield and remote anemometer wind information to aircraft arriving at or departing from the airport. Currently, the system is operating at seven major airports around the country.

Vortex Advisory System (VAS)

Wake vortices, strong rotating gusts of wind that trail behind large jet aircraft on approach and landing, present a definite danger to following aircraft, especially smaller ones; in addition these vortices reduce airport capacity because of the need to maintain large spaces between landing aircraft. FAA's wake vortex program was established to deal with this problem.

The program's primary objective is to develop a system to provide increased airport capacity by minimizing the impact of trailing wake vortices on the safe and efficient management of air traffic in terminal airspace. Specifically, the Vortex Advisory System (VAS) will provide aircraft separation data to the controller based on the measurement and analysis of wind conditions in the approach corridor. The VAS utilizes a network of anemometers located in the runway approach zones to measure wind conditions and determine when separations between pairs of landing aircraft can be set at 5 kilometers. A by-product of the system is an accurate assessment of the wind conditions in all runway approach corridors.

A prototype VAS began an operational test at Chicago's O'Hare International Airport.

Aviation Safety

Transport Safety

During 1978 FAA conducted studies in concert with NASA addressed to establishing the safety and certification requirements of digital flight control and avionic systems for use in designing the next generation of transport aircraft. Digital systems were tested to determine their effectiveness in the presence of lightning, and studies were made of the reliability of multiple, redundant digital equipment. In addition, the two agencies held a seminar at NASA's Dryden Flight Research Center to determine the general reliability of both the hardware and software components of these systems. Finally, with the successful development of a computer model capable of predicting the crushing and distortion of light-aircraft structures during crash impact, the two agencies initiated a special program to adopt this model to large aircraft structures and thus improve crashworthiness standards generally.

Fire Safety

In the area of fire safety, FAA

- Intensified its post-crash cabin fire research and development program. Tests quantifying cabin hazards created by the combustion products of burning fuel spills showed that in the first five minutes following impact, heat and smoke became stratified in the cabin and tended to become the principal hazards to escape. The tests also showed that concentrations of such gases as carbon monoxide and carbon dioxide were not nearly as significant in impeding or preventing escape. Winds as low as 5 kilometers per hour readily carried combustion products into the cabin, greatly increasing the magnitude and growth rate of hazards facing cabin occupants.
- Continued to work on a two-year research and development effort to determine the relative combustion hazard of specific transport-aircraft cabin materials in a post-crash fire. The object of the program is to positively identify which of these materials give occupants of the plane the best chance to escape safely.
- Engaged in the further validation of an FAA-developed aircraft cabin-fire mathematical model, using data obtained from ongoing FAA-NASA cabin-fire tests. This model will provide an analytical definition of the cabin environment during a particular post-crash scenario.

- Signed a memorandum of understanding with the United Kingdom concerning the antimisting kerosene program. The signatories agreed to bring this program to a level of activity sufficient to determine, within two years, whether the antimisting concept has sufficient merit to justify proceeding with the remaining work needed to determine the extent to which this modified fuel minimizes the fireball that so often accompanies impact-survivable crashes.

Aviation Security

Research and development work aimed at deterring acts of terrorism and sabotage aboard aircraft and at airports was concentrated in 1978 on the development of improved techniques for the detection of explosives in luggage. The work included:

- Development of a new computer algorithm that significantly improves the effectiveness of an automated radiation contrast system to detect bombs. This advance will be applied to preproduction models currently being fabricated for test.
- Delivery for testing at airports of a transportable experimental bomb detector system employing nuclear magnetic resonance techniques.
- Examination of computer-aided dual-energy x-ray techniques for detection of explosives.
- Conducting of tests with small animals to verify some initial findings of Canadian researchers that gerbils, for example, can detect minute quantities of explosive vapor—quantities too minute to be detected with existing electronic equipment.
- Beginning of construction on a transportable model of a bomb detector using thermal neutrons.

Nondestructive Testing of Airport Pavements

Airport pavements must be evaluated periodically for strength characteristics and load carrying capabilities. The evaluations are necessary because they provide the airport owners with valuable diagnostic information that can be used in scheduling major repairs or rehabilitations rather than having emergency pavement failures.

Conventional evaluation calls for cutting 1.2-meter-square test pits into the pavement, conducting plate-bearing tests, and sampling materials. Destructive tests such as these are costly and time consuming; more important, they require shutting down the runway or taxiway. There is, however, an alternative: nondestructive testing that makes shutdowns unnecessary. Vibratory loads are applied to the surface of the pavement by mobile equipment,

which can be moved quickly out of the way. Pavement deflection in response to the vibrating load is measured, and pavement strength and load-carrying capabilities are calculated by computers. In addition, alternative rehabilitation designs are considered, as well as the cost and benefit of each. Thus airport operators receive an economic rationale for decision-making.

A proprietary method of nondestructive testing known as the frequency sweep method was purchased for the public by FAA from Dr. Nai Yang and validated at four airports during 1978. Seminars explaining the method and its results were held at each of the four airports, and a fifth seminar was held in late fall in Washington, D.C. Attendance at the seminars was indicative of the strong interest among airport operators, both nationally and internationally, in nondestructive testing.

Aviation Medicine

The FAA medical research program devotes a portion of its resources to the analysis, assessment, and improvement of the role of the human operators as a part of the air traffic control system so as to increase efficiency, reliability, and safety. Research in this program also focuses on the performance and proficiency, as well as the mental and physical health, of air traffic control specialists.

One of the most significant undertakings—a five-year medical study of more than 400 male air traffic controllers from the Boston and New York areas—was completed in 1978. The study found these controllers to be as healthy as men of similar ages in the general population, except for a higher than normal rate of hypertension. These findings contrast with the generally held aviation industry view that controlling air traffic is associated with an unusually high incidence of ulcers, psychiatric disorders, and other stress-related medical problems.

Conducted for the Federal Aviation Administration by the Boston University School of Medicine, the study found that 135 of the 416 controllers who volunteered for the program already had borderline or definite hypertension at their first examination. In addition, 36 developed hypertension during the course of the study. The overall rate of hypertension was about twice the national norm. The 970-page study cautions, however, against the conclusion that air traffic control work by itself causes hypertension. It notes that work was only one of a “risk factors” contributing to the development of this disease.

Boston University began the five-year project in 1972, under a \$2.8-million FAA contract, to determine the nature and extent of health changes in air

traffic controllers and how these health changes might be predicted. The actual medical data on the controller volunteers was collected over a three-year period beginning in 1973.

The study found that less than one percent of the controllers had physiological symptoms of alcoholism, substantially lower than the national average, and that the rate of alcohol abuse was about the same as that derived from survey data on other occupations. A potential health problem identified in the study was the high use of alcohol in social drinking after work.

The study team also found that controllers experienced fewer psychiatric disorders than the gen-

eral population, except for a relatively high rate of "impulse control difficulties," such as an inability to control anger. Slightly more than one half of the men showed some problem at one time or another during the three years they were under examination, but only a few displayed a chronic problem. The report notes that comparisons of these findings with other occupational groups was not possible because no other group has been studied so intensively as the controllers over so long a period of time.

The study was specifically related to controllers in the eastern United States; its applicability to other areas is being evaluated by FAA.

Appendixes

APPENDIX A-1

U.S. Spacecraft Record

Year	Earth orbit		Earth escape		Year	Earth orbit		Earth escape	
	Success	Failure	Success	Failure		Success	Failure	Success	Failure
1957	0	1	0	0	1968	61	15	3	0
1958	5	8	0	4	1969	58	1	8	1
1959	9	9	1	2	1970	36	1	3	0
1960	16	12	1	2	1971	45	2	8	1
1961	35	12	0	2	1972	33	2	8	0
1962	55	12	4	1	1973	23	2	3	0
1963	62	11	0	0	1974	27	2	1	0
1964	69	8	4	0	1975	30	4	4	0
1965	93	7	4	1	1976	33	0	1	0
1966	94	12	7	¹ 1	1977	27	2	2	0
1967	78	4	10	0	1978	34	2	7	0
					Total	923	129	79	15

¹ This Earth escape failure did attain Earth orbit and therefore is included in the Earth orbit success totals.

NOTES: The criterion of success or failure used is the attainment of Earth orbit or Earth escape rather than a judgment of mission success.

This tabulation includes spacecraft from cooperating countries which were launched by U.S. launch vehicles.

"ESCAPE" flights include all that were intended to go to at least an altitude equal to lunar distance from Earth.

APPENDIX A-2

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

Year	United States	U.S.S.R.	France	Italy	Japan	People's Republic of China	Australia	United Kingdom
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 1	1	1		
1971	30	83	1	¹ 2	2	1		1
1972	30	74		¹ 1	1			
1973	23	86						
1974	22	81		¹ 2	1			
1975	27	89	3	1	2	3		
1976	26	99			1	2		
1977	24	98			2			
1978	32	88			3	1		
Total	727	1163	10	8	13	8	1	1

¹ Includes foreign launchings of U.S. spacecraft.

NOTE: This tabulation enumerates launchings rather than

spacecraft. Some launches did successfully orbit multiple spacecraft.

Successful U.S. Launches—1978

Launch date (G.m.t.) Spacecraft name Cospas designation Launch vehicle	Spacecraft data	Apogee and perigee (kilometers) Period Inclination to equator (degrees)	Remarks
Jan. 7 Intelsat IV-A F-3 2A Atlas-Centaur	Objective: To launch satellite into transfer orbit. Satellite to provide 6250 two-way voice circuits plus two television channels simultaneously or a combination of telephone, TV, and other forms of communication traffic. Spacecraft: Cylindrical shaped satellite, overall height of 6.99 m and 2.38 m in diameter. Consists of two main elements: rotating cylinder covered with solar cells contains power subsystem; positioning and orientation subsystems; despun Earth-oriented platform atop rotating cylinder contains communications repeaters (transponders), new antenna reflectors, and telemetry and command subsystems. Antenna reflectors are supported by a single tubular mast. 134.6-cm transmit and 88.9-cm receive quasi-square reflectors are constructed of a metallic mesh on an open web frame. Feed horn arrays and global horns are cantilevered from the base of the mast. Telemetry and command omnidirectional bicone antenna is mounted on the mast tip. Weight at liftoff: 1515 kg. Weight after apogee motor fire: 825.5 kg.	35,797 35,634 1432.4 0.4	Fifth in a series of improved Intelsat IV-A spacecraft with almost two-thirds greater communications capacity than Intelsat IV. Launched by NASA for ComSat Corp., manager of Intelsat. Apogee motor fired Jan. 8 and satellite placed on station at initial position of 74° east longitude. Spacecraft later to be moved to 60° east longitude off the east coast of Africa to serve as backup spacecraft to Intelsat IV-A F-6 launched Mar. 31, 1978.
Jan. 26 IUE 2A Delta	Objective: To launch spacecraft into elliptical geosynchronous orbit. Satellite to provide an orbital ultraviolet observatory for investigation of stellar atmospheres and interplanetary medium, and celestial objects of different galaxies and quasars. Spacecraft: Octagonal cylinder 1.5 m tall and 1.3 m between opposing faces. Telescope tube, .5 m in diameter, extends from forward end of cylinder and an apogee motor from the rear, giving an overall length of 4.2 m. Weight: 670.8 kg, of which 123.4 kg is scientific instrumentation.	45,887 25,669 1435.7 28.6	Launched into successful transfer orbit. Apogee boost motor fired Jan. 26 placing spacecraft above South America. Three-axis stabilization obtained Jan. 28. Scientific instrumentation functioning normally and returning data. Preliminary data received suggests possibility of massive black hole at the center of some groups of stars in our galaxy called globular clusters.
Feb. 9 Fltsatcom 1 16A Atlas-Centaur	Objective: To place satellite in successful transfer orbit. Spacecraft: Dual hexagonal satellite composed of a payload module and spacecraft module, 39.9 m high. Weight: 1874 kg.	35,978 167 634.2 26.5	First of four planned satellites, successfully launched by NASA for the Navy and the Dept. of Defense. Apogee kick motor fired Feb. 11, placing spacecraft in desired synchronous orbit. Still in orbit.
Feb. 22 Navstar 1 20A Atlas F	Objective: To support the Global Positioning System. Spacecraft: Irregular cylinder with four extended solar panels and complex of antennas. Weight: 433 kg.	20,183 20,183 718.0 63.0	Still in orbit.
Feb. 25 Defense 21A Titan IIIB-Agena	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	34,272 805 720.0 63.5	Still in orbit.

Successful U.S. Launches—1978

Launch date (G.m.t.) Spacecraft name Cospas designation Launch vehicle	Spacecraft data	Apogee and perigee (kilometers) Period Inclination to equator (degrees)	Remarks
Mar. 5 Landsat 3 26A Delta	Objective: To acquire multispectral imagery over the U.S. and foreign countries sufficient to improve remote sensing interpretive techniques and to demonstrate the practical applications of Landsat imagery for crop inventory and other data uses for a period of at least one year. Spacecraft: Similar basic structure and design as Nimbus satellites. 3.04 m high and 1.52 m in diameter, 3.96 m with solar panels deployed. Carries five-channel multispectral scanner (MSS), a two-camera return beam vidicon (RBV), a data collection system (DCS), and two wideband video tape recorders (WBVTR) capable of giving spacecraft sensors near-global coverage capability. Three-axis stabilized. Video data from RBV can be transmitted in both real time and from wideband recorder system. Weight: 900 kg.	914 890 103.0 99.1	Successfully launched into circular, near-polar Sun-synchronous orbit, allowing spacecraft to photograph nearly entire globe during an 18-day period. Landsat 1 launched in 1972, and Landsat 2 placed in orbit in 1975. Instrumentation operating and returning data, except for fifth band (thermal infrared) of multispectral scanner, which failed in 1978. Piggyback payload Plasma Interaction Experiment (PIX) attached to the Delta second stage. Weight: 34 kg.
Mar. 5 Oscar 8 26B Delta	Objective: To place satellite into a Sun-synchronous orbit. Spacecraft to provide continuous radio communications using small amateur ground terminals. Spacecraft: Rectangular shape with solar cells on exterior; carries two transponders on same uplink frequency centered on 145.9 MHz, downlink frequencies centered on 29.4 MHz and 435.1 MHz. Only one transponder to be used at any one time, because of power limitation. Spacecraft magnetically stabilized. Weight: 27 kg.	915 902 103.2 99.0	Launched by NASA as secondary payload with Landsat 3, as replacement for Oscar 6. Product of cooperative effort by U.S., Canada, Japan, and West Germany.
Mar. 16 Defense 29A Titan IIID	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	239 172 88.4 96.4	Decayed September 11.
Mar. 16 Defense 29B Titan IIID	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	650 635 97.2 95.8	Still in orbit.
Mar. 31 Intelsat IV-A F-6 35A Atlas-Centaur	Objective: To launch satellite into successful transfer orbit from which synchronous orbit can be achieved. Spacecraft: Cylindrical shape, 6.99 m high and 2.38 m in diameter. Solar panel height 2.82 m. Satellite can carry 6250 two-way voice circuits plus two television channels, a two-thirds increase in capacity over previous Intelsat series. Weight at liftoff: 1515 kg. Weight after apogee motor fire: 825.5 kg.	35.851 35.730 1436.3 0.3	Sixth and last in a series of improved satellites launched by NASA for ComSat Corp., manager of Intelsat. Apogee kick motor fired Apr. 1 to place spacecraft in final position at 63° east longitude off the east coast of Africa. Began operations in Nov.
Apr. 7 Defense 38A Atlas-Agena D	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	41.411 6528 615.5 28.4	Still in orbit.
Apr. 7 BSE 39A Delta	Objective: To launch satellite into synchronous transfer orbit. Satellite designed to conduct experiments in direct broadcast television transmission and reception technology. Spacecraft: Rectangular electronics module 1.3 m wide, 1.2 m long, and 3.9 m high, including apogee boost motor. Deployable solar panels extend 8.9 m in length and are 1.5 m wide. Three-axis stabilized. Weight at launch: 665 kg. Weight after apogee boost motor fire: 327 kg.	35.662 35.115 1415.7 0.1	Japanese Director Broadcast Satellite-Experimental (Japan/BSE) launched by NASA for the National Space Development Agency (NASDA). Apogee boost motor fired Apr. 8 and spacecraft placed in geostationary orbit at 110° east longitude above the equator and south of Japan. Satellite named Yuri.

Successful U.S. Launches—1978

Launch date (G.m.t.) Spacecraft name Cospar designation Launch vehicle	Spacecraft data	Apogee and perigee (kilometers) Period Inclination to equator (degrees)	Remarks
Apr. 26 HCMM (AEM 1) 41A Scout	Objective: To launch spacecraft into near-Earth, circular Sun-synchronous orbit of sufficient accuracy to enable instruments to conduct research into the feasibility of using day/night thermal imagery to generate apparent thermal inertial values and temperature cycle data that could aid in: determining rock types and possible mineral deposit locations; measuring and monitoring surface soil moisture changes; measuring plant canopy temperatures at frequent intervals to determine water loss and plant stress; measuring urban heat islands; mapping surface thermal gradients on land and in water; and deriving information from snow fields for water runoff prediction. Spacecraft: Consists of a basic module which provides attitude control, data handling, communications, command and power subsystems; and instrument module containing the Heat Capacity Mapping Radiometer (HCMR) and its supporting equipment. Two solar panels mounted on spacecraft structure provide power. 63.4 cm in height, 161.85 cm with solar panels extended. Weight: 134.3 kg.	646 558 96.7 97.6	Heat Capacity Mapping Mission (HCMM), also known as Applications Explorer Mission A (AEM-A), successfully launched. Satellite is first in a series of low-cost, modular spacecraft to operate in special orbits that satisfy mission-unique experimental data acquisition requirements. Orbits allows measurement of the Earth's surface for its maximum temperature and then 12 hours later measures the same area's minimum temperature.
May 1 AMS-3 42A Thor-Burner 2	Objective: To support the Defense Meteorological Satellite Program. Spacecraft: Similar to the NASA Tiros-N.	831 829 101.3 98.7	Still in orbit.
May 11 OTS 2 44A Delta	Objective: To place satellite into synchronous transfer orbit of sufficient accuracy to allow spacecraft to achieve stationary synchronous orbit. To test concepts to be used in providing satellite links in the 1980s for routing of portions of the intra-European telephone, telegraph, and telex traffic as well as television relay for Western Europe. Spacecraft: Six-sided satellite includes a payload module, service module, and an antenna assembly, measuring 1.62 m wide, 2.39 m high, and 9.26 m across with solar array deployed. Three-axis stabilized. Weight at launch: 865 kg. Weight in geostationary orbit: 444 kg.	35.780 35.073 1417.7 0.0	Launched by NASA for the European Space Agency (ESA) as a replacement for OTS-A which was destroyed when its launcher exploded 54 seconds after lift-off Sept. 13, 1977. Apogee motor fired May 13 and final geosynchronous position attained May 24 at 10° east longitude over Gabon. ESA confirmed satellite functioning satisfactorily on July 7.
May 13 Navstar 2 47A Atlas F	Objective: To support the Global Positioning System. Spacecraft: Irregular cylinder with four extended solar panels and complex of antennas. Weight: 433 kg.	20,182 20,180 718 62.9	Still in orbit.

Successful U.S. Launches—1978

Launch date (G.m.t.) Spacecraft name Cospas designation Launch vehicle	Spacecraft data	Apogee and perigee (kilometers) Period Inclination to equator (degrees)	Remarks
May 20 Pioneer Venus 1 51A Atlas-Centaur	Objective: To determine structure of upper atmosphere and ionosphere of Venus; to observe interaction of the solar wind with Venus ionosphere and with the small magnetic field; observe characteristics of atmosphere and surface of Venus on a planetary scale by use of remote sensing; to measure planet's gravitational field; and to detect gamma ray bursts. Spacecraft: Cylindrical module 1.2 m high, including antenna mast height is 4.5 m, and 2.5 m in diameter. Power derived from solar cells mounted around outside surface of spacecraft, and two nickel-cadmium batteries. Instruments mounted in basic satellite structure include Retarding Potential Analyzer, Ion Mass Spectrometer, Electron Temperature Probe, Ultraviolet Spectrometer, Neutral Mass Spectrometer, Cloud Photopolarimeter, Infrared Radiometer, Magnetometer, Plasma Analyzer, Radar Mapper, Electric Field Detector, and Gamma Ray Burst Detector. Spin stabilized. Weight at liftoff: 582 kg. Weight after Venus orbital insertion: 368 kg.	Trans-Venus Trajectory	Launched successfully on trans-Venus trajectory, spacecraft taking pictures of Venus and conducting detailed scientific examination of the planet from orbit. Insertion into Venus orbit took place Dec. 4. First image received Dec. 5. Orbiter discovered that higher temperatures were present at poles than at equator. Cloud-top temperatures on the night side of Venus are slightly higher than on the day side. Additional data being received.
June 10 Defense 58A Titan IIIC	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	42,039 29,929 1446.3 12.0	Still in orbit.
June 14 Defense 60A Titan IIID	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	514 225 91.8 96.9	Still in orbit.
June 16 Goes 3 62A Delta	Objective: To launch spacecraft into synchronous orbit of sufficient accuracy to enable satellite to provide continuous observations of the Earth's atmosphere on an operational basis. Spacecraft: Cylindrical shape 190.5 cm in diameter and 344 cm long from the top of the magnetometer to the bottom of the apogee boost motor. Apogee boost motor is ejected after synchronous orbit is reached. Primary structural member is a thrust tube located in the center of the cylinder. Radiometer/telescope instrument, extending the length of the spacecraft, is located in and supported by the thrust tube. The scanning mirror looks out through an opening in the cylindrical solar arrays of the spacecraft. A space environment monitor (SEM) system to measure the magnitude and direction of the magnetic field, the intensity of solar X-ray radiation, and energy level and quantity of energetic particles is included in the payload. Spin stabilized. Weight at liftoff: 635 kg. Weight in orbit: 293 kg.	35,805 35,769 1436.1 0.9	Third operational spacecraft of a series of Geostationary Operational Environmental Satellites launched by NASA for NOAA. Spacecraft successfully placed in transfer orbit, and apogee boost motor fired June 16. Satellite placed in synchronous orbit at 135° west longitude, replacing Goes 1 which was moved to Indian Ocean to support the GARP Global Weather Experiment. Spacecraft turned over to NOAA for operational use on July 5. Goes 3 to observe much of the Pacific Ocean and the western half of the United States.

Successful U.S. Launches—1978

Launch date (G.m.t.) Spacecraft name Cospas designation Launch vehicle	Spacecraft data	Apogee and perigee (kilometers) Period Inclination to equator (degrees)	Remarks
June 27 Seasat 1 64A Atlas F	Objective: To demonstrate techniques for global monitoring of oceanographic phenomena and features, provide data for both applications and scientific users, and determine key features of an operational ocean dynamics monitoring system. Spacecraft: Two major hardware elements: Agena bus provides both launch function and satellite support, including attitude control, power, guidance, telemetry and command functions; sensor module provides platform for five sensors, antennas, laser retroreflector, tracking aids, and a SAR downlink. Two modules measure 21 m long, with a maximum diameter of 1.5 m without antennas deployed. Three-axis stabilized. Weight in orbit: 2300 kg.	798 775 100.6 108.0	Proof-of-concept mission successfully launched. All sensors turned on simultaneously July 7. Spacecraft ceased transmitting data Oct. 9. Subsequent attempts to reestablish contact were unsuccessful. NASA satellite tracking support (except laser tracking) terminated Nov. 10. Data being processed by the Jet Propulsion Laboratory.
June 29 Comstar 3 68A Atlas-Centaur	Objective: To launch satellite into a transfer orbit of sufficient accuracy for the spacecraft to achieve synchronous orbit. Satellite to provide 14,000 two-way high-quality voice circuits. Spacecraft: Cylindrical shape with overall height of 610 cm and 244 cm diameter. 14,000 solar cells mounted on exterior of satellite. Nickel-cadmium batteries provide power during launch and twice-a-year solar eclipse periods. Weight at launch: 1518 kg. Weight in orbit: 792 kg.	35,787 35,784 1436.1 0.1	Launched by NASA for COMSAT General Corp. Apogee boost motor fired July 1 and satellite arrived on station Aug. 16 at 87° west longitude over equator on a line south of Mobile, Alabama. Spacecraft became operational Sept. 7 when American Telephone and Telegraph Company began commercial operations.
July 14 Geos 2 71A Delta	Objective: To place satellite into synchronous transfer orbit that will allow the satellite to achieve stationery synchronous orbit. Spacecraft to make scientific studies of the magnetosphere. Spacecraft: Cylindrical shape, 1.6 m in diameter and 1.1 m high. Eight booms varying in length between 1.5 m and 2.0 m. Two-thirds of cylinder surface covered with solar cells. Weight at launch: 573 kg. Weight in orbit: 237 kg.	35,810 35,772 1436.3 0.7	Successfully launched by NASA for the European Space Agency (ESA). Apogee boost motor fired July 15. Satellite reached geosynchronous orbit on July 26 at 6° east longitude. Spacecraft to perform same experiments as Geos 1, which failed to achieve satisfactory orbit. Geos 2 to serve as reference spacecraft for the International Magnetospheric Study (IMS).
Aug. 5 Defense 75A Titan IIIB	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	39,053 315 697.1 62.5	Still in orbit.
Aug. 8 Pioneer Venus 2 78A Atlas-Centaur	Objective: To determine the nature and composition of the clouds of Venus; the composition and structure of the atmosphere; and the general circulation pattern of the atmosphere by means of multiple entry probes and an instrumented bus. Spacecraft: Cylindrical bus carrying four atmospheric entry probes. From the top of the main probe to the bottom of the bus it measures 2.9 m; diameter is 2.5 m. Four probes carried on the bus by a large inverted cone structure. Three small probes equally spaced around larger centrally located cone. Large probe is 1.5 m in diameter and weighs 316 kg. Three smaller probes are identical, 0.8 m in diameter, and weight 90 kg. Probes are not designed to survive impact on Venusian surface. Spin stabilized. Total spacecraft weight at launch: 904 kg, of which 51 kg is scientific instrumentation.	Trans-Venus Trajectory	Successfully launched toward the cloud-shrouded planet. Large probe separated from bus Nov. 15, three smaller probes separated Nov. 20. Four probes reached Venus' surface, bus burned up in the atmosphere. Preliminary results indicate the primary constituent of the atmosphere is carbon dioxide with large amounts of argon, neon, and sulfur. One probe transmitted data for an hour after impact. Dust cloud created on impact took several minutes to dissipate. Temperature sensor on all four probes failed at an altitude of 14.5 km when temperature climbed to 630 K (680° F), indicating that sulfuric acid at that high temperature could have caused at least a partial short-circuit. Data presently being analyzed.

Successful U.S. Launches—1978

Launch date (G.m.t.) Spacecraft name Cospas designation Launch vehicle	Spacecraft data	Apogee and perigee (kilometers) Period Inclination to equator (degrees)	Remarks
Aug. 12 ISEE 3 79A Delta	Objective: To obtain detailed measurements of the solar wind and its fluctuations. To launch spacecraft into transfer trajectory similar to an interplanetary mission, and insert satellite into halo orbit near the Sun-Earth libration point. Spacecraft: 16-sided cylinder, 173 cm in diameter and 161 cm high. One solar array located forward of equipment section and another below that section. Majority of scientific instruments mounted on the equipment shelf. Four equally spaced rigid booms are attached to the main structure. Magnetometer instrument mounted on +x axis rigid boom. Weight: 479 kg.	108,920 181 67,852.9 1.0	Third spacecraft in a series of three International Sun-Earth Explorers. Successfully inserted into halo orbit Nov. 20. All 12 experiments are operational. Unusual orbit of ISEE 3 will enable it to detect solar wind or particles speeding away from the Sun a full hour before the two other spacecraft do so. ISEE 1 managed by the Goddard Space Flight Center, ISEE 2 by the European Space Agency, and ISEE by GSFC.
Oct. 7 Navstar 3 93A Atlas F	Objective: To support the Global Positioning System. Spacecraft: Irregular cylinder with four extended solar panels and complex of antennas. Weight: 433 kg.	20,314 20,275 722.5 62.8	Still in orbit.
Oct. 13 Tiros-N 96A Atlas F	Objective: To launch spacecraft into a Sun-synchronous orbit of sufficient accuracy to enable satellite to accomplish its operational mission requirements. To measure temperature and humidity in the Earth's atmosphere, surface temperature, surface and cloud cover, water-ice-moisture boundaries, and proton and electron flux near the Earth. Spacecraft: Launch configuration, including the apogee boost motor, is 371 cm high and 188 cm in diameter. In orbit solar panel deploys. Tiros-N bus is a modified U.S. Air Force Block 5D spacecraft/bus designed to have a growth capability of 25%. Spacecraft structure composed of four major elements: reaction control equipment support structure (RSS); equipment support module (ESM); instrument mounting platform (IMP); and solar array. Instrumentation includes: 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 the TIROS Operational Vertical Sounder (TOVS) composed of the three following instruments: High Resolution Infrared Radiation Sounder (HIRS/2), Stratospheric Sounding Unit (SSU), and the Microwave Sounding Unit (MSU). Weight at launch, including apogee kick motor: 1405 kg. Weight in orbit. 723 kg.	865 850 102.0 98.9	Successfully launched by NASA. Apogee kick motor fired Oct. 13. Spacecraft turned over to NOAA for operation Nov. 6. First of a series of eight third-generation operational meteorological polar orbiting spacecraft. Tiros-N, as series prototype, will provide operating experience for subsequent NOAA satellites in this series. Satellite is a primary source of data for the Global Atmospheric Research Program's Global Weather Experiment, an international cooperative program involving some 140 countries, which began Dec. 1, 1978.

Successful U.S. Launches—1978

Launch date (G.m.t.) Spacecraft name Cospar designation Launch vehicle	Spacecraft data	Apogee and perigee (kilometers) Period Inclination to equator (degrees)	Remarks
Oct. 24 Nimbus 7 98A Delta	Objective: To provide continuous environmental data to help scientists throughout the world determine the physical characterization of the global atmosphere, the oceans, the dynamic atmosphere-ocean interface, and the Earth's heat balance. Spacecraft: Butterfly shaped when in orbit, measures 3 m high and 2 m wide. Solar panels provide about 550 watts of peak power. Earth-oriented, three-axis stabilized. Scientific instrumentation composed of Coastal Zone Color Scanner (CZCS); Scanning Multichannel Microwave Radiometer (SMMR); the Limb Infrared Monitoring of the Stratosphere (LIMS); Solar Backscattered Ultraviolet and Total Ozone Mapping System (SBUV/TOMS); Stratospheric and Mesospheric Sounder (SAMS); Stratospheric Aerosol Measurement II (SAM II); Earth Radiation Budget (ERB), and Temperature-Humidity Infrared Radiometer (THIR). Weight 987 kg.	953 938 104.0 99.3	Last in a series of Nimbus meteorological satellites first launched in Aug. 1964 achieved satisfactory orbit. All eight sensors have been activated and are returning data. First satellite designed to monitor the Earth's atmosphere for manmade and natural pollutants.
Oct. 24 Cameo 98B Delta	Objective: To study solar energy and plasma flows and electric fields in Arctic regions through release of barium and lithium in and above the Earth's ionosphere. Experiment is attached to the second stage of the Delta launch vehicle. Composed of five canisters. Contents will be ejected at specified intervals; one over northern Scandinavia, and four over northern Alaska.	953 952 104.1 99.3	Project Cameo (Chemically Active Materials Ejected in Orbit) successfully launched as piggyback payload with Nimbus 7. Barium contents released from four canisters attached to Delta second stage Oct. 29. Cloud observed by sensitive instruments in western U.S., Canada, and Hawaii. Lithium ejected over Scandinavia Nov. 6 in daylight. Instrumentation picked up cloud in Norway.
Nov. 13 HEAO 2 103A Atlas-Centaur	Objective: To obtain high resolution data on x-ray sources in the range from 0.2 to 4 thousand electron volts, to perform high spectral sensitivity measurements with both high and low dispersion spectrographs, and to perform high sensitivity measurements of transient x-ray behavior; to operate spacecraft and acquire scientific data for at least 1 year. Spacecraft: Octagonal shape, 9 m in length and 3 m in diameter. Spacecraft equipment module (SEM) contains all functional subsystems necessary to operate and control the observatory and experiments, except solar array, forward antenna, and the experiment accommodation assemblies (EAA), which are attached to the experiment module (EM). This module provides maximum experiment volume while minimizing overall observatory length, and meets all requirements for experiment support. Instrumentation includes focusing x-ray telescope, a high resolution imaging detector (HRI), an imaging proportional counter (IPC), a solid state spectrometer (SSS), a focal plane Bragg crystal spectrometer (FPCS), and a monitor proportional counter (MPC). Solar cells mounted on exterior panels. Weight: 3152 kg, including 1465 kg of experiments.	543 522 95.3 23.5	Second in a series of three NASA High Energy Astronomical Observatories. Launched successfully into orbit. Telescopes may be able to detect x-rays from objects two-thirds of the way toward the edge of the Universe—i.e., radiation created 10 billion years ago. Unlike HEAO 1, this spacecraft will be able to investigate specific stars or points in the sky; reaction wheels that control torque are installed to provide a precise and highly accurate pointing capability of one arc minute or better for the planned mission lifetime of one year.

Successful U.S. Launches—1978

Launch date (G.m.t.) Spacecraft name Cospar designation Launch vehicle	Spacecraft data	Apogee and perigee (kilometers) Period Inclination to equator (degrees)	Remarks
Nov. 19 NATO III C 106A Delta	Objective: To place satellite into transfer orbit with sufficient accuracy to allow spacecraft to be placed into a stationary synchronous orbit. Spacecraft: Drum-shape, 2.18 m in diameter, 2.23 m long, with an overall length of 2.92 m including antennas. Spin-stabilized. Weight at launch: 706 kg. Weight after apogee kick motor fire: 346 kg.	35,891 184 632.8 27.2	Successfully launched by NASA. Third in a series of advanced NATO communications satellites. Apogee kick motor fired Nov. 20. Satellite on station above the equator over the Atlantic Ocean between 45° and 50° west longitude. NATO III A launched Apr. 1976, and in Jan. 1977 NATO III B placed in orbit.
Dec. 11 Navstar 4 112A Atlas F	Objective: To support the Global Positioning System. Spacecraft: Irregular cylinder with four extended solar panels and complex of antennas. Weight: 433 kg.	20,314 20,266 722.3 63.2	Still in orbit.
Dec. 14 DSCS II-11 113A Titan IIC	Objective: Communications. Spacecraft: Not announced.	36,411 35,796 1,452.3 2.4	Still in orbit.
Dec. 14 DSCS II-12 113B Titan IIC	Objective: Communications. Spacecraft: Not announced.	36,415 36,262 1464.4 2.4	Still in orbit.
Dec. 16 Anik 4 (Telesat D) 116A Delta	Objective: To launch spacecraft into a highly elliptical orbit of sufficient accuracy to enable satellite to achieve geosynchronous orbit. Satellite to provide transmission of television, voice, and other data throughout Canada. Spacecraft: Box shaped with a length of 325.9 cm including antenna of 112 cm and a diameter of 217.4 cm. Weight at liftoff: 887 kg. Weight in orbit: 474 kg.	35,896 185 632.9 27.3	Launched successfully by NASA. Second generation satellite, fourth in a series orbited for Canada's Domestic Communications Satellite System. Replaces Anik A1 (Telesat A) launched Nov. 9, 1972. Anik 4 apogee boost motor fired Dec. 9, 1978. Satellite stationed at 109° west longitude, due south of California.

U.S. Applications Satellites 1974-1978

Date	Name	Launch Vehicle	Remarks
COMMUNICATIONS			
Jan. 19, 1974	Skynet 2A	Thor-Delta (TAT)	Launched for the United Kingdom in response to an agreement to augment the DSCS program. Spacecraft failed to achieve the proper orbit.
Apr. 13, 1974	Westar 1	Thor-Delta (TAT)	Launched for the Western Union Co. to establish a domestic communications link.
May 30, 1974	ATS 6	Titan IIIC	Multipurpose experimental satellite especially designed for regional services in North America and later India.
Oct. 10, 1974	Westar 2	Thor-Delta (TAT)	Launched for the Western Union Co. as part of their domestic communications links.
Nov. 21, 1974	Intelsat IV (F-8)	Atlas-Centaur	Sixth in high-capacity series. Positioned over Pacific.
Nov. 23, 1974	Skynet 2B	Thor-Delta (TAT)	Launched for the United Kingdom in response to an agreement to augment the DSCS program. Spacecraft positioned over Indian Ocean.
Dec. 19, 1974	Symphonie 1	Thor-Delta (TAT)	First of two experimental satellites for France and West Germany. Spacecraft positioned over Atlantic.
May 7, 1975	Anik 3 (Telesat 3)	Thor-Delta (TAT)	Launched for Canada.
May 22, 1975	Intelsat IV (F-1)	Atlas-Centaur	Eighth in high-capacity series. Positioned over Indian Ocean.
Aug. 27, 1975	Symphonie 2	Thor-Delta (TAT)	Launched for France and West Germany. Positioned over the Atlantic.
Sep. 26, 1975	Intelsat IV-A (F-1)	Atlas-Centaur	First of a new series double the capacity of its predecessors. Positioned over the Atlantic.
Dec. 13, 1975	RCA-Satcom-1	Thor-Delta (TAT)	Launched for RCA as first of their communications satellite series. Positioned over the Pacific.
Jan. 17, 1976	CTS 1	Thor-Delta (TAT)	Canadian-U.S., most powerful experimental satellite.
Jan. 30, 1976	Intelsat IV-A (F-2)	Thor-Delta (TAT)	Positioned over Atlantic.
Feb. 19, 1976	Marisat 1	Thor-Delta (TAT)	For maritime use by Comsat, over the Atlantic.
Mar. 15, 1976	LES 8/9	Titan IIIC	Experimental satellites with radioisotope power sources.
Mar. 26, 1976	RCA-Satcom 2	Thor-Delta (TAT)	Second of three.
Apr. 22, 1976	NATO IIIA	Thor-Delta (TAT)	First of new series.
May 13, 1976	Comstar 1	Atlas-Centaur	Placed over Pacific for AT&T by Comsat.
June 10, 1976	Marisat 2	Thor-Delta (TAT)	For maritime use by Comsat, over the Pacific.
July 8, 1976	Palapa 1	Thor-Delta (TAT)	Indonesian domestic communications.
July 22, 1976	Comstar 2	Thor-Delta (TAT)	Placed south of the United States for AT&T by Comsat.
Oct. 14, 1976	Marisat 3	Thor-Delta (TAT)	Placed over Indian Ocean.
Jan. 28, 1977	NATO IIIB	Thor-Delta (TAT)	Second of a new series.
Mar. 10, 1977	Palapa 2	Thor-Delta (TAT)	Indonesian domestic communications.
May 12, 1977	DSCS II-7,8	Titan IIIC	Defense communications.
May 26, 1977	Intelsat IV-A (F-4)	Atlas-Centaur	Positioned over Atlantic.
Aug. 25, 1977	Sirio	Thor-Delta (TAT)	Italian experiment.
Dec. 15, 1977	Sakura	Thor-Delta (TAT)	Japanese experiment.
Jan. 7, 1978	Intelsat IV-A (F-3)	Atlas-Centaur	Positioned over Indian Ocean.
Feb. 9, 1978	Fltsatcom 1	Atlas-Centaur	First of a new Defense series.
Mar. 5, 1978	Oscar 8	Thor-Delta (TAT)	Secondary payload with Landsat 3, replacement for Oscar 6 for amateur radio communications.
Mar. 31, 1978	Intelsat IV-A (F-6)	Atlas-Centaur	Positioned over Indian Ocean.
Apr. 7, 1978	BSE	Thor-Delta (TAT)	Japanese experimental direct-broadcast satellite for television; named Yuri; domestic satellite.
May 11, 1978	OTS 2	Thor-Delta (TAT)	European Space Agency experimental relay satellite; domestic satellite.
June 29, 1978	Comstar 3	Atlas-Centaur	Positioned south of U.S. over the equator by Comsat; domestic satellite.
Nov. 19, 1978	NATO IIIC	Thor-Delta (TAT)	Final one of this military series.
Dec. 14, 1978	DSCS II-11,12	Titan IIIC	Defense communications (dual launch).
Dec. 16, 1978	Anik 4 (Telesat D)	Thor-Delta (TAT)	Launched for Canada; domestic satellite.
WEATHER OBSERVATION*			
May 17, 1974	SMS 1	Thor-Delta (TAT)	First full-time weather satellite in synchronous orbit.
Nov. 15, 1974	Noaa 4 (ITOS-G)	Thor-Delta (TAT)	Second generation operational meteorological satellite.
Feb. 6, 1975	SMS 2	Thor-Delta (TAT)	Second full-time weather satellite in synchronous orbit.
June 12, 1975	Nimbus 6	Thor-Delta (TAT)	To build numerical models for Global Atmospheric Research Program.
Oct. 16, 1975	Goes 1	Thor-Delta (TAT)	First fully operational synchronous-orbit weather satellite.
July 29, 1976	Noaa 5 (ITOS-H)	Thor-Delta (TAT)	Second generation operational satellite.
June 16, 1977	Goes 2	Thor-Delta (TAT)	Second of this series.
July 14, 1977	Himawari	Thor-Delta (TAT)	Japanese geosynchronous satellite.
Nov. 23, 1977	Meteosat	Thor-Delta (TAT)	European Space Agency geosynchronous satellite.
May 1, 1978	AMS 3	Thor-Burner 2	A Defense meteorological satellite.
June 16, 1978	Goes 3	Thor-Delta (TAT)	Third of this series for NOAA.
Oct. 13, 1978	Tiros-N	Atlas F	First of a third generation for NOAA, also experimental satellite for NASA.
Oct. 24, 1978	Nimbus 7	Thor-Delta (TAT)	Last of this experimental series for NASA.

U.S. Applications Satellites 1974-1978

Date	Name	Launch Vehicle	Remarks
EARTH OBSERVATION			
Jan. 22, 1975	Landsat 2	Thor-Delta (TAT)	Second experimental Earth resources technology satellite. Acquired synoptic multi-spectral repetitive images that are proving useful in such disciplines as agriculture and forestry resources, mineral and land resources, land use, water resources, marine resources, mapping and charting, and the environment.
Mar. 5, 1978	Landsat 3	Thor-Delta (TAT)	Third experimental Earth-resources satellite.
Apr. 26, 1978	HCMM (AEM-1)	Scout	Experimental, low-cost, limited-function heat-capacity mapping mission for Earth resources.
June 27, 1978	Seasat 1	Atlas F	Proof-of-concept oceanographic-phenomena data-collection satellite.
GEODESY			
Apr. 9, 1975	Geos 3	Thor-Delta (TAT)	To measure geometry and topography of ocean surface.
May 4, 1976	Lageos	Thor-Delta (TAT)	Laser geodynamic satellite.
NAVIGATION			
Jul. 14, 1974	NTS 1	Atlas F	Navigation technology satellite.
Oct. 12, 1975	Tip 2	Scout	Transit Improvement Program.
Sep. 1, 1976	Tip 3	Scout	Transit Improvement Program.
June 23, 1977	NTS 2	Atlas F	Forerunner of Navstar Global Positioning System.
Oct. 28, 1977	Transit	Scout	Developmental model.
Feb. 22, 1978	Navstar 1	Atlas F	Global Positioning System satellite.
May 13, 1978	Navstar 2	Atlas F	Global Positioning System satellite.
Oct. 7, 1978	Navstar 3	Atlas F	Global Positioning System satellite.
Dec. 11, 1978	Navstar 4	Atlas F	Global Positioning System satellite.

* Does not include Department of Defense weather satellites which are not individually identified by launch.

U.S.-Launched Scientific Payloads 1974-1978

Date	Name	Launch Vehicle	Remarks
Feb. 18, 1974	San Marco 4	Scout	Diurnal variations in equatorial neutral atmosphere. (Italian payload and launch.)
Mar. 9, 1974	UK X-4 (Miranda)	Scout	Measure density of Sun-reflecting particles near the spacecraft, and test engineering systems. (United Kingdom payload.)
June 3, 1974	Hawkeye (Explorer 52)	Scout	Plasma properties of the magnetosphere over the north polar cap.
July 16, 1974	Aeros 2	Scout	Measure aeronomic parameters of upper atmosphere and solar UV. (German payload.)
Aug. 30, 1974	ANS	Scout	Study stellar UV and x-ray sources. (Netherlands payload.)
Oct. 15, 1974	Ariel 5	Scout	Study galactic and extragalactic x-ray sources. (United Kingdom payload.)
Nov. 15, 1974	Intasat	Thor-Delta (TAT)	Measure ionospheric total electron content, ionospheric irregularities and scintillation. (Spanish payload.)
May 7, 1975	SAS-C (Explorer 53)	Scout	Measure x-ray emission of discrete extragalactic sources. (Italian-launched.)
June 21, 1975	Oso 8	Thor-Delta (TAT)	To study minimum phase of solar cycle.
Aug. 9, 1975	COS-B	Thor-Delta	Extraterrestrial gamma radiation studies. (ESA European satellite.)
Oct. 6, 1975	Atmosphere (Explorer 54)	Thor-Delta	Photochemical processes in absorption of solar energy.
Nov. 20, 1975	Atmosphere (Explorer 55)	Thor-Delta	Photochemical processes in absorption of solar energy. Measure spatial distribution of ozone.
Mar. 15, 1976	Solrad HiA/HiB	Titan IIIC	Measure radiation and particles at close to 120,000 km circular.
May 22, 1976	P-76-5	Scout	Plasma effects on radar and communications.
July 8, 1976	SESP 74-2	Titan IIID	Particle measurements up to 8000 km.
Apr. 20, 1977	Geos	Thor-Delta (TAT)	European Space Agency, study of magnetic and electric fields from geosynchronous orbit (not attained).
Aug. 12, 1977	HEAO 1	Atlas-Centaur	X-ray and gamma ray astronomy.
Oct. 22, 1977	ISEE 1, 2	Thor-Delta (TAT)	Magnetosphere and solar wind measurements (for NASA and European Space Agency respectively).
Jan. 26, 1978	IUE	Thor-Delta (TAT)	Ultraviolet observation of astronomical phenomena, in elliptical geosynchronous orbit.
July 14, 1978	Geos 2	Thor-Delta (TAT)	European studies of magnetosphere, in geosynchronous orbit.
Aug. 12, 1978	ISEE 3	Thor-Delta (TAT)	International Sun-Earth Explorer, in halo orbit near Earth-Sun libration point.
Oct. 24, 1978	Cameo	Thor-Delta (TAT)	Barium and lithium cloud experiments, carried in rocket body of Nimbus 7 launcher.
Nov. 13, 1978	HEAO 2	Atlas-Centaur	High-resolution observations of astronomical x-ray sources.

U.S.-Launched Space Probes 1974-1978

Date	Name	Launch Vehicle	Remarks
Dec. 10, 1974	Helios 1	Titan IIIE-Centaur	Flew in highly elliptic orbit to within 44 million km of the Sun, measuring solar wind, corona, electrons, and cosmic rays. Payload had 7 West German experiments, 3 U.S.
Aug. 20, 1975	Viking 1	Titan IIIE-Centaur	Lander descended, landed safely on Mars on Plains of Chryse, while Orbiter circled the 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.
Sep. 9, 1975	Viking 2	Titan IIIE-Centaur	Lander descended, landed safely on Mars on Plains of Utopia, while Orbiter circled the planet photographing it and relaying all data to Earth. Lander photographed its surroundings, tested soil samples for signs of life, and took measurements of the atmosphere.
Jan. 15, 1976	Helios 2	Titan IIIE-Centaur	Flew in highly elliptical orbit to within 41 million km of the Sun, measuring solar wind, corona, electrons, and cosmic rays. Payload had same West German and U.S. experiments as Helios 1 plus a cosmic-ray burst detector.
Aug. 20, 1977	Voyager 2	Titan IIIE-Centaur	Jupiter and Saturn flyby mission. Was to swing around Jupiter in July 1979 and arrive at Saturn in 1981, possibly going on to Uranus by 1986.
Sep. 5, 1977	Voyager 1	Titan IIIE-Centaur	Jupiter and Saturn flyby mission. Passing Voyager 2 on the way, was to swing around Jupiter in Mar. 1979 and arrive at Saturn in Nov. 1980.
May 20, 1978	Pioneer Venus 1	Atlas-Centaur	Venus orbiter; achieved Venus orbit Dec. 4, returning imagery and data.
Aug. 8, 1978	Pioneer Venus 2	Atlas-Centaur	Carried 1 large, 3 small probes plus spacecraft bus; all descended through Venus atmosphere Dec. 9, returned data.

History of U.S. and Soviet Manned Space Flights

Spacecraft	Launch Date	Crew	Flight time	Highlights
Vostok 1	Apr. 12, 1961	Yuri A. Gagarin	1 h 48 min.	First manned flight.
Mercury-Redstone 3	May 5, 1961	Alan B. Shepard, Jr.	15 min	First U.S. flight; suborbital.
Mercury-Redstone 4	July 21, 1961	Virgil I. Grissom	16 min.	Suborbital; capsule sank after landing.
Vostok 2	Aug. 6, 1961	Gherman E. Titov	25 h 18 min.	First flight exceeding 24 h.
Mercury-Atlas 6	Feb. 20, 1962	John H. Glenn, Jr.	4 h 55 min.	First American to orbit.
Mercury-Atlas 7	May 24, 1962	M. Scott Carpenter	4 h 56 min.	Landed 400 km beyond target.
Vostok 3	Aug. 11, 1962	Andrian G. Nikolayev	94 h 22 min.	First dual mission (with Vostok 4).
Vostok 4	Aug. 12, 1962	Pavel R. Popovich	70 h 57 min.	Came within 6 km of Vostok 3.
Mercury-Atlas 8	Oct. 3, 1962	Walter M. Schirra, Jr.	9 h 13 min.	Landed 8 km from target.
Mercury-Atlas 9	May 15, 1963	L. Gordon Cooper, Jr.	34 h 20 min.	First U.S. flight exceeding 24 h.
Vostok 5	June 14, 1963	Valery F. Bykovsky	119 h 6 min.	Second dual mission (with Vostok 6).
Vostok 6	June 16, 1963	Valentina V. Tereshkova	70 h 50 min.	First woman in space; within 5-km of Vostok 5.
Voskhod 1	Oct. 12, 1964	Vladimir M. Komarov Konstantin P. Feoktistov Dr. Boris G. Yegorov	24 h 17 min.	First 3-man crew.
Voskhod 2	Mar. 18, 1965	Aleksei A. Leonov Pavel I. Belyayev	26 h 2 min.	First extravehicular activity (Leonov, 10 min).
Gemini 3	Mar. 23, 1965	Virgil I. Grissom John W. Young	4 h 53 min.	First U.S. 2-man flight; first manual maneuvers in orbit.
Gemini 4	June 3, 1965	James A. McDivitt Edward H. White, II	97 h 56 min.	21-min. extravehicular activity (White).
Gemini 5	Aug. 21, 1965	L. Gordon Cooper, Jr. Charles Conrad, Jr.	190 h 55 min.	Longest-duration manned flight to date.
Gemini 7	Dec. 4, 1965	Frank Borman James A. Lovell, Jr.	330 h 35 min.	Longest-duration manned flight to date.
Gemini 6-A	Dec. 15, 1965	Walter M. Schirra, Jr. Thomas P. Stafford	25 h 51 min.	Rendezvous within 0.3 m of Gemini 7.
Gemini 8	Mar. 16, 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	June 3, 1966	Thomas P. Stafford Eugene A. Cernan	72 h 21 min.	Extravehicular activity; rendezvous.
Gemini 10	July 18, 1966	John W. Young Michael Collins	70 h 47 min.	First dual rendezvous (Gemini 10 with Agena 10, then Agena 8).
Gemini 11	Sept. 12, 1966	Charles Conrad, Jr. Richard F. Gordon, Jr.	71 h 17 min.	First initial rendezvous; first tethered flight; highest Earth-orbit altitude (1372 km).
Gemini 12	Nov. 11, 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	Apr. 23, 1967	Vladimir M. Komarov	26 h 37 min.	Cosmonaut killed in reentry accident.
Apollo 7	Oct. 11, 1968	Walter M. Schirra, Jr. Donn F. Eisele R. Walter Cunningham	260 h 9 min.	First U.S. 3-man mission.
Soyuz 3	Oct. 26, 1968	Georgi Beregovoy	94 h 51 min.	Maneuvered near unmanned Soyuz 2.
Apollo 8	Dec. 21, 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	Jan. 14, 1969	Vladimir Shatalov	71 h 23 min.	Soyuz 4 and 5 docked and transferred 2 cosmonauts from Soyuz 5 to Soyuz 4.
Soyuz 5	Jan. 15, 1969	Boris Volynov Aleksey Yeliseyev Yevgeniy Khrunov	72 h 56 min.	
Apollo 9	Mar. 3, 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 take-off from lunar surface and rejoining with command module.
Apollo 10	May 18, 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	July 16, 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	Oct. 11, 1969	Georgiy Shonin Valeriy 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	Oct. 12, 1969	Anatoliy Filipchenko Vladislav Volkov Viktor Gorbato	118 h 41 min.	
Soyuz 8	Oct. 13, 1969	Vladimir Shatalov Aleksey Yeliseyev	118 h 50 min.	

History of U.S. and Soviet Manned Space Flights

Spacecraft	Launch Date	Crew	Flight time	Highlights
Apollo 12	Nov. 14, 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 III spacecraft which landed in Ocean of Storms on Apr. 19, 1967.
Apollo 13	Apr. 11, 1970	James A. Lovell, Jr. Fred W. Haise, Jr. John L. Swigert, Jr.	142 h 55 min.	Mission aborted due to explosion in the service module. Ship circled Moon, with crew using LEM as "lifeboat" until just prior to reentry.
Soyuz 9	June 1, 1970	Andrian G. Nikolayev Vitaliy I. Sevastianov	424 h 59 min.	Longest manned space flight to date, lasting 17 days 16 h 59 min.
Apollo 14	Jan. 31, 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	Apr. 22, 1971	Vladimir Shatalov Aleksy Yeliseyev Nikolai Rukavishnikov	47 h 46 min.	Docked with Salyut 1, but crew did not board space station launched Apr. 19. Crew recovered Apr. 24, 1971.
Soyuz 11	June 6, 1971	Georgiy Timofeyevich Dobrovolskiy Vladislav Nikolayevich Volkov	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 June 30, 1971.
Apollo 15	July 26, 1971	Viktor Ivanovich Patsayev David R. Scott Alfred M. Worden James Bensen Irwin	295 h 12 min.	Fourth manned lunar landing and first Apollo "J" series mission which carry the Lunar Roving Vehicle. Worden's in-flight EVA of 38 min 12 s was performed during return trip.
Apollo 16	Apr. 16, 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	Dec. 7, 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	May 25, 1973	Charles Conrad, Jr. Joseph P. Kerwin Paul J. Weitz	627 h 50 min.	Docked with Skylab 1 for 28 days. Repaired damaged station.
Skylab 3	July 28, 1973	Alan L. Bean Jack R. Lousma Owen K. Garriott	1427 h 9 min.	Docked with Skylab 1 for over 59 days.
Soyuz 12	Sept. 27, 1973	Vasiliy Lazarev Oleg Makarov	47 h 16 min.	Checkout of improved Soyuz.
Skylab 4	Nov. 16, 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	Dec. 18, 1973	Petr Klimuk Valentin Lebedev	188 h 55 min.	Astrophysical, biological, and Earth resources experiments.
Soyuz 14	July 3, 1974	Pavel Popovich Yuriy Artyukhin	377 h 30 min.	Docked with Salyut 3 and Soyuz 14 crew occupied space station for over 14 days.
Soyuz 15	Aug. 26, 1974	Gennadiy Sarafanov Lev Demin	48 h 12 min.	Rendezvoused but did not dock with Salyut 3.
Soyuz 16	Dec. 2, 1974	Anatoliy Filipchenko Nikolai Rukavishnikov	142 h 24 min.	Test of ASTP configuration.
Soyuz 17	Jan. 10, 1975	Aleksy Gubarev Georgiy Grechko	709 h 20 min.	Docked with Salyut 4 and occupied station during a 29-day flight.
Anomaly	Apr. 5, 1975	Vasiley Lazarev Oleg Makarov	20 min.	Soyuz stages failed to separate; crew recovered after abort.
Soyuz 18	May 24, 1975	Petr Klimuk Vitaliy Sevastianov	1511 h 20 min.	Docked with Salyut 4 and occupied station during a 63-day mission.
Soyuz 19	July 15, 1975	Aleksy Leonov Valeriy Kubasov	142 h 31 min.	Target for Apollo in docking and joint experiments ASTP mission.
Apollo	July 15, 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	July 6, 1976	Boris Volynov Vitaliy Zholobov	1182 h 24 min.	Docked with Salyut 5 and occupied station during 49-day flight.
Soyuz 22	Sept. 15, 1976	Valeriy Bykovskiy Vladimir Aksenov	189 h 54 min.	Earth resources study with multispectral camera system.
Soyuz 23	Oct. 14, 1976	Vyacheslav Zudov Valeriy Rozhdestvenskiy	48 h 6 min.	Failed to dock with Salyut 5.
Soyuz 24	Feb. 7, 1977	Viktor Gorbato Yuriy Glazkov	425 h 23 min.	Docked with Salyut 5 and occupied station during 18-day flight.

History of U.S. and Soviet Manned Space Flights

Spacecraft	Launch Date	Crew	Flight time	Highlights
Soyuz 25	Oct. 9, 1977	Vladimir Kovalenok Valeriy Ryumin	48 h 46 min.	Failed to achieve hard dock with Salyut 6 station.
Soyuz 26	Dec. 10, 1977	Yuriy Romanenko Georgiy Grecho	898 h 6 min.	Docked with Salyut 6. Crew returned in Soyuz 27; crew duration 2314 h.
Soyuz 27	Jan. 10, 1978	Vladimir Dzhaniybekov Oleg Makarov	1514 h.	Docked with Salyut 6. Crew returned in Soyuz 26; crew duration 142 h 59 min.
Soyuz 28	Mar. 2, 1978	Aleksey Gubarov Vladimir Remek	190 h 17 min.	Docked with Salyut 6. Remek was 1st Czech cosmonaut to orbit.
Soyuz 29	June 15, 1978	Vladimir Kovalenok Aleksandr Ivanchenkov	1911 h 23 min.	Docked with Salyut 6. Crew returned in Soyuz 31; crew duration 3350 h 48 min.
Soyuz 30	June 27, 1978	Petr Klimuk Miroslaw Heraszewski	190 h 4 min.	Docked with Salyut 6. Heraszewski was 1st Polish cosmonaut to orbit.
Soyuz 31	Aug. 26, 1978	Valeriy Bykovskiy Sigmund Jähn	1628 h 14 min.	Docked with Salyut 6. Crew returned in Soyuz 29; crew duration 188 h 49 min. Jähn was 1st German Democratic Republic cosmonaut to orbit.

U.S. Space Launch Vehicles

Vehicle	Stages	Propellant ³	Thrust (in kilo- newtons)	Max. dia. (m)	Max. Payload (kg)			First launch
					Height (m)	555-km orbit	Escape	
Scout	1. Algol IIIA	Solid	481.7	1.12	21.95	186 ⁴	38.6 ⁴	1972(60) ¹
	2. Castor IIA	Solid	281.1					
	3. Antares IIB	Solid	126.8					
	4. Altair III	Solid	26.9					
Thor-Delta 2900 series	1. Thor plus 9 TMX 354-5	LOX/RP-1 Solid	911.9 694.2 ⁵	2.44	35.36	1769 ⁴	476 ⁴	1973(60) ¹
	2. Delta (DSV-3)	N ₂ O ₄ /Aerozine	46.8					
	3. TE 364-4	Solid	61.9					
Atlas F/TE 364-4	1. Atlas booster & sustainer	LOX/RP-1	1970.6	3.05	25.91	1497 ⁴		1977(60) ¹
	2. TE 364-4	Solid	61.9					
Atlas-Agena	1. Atlas booster & (SLV/3A)	LOX/RP-1	2237.5	3.05	40.54	2720 ⁴	454 ⁴	1968(60) ¹
	2. Agena	IRFNA/UDMH.	71.2					
Titan IIB-Agena	1. LR-87	N ₂ O ₄ /Aerozine	2353.1	3.05	48.46	3629 ⁵		1966
	2. LR-91	N ₂ O ₄ /Aerozine	444.8					
	3. Agena	IRFNA/UDMH.	71.2					
Titan IIC	1. Two 5-segment	Solid	11,565.4	3.05	40.54	—	1461 ⁷	1965
	2. LR-87	N ₂ O ₄ /Aerozine	2353.1					
	3. LR-91	N ₂ O ₄ /Aerozine	444.8	3.05				
	4. Transtage	N ₂ O ₄ /Aerozine	71.2					
Titan III(23)D	1. Two 5-segment	Solid	11,565.4	3.05	46.94	11,113 ⁸		1971
	2. LR-87	N ₂ O ₄ /Aerozine	2353.1					
	3. LR-91	N ₂ O ₄ /Aerozine	444.8					
Titan III(34)D	1. Two 5½-segment	Solid	13,540.4	3.05	49.36	12,564 ⁸		1981
	2. LR-87	N ₂ O ₄ /Aerozine	2353.1					
	3. LR-91	N ₂ O ₄ /Aerozine	444.8					
Titan III(34)D/IUS	1. Two 5½-segment	Solid	13,540.4	3.05	48.00	1909 ⁹	1909 ⁹	1980
	2. LR-87	N ₂ O ₄ /Aerozine	2353.1					
	3. LR-91	N ₂ O 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 ¹⁰		1976(66) ¹
	2. TE 364-4	Solid	61.9					
	3. TE 364-15	Solid	44.5					
Thor SLV-2A/Block 5D-2	1. Thor plus 3 TX 354-5	LOX/RP-1 Solid	756.2 689.5 ⁵	2.44	24.23	653 ¹⁰		1980(63) ¹
	2. TE 364-4	Solid	61.9					
	3. TE 364-15	Solid	44.5					

¹ The date of first launch applies to this latest modification with a date in parentheses for the initial version.

² Set of 3.

³ 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/N₂H₄-N₂O₄/Aerozine; Liquid Oxygen and Liquid Hydrogen—LOX/LH.

⁴ Due east launch.

⁵ Polar launch.

⁶ Polar 185 km (nominal).

⁷ Synchronous equatorial (nominal).

⁸ Polar 185 km (current estimate).

⁹ Synchronous equatorial (current estimate).

¹⁰ Polar 833 km (from WTR).

Space Activities of the U.S. Government

22-YEAR BUDGET SUMMARY—BUDGET AUTHORITY
(In millions of dollars)

	NASA		Defense	Energy	Com- merce	Interior	Agricul- ture	NSF	Total Space
	Total	Space ¹							
1959	330.9	260.9	489.5	34.3	...	...	...	...	784.7
1960	523.6	461.5	560.9	43.3	...	...	...	.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	3294.6
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	6741.5
1968	4587.3	4430.0	1921.8	145.1	28.1	.2	.5	3.2	6551.4
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	4824.8
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. ²	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 Est.	4561.9	4032.5	3250.4	38.2	104.0	9.9	8.2	2.4	7445.6
1980 Est.	4723.0	4166.1	4023.4	34.1	99.7	11.6	13.1	2.4	8350.4

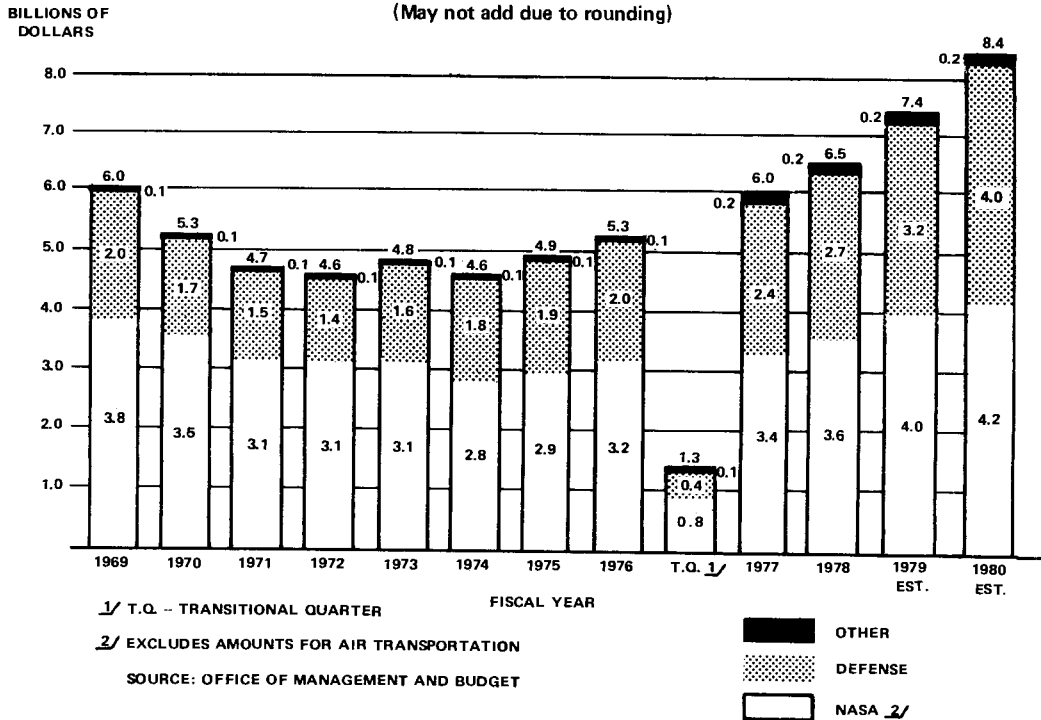
¹ Excludes amounts for air transportation.

² T.Q.—Transitional Quarter.

Source: Office of Management and Budget.

U.S. Space Budget - Budget Authority 1969-1980

(May not add due to rounding)



Space Activities Budget

(In millions of dollars)

	Budget Authority			Outlays		
	1978 Actual	1979 Est.	1980 Est.	1978 Actual	1979 Est.	1980 Est.
Federal space programs:						
NASA ¹	3622.9	4032.5	4166.1	3582.4	3925.8	4053.8
Defense	2728.8	3250.4	4023.4	2457.0	2998.5	3463.3
Energy	34.4	38.2	34.1	28.6	36.4	37.6
Commerce	102.8	104.0	99.7	100.7	101.9	97.7
Interior	9.7	9.9	11.6	9.4	9.5	11.1
NSF	2.4	2.4	2.4	2.4	2.4	2.4
Agriculture	7.7	8.2	13.1	7.7	8.2	13.1
Total	6508.7	7445.6	8350.4	6188.2	7082.7	7679.0
NASA:						
Space flight	2192.4	2423.5	2332.1	2260.0	2370.6	2339.0
Space science, applications, & technology	1065.0	1227.3	1400.8	971.8	1169.7	1309.7
Air transportation	437.2	529.4	556.9	397.6	475.5	539.2
Supporting operations	369.1	383.6	435.2	354.2	387.4	407.1
Less receipts	-3.6	-1.9	-2.0	-3.6	-1.9	-2.0
Total NASA	4060.1	4561.9	4723.0	3980.0	4401.3	4593.0

¹ Excludes amounts for air transportation.

Source: Office of Management and Budget.

Aeronautics Budget

(In millions of dollars)

	Budget Authority		
	1978 Actual	1979 Est.	1980 Est.
Federal aeronautics programs:			
NASA ¹	437.2	529.4	556.9
Department of Defense ²	2806.6	2267.3	2083.0
Department of Transportation ³	94.4	94.4	92.6
Total	3338.2	2891.1	2732.5

¹ Research and Development, Construction of Facilities, Research and Program Management.² Research, Development, Testing, and Evaluation of aircraft and related equipment.³ Federal Aviation Administration Research and Development.

Source: Office of Management and Budget.

The White House Fact Sheets

June 20, 1978

U.S. National Space Policy

The President directed under a Presidential review memorandum that the NSC Policy Review Committee (PRC) thoroughly review existing policy and formulate overall principles which should guide our space activities. The major concerns that prompted this review arose from growing interaction among our various space activities.

This review examined and the resultant Presidential directive establishes:

- A Government policy oversight system to review and revise space policy as needed;
- Ground rules for the balance and interaction among our space programs to ensure achievement of the interrelated national security, economic, political, and arms limitation goals of the United States; and
- Modifications to existing policies, the appropriate extent of the overlapping technology, and product dissemination by the sectors.

This Presidential directive establishes an NSC Policy Review Committee to provide a forum to all Federal agencies for their policy views, to advise on proposed changes to national space policy, to resolve issues referred to the Committee, and to provide for rapid referral of issues to the President for decision as necessary. This Committee will be chaired by the Director of the Office of Science and Technology Policy, Frank Press. Recognizing that the civilian space program is at the threshold of change, the President has asked the PRC to assess the needs and aspirations of the Nation's civil space program. The United States has built a broad national base in space and aeronautics. At issue is how best to capitalize on prior investments and set the needed direction and purpose for continued vitality in the future.

Under the Presidential review memorandum the emphasis was to resolve potential conflicts among the various space program sectors and to recommend coherent space principles and national space policy. In focusing upon these issues, the Policy Review Committee concluded that our current direction set forth in the Space Act of 1958 is well founded and that the preponderance of existing problems was related to interactions and resultant stresses among the various space programs. For this reason, the classified portion of the recently signed Presidential directive concentrates on overlap questions. It does not deal in detail with the long-term objectives of our defense, commercial, and civil programs. Determining our civil space policy, outlined above, will be the next step.

As a result of this in-depth review, the President's directive establishes national policies to guide the conduct of United States activities in and related to space programs. The objectives are (1) to advance the interests of the United States through the exploration and use of space and (2) to cooperate with other nations in maintaining the freedom of space for all activities which enhance the security and welfare of mankind. The space principles set forth in this directive are:

- The United States will pursue space activities to increase scientific knowledge, develop useful commercial and Government applications of space technology, and maintain United States leadership in space technology.
- The United States is committed to the principles of the exploration and use of outer space by all nations for peaceful purposes and for the benefit of all mankind.
- The United States is committed to the exploration and use of outer space in support of its national well-being.

—The United States rejects any claims to sovereignty over outer space or over celestial bodies, or any portion thereof, and rejects any limitations on the fundamental right to acquire data from space.

—The United States holds that the space systems of any nation are national property and have the right of passage through and operations in space without interference. Purposeful interference with space systems shall be viewed as an infringement upon sovereign rights.

—The United States will pursue activities in space in support of its right of self-defense and thereby strengthen national security, the deterrence of attack, and arms control agreements.

—The United States will conduct international cooperative space activities that are beneficial to the United States scientifically, politically, economically, and/or militarily.

—The United States will develop and operate on a global basis active and passive remote sensing operations in support of national objectives.

—The United States will maintain current responsibility and management relationships among the various space programs, and, as such, close coordination and information exchange will be maintained among the space sectors to avoid unnecessary duplication and to allow maximum cross-utilization of all capabilities.

Our civil space programs will be conducted to increase the body of scientific knowledge about the Earth and the universe; to develop and operate civil applications of space technology; to maintain United States leadership in space science, applications, and technology; and to further United States domestic and foreign policy objectives within the following guidelines:

—The United States will encourage domestic commercial exploitation of space capabilities and systems for economic benefit and to promote the technological position of the United States; however, all United States Earth-oriented remote sensing satellites will require United States Government authorization and supervision or regulation.

—Advances in Earth imaging from space will be permitted under controls and when such needs are justified and assessed in relation to civil benefits, national security, and foreign policy. Controls, as appropriate, on other forms of remote Earth sensing will be established.

—Data and results from the civil space programs will be provided the widest practical dissemination to improve the condition of human beings on Earth and to provide improved space services for the United States and other nations of the world.

—The United States will develop, manage, and operate a fully operational Space Transportation System (STS) through NASA, in cooperation with the Department of Defense. The STS will service all authorized space users—domestic and foreign, commercial and governmental—and will provide launch priority and necessary security to national security missions while recognizing the essentially open character of the civil space program.

Our national security related space programs will conduct those activities in space which are necessary to our support of such functions as command and control, communications, navigation, environmental monitoring, warning and surveillance, and space defense, as well as to support the formulation and execution of national policies; and to support the planning for and conduct of military operations. These programs will be conducted within the following guidelines:

—Security, including dissemination of data, shall be conducted in accordance with Executive orders and applicable directives for protection of national security information. Space-related products and technology shall be afforded lower or no classification where possible to permit wider use of our total national space capability.

—The Secretary of Defense will establish a program for identifying and integrating, as appropriate, civil and commercial resources into military operations during national emergencies declared by the President.

—Survivability of space systems will be pursued commensurate with the planned need in crisis and war and the availability of other assets to perform the mission. Identified deficiencies will be eliminated, and an aggressive, long-term program will be applied to provide more assured survivability through evolutionary changes to space systems.

—The United States finds itself under increasing pressure to field an anti-satellite capability of its own in response to Soviet activities in this area. By exercising mutual restraint, the United States and the Soviet Union have an opportunity at this early juncture to stop an unhealthy arms competition in space before the competition develops a momentum of its own. The two countries have commenced bilateral discussions on limiting certain activities directed against space objects, which we anticipate will be consistent with the overall U.S. goal of maintaining any nation's right of passage through and operations in space without interference.

—While the United States seeks verifiable, comprehensive limits on antisatellite capabilities and use, in the absence of such an agreement, the United States will vigorously pursue development of its own capabilities. The U.S. space defense program shall include an integrated attack warning, notification, verification, and contingency reaction capability which can effectively detect and react to threats to U.S. space systems.

October 11, 1978

U.S. Civil Space Policy

The President announced today a space policy that will set the direction of U.S. efforts in space over the next decade. The policy is the result of a four-month interagency review requested by the President in June 1978. American civil space policy will be centered around three tenets:

First: Our space policy will reflect a balanced strategy of applications, science and technology development containing essential key elements that will:

—Emphasize space applications that will bring important benefits to our understanding of earth resources, climate, weather, pollution and agriculture, and provide for the private sector to take an increasing responsibility in remote sensing and other applications.

—Emphasize space science and exploration in a manner that retains the challenge and excitement and permits the nation to retain the vitality of its space technology base, yet provides short-term flexibility to impose fiscal constraints when conditions warrant.

—Take advantage of the flexibility of the space shuttle to reduce the cost of operating in space over the next two decades to meet national needs.

—Increase benefits for resources expended through better integration and technology transfer among the national space programs and through more joint projects when appropriate, thereby increasing the return on the \$100 billion investment in space to the benefit of the American people.

—Assure American scientific and technological leadership in space for the security and welfare of the nation and continue R&D necessary to provide the basis for later programmatic decisions.

—Demonstrate advanced technological capabilities in open and imaginative ways having benefit for developing as well as developed countries.

—Foster space cooperation with nations by conducting joint programs.

—Confirm our support of the continued development of a legal regime for space that will assure its safe and peaceful use for the benefit of mankind.

Second: More and more, space is becoming a place to work—an extension of our environment. In the future, activities will be pursued in space when it appears that national objectives can most efficiently be met through space activities.

Third: It is neither feasible nor necessary at this time to commit the United States to a high-challenge space engineering initiative comparable to Apollo. As the resources and manpower requirements for shuttle development phase down, we will have the flexibility to give greater attention to new space applications and exploration, continue programs at present levels or contract them. To meet the objectives specified above, an adequate Federal budget commitment will be made.

Space Applications

As a part of his overall review and in accordance with his desire to increase emphasis on uses of space for a wide variety of practical and economic benefits the President made the following decisions:

Remote Sensing Systems. Since 1972 the United States has conducted experimental civil remote sensing through Landsat satellites. There are many successful applications and users, including Federal departments, other nations, a number of states, and a growing number of commercial organizations. The United States will continue to provide data from the developmental Landsat program for all classes of users. Operational uses of data from the experimental system will continue to be made by public, private, and international users. Specific details and configurations of the Landsat system and its management and organizational factors will evolve over the next several years to arrive at the appropriate technology mix, test organizational arrangements, and develop the potential to involve the private sector.

Integrated Remote Sensing System. A comprehensive plan covering expected technical, programmatic, private sector, and institutional arrangements for remote sensing will be explored. NASA will chair an interagency task force to examine options for integrating current and future systems into an integrated national system. Emphasis will be placed on defining and meeting user requirements. This task force will complete its review prior to the FY 1981 budget cycle.

Weather Satellites. Separate operational requirements for meteorological data over the past two decades have led to separate Defense and Commerce's National Oceanic and Atmospheric Administration (NOAA) weather satellites. The Defense community, NASA, and NOAA will conduct a review of meteorological satellite programs to determine the degree to which these programs might be consolidated in the 1980s and the extent to which separate programs supporting specialized defense needs should be maintained. The possibility of integrated systems for ocean observations from space will also be examined.

The Private Sector. Along with other appropriate agencies, NASA and Commerce will prepare a plan of action on how to encourage private investment and direct participation in civil remote sensing systems. NASA and Commerce will be the contacts for the private sector on this matter and will analyze proposals received before submitting to the Policy Review Committee (Space) for consideration and action.

Communications Satellite R&D. United States leadership in communications satellite systems will be supported by NASA. Selected technological opportunities to provide better frequency and orbit utilization and other long-term opportunities will be pursued.

Communications Satellite Services. Some areas of communications services—such as educational and health services and basic communications services for remote areas—involve low-volume and intermittent use and have evidenced little interest from commercial satellite operators. The Department of Commerce's National Telecommunications and Information Administration (NTIA) will assist in market aggregation, technology transfer, and possible development of

domestic and international public satellite services. This direction is intended to stimulate the aggregation of the public service market drawing on the technology that is already in existence. The Agency for International Development and Interior will work with NTIA in translating domestic experience in public service programs into potential programs for lesser-developed countries and the remote territories.

Future Applications and Economic Activity. It is too early to make a commitment to the development of a satellite solar power station or space manufacturing facility due to the uncertainty of the technology and economic cost-benefits and environmental concerns. There are, however, very useful intermediate steps that will allow the development and testing of key technologies and experience in space industrial operations to be gained. The United States will pursue an evolutionary program that is directed toward assessing new options which will be reviewed periodically by the Policy Review Committee (Space). The evolutionary program will stress science and basic technology—integrated with a complementary ground R&D program—and will continue to evaluate the relative costs and benefits of proposed activities.

Space Science and Exploration

The President reviewed the space science and planetary exploration program and determined that the United States' priorities at any given time will depend on the promise of the science, the availability of the particular technology, and the budgetary situation. The United States will maintain a position of leadership in space science and planetary exploration and will:

- Continue a vigorous program of planetary exploration to understand the origin and evolution of the solar system. The goal in the years ahead is to continue the reconnaissance of the outer planets and to conduct more detailed exploration of Saturn, its moons, and its rings; to continue comparative studies of the neighboring planets, Venus and Mars; and to conduct reconnaissance of comets and asteroids.
- Utilize the space telescope and free-flying satellites to usher in a new era of astronomy, as we explore interstellar molecules, quasars, pulsars, and black holes to expand our understanding of the universe.
- Develop a better understanding of the sun and its interaction with the terrestrial environment through space systems—such as the Solar Maximum Mission and the Solar Polar Mission—that will journey towards the sun and earth-orbiting satellites that will measure the variation in solar output and determine the resultant response of the earth's atmosphere.
- Utilize the space shuttle and spacelab, alone and in cooperation with other nations, to conduct basic research that complements earth-based life science investigations and human physiology research.

Our policy in international space cooperation will include two basic elements: (1) to pursue the best science available regardless of national origin and expand our international planning and coordinating effort; and (2) to seek cooperative support for experiments-spacecraft which have been chosen on sound scientific criteria.

Increased Benefit for Resources Expended

As a result of the President's review, decisions were made that will increase the benefit to the United States for resources expended.

Strategy to Utilize the Shuttle. The Administration will make incremental improvements in the shuttle transportation system as they become necessary. Decisions on extending the shuttle's stay time in orbit and future upper stage capabilities (e.g., the reusable space tug and orbital transfer vehicle) will be examined in the context of our emerging space policy goals. An interagency task force will make recommendations on what future capabilities are needed. This task

force will submit the findings to the Policy Review Committee (Space) prior to the FY 1981 budget cycle.

Technology Sharing. The Policy Review Committee (Space) will take steps to enhance technology transfer between the space sectors. The objective will be to maximize efficient utilization of the sectors while maintaining necessary security and current management relationships.

BACKGROUND

Early in his Administration, the President directed a National Security Council review of space policy. The emphasis was on coherent space principles and national space policy and did not deal in detail with the long-term objectives of our defense, commercial, and civil programs. The review, completed in May 1978, resulted in a Presidential Directive that set the basic framework for our civil space policy completed last week. The President's May 1978 directive established a Policy Review Committee (Space) to provide a forum for all Federal agencies in which to advise on proposed changes to national space policy and to provide for rapid referral of issues to the President for decision. This Committee is chaired by the Director of the Office of Science and Technology Policy, Frank Press. In June 1978 the President directed the Policy Review Committee (Space) to assess the future needs of the nation's civil space program, and their report formed the basis for the policy decisions outlined here. The following agencies and departments participated: The National Aeronautics and Space Administration, Commerce, Interior, Agriculture, Energy, State, National Science Foundation, Agency for International Development, Defense, Director of Central Intelligence, Joint Chiefs of Staff, and Arms Control and Disarmament Agency, as well as the Domestic Policy Staff, the National Security Council Staff, and the Office of Management and Budget.