

# **Aeronautics and Space Report of the President**

*1977 Activities*

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# Aeronautics and Space Report of the President

*1977 Activities*



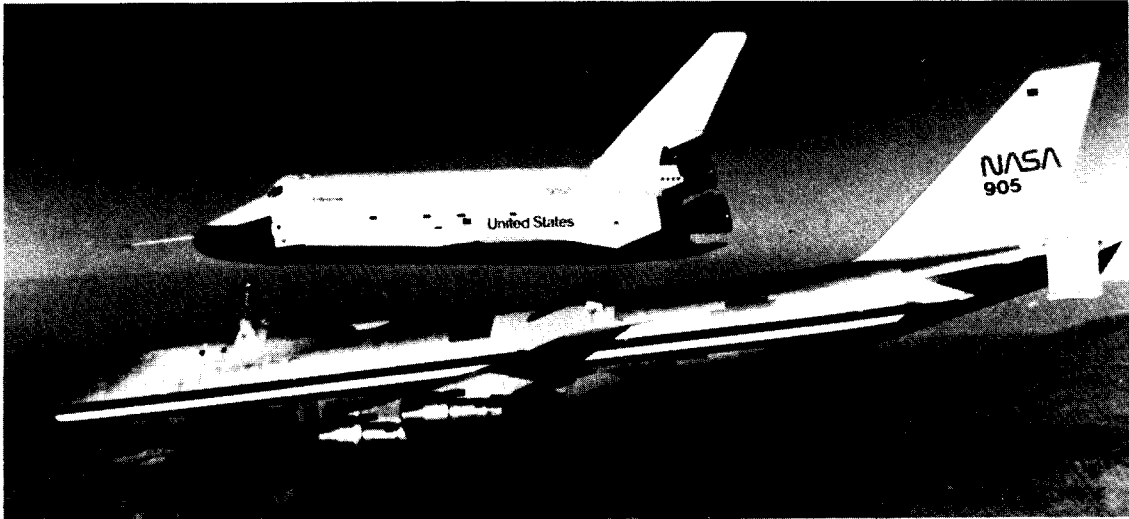
**National Aeronautics and Space Administration  
Washington, D.C. 20546**

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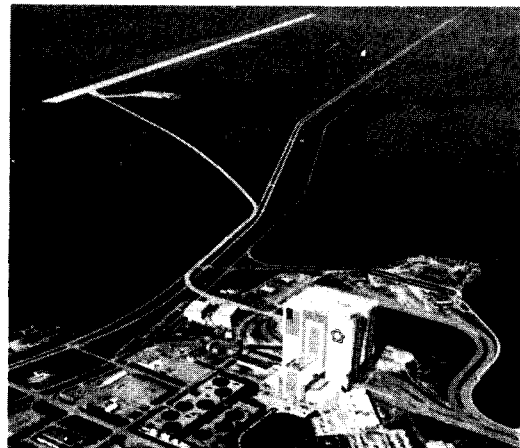
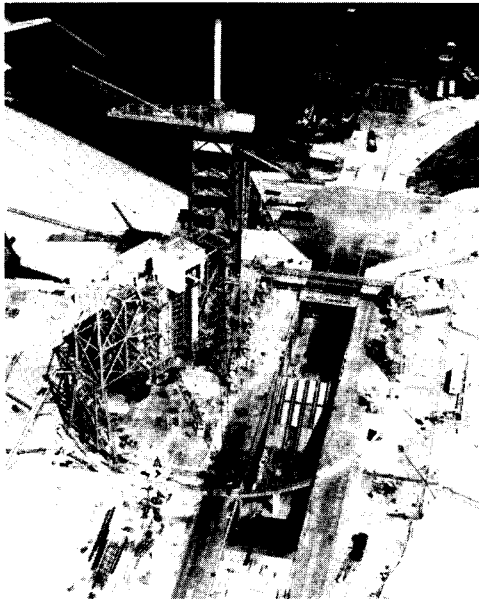
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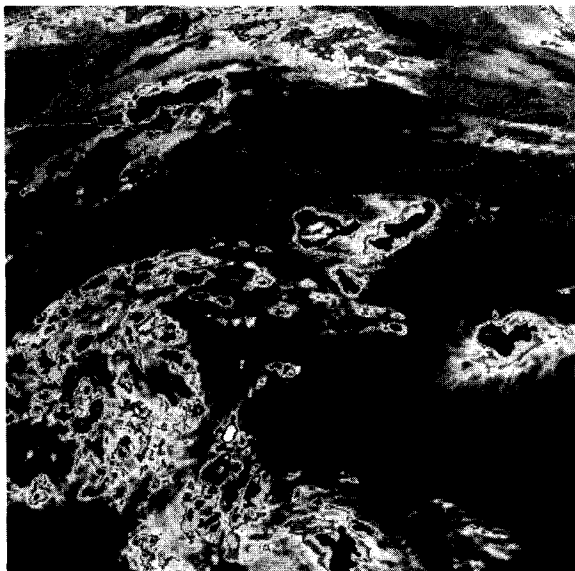
## Aerospace Events of 1977

The United States in 1977 conducted the successful approach and landing tests of the Space Shuttle Orbiter, neared completion of the Shuttle facilities at the Kennedy Space Center, made operational use of data from the network of environmental satellites, and continued work to improve military aviation.

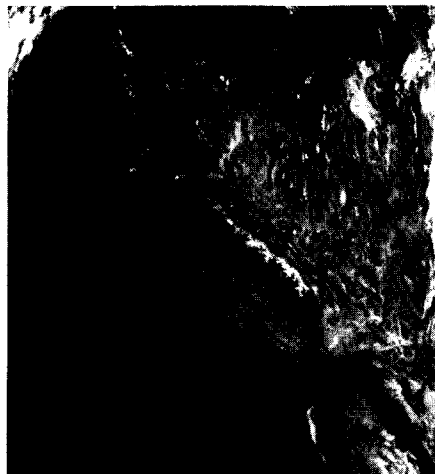


On October 12, 1977, Enterprise, the Space Shuttle's Orbiter No. 1 (above) separated from its 747 carrier aircraft and began its 5-minute glide to its first landing on a concrete runway. This was the last of five approach and landing flights conducted in 1977 at NASA's Dryden Flight Research Center at Edwards, California. The live flights confirmed the Orbiter's ability to descend through the atmosphere and make an airplane-like landing. In preparation for the orbital flight tests scheduled for 1979, the Shuttle facilities at Kennedy Space Center in Florida neared completion. These October photos show (below, left) Launch Complex 39 being reworked from its Apollo launch configuration to its Shuttle configuration, and (below, right) the Orbiter landing facility (at top) and tow road leading to the pair of rectangular buildings where Orbiters will be refurbished after flight.

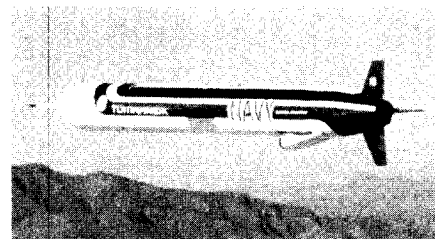




Environmental satellites continued to provide data used in operational weather forecasting and resources monitoring. At left, an enhanced infrared image from the Goes 1 satellite shows areas of precipitation across North America on July 19, 1977. The densest precipitation is seen over western Pennsylvania; indeed, it was causing the Johnston flood of July 19-20. A threatening absence of precipitation is evident below in contrast between the April snow pack in the Sierra Nevada Mountains in 1975 (left) and 1977 (right). This radiometer image from the NOAA 5 weather satellite gave accurate warning of the severe water shortage in the Western states during the summer of 1977.



In 1977, the Department of Defense conducted flight tests of the Navy's Tomahawk cruise missile (right) and deployed increasing numbers of the new F-16 fighter aircraft (below) to the fleet's aircraft carriers.





# Summary of United States Aeronautics and Space Activities in 1977

## Introduction

The national programs in aeronautics and space made steady progress in 1977 toward their long-term objectives. In aeronautics the goals were improved performance, energy efficiency, and safety in our aircraft. In space the goals were: better remote sensing systems to generate more sophisticated information about the Earth's environment; cost-effective, versatile space transportation; and understanding the origins and processes of the Earth, the solar system, and the Universe.

Aeronautical research made real gains toward developing technologies that would enable future transport aircraft to reduce fuel consumption by up to 50 percent along with lower noise and emission levels.

The United States attempted 26 launches into space in 1977; 24 of them put 29 satellites into orbit. NASA orbited 15 satellites in 14 launches; 2 launches failed, and a third placed a satellite into elliptical instead of synchronous orbit. DoD orbited 14 satellites in 10 launches, with another 2 launched for DoD by NASA. Of the NASA total, only 4 were NASA launches; costs of launching the remainder were reimbursed by governmental, international, and commercial customers. The NASA launches included a high-energy astronomy satellite, two planetary satellites heading toward Jupiter, and a radiation-counting satellite focused on the magnetosphere.

This chapter will summarize highlights of the year, arranged topically rather than by agency. Subsequent chapters will be devoted to the aeronautics and space activities of the six Federal agencies with the largest programs in those areas, as determined by their budgets.

## Communications

Communications satellites were the first space systems to demonstrate commercial feasibility and are still the largest and fastest growing segment of space development.

## Operational Space Systems

*Intelsat.* The International Telecommunications Satellite Organization (Intelsat) increased its membership by 24 countries in 1977, bringing the total to 101. Its space capability was also augmented, by the launch on May 26, 1977, of another Intelsat IV-A satellite into synchronous orbit to serve the Atlantic Ocean region.

*Marisat.* The Marine Satellite (MARISAT) consortium expanded commercial service to the Indian Ocean in 1977, adding to its service in the Atlantic and Pacific for commercial shipping and in all three oceans for the U.S. Navy. The number of U.S. ships equipped with MARISAT terminals tripled and that of the world fleet doubled. Constant contact with the home office makes ship deployment much more cost-effective and speeds delivery of goods.

*Military Communications Satellites.* The three major operating requirements for military communication by satellite are (1) high-capacity worldwide point-to-point communication, (2) moderate-capacity service to mobile users, and (3) command and control communication for strategic forces.

For the first of these needs, in 1977 the Defense Communications Satellite Program (DSCS) had four operational spacecraft: two DSCS satellites launched in May 1977 and deployed over the Atlantic and west Pacific, a DSCS experimental satellite launched in December 1973 and now over the Indian Ocean, and NATO IIIB on loan for temporary use over the eastern Pacific. Four more DSCS II satellites were scheduled for launch in 1978 and development continued of the improved DSCS III model.

The moderate-capacity requirement will be met by the Fleet Satellite Communications Service (FLTSATCOM) for contacting mobile units of the Navy and Air Force. The first satellite is scheduled for launch early in 1978.

The strategic command and control system is now provided by transponders on several satellites, pending development of a strategic satellite system.

*Domestic Commercial Satellites.* At the beginning of 1977, three domestic communications satellite systems were already in operation in the 4 and 6 GHz (gigahertz) bands. This year the Federal Communications Commission authorized Satellite Business Systems to develop and flight-test satellites operating in the 12- and 14-GHz bands to provide wideband, switched communications for private networks serving large industrial and government users who have voice, data, and image traffic between stations located on customer premises. The Corporation of Public Broadcasting and the Public Broadcasting Service were authorized to construct and operate 150 Earth stations in a domestic satellite system to all public television stations in the U.S.

### *Space Communications Experiments*

*Experimental Satellites.* Two experimental communications satellites continued in use in 1977. The ATS 6 (Applications Technology Satellite 6) began its third year in orbit with a program of 20 experiments in public-service broadcasting and in science and technology. In addition to its U.S. coverage, it is being used to transmit experimental programming to the Trust Territories, Pacific Islands. The other satellite is the CTS 1 (Communications Technology Satellite), a joint Canadian-U.S. venture exploring high-power space communication to small receivers on the ground in remote areas. By the end of 1977, 15 of 18 U.S. experiments on CTS 1 were operating in educational, health, social services, and information exchange.

*Communications Studies.* With demands on the finite electromagnetic spectrum increasing, NASA continued research on means for more efficient use, as well as expansion of, the communications spectrum. A number of U.S. agencies participated in the important 1977 World Administrative Radio Conference on Broadcast Satellites (where a flexible interim plan was adopted for use of the 12-GHz band for satellites in the Western Hemisphere as opposed to rigid allotments elsewhere). Preparations were also under way for the 1979 World Administrative Radio Conference whose revisions of radio regulations are intended to apply for the next 20 years.

The United Nations Committee on the Peaceful Uses of Outer Space, and its scientific and legal subcommittees, met in 1977 to continue discussions of the principles involved in direct broadcast of television by satellite.

### **Earth's Resources**

Sensors on space and aircraft platforms continued in 1977 to inventory and monitor condi-

tions in the Earth's atmosphere and water and on its land surface. These data were increasingly used in analysis and protection of the environment.

### *Inventorying and Monitoring*

*Landsat Experiments.* The experimental Landsat program continued to produce data from satellites Landsat 1 and 2, even though the performance of Landsat 1, after five years in orbit, was degraded by several system failures. Landsat-C neared completion, with launch scheduled early in 1978; fabrication of Landsat D was begun.

After several years of experimentation, a number of Landsat projects are operational or nearly so. In the Department of Interior

- a Landsat-based resources information system assists the tribal government of the Colville Indian reservation in its decision making;
- the requirement to maintain a current inventory of all public lands and their resources has become heavily dependent on digital data from Landsat and aerial survey;
- automated inventories of irrigated crops and wetlands have become possible through Landsat data supported by aerial infrared photography;
- the Salt-Verde river system in Arizona is managed by a cooperative project using Landsat, NOAA, and GOES satellite imagery and aerial surveys to map snow cover and monitor six reservoirs;
- classification and monitoring of mining activities in such diverse areas as Montana-Wyoming, New Mexico, Florida, and South Carolina;
- study of Landsat and aerial imagery for linear features that may relate to fault and fracture systems, which would help evaluate mine safety and locate and monitor leakage in surface and underground mines.

Internationally the Department of Interior assisted the United Nations, five Central American countries, and Chile and Bolivia in using Landsat data to inform themselves on resources and geological problems.

The Department of Agriculture completed the third year of its LACIE program, in conjunction with NOAA and NASA. Designed to test satellite potential for prediction of world wheat crops, the program demonstrated enough promise to encourage the Department to acquire its own computers for further experimentation. LACIE is scheduled for completion and final evaluation in 1978.

NASA released three applications projects to the users for operational employment: the Coast Guard would use satellite-derived data to monitor ice



formation in the Great Lakes; the Corps of Engineers would use Landsat data to predict water run-off in flood-prone areas; and Georgia decided to use the satellite-based inventorying system for the state's natural resources, a system already in use in Mississippi.

*Monitoring the Sea State.* Several agencies conducted experiments that used satellite data to measure the dynamic state of Earth's oceans. NASA used data from Geos 3 in 1977 to refine models of the Earth's gravity field, which in turn yields a more precise geoid. This is helpful in tracking circulation features such as the Gulf Stream and to measure the height of waves.

The Department of the Interior compiled satellite infrared measurements of monthly sea-surface temperatures for the past several years. They were considered useful in long-range weather forecasting and studies of climate dynamics. In the process of compiling the data, Interior discovered that a large cold-water anomaly had developed in the North Pacific in the fall of 1976 and reached its peak in February 1977. In late summer 1977 another such anomaly seemed to be developing.

The Department of Defense finished installing the Satellite Data Processing Center at the Navy's Fleet Numerical Weather Center in Monterey, California. It will receive and process data from DoD weather satellites and also from NASA's Seasat-A, scheduled for launch in May 1978. The processed data will be used in weather and ocean analyses and forecasts.

Several other projects were operating in 1977 to set baselines for interpretation of Seasat-A data. NASA joined with commercial users of Seasat data in a two-year demonstration program, embracing areas such as offshore oil and gas exploration, fisheries, and shipping safety. NOAA planned some 35 experiments related to Seasat—experiments involving winds and waves, currents and circulation dynamics, surface temperatures, geodesy, and sea ice.

*Mapping the Ocean Bottom.* NASA has used a scanning laser beam on an aircraft to experiment with mapping the topography of the ocean bottom in coastal regions. The experiment indicated that the method can produce high quality bathymetric maps quickly and economically. The Defense Mapping Agency and NOAA are specifying the requirements for an operational system for use in aircraft.

*Monitoring Pollution.* In 1977, sensors on aircraft platforms demonstrated their ability to track and monitor an impressive array of pollution problems. The emphasis in the cooperative program between the Environmental Protection Agency (EPA) and NASA has continued to be on energy-related research and development.

Using airborne and ground-based measurements, an EPA experiment in the Midwest succeeded for the first time in tracking sulfur dioxide from a single power-plant plume, observing the conversion in the atmosphere into significant amounts of acid sulfate aerosol, and tracking the chemicals as far as 300 kilometers downwind. Of great consequence to EPA's strategy for control of air pollution, the results were obtained by close orchestration of airborne and ground-based measurements. Since coal-fired power plants are expected to multiply rapidly across the U.S. over the next 20 years, this technique will be of increasing importance in determining the distant-source contribution to local and regional air pollution.

In addressing another kind of energy-related pollution problem, EPA and NASA explored the use of an airborne multi-spectral scanner to monitor and characterize the environmental impacts of the expected major increase in western strip mining in the next few years. By adapting the scanner to this purpose, in place of usual aerial photography, and by feeding its data into an automated land-use-data classification system, a single mission can cover a number of mines and the data can be rapidly interpreted, stored, and relayed to EPA and state regulatory offices.

In water pollution, NASA responded to a request from NOAA for satellite and aircraft data on the oil spill from the *Argo Merchant* off Nantucket Island in December 1976. Aside from their immediate operational use, the data are being studied by NOAA to improve mathematical models predicting oil spill behavior.

### *Environmental Analysis and Protection*

In addition to the efforts in collection and cataloging of data about the Earth and its atmosphere, there were substantial activities devoted to both operational and experimental programs to analyze and predict the processes of natural and man-made change in the environment.

*Weather Satellite Operations.* During 1977 the National Oceanic and Atmospheric Administration (NOAA) of the Department of Commerce operated two polar-orbiting weather satellites, Noaa 4 and 5, to report daily weather data around the Earth. Of the geostationary satellites that focus constantly on the weather patterns of North America and its sea approaches, the Goes 2 (Geostationary Operational Environmental Satellite) was launched in June 1977 to replace Goes 1 as the eastern operational satellite, while SMS 2 (Synchronous Meteorological Satellite) remained the western operational satellite.

Tiros-N, NASA's experimental version of the next generation of polar-orbiting weather satellites, was moved along on schedule toward its launch date in mid-1978; NOAA-A, the first operational model of the new series, is scheduled for launch late in 1978. Tiros-N will provide higher resolution visual and infrared imagery of the Earth's cloud cover, will measure moisture and temperature, and monitor proton and electron flux near the Earth.

The military meteorological satellite system (Defense Meteorological Satellite Program) continued to support military operations, with weather data for the entire Earth provided four times a day from two polar-orbiting satellites. The first of the new generation of military weather satellites—the Block 5D, parallel to Tiros-N but with different sensors—became operational in 1977 and offered noon and midnight imagery in visual and infrared wavelengths of cloud cover at a quality previously unattainable. The second satellite in this series was also launched in 1977 and declared operational in July.

*Weather Research.* In 1977, Federal agencies continued research to improve our ability to analyze and forecast weather conditions.

In the global arena, the U.S., among other nations, performed preliminary studies and experiments that would contribute to the effectiveness of the upcoming Global Atmospheric Research Program (GARP). Involving some 145 nations, this large international program in meteorology will take place in 1978–1979.

To improve our ability to detect, track, and monitor severe storms, NASA and NOAA are working on an advanced instrument for use in GOES satellites to be launched in the 1980s. This instrument will be able to report the 3-dimensional structure of atmospheric temperature and water vapor distribution. Such information could make possible earlier and more accurate storm warnings to the public.

NOAA field-tested techniques using imagery from infrared and visible satellite instruments to estimate hourly rainfall from convective clouds. Tests in three states in this country and in Venezuela showed a good correlation between imagery and ground areas of no precipitation and reasonable estimates of rainfall in areas of heavy precipitation. The technique will help in pinpointing areas in danger of flash flooding. Satellite data also were used in NOAA research on development and modification of convective cloud systems. Rainfall estimates derived from satellite imagery were applied to analysis of broad-area cumulus modification experiments. Similarly satellite data, as well as aircraft and radar data, from Hurricane Anita

(September 1977) are being analyzed to learn whether hurricane cloud systems show characteristic cloud developments that indicate storm strength and potential.

*Atmospheric Research.* Widespread concern arose earlier in the 1970s that some combination of natural and man-made gases and particles was threatening to thin the ozone layer to a dangerous level. This concern led to a multi-agency effort to gather enough data to understand the complex interactions going on in the stratosphere and to ascertain the danger level and possible remedies.

NASA in 1977 continued its measurements of quantities and distribution of ozone and other important stratospheric gases and of changes over time. A new project studied the vertical movement of aerosols and gases between the lower atmosphere (troposphere) and the upper atmosphere (stratosphere). In the summer of 1977 NASA dispatched an experiment team to Panama to employ U-2 and Lear Jet aircraft, as well as balloons and sounding rockets, to measure the upward movement from troposphere to stratosphere in the tropical zone. In 1978 it is planned to measure the reverse movement downward from stratosphere to troposphere that is thought to occur in the mid-latitudes.

The measurement program in the stratosphere produced new insights into the role of chlorine oxide compounds in the destruction of ozone. It was shown in 1977 that their role is larger than previously thought. The important gases have been identified and measured and evidence has been adduced that the world's total atmosphere mixes more rapidly than had been predicted.

NOAA also mounted a comprehensive investigation into the distribution of nitrogen dioxide in the stratosphere, using ground-based and airborne spectrometers. Fluorocarbons F-11 and F-12 and nitrous oxide were measured with balloon-grab techniques. Laboratory test measurements considerably lowered the predictions of ozone destruction by emissions from supersonic aircraft and correspondingly raised predictions of destruction by chlorofluorocarbons.

Two forms of environmental degradation stemming from aircraft are exhaust emissions and engine noise. NASA continued its several-year research effort in both areas in 1977. Experiments with the clean combustor, designed to lessen emissions from large turbine engines during takeoff and landing, were completed. Emissions were within the standards set by the Environmental Protection Agency for 1979, well below the level of current combustors. Research was begun on reducing emissions during stratospheric cruise. This

research centers on improving combustors and on fuel preparation.

Aircraft noise research investigated, among other components, fuel nozzles and acoustic aspects of the inlet ducts. One nozzle configuration was the inverted-velocity-profile nozzle, which causes the high velocity of the jet to occur in the outer region instead of at the center as in bypass exhaust systems. In combination with multi-element mechanical suppressors, this arrangement seems likely to reduce noise from the high-velocity jet.

For the engine inlet ducts, a new technique was developed that simplifies and makes more accurate the description of the sound radiation pattern from ducts and enables quick, effective design of acoustic liners.

*Earth Dynamics.* Experiments related to Earth dynamics involve mineral and energy reserves, earthquake forecasts, and geodetic surveys.

Trial models of natural resources in interesting formations were being developed from gravity data derived from satellite-to-satellite tracking, magnetic field data from the Orbiting Geophysical Observatory, and other geophysical data.

In studies of the recently discovered tectonic plates, NASA has every other year for the last five years emplaced mobile laser ranging stations on both sides of the San Andreas Fault. By ranging on satellites, the lasers have tried to delineate relative motion between the North American Plate and the Pacific Plate. For the first time, analysis indicated that movement may have been detected. Another effort in 1978 will try to verify these findings.

Another form of laser ranging uses the Moon as target. Three widely dispersed Earth stations are returning data now and another four stations are being built. The full network will observe polar motions and variations in the Earth's rotation rate, with much greater accuracy than any previous system.

The Department of Commerce operated a series of cross checks on different systems for determining position on the Earth with the greatest accuracy. Computer simulations of laser observations of the Lageos satellite positioned geodetic stations within 5 centimeters. A single photoelectron laser has been studied that would reduce costs and improve accuracy of locating ranging stations. The prospects are that a 1.5-centimeter accuracy could be achieved.

The Smithsonian Institution summarized the results of satellite tracking with its laser tracking network in the fourth and final version of the *Smithsonian Standard Earth*, a mathematical representation of the Earth's shape, size, and gravity field.

Space science is normally considered to begin at an altitude where Earth science leaves off—namely, at the interface between the Earth's magnetic field and the Sun's exhalations, the solar wind. From this departure point, space science moves outward through the solar system to the detectable portion of the Universe.

#### *Earth-Sun Studies*

Effects in the Earth's magnetosphere, the solar wind, and activities on the Sun are the components of this complex field of studies.

*Effects near the Magnetosphere.* A new technique for measurement of the interactions of the solar wind and the Earth's magnetosphere became possible with the launch in October 1977 of two International Sun-Earth Explorers. The program also marked a new dimension in international cooperation: one satellite was managed by the U.S., the other by the European Space Agency, with experiments of intermingled origin on both satellites. Their data will enable experimenters to distinguish spatial plasma structures from the complex temporal effects of the solar wind impacting on the Earth's magnetic field. A third ISEE satellite will be launched in 1978 into an extended trajectory where it can measure the solar wind before it arrives at the magnetosphere, as well as solar events. Later the three satellites will be joined by the Solar Maximum Mission for quadrilateral studies of the Earth-Sun interactions.

NOAA has used GOES satellite measurements of solar x-rays, taken at the distance of geosynchronous orbit, to detect solar flares before their x-ray and extreme-ultraviolet radiation reach the ionosphere. One use of these data will combine them with high time-resolution measurements of the ionospheric effects.

Other NOAA research demonstrated that energetic ions in the interplanetary medium outside the Earth's magnetosphere originated from within the magnetosphere. Thus the Earth joins the Sun and Jupiter as a source, within our solar system, of the energetic particles and low-energy cosmic rays found in the interplanetary medium.

*The Solar Wind.* NOAA studied several models of the chemical composition of the solar wind. Some of the recent work addressed the historical puzzle of the large quiet period in Earth reactions to the solar wind from 1645–1715. This abnormally long quiet period, when there was visible evidence of absence of solar activity, was attributed to a steady-state solar wind.

*Study of the Sun.* NASA's Orbiting Solar Observatory 8 (OSO 8) preserved its continuity of observation of the Sun by monitoring the new activity beginning with the upswing of the solar cycle. Aspects previously under study are the downflow circulation patterns in the solar atmosphere that were detected by Skylab; tiny magnetic regions that brighten like solar flares shortly after they appear; and x-ray bright points, which have a puzzling rate of appearance at solar minimum—twice the rate observed when discovered by Skylab in the middle of the solar cycle.

The findings of the x-ray observations taken by Skylab showed that holes in the Sun's corona are sources of the high-speed streams of ejected matter that strike the Earth's magnetosphere. One of the major discoveries in study of the Sun in recent years, this knowledge has been used by National Science Foundation observatories to detect coronal holes, from Earth, in normal daily observations. The holes are reliable predictors of magnetic storms on Earth. Corollary research has shown that the form of the Sun's corona is irregular. In part these irregularities account for the time differences in particles arriving at Earth.

As part of the DoD program, Air Force scientists are studying the theory of processes leading to solar flares and the time history of high-energy particles from solar flares. Particularly they are studying variations in ultraviolet emissions from the Sun as reported by Atmospheric Explorers C, D, and E and sounding rockets.

### *Study of the Moon and Planets*

*The Moon and Meteorites.* Study of meteorites continued to offer clues to the early history of the solar system: tiny platinum-bearing particles in meteorites may be interstellar materials that existed before the solar system did; composition of magnesium in meteorites indicates that radioactive aluminum-26 was present when the meteorites were formed, so the radioactivity may have provided the heat for the widespread early melting that took place on the Moon and planets.

Studies of the Moon provided new models for the major processes affecting the terrestrial planets. For instance, it now appears that 4 to 4.5-billion years ago the Moon had a strong magnetic field; when the Moon cooled, the field gradually disappeared. This relationship between heat and magnetism may offer better understanding of such planetary differences as Earth with a strong magnetic field, Mercury with a weak magnetic field, and Mars with much ancient volcanism but no magnetic field.

*The Planets.* The discovery of rings around the planet Uranus was the most dramatic discovery of 1977. Too faint to be seen by the largest telescope, the rings were found by their causing a gap in the observation of an occultation of a moderately bright star and their existence was verified by observations of several ground-based telescopes and the 90-centimeter telescope mounted in NASA's specially equipped C-141 aircraft known as the Kuiper Airborne Observatory.

On Mars, the Viking orbiters and landers continued to return data on the atmosphere, meteorology, surface chemistry, and the moon Phobos. The biology and organic chemistry instruments on the landers completed their useful life in 1977. The major question remains whether there is evidence of life on Mars. Intensive investigation continued.

Two Voyager satellites were launched in August and September on a trajectory to Jupiter and then to Saturn. Depending on results, Voyager 2 may fly on to the planet Uranus.

Development work on the Galileo mission was begun in 1977. It will consist of a probe that will descend into Jupiter's atmosphere and an orbiter that will study the planet, its environment, and satellites for more than a year.

The National Science Foundation used the 330-meter-diameter radio-radar telescope at Arecibo, Puerto Rico, to produce contour maps of the surface of Venus. The high-quality data permit rapid accumulation and analysis, providing information critical to the understanding of the chemical, structural, and topographic features of the Venusian surface.

### *Studies of the Universe*

NASA launched a major astronomy satellite in August 1977, the High Energy Astronomy Satellite I (HEAO I). The largest automated satellite ever launched, HEAO I is the first of the three scheduled to be launched at intervals of a year. Instrumented for study of x-rays, gamma rays, and cosmic rays, these satellites are expected to return fundamental data on the nature of some of the new discoveries in the Universe, such as pulsars, quasars, and possibly black holes. During the first month HEAO I was operational, a rare and transient x-ray nova was observed; within days it became one of the brightest x-ray sources in the sky.

Work continued on the development of the Space Telescope. Planned as a semipermanent space laboratory, the Space Telescope is a high-resolution instrument that, beginning in 1983, will be able to observe objects much farther away from Earth than can any ground-based telescope. The European Space Agency will provide one of the

instruments as well as scientists to operate the experiments.

The Smithsonian Institution continued its long-term analysis of data from the Uhuru satellite, publishing the *Fourth Uhuru Catalog* listing 339 sources of x-ray emissions—nearly twice the number previously known. In addition to sources within the Milky Way associated with neutron stars and black holes, many extragalactic objects were identified, such as Seyfert galaxies, quasars, and clusters of galaxies. Items in the last category each contained some 1000 galaxies in a relatively complex grouping. These “super-clusters of galaxies” are apparently bound together gravitationally by vast amounts of very hot, tenuous, hydrogen-helium gas. If such clusters are common throughout space, the mass of the previously undetected gas might provide a significant percentage of the “missing mass” theoretically needed to close the Universe.

## Transportation

Some of the science and much of the technology in aeronautics and space are devoted to devising new transportation systems or improving the efficiency and versatility of existing transportation systems.

### *Space Transportation System*

The Space Transportation System, a major advance that marks a new way of doing business in space and a new plateau of maturity in the U.S. program of space exploration, moved steadily nearer to completion during 1977. The main components of the flight system—the orbiter, the solid-fuel booster motors, the external fuel tank, and Spacelab—were in various phases of testing. The Inertial Upper Stage—formerly the Interim Upper Stage—being developed by the Department of Defense to boost heavy payloads into orbits beyond the performance curve of the orbiter, was nearing the end of its intensive design phase. The Spinning Upper Stages, now in design, are being developed in two sizes as a private venture and are intended to loft lightweight payloads from the orbiter to higher orbits.

The most visible progress on the Space Transportation System in 1977 was the series of approach and landing tests conducted at NASA's Dryden Flight Research Center in California. A 747 commercial airliner was modified to serve as the carrier aircraft for piggyback captive flights of the orbiter, then for releasing the orbiter in mid-air to make free flights and landings. The Enterprise, the first orbiter, is to be modified and flown on the 747 to

Marshall Space Flight Center in Huntsville, Alabama, to be used in vibration testing. The second orbiter will be the first one to venture into orbit. It was being assembled and will be checked out in mid-1978 before being ferried on the 747 to Kennedy Space Center, Florida, to be readied for the orbital flight tests.

Less visible was the progress on the ground facilities being readied at Kennedy Space Center and being planned at Vandenberg Air Force Base, California, or on the flight components still under construction. The big solid-fueled boosters were test-fired for the first time in July 1977 and the booster recovery parachutes functioned well in drop tests. The External Tank, which will contain the fuel and oxydizer for the orbiter's three main engines, is the one expendable portion of the Space Shuttle. Manufactured in a way that emphasizes standardized, low-cost techniques, the first tank was shipped to the National Space Technology Laboratory, Mississippi, in September 1977 for testing.

Spacelab, the orbital laboratory that can be fitted into the cargo compartment of the orbiter and provide support for manned or automated experiments, is being funded and built by the European Space Agency. In 1977 Spacelab moved past the halfway point in the design of components and systems; all designs are to be ready for the critical design review scheduled for February 1978. Manufacture of many components for the flight unit is under way; the completed unit is to be delivered to NASA in two segments, one late in 1979 and the other, early in 1980. Spacelab is scheduled to orbit for the first time in December 1980.

The operational structure for the Space Transportation System is well advanced. In addition to the basic NASA and DoD missions, NASA has been negotiating launch agreements with organizations such as Comsat, Western Union, and Telesat/Canada. Also, in May 1977 the U.S. and U.S.S.R. signed a second five-year bilateral agreement continuing their space cooperation. In November NASA representatives met in Moscow with Soviet counterparts to discuss experiments that might be included in a long-duration space mission involving the American Shuttle and the Russian Salyut space station. Three meetings in 1978 would further evaluate experiments and recommend a program to the respective governments. Shuttle flights for 1980–1981 are now fully booked; cargo manifests have been developed for the first few years of Shuttle operations. A handbook for users has been published; user charges have been set for all classes of users for the first years of operations, subject to adjustment only for inflation. Advance deposits on

over 150 payload items were received by NASA from industry, educational institutions, and persons.

When NASA invited applications for flight crew positions on STS, more than 20,000 persons requested application forms and more than 8000 were received and processed.

### *Expendable Launch Vehicles*

The United States space program had a total of 26 launches in 1977; 24 of them were successful in orbiting 29 satellites. The two complete failures involved one Delta and one Atlas-Centaur vehicle; one of the lost payloads was for the European Space Agency and one—Intelsat IV-A—for the Comsat Corporation. A second Delta vehicle had an upper-stage failure, putting the European Space Agency payload into an orbit from which it is only 70 percent effective. Other vehicles used were Scout, Atlas, Thor, and Titan III.

### *Research for Spacecraft Improvement*

A broad range of research projects sought ways to strengthen, lighten, improve electronics, and augment power sources on spacecraft.

*Materials and Structures.* Thermal protection for re-entering spacecraft was improved by a new, reusable insulation material with improved strength, wear, and impact properties. Also a new thermal coating, called "second surface mirror," prevents secondary thermal buildup from glare while saving weight.

Structural weight may well be reduced by use of graphite-polyimide structures. In 1977 four such materials were identified as having potential for structural use at temperatures of 315°C for as long as 500 re-entry cycles; weight reduction was estimated at 28 percent.

*Electronics.* A linear charge-coupled sensor array that can image in the near-infrared has been designed for remote sensing of Earth's and other planets' environments. Since it processes signals on the same chip as the imager, it saves significant amounts of size, weight, and power.

NASA demonstrated in 1977 a robot that combines and coordinates vision, locomotion, and manipulation. A unique visual memory and improved computer techniques enable the robot to process TV images more than 10 times faster than previous systems.

*Space Propulsion.* In liquid-fuel propulsion, components for a small, reusable, high-performance engine burning hydrogen and oxygen and intended for use on orbital transfer vehicles achieved a record specific impulse of 478 seconds.

Solid propellants withstood the stringent sterilization standards for Viking and hence could be used to launch payloads from the surface of other planets without risk of contaminating the planetary surface.

### *Aeronautical Transportation*

As in space transportation, aeronautical transportation involves military and civil systems that are already operational or are in active development.

*Operational Aircraft and Airborne Systems.* Among government agencies, DoD has the major concern for operational aircraft.

**FIGHTER AIRCRAFT.** The F-16 multi-mission fighter was approved for full production in 1977; the first of 1388 aircraft will be delivered in August 1978. In May 1977 the European partners in the F-16—Belgium, Norway, the Netherlands, and Denmark—signed agreements to purchase 348 aircraft. The F-16 represents the largest co-production program ever attempted, with over \$2 billion in contracts in Europe. The first customer outside the consortium was Iran, which signed an agreement to buy 160 aircraft.

The F-15 air superiority fighter continued to be produced at the rate of nine aircraft per month and more than 250 had been delivered to operational units by the end of the year.

The F-18 carrier-based strike fighter, approved for full development in 1975, is scheduled to make its first flight in October 1978. It will complement the more sophisticated F-14A, which is now routinely making extended deployments on carriers in the Atlantic and Pacific Fleets.

The A-10 close-air-support aircraft was in production, with some 75 of the approved 339 delivered. The first operational squadron was activated in June 1977 and initial operational capability was achieved three months ahead of schedule, in October.

The AV-8B is the follow-on version of the successful AV-8A, the Marine Corps' light attack vertical/short-takeoff-and-landing (V/STOL) aircraft. In 1977 it completed the first phase of wind-tunnel testing at NASA's Ames Research Center. The data confirm the design intention that this version should double the range or payload of the AV-8A. Two prototype aircraft are under production contract.

**BOMBER AIRCRAFT.** Although production of the B-1 bomber was halted, the three research, development, test, and evaluation aircraft continued their flight-test program at Edwards AFB, California. The flights measured overall performance and structural air loads and evaluated the avionics.

**TRANSPORT AIRCRAFT.** The Advanced Medium STOL Transport (AMST) had four prototypes completing a Phase I flight-test program in 1977. In 1397 hours of flight, they demonstrated STOL performance and operational utility.

**HELICOPTERS.** Several configurations of helicopters were continued in development toward a number of specialized functions. The Army's UH-60A Black Hawk is intended to support ground forces, both in combat and service roles. The first of 15 aircraft is scheduled for delivery in August 1978; there are contract options for another 353 over the next three years.

The Advanced Attack Helicopter completed full engineering development in 1977, with emphasis on integration of the armament and fire control. Fabrication of additional prototypes was deferred until 1978.

In the Cobra/Tow program, delivery of 290 retrofitted Cobra helicopters with the highly effective Tube Launched Optically Tracked Wire Guided (Tow) missile was completed in October 1977. The first of 297 new, upgraded Cobra/Tows was delivered in March 1977. The Army plans to retrofit another 400 Cobras and to modernize the entire fleet with, among other improvements, composite helicopter blades that will increase aircraft survivability and double the life of the blades.

The Air Force completed initial flight testing in 1977 of the H-3 combat rescue helicopter equipped with Pave Low III. This sophisticated sensing system enables low-level penetration of unfriendly territory and recovery of air crews in total darkness and bad weather.

**CRUISE MISSILES.** The Tomahawk is a long-range high-subsonic-speed cruise missile that can be fired through submarine torpedo tubes or from ships, aircraft, or mobile land platforms. It is under development in two versions: a conventionally armed anti-ship weapon for the Navy and a nuclear-armed land attack weapon for the Air Force.

*Operational Airway Systems.* The Department of Transportation has responsibility for operation of the National Aviation System. Progress was made in several areas in 1977.

**AIR SAFETY.** In 1977 the Minimum Safe Altitude Warning system was installed in all 63 major air terminals in the U.S. Begun in 1973, this computerized system provides automatic surveillance and altitude data to alert the controller to aircraft flying below minimum safe altitudes. A companion alert system will now be extended to the en route air traffic control system. Here the same kind of aircraft equipment will feed the computers at the 20 Air Route Traffic Control Centers. A demonstration is scheduled for the fall of 1978.

Wind shear is another threat to air safety in terminal areas. Since 1971 seven air carrier accidents have been involved with wind shear—a sudden change in wind speed or direction at the edges of airports where aircraft are flying close to the ground at low speeds as they approach or depart the airport. Research efforts were begun to measure and attempt to predict wind shear, and develop avionics that will enable pilots to cope with wind shear effects.

The conflict-alert warning system was installed in the last of the en route stations in 1977 and efforts were begun to install it in terminals. This is another computer-based system in which the system projects the existing position of aircraft under surveillance, predicts any situations where aircraft come within 40 seconds of unsafe separation, and warns the controller by audio and visual signal so that the pilots can be contacted. Field testing of terminal equipment was completed in 1977 and is to be installed in major air terminals by early 1978.

**AIR TRAFFIC CONTROL.** To meet the need for an improved instrument landing system in the U.S., the FAA has been developing since the early 1970s the Microwave Landing System. In 1977 the system reached its third phase—prototype development and evaluation. Two prototype Small Community systems and two Basic Systems were delivered in mid-1976 and have been in test and evaluation. Also the FAA-developed Microwave Landing System based on the Time Reference Scanning Beam was submitted to the International Civil Aviation Organization as the U.S. candidate for international standardization of landing systems. NASA joined FAA in demonstrating coupled approaches and automatic landings using the microwave system and a 737 transport where display, navigation, and flight control systems marked application of all-digital systems to a conventional transport aircraft.

**AIRWAYS MODERNIZATION.** The Flight Service Stations provide pilots with weather briefings, process flight plans, and provide emergency assistance and search and rescue. The format in which the stations have traditionally operated is highly labor-intensive. Demand for services has grown steadily and is expected to triple by 1995. Both to minimize human error and to restrain costs, initial steps were taken to modernize the stations.

Another modernization was to upgrade the automation capability of the Air Traffic Control Centers to control and coordinate the flow of air traffic. In 1977 a computer was installed in the center in Jacksonville, Florida, for this purpose and software was ordered for its use. When in op-

eration in late 1978, this improvement in flow control should enable controllers to balance capacity against demand, thus improving the use of the airspace and saving aircraft fuel by minimizing the need for flying holding patterns.

### *Research for Aeronautics Improvement*

The Federal commitment to maintain the competitive edge for American commercial transports, military aircraft, and general aviation continued in 1977 as NASA and DoD pursued research and development improvements for aircraft and airborne systems, and the FAA researched improvements in safety and efficiency in the air and ground segments of the National Aviation System.

*Aircraft and Airborne Systems.* In addition to research to minimize adverse environmental effects of aircraft (see the *Earth's Resources* section of this summary chapter), NASA pursued new technology that will reduce fuel consumption of future transport aircraft by as much as 50 percent.

**ENGINES.** NASA seeks to reduce fuel consumption while lessening deterioration over time of current and future turbofan engines. Work began this year on redesigning the fan blades and improving the durability of the high-pressure seals. NASA also explored next-generation technology for a turbofan engine with much lower fuel consumption.

**AERODYNAMICS.** Wind-tunnel testing provided a basic data base on the supercritical wing which can be applied to the design of future transport aircraft. Also identified for testing were other components such as winglets, propulsion system integration, and active controls for reducing wing loading. A Lockheed L1011 aircraft equipped with active controls began baseline data flights in 1977. The search for a supercritical wing of minimum weight has led to wind-tunnel testing of a full-scale wing section having the laminar-flow suction system integrated into the primary structure. The results are promising for future transports.

**STRUCTURES.** Advanced composite materials were being researched by NASA in 1977 and components were being test-flown. One of these components—ten copies of the upper aft rudder of the DC-10—was in routine flight in 1977 and a second, the vertical fin on the L1011 aircraft, entered design verification.

In DoD each service has research projects in structures and materials. The Navy is seeking to replace the metal rotor blade on the CH-46 helicopter with a fiberglass one that is resistant to corrosion, small defects, and rapid failure propagation, needing only visual pre-flight inspections and lengthening the repair cycle by 500 percent. Four different components made of composites com-

pleted laboratory and fatigue tests and are being fabricated for testing on operational aircraft. The Army concentrated its structures and materials program on helicopter composite components because of the higher penalty that weight imposes on helicopters and the heavier vibration stresses that can induce metal fatigue. Both the Black Hawk and Advanced Attack Helicopter flew in 1977 with aerodynamic surfaces and structural, fuselage components made of composites. Two other helicopters—the AH-1 Cobra gunship and the CH-47 cargo helicopter—were equipped with new composite rotor blades as the beginning of a modification and improvement program.

**IMPROVEMENT OF LONG-HAUL AND SHORT-HAUL AIRCRAFT.** In research on future long-haul aircraft, NASA found that the old formula for adapting subsonic aircraft to market demands by stretching or shrinking the length of the fuselage was not well suited to supersonic aircraft. The intricate interrelationship between wing and fuselage design on supersonic aircraft dictated a new approach. In 1977 the U.S. applied for a patent on a different concept employing lateral rather than longitudinal fuselage changes, providing wider or narrower cross sections of the cabin area to alter the capacity of supersonic aircraft.

In the short-haul sector, the Quiet Short-Haul Research Aircraft neared completion in 1977 with fabrication and installation of the new propulsive-lift wing and the engine nacelles. Following its delivery to NASA in 1978, this aircraft is intended to validate in flight the technology the aviation industry needs to manufacture quiet short-takeoff-and-landing aircraft.

**AIRCRAFT FIRE SAFETY.** In 1977 the FAA continued its research and development toward reducing the hazards from postcrash fires. A two-year study was begun to design a system that ranks the interior materials in a transport cabin for their collective combustion hazards. A simulated wide-body transport cabin was used in cabin-fire tests to assess hazards from the burning of materials inside the cabin and the by-products entering the cabin from fuels burning outside. Tests were performed with the Navy to evaluate an antimisting additive in aircraft fuels and the extent to which it minimizes the crash fireball.

*Airway Systems.* FAA and NASA continued research to improve the safety and efficiency of the airway system.

**SAFETY OF FUTURE TRANSPORTS.** A number of new, sophisticated systems are nearing readiness for incorporation in the next generation of jet transport aircraft: e.g., active control systems, composite control systems, digital avionics, and digital flight



control systems. Even though more complex and expensive than equipment they would replace, they are likely to be used because they promise operating efficiencies and lower operating costs not achievable by any other means. A broad program has been inaugurated by the FAA and NASA to determine guidelines for the certification of these new technologies.

**AVIATION SECURITY.** Protection against acts of terrorism or sabotage on aircraft or at airports continued to receive research attention in 1977. An experimental automated radiation-contrast system demonstrated excellent ability to detect bombs in baggage. The system is being bought for operational use at airports.

Other tests specified locations on commercial aircraft where any bombs found in flight could be secured with least risk to passengers and the aircraft. In all tests incorporating these least-risk procedures, damage was confined to levels that would permit the aircraft to land safely.

### Space Energy

Research on exploitation of energy in space takes two forms: improvement of energy sources on spacecraft and exploration of Sun-related energy sources for Earth application.

#### *Space Power*

Electrical energy sources available for use on or by spacecraft have traditionally been batteries, solar cells, fuel cells, and radioisotope thermoelectric generators. Future missions and their power requirements demand dynamic power systems that will generate substantially higher voltages over long mission profiles.

*Solar Cells, Batteries, and Fuel Cells.* Experimental solar cells were produced in 1977 that were five times thinner and lighter than those now in use in space. A blend of the silver-zinc battery and the hydrogen-oxygen fuel cell—the silver-hydrogen battery—was tested in 1977 in simulated synchronous orbit. Not only does it weigh half as much as conventional batteries, but use of the same fuel as the main propulsion system would offer further weight savings by eliminating redundant tankage and reserve fuel.

*Radioisotope Thermoelectric Generators.* The Viking spacecraft that operated on the surface and in orbit about the planet Mars in 1976 and 1977 depended for long-term, reliable electric power on radioisotope thermoelectric generators supplied by the Department of Energy. Not only did the units survive the extremes of diurnal and seasonal tem-

perature variations that are characteristic of Mars, but they supplied heat to some of the systems in the lander spacecraft during the colder periods. Similar evidence of durable performance came from DoD's Les 8 and 9 satellites; since March 1976 they have functioned without interruption.

Each of the two Voyager spacecraft launched in August and September 1977 has three large isotope generators on board that produce a total electric output of 475 watts per spacecraft. For the two spacecraft this totals as much nuclear power as all other missions currently in space. Not only are the power units expected to be functioning at Jupiter encounter in 1979 and Saturn encounter in 1980–1981, but the power sources should be adequate for the approach to Uranus in 1986 and possibly for the pass of Neptune in 1989. Like the other flight-model nuclear power sources NASA has used, these are encased in proven containers that do not leak radiation even under the stress of accidental re-entry.

*Dynamic Power Systems.* Experimental work continued on the materials and systems that might best be used in a dynamic power system for spacecraft that could produce electric power in the 1–2 kilowatt range and beyond. The Department of Energy is investigating the competitive performances of the Brayton and Rankine engine systems. Ground tests are scheduled in early 1978 to enable selection of the better system for development.

#### *Energy Systems Applications*

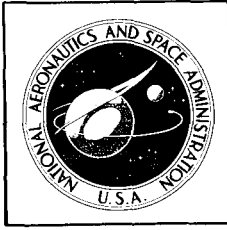
In 1977, the space program continued to contribute to the development and evaluation of new energy sources for use on Earth.

*Solar Cells.* The Department of Energy sponsors work on reducing the weight and cost of solar cells for use on Earth. Two projects allocated to NASA are the Low Cost Silicon Array at the Jet Propulsion Laboratory, which attempts to reduce cost and increase the lifetime of solar arrays, and the Test and Applications Project at the Lewis Research Center, which experiments with applications of solar cells that might interest commercial users. In two years the market for solar cells has increased by a factor of ten, the cost of arrays has been cut in half, and the number of companies making solar arrays for domestic use has doubled.

*Satellite Power Systems.* Since 1968 the intriguing concept of large power stations in geosynchronous orbit, converting the Sun's energy into microwave energy and transmitting it to Earth, has stimulated interest and study. In recent years it was studied by NASA; in 1976 management responsibility was transferred to the Department of Energy. In 1977, the Department of Energy and

NASA embarked on a three-year program, ending in 1980, to investigate all the considerations involved in a decision to proceed with development. NASA continued defining the hardware systems and the Department of Energy assumed responsi-

bility for study of health, safety, and environmental questions; of socio-economic, international, and other institutional issues; and of comparisons with other major sources of electrical power.



# National Aeronautics and Space Administration

## Introduction

Since 1958, the National Aeronautics and Space Administration (NASA) has been the civilian agency of the United States government empowered to plan, direct, and conduct research and development pertaining to space and aeronautics. This program is carried out in concert with a number of other civilian government agencies—foreign, Federal, state, and local—who have research or operational interests in these fields. The military space and aeronautics program is conducted by the Department of Defense (DoD). NASA exchanges information and provides research and development assistance to DoD.

Several broad objectives have shaped NASA's space and aeronautics programs over the years. In space the goals have been the development of technology and techniques for more effective space operations; demonstration of the practical utility of space systems and technology; and scientific investigation of the beginnings, development, and processes of the Earth and its atmosphere, of the planets, moons, and Sun of our solar system, and of the intricate diversity of the Universe. In aeronautics the goals have been research and development to improve the aerodynamics, structures, engines, and overall performance of aircraft in ways that make them more efficient, safer, and environmentally acceptable.

The year 1977 was marked by solid progress toward these goals. In space NASA had a total of 16 launches, of which 14 orbited 15 satellites. Of these satellites, 10 were launched for international, national, or commercial customers, 3 were in furtherance of NASA's own programs, and 2 were cooperative satellites. In aeronautics, a number of weight- and energy-saving projects made good progress.

## Applications to Earth

Experimentation with and demonstration of space systems that have potential application for use in the public or private sector proceeded in

1977. Communications, environmental research, weather forecasting, and Earth resources were the major targets.

## Communications

*Applications Technology Satellite 6 (ATS 6).* In January 1977 ATS 6, now stationed over the mid-Pacific opposite the U.S., began its third year in orbit with a program of 20 experiments. Most of these are in public service disciplines, with the rest in space science and technology applications. Also, its location enables it to transmit experimental programming to the Trust Territories, Pacific Islands.

*Communications Technology Satellite (CTS 1).* This joint Canadian-U.S. satellite, the most powerful transmitter yet launched, was orbited in 1976 to experiment with satellite communications to low-cost ground stations on the 12-GHz frequency, which is allocated specifically for satellite broadcasting without power limitations. By the end of 1977, 15 of the 18 U.S. experiments had started operations. They cover a wide range of educational, health, social services, and information-exchange investigations.

*Study of Future Communications.* NASA continued research on improved components for space communications and demonstrated transmissions with experimental hardware to extend capabilities in transmission of voice, data, and television. In response to growing concern over present and impending overcrowding of the electromagnetic spectrum caused by the worldwide upsurge in use of communications, NASA

- developed techniques for compressing bandwidth, thus making more effective use of the available frequency spectrum.
- studied means to open up new regions of the communications spectrum.
- studied, experimented with, and modeled such problems as radio frequency interference between satellites and between satellites and ground communications, optimum spacing of satellites for communication, problems of intra-

and inter-regional frequency and orbit sharing, and adverse propagation effects.

NASA was deeply involved in supporting with technical consultation other Federal agencies that have policy, regulatory, or operational responsibility in communications—primarily the Office of Telecommunications Policy, Executive Office of the President; the Department of State; the Federal Communications Commission; and the Department of Health, Education and Welfare. An important part of this was NASA's participation (with more than 50 technical papers) in the 1977 World Administrative Radio Conference on Broadcast Satellites.

Even as this conference was taking place, NASA was also assisting in preparations for the 1979 World Administrative Radio Conference. That conference is expected to completely revise the international radio regulations. NASA's particular interest has been in such areas as remote sensing, Earth exploration, search and rescue, and public services broadcasting.

*Communications for Public Service.* Studies were begun on the concept, technology, and economics of space communications for health care, education, and public safety applications. NASA solicited user involvement in defining requirements and economic viability.

#### *Data Collection via Satellite*

Three new initiatives in data collection were begun in 1977:

- the U.S. Army Corps of Engineers, with NASA support, began work on the National Water Resources Information Center, in Washington, D.C.
- the U.S. Geological Survey, assisted by the Comsat Corporation, began the evaluation of the potential use of commercial satellites—specifically the Canadian Anik communications satellite—to transmit remote-station environmental data from the northeastern U.S. and Canada and from Virginia.
- the Department of Agriculture began operational use of space data collection from unattended data collection platforms in Utah and other western states.

*Satellite-Aided Search and Rescue.* The ability of satellites to aid in search and rescue of distressed land, sea, or air vehicles was demonstrated in September 1977 when a balloon with two crewmen, attempting to cross the Atlantic to France, was caught in a heavy snowstorm and forced down in the North Atlantic off Iceland. The storm had blown them far off course and disrupted their

radio communications. But aboard was an experimental transmitter sending signals to the Nimbus 6 satellite; observers were able to track the balloon during the four days of its flight and locate its downed position within about 3 kilometers for the rescue helicopter.

Approval was obtained in 1977 for the joint Canadian-U.S. Search and Rescue Mission to conduct a demonstration of locating aircraft and ships in distress. The space segment—an antenna, receiver, processor, and transmitter—would be mounted on a Tiros-N weather satellite to be launched in 1981–1982. Ground stations would be sited to provide coverage of the continental U.S. and most of Canada. The Soviet Union and France, among other nations, have made commitments to participate in the demonstration.

#### *Earth Resources*

During 1977, use and evaluation of remotely sensed data from aircraft and satellites continued in a wide variety of uses.

Both Landsat 1 and 2 were operational throughout the year, although after five years in orbit the performance of Landsat 1 was degraded by the failure of band 4 of the multispectral scanner, deterioration of its power supply, and depletion of its attitude control gas. The portable Landsat ground station, which had been sending data from Pakistan for development of worldwide wheat estimates as well as for regional resources projects, ended operations in October 1977.

During the year, Landsat-C neared completion, with launch scheduled for early 1978. Design and construction of Landsat-D, the second-generation Earth resources satellite intended for launch in 1981, was opened to bids from industry in August 1977. In April the new, sophisticated prime sensor for Landsat-D, the Thematic Mapper, began development. Another type of Earth resources satellite, the spacecraft for the Heat Capacity Mapping Mission, was completed and undergoing final test at the end of the year, with launch scheduled for mid-April 1978.

Three Earth resources experiments were selected for flight on the second Shuttle Orbital Flight Test in July 1979: (1) an adaptation of the Seasat radar for geological and other land applications; (2) a Shuttle multispectral radiometer to investigate for resources applications the newly accessible spectral bands in the infrared region of the spectrum; and (3) an ocean color experiment.

The Applications Systems Verification and Transfer program is a mechanism by which discrete applications projects are brought to full development and released to users. In 1977 NASA and

users completed or nearly completed three projects; four new ones were approved in 1977. Those released to users were:

- the Coast Guard adopted for operational use on the Great Lakes the ice-monitoring techniques developed in the Icewarn project.
- a Water Management and Control project was completed for the Corps of Engineers—using Landsat data to predict run-off in flood-prone areas.
- techniques developed in the Natural Resources Information System with the state of Mississippi have been adopted by the state of Georgia, relying on the capabilities of the Georgia Institute of Technology.

Of the continuing experimental Earth resources projects, one of the most extensive has been the Large Area Crop Inventory Experiment (LACIE). In 1977 it completed its third year of devising and testing techniques for accurately forecasting each year's worldwide wheat production. LACIE is a joint endeavor by the U.S. Department of Agriculture, the National Oceanic and Atmospheric Administration (NOAA), and NASA. LACIE is scheduled for completion and final evaluation in mid-1978. Applied to the U.S. Great Plains, LACIE in the last two years had forecast wheat production with a 10 percent of the forecasts of the Department of Agriculture's Statistical Reporting Service for the winter wheat region. Spring wheat estimates were not as accurate, but new techniques are being tested to improve the projections. The Department of Agriculture has acquired its own advanced imaging processing equipment to further test LACIE forecasting techniques.

### *Weather and Climate*

NASA's weather and climate program focuses on development of applications for weather observations from space: detecting, tracking, and predicting severe storms; forecasting the daily weather events; and defining the dynamics of climatic functions. In 1977 emphasis was on support of the International Global Atmospheric Research Program (GARP) and the National Weather Service, and extending the capabilities of our current satellite systems. NASA is also working with the National Science Foundation and the National Oceanic and Atmospheric Administration to marshal the nation's most appropriate resources under a U.S. Climate Plan. NASA's participation will include satellite remote sensors, data applications, data management, and a variety of numerical modeling activities.

Preparations for the First GARP Global Experiment (FGGE), to be conducted during 1978–1979 and involving 145 countries, are nearing completion. A series of preparatory Data Systems Tests has been completed and the data analyzed by major modeling groups and other private and government research groups. For satellite-derived data, the two key sources are sounder-measured vertical temperature profiles and cloud-track-measured wind fields. Two research instruments on Nimbus 6 contributed to the development of an improved, operational instrument and better sounding techniques that are expected to be integrated into the Tiros-N satellite in time for use in the FGGE. Over the last half of 1977, basic geophysical data sets and analyzed wind-field data were distributed to the major modeling centers in the U.S. These are the most comprehensive sets of meteorological data ever assembled; they have been very helpful in experimental forecasting.

By the end of 1977 five passenger airliners had been outfitted with automatic equipment that will collect meteorological data and immediately relay them to weather forecasters via communications satellites. In the future, this system can provide weather data from areas of the tropics and vast regions of the Southern Hemisphere that have seldom been reported on. Also these data will be beneficial to all other aircraft flying these routes in the form of up-to-the-minute flight planning, which offers economies in time and fuel and gains in flight safety.

GOES satellites launched after 1980 will be able to observe the three-dimensional structure of the atmospheric temperature and water-vapor distribution with an instrument being developed by NASA. These new capabilities promise exciting advances in ability to detect, track, and monitor the evolution of severe storms, enabling earlier warning to the public. Extensive research and development will be needed to bring this technology to operational status. NASA is organizing and will conduct the necessary demonstration experiments in conjunction with NOAA.

Work continued on the Atmospheric Cloud Physics Laboratory, scheduled to orbit in the Shuttle Spacelab 3 in 1981. It will be a versatile tool for studying basic physical factors in the formation, growth, and interaction of water droplets and ice crystals within the atmosphere. At the close of 1977, proposals from the scientific research community at large were being reviewed for selection of those experiments that offer the fullest possible benefit from this research facility.

## *Environmental Quality*

The study of environmental quality is aimed at developing, demonstrating, and transferring space technology that measures and monitors those aspects of the environment which affect the quality of Earth's atmosphere and water.

The major focus of research in the upper atmosphere is on the continuing measurements of quantities and distribution of global ozone and other important stratospheric species and of how they change with time. One important dynamic process being studied is the interchange of gases and aerosols between the lower atmosphere (troposphere) and the upper atmosphere (stratosphere)—a process usually referred to as troposphere-stratosphere exchange. During the summer of 1977, NASA conducted an experiment from the Panama Canal Zone to measure this exchange as it takes place in the tropics. It is thought that this region, known as the Intertropical Convergence Zone, is the location of major upward transport from the troposphere to the stratosphere. A related experiment, to measure the transport from the stratosphere to the troposphere, is planned for 1978 at the mid-latitudes in the jet folding region, where major downward transport is thought to occur.

Remote sensing techniques for measuring quantities of key tropospheric pollutants in the lower atmosphere continued to improve during 1977. NASA and the state of Maryland began a project in the fall of 1976 to measure the dispersion of aerosols emitted from power-generating plants. NASA used a ground-based laser radar (lidar) for the measurements. Maryland's Department of Natural Resources is using the data to improve the mathematical models used to predict the environmental impact of powerplant emissions and to help the state pick the most suitable locations for future power plants. Another NASA experiment began in 1976 over Lake Michigan, using an airborne sensor to measure carbon monoxide in the urban plume generated by the cities of Chicago and Gary. The sensor, a developmental instrument called a gas filter correlation radiometer, succeeded in measuring carbon monoxide distributions as far as 160 kilometers downwind. Maps of the distribution are being used to evaluate the rate of dispersion and, together with other measurements, to study the chemical reactions within urban pollution plumes. The sensor is a prototype of one that will be flown on an early Shuttle mission to measure the differences in carbon monoxide concentrations between the heavily populated northern hemisphere and the less populated southern hemisphere.

Water-quality monitoring in 1977 found NASA active in studying both national and international

environmental problems. When the *Argo Merchant* spilled its cargo of oil in December 1976 off Nantucket Island, NASA responded to a request from NOAA with aircraft and satellite data on the trajectory of the oil slick. The data are being used by NOAA to evaluate mathematical models for improved prediction of the life cycle of oil spills at sea.

In support of the International Joint Agreements on the Great Lakes between the U.S. and Canada, NASA used remote imagery from Landsat satellites and aircraft sensors to estimate the amount of sediment entering the Lakes from their tributaries. The data were also used, together with measurements taken at the surface, to produce contour maps of other important pollution parameters such as Secchi depth, silica, sulfates, and nutrients.

## *Earth and Ocean Dynamics*

Earth dynamics are monitored and studied to help in the assessment of mineral and energy resource potential, to forecast earthquakes, and to do geodetic surveying. Applications derive from studies of such physical characteristics of the solid Earth as its gravity and magnetic fields; the tectonic plates which form its crust; crustal deformation caused by earthquakes, subsidence, and post-glacial uplifting; the wobble of the Earth around its polar axis; and variations in the Earth's rotational rate.

New models of the gravity field, derived from satellite-to-satellite tracking, provide better definition of the short wavelength components of the gravity fields. These gravity data, along with magnetic-field data from the Orbiting Geophysical Observatory and geophysical data, are currently being used to develop trial models of resources in interesting formations. A Magnetic Field Satellite (Magsat) under development is a joint NASA/U.S. Geological Survey project. To be launched in 1979, it will provide an updated and more accurate model of the global magnetic field.

In tectonic research, NASA has since 1972 placed mobile laser ranging stations on sites on either side of the San Andreas Fault every two years and, by ranging on satellites, tried to detect relative motion between the North American Plate and the Pacific Plate. Analysis of these long-term observations indicates that, for the first time, tectonic plate motion may have been detected. Additional measurements are planned for the fall of 1978 to verify these preliminary conclusions.

Another form of measurement is Very Long Baseline Interferometry. In 1976 NASA used this method to measure the distance between large

radio astronomy antennas in Boston and California with a repeatable accuracy of +10 centimeters. In 1977, mobile lasers were deployed at these sites and a third antenna site in California to cross-compare the measurements from satellite laser ranging with those from interferometry. Analysis is expected to confirm the absolute accuracy of both sets of distance measurements.

Another use of laser ranging employs the Moon as target. Lunar laser ranging data are being acquired by the McDonald Observatory in Texas; the Haleakala Observatory in Hawaii; and a station near Canberra, Australia. Similar stations are being constructed in Japan, France, West Germany, and the Soviet Union. When completed, this widely distributed group of stations will be able to observe polar motion and variations in the Earth's rotation rate with much greater accuracy than is attainable through the International Latitude Service using classical astronomical methods.

Another form of Earth measurement that NASA is involved in is the experiment, at the request of the National Geodetic Survey, to attempt to resolve a discrepancy in the measurement of sea level on the Pacific coast, as determined by conventional land and ocean techniques. A mobile interferometry unit, the Geos 3 satellite, and Doppler satellite tracking have been used to acquire a set of data that are being analyzed by the Survey.

#### *Ocean Condition Monitoring and Forecasting*

In monitoring and forecasting ocean conditions, satellite data are used for understanding and forecasting the marine environment, developing ocean sensing techniques, and evaluating the benefits of ocean satellite data.

Data from Geos 3 continued to be used during 1977 to refine models of the Earth's gravity field; more precise definition of the shape of the geoid is needed to track ocean circulation features such as the Gulf Stream and to map the seastate (wave heights) in the North Atlantic. The more precise definition of the ocean geoid has led to much improved correlation with subsurface tectonic features such as ridges, escarpments, and trenches. The Geos 3 radar altimeter has also demonstrated a limited capability for mapping over land and ice.

The promising new technology for ocean monitoring is the Seasat-A satellite, scheduled for launch in May 1978. A Seasat demonstration program got under way in 1977 at the request of commercial users to validate economic benefits. A series of two-year experiments will be conducted in several areas of ocean commerce, including offshore oil and gas exploration, marine fisheries, and maritime safety. To support these experiments, the users

plan to devote \$20 million worth of capital equipment and \$1 million in operating and personnel expenses.

Mapping of ocean-bottom topography in coastal regions or detection of ocean-surface pollutants has been done experimentally by the Airborne Oceanographic Lidar, which uses a scanning laser beam in either a bathymetric or fluoro-sensing mode. Data from the lidar are being used by DoD's Defense Mapping Agency and NOAA's National Oceanic Survey to define instrument specifications for an operational airborne bathymetric mapping system. The experimental data indicate that high-quality bathymetric maps can be produced quickly and economically with this technique.

#### *Materials Processing in Space*

Work in 1977 on materials processing in space was mostly preparatory for the extended series of experiments that will begin with the Space Shuttle flights.

Two short-duration rocket flights this year marked the first flights of two systems for containerless processing of materials in space. In one of these systems, electromagnetic fields simultaneously hold materials in place without physical contact and heat the materials. In the other system, stationary sound waves in an appropriate gas apply positioning forces on the materials; this positioning feature was tested on its first flight and means for sample heating will be tested later. Both systems will process materials that cannot be kept pure when heated in containers; experiments will also be possible with new glasses that could be converted into unwanted crystalline forms if melted in contact with foreign materials.

Electrical separation of different types of living cell was tested in space on the Apollo-Soyuz flight in 1975 with encouraging results, but further progress has been slowed because there was at that time no efficient means of rapid measurement of the motion of different cells in an electric field. A ground-based system to measure such motion was designed and constructed in 1977, making it possible to predict the results of separation runs in space. It is also expected to have significant applications in general medical and biological research.

The first solicitation for proposals of materials investigations to be performed on Space Shuttle flights was made and produced a total of 120 responses. A first group of 14 investigations was selected for flight on early missions and another 19 projects were marked for further development prior to selection decisions. The general objectives of the materials experiments on the early Shuttle

missions will be to develop understanding of fundamental processes and properties of materials and to demonstrate the value of space for materials work. Subjects of space investigations will include crystal growth from solutions, melts and vapor phases; production of specialized composite materials; containerless glass processing; and synthesis of large-size latex particles that are uniform in size.

## Science

### *Study of the Earth's Upper Atmosphere*

The comprehensive plan that was drafted in 1976 to develop a solid body of knowledge on the physics, chemistry, and transfer processes of the upper atmosphere was extensively reviewed by the scientific and technical communities, a stratospheric research advisory committee, and other Federal agencies. In implementing the plan, NASA has embarked on a broad-based program of research, technology, and monitoring embracing over 120 tasks. To sharpen the focus of the program, a strategy has been devised with the guidance and assistance of the advisory committee, clearly stating the key scientific questions and problems that now limit understanding of the stratosphere—especially the ozone—and specifying what measurements are required to answer those questions and how best to obtain them.

As part of the study of the upper atmosphere, a combination of field measurements, theoretical calculations, and laboratory measurements have in the past year changed the understanding of the relative importance of man-made nitrogen oxide ( $\text{NO}_x$ ) compounds as compared to chlorine oxide ( $\text{ClO}_x$ ) compounds in the destruction of ozone.  $\text{ClO}_x$  is now thought to be a major contributor to the destruction of odd oxygen (including ozone) in the upper atmosphere.

Six balloon profile measurements of chlorine ( $\text{Cl}$ ) and chlorine monoxide ( $\text{ClO}$ ) have indicated that the amount of  $\text{ClO}$  in the stratosphere is highly variable. Other measurements have given readings simultaneously of the amounts of the oxygen radical  $\text{OH}$ , nitric oxide ( $\text{NO}$ ), oxygen ( $\text{O}$ ), ozone ( $\text{O}_3$ ),  $\text{Cl}$ , and  $\text{ClO}$ . Latitude and altitude distributions of nitrous oxide ( $\text{N}_2\text{O}$ ) and the chlorofluoromethanes F-11 and F-12 were also measured. The findings were that concentrations of each of these latter species drop off rapidly above 12 kilometers altitude at latitudes greater than about  $30^\circ$ . No interhemispheric differences were observed for concentration distributions of  $\text{N}_2\text{O}$  ( $\leq 1\%$ ). For F-11 and F-12, only small differences of 10–12% were observed, indicating that the

world's total atmosphere is mixing more quickly and efficiently than was predicted.

Both spectroscopic and filter-collection measurements have been obtained of hydrogen chloride ( $\text{HCl}$ ) and hydrogen fluoride ( $\text{HF}$ ) in the stratosphere. These provide information about natural and man-made contributions to reactive species in the upper atmosphere.

Backscattered ultraviolet measurements of ozone were obtained by the Atmospheric Explorer-E satellite until March 1977. When combined with recalculated data from the Nimbus satellites, these measurements should comprise the most complete data set for global ozone yet available.

In the continuing effort to improve theoretical models, such models were expanded to incorporate radiative feedback, temperature feedback, scattering, and albedo effects. The diurnal effects on ozone depletion are being investigated in some detail, and work is under way to integrate chemistry into existing general circulation models and to study the effects and importance of aerosols on stratospheric phenomena.

Measurements of new reaction rates between important minor species in the  $\text{HO}_x$ ,  $\text{ClO}_x$ ,  $\text{NO}_x$ , and  $\text{O}_x$  families, plus extension of existing rates to stratospheric temperature and pressure conditions have continued to improve data for the photochemical models. A complete list of reaction rates has been compiled for all known atmospheric reactions of importance.

In assessing man-made effects, the predictions on depletion of ozone by Space Shuttle flights have been incorporated into a draft environmental impact statement and an aircraft assessment has been provided to the Federal Aviation Administration, Congress, the regulatory agencies, and the National Science Foundation. Assuming 60 Shuttle flights per year, the model calculations predict that the mean ozone concentrations in the northern hemisphere will be reduced by about 0.25 percent with an uncertainty factor of two. Most of this reduction is produced by chlorine compounds in the Shuttle exhaust. After replacement of the present fuel with a non chlorine-producing fuel, the ozone layer would return to normal in about five years.

New calculations have been completed on the ozone reductions that would be caused by continued chlorofluoromethane (CFM) releases at the 1975 rate. The National Academy of Sciences has defined error limits from uncertainties in chemistry, transport, and the release rates. When these error limits are applied, the prediction of ozone reduction becomes 4 percent to 30 percent. In the case of the CFMs, unlike the case of the Shuttle effluents, the return to an unperturbed ozone level is predicted to require many years because of the



slow diffusion of CFMs upward into the stratosphere.

### *Study of the Sun and its Earth Relationships*

It is now well known that certain effects in the Earth's upper atmosphere—magnetic storms and short-wave fadeouts, for example—are associated with variations in the output of the particle and/or ultraviolet light fluxes from the Sun. NASA attempts to understand how changes in solar environment affect the Earth and, if possible, predict the occurrence of solar phenomena that shape and control the changing space environment of the Earth. This entails study of the Sun itself, the solar wind, and the effects on the Earth's magnetic field and upper atmosphere.

*Study of the Sun.* In its third year of operation, the Orbiting Solar Observatory 8 (OSO 8) combined continuation of established observation programs with a watch on the new solar activity marking the beginning of the new solar cycle. Among the programs already under way is the study of the newly discovered downflow circulation patterns in the solar atmosphere. This may be important in understanding the energy or mass transport into the solar corona and hence in the generation of the solar wind. The study of new activity includes observations of tiny magnetic regions which undergo flare-like brightening within hours after emerging through the Sun's surface. Study of these simple features may provide new insight into complex flares in older active regions, in which explosive bursts of mass and energy can be expelled toward the Earth. Another new feature was detected by a soft x-ray telescope flown on two different sounding rockets in conjunction with the recent minimum of solar activity. The telescope found that the number of x-ray bright points at solar minimum was double the number observed during the Skylab mission. Since such bright points are a direct measure of magnetic flux, these observations suggest that more magnetic fields are emerging at solar minimum than when Skylab first discovered them, near the middle of the solar cycle. This evidence may have considerable effect on our understanding of the nature of the solar cycle itself.

The next stage of solar investigation will involve the Solar Maximum Mission (SMM). It will provide temporal and spatial high-resolution observations of solar flares in those gamma-ray, x-ray, and extreme-ultraviolet wavelengths where solar flares release most of their radiative energy. These wavelengths are also the ones absorbed by the Earth's upper atmosphere and therefore are most likely to cause atmospheric effects. Also the SMM

carries a special coronagraph capable of detecting mass ejections as they leave the Sun on their journey toward Earth. Both the spacecraft and the experiments are on schedule for launch in October 1979.

*Study of the Solar Wind.* An analysis finished in 1977 showed the first visible evidence of the passage of a high-speed solar wind stream through interplanetary space. This occurred when the ion tail of comet Kohoutek (being observed by NASA's Cometary Research Observatory in New Mexico) showed severe distortions as a result of interaction with a high-speed wind stream from a solar coronal hole (observed by solar telescopes on Skylab and measured *in situ* by Interplanetary Monitoring Platform 8). This same wind stream several days later caused a severe geomagnetic storm in the vicinity of the Earth. The unique series of observations offers an unparalleled opportunity for the study of the origin of solar wind streams and then their propagation in an area of space which so far has been little studied.

*Study of the Solar Effects near the Earth.* The two International Sun-Earth Explorer satellites launched in October 1977 into looping trajectories around the Earth mark both a high degree of international cooperation and the first time two satellites were designed to be used together to study the Earth's immediate space environment. With one satellite managed by NASA and the other by the European Space Agency and with European and U.S. experiments on each, ISEE 1 and 2 will be investigating the interaction of the solar particle flux (solar wind) with the Earth's magnetosphere. With their similar instrumentation and variable distance from each other, they can separate spatial plasma structures from the complex temporal effects caused by the impact of the solar wind on the magnetic field of the Earth. ISEE-C will be launched in 1978 and positioned farther out where it can measure the free-flowing solar wind and special solar events, such as flares, about an hour before the particles reach ISEE 1 and 2. With this kind of triangulation, the total set of data will offer a much more complete description of the complex interactions than has been possible until now. And when the Solar Maximum Mission is in orbit, the three ISEEs will join the SMM in complementary studies of solar flares, the disturbances they cause in the solar wind, and the effects of these disturbances in the magnetosphere.

### *Study of the Moon and Planets*

*The Moon and Meteorites.* Studies of the Moon and meteorites continue to unveil new, unique information about the origin and early history of

the solar system. Recent analyses of lunar rocks and of meteorites have produced the following discoveries:

- tiny platinum-bearing particles found in the Allende meteorite may be interstellar materials that existed before the solar system was formed
- the composition of magnesium in some meteorites indicates that radioactive aluminum-26 was present when the meteorites formed; this radioactivity may have provided the heat needed for the widespread early melting that occurred on the Moon and planets
- recently opened cores of "lunar soil" are providing direct measurements of the history of the Sun's activity for perhaps a billion years into the past
- the U.S.S.R.'s Moon samples returned by Luna 24 and provided to NASA under the terms of the joint exchange agreement, are a chemically unique type of volcanic lava. They show that the volcanic history of the Moon is more complex in its chemistry than previously thought.

Studies of the Moon also continue to provide new models for the major processes that affect the terrestrial planets—early melting, meteorite bombardments, widespread volcanic eruptions, and planetary magnetic fields. For example, recent investigations indicate that the Moon had a strong magnetic field in the far past (4 to 4.5 billion years ago) when it was hot and volcanically active, but that this field gradually disappeared as the Moon cooled. This relationship between thermal history and planetary magnetism may offer better understanding of other planets: the Earth, with its strong magnetic field and continuous volcanism; Mercury, with its weak magnetic field; and Mars, with its ancient volcanism and no magnetic field.

*The Planets.* The most significant planetary discovery of the year was the rings around the planet Uranus. The rings were detected as being the cause of an unexpected gap in the observation of the occultation of a moderately bright star by Uranus. The discovery was verified by observations made with several ground-based telescopes and NASA's Kuiper Airborne Observatory, a C-141 aircraft mounting a 90-centimeter telescope. The existence of rings around Uranus—a phenomenon hitherto known only in the case of Saturn—was an important and completely unexpected discovery.

**VIKING MISSIONS.** The four Viking spacecraft (two orbiters and two landers) continued to operate normally and returned science data from the planet Mars. Major discoveries have been made in atmospheric composition, meteorology, surface

properties and chemistry, and the study of the moon Phobos. Massive dust storms have been observed; seasonal variation in meteorology measured; a Mars quake detected; variations in atmospheric water vapor measured; large amounts of water discovered at the north pole; and nitrogen, krypton, and xenon gases found in the atmosphere. The moon Phobos is much less dense than Mars, indicating that the moon probably is a captured body.

The biology and organic chemistry instruments on the Viking landers have completed their useful life. Results from these investigations continue to tantalize scientists; intense study and laboratory experimentation are trying to unravel the puzzle. Of major importance in the data is whether there is or is not evidence of life on Mars. The final results will affect understanding of the origin of life on Earth.

**PIONEERS 10 AND 11.** Pioneers 10 and 11 continued to provide valuable data on interplanetary space as they cruise through the outer solar system. The spacecraft made successful flybys of Jupiter in 1973 and 1974, after which 10 moved out toward interplanetary space and 11 used Jupiter's gravity to swing onto a trajectory that will encounter Saturn in September 1979.

**VOYAGER.** Two Voyager spacecraft were launched successfully by Titan-Centaur boosters from Kennedy Space Center on August 20 and September 5, 1977. Both spacecraft are operating normally as they cruise toward the planets Jupiter and then Saturn. Scientific observations of the former will begin in December 1978; Voyager 1's closest approach to Jupiter will occur on March 5, 1979. Voyager 2 is on a slightly slower trajectory; it will begin science observations of Jupiter in April 1979 and its closest approach will be on July 9, 1979. Both spacecraft will use Jupiter's gravitational field to swing around toward Saturn, arriving in 1980–1981. After that encounter, Voyager 2 may be deflected into a four-year flight to the planet Uranus.

**PIONEER VENUS.** One of the most challenging questions about Venus is why a planet that is so much like Earth in many respects has an atmosphere that is vastly different. The primary objective of the Pioneer Venus mission is to study the Venusian atmosphere. Two spacecraft will be launched: a Multiprobe—a bus with four atmospheric-entry probes—in August 1978, and an Orbiter in May 1978. Both spacecraft will arrive at Venus in December 1978. The probes will enter the Venusian atmosphere at the same time but at widely separated points.

**GALILEO.** Begun in 1977, the Galileo mission will consist of an entry probe that will make

direct measurements in Jupiter's atmosphere and an orbiter that will orbit for over a year, studying Jupiter, its satellites, and its magnetosphere. The Federal Republic of Germany, by cooperative agreement with NASA, will provide the orbiter retropropulsion system and two of the experiments. The Galileo mission will be launched by the Shuttle/Inertial Upper Stage in January 1982.

### *Studies of the Universe*

NASA's research in astrophysics is pointed toward the solution of such fundamental questions as: what is the origin of the Universe? What is the origin of the elements of which the Earth and human bodies are constructed? What high-energy processes occur in space?

The tools used in such research are satellites with differing assortments of specialized instruments; ground-based telescopes; and the specially instrumented sounding rockets, balloons, and aircraft that can fly high enough to escape most of the filtering of electromagnetic energy by the Earth's atmosphere.

*High Energy Astronomy Observatory.* A major event in astronautical research was the successful launch on August 12, 1977, of the High Energy Astronomy Observatory 1 (HEAO 1). The spacecraft was boosted by an Atlas-Centaur rocket into a nearly circular, low-altitude, low-inclination orbit which will minimize the radiation background for the experiments. The largest Earth-orbiting unmanned scientific spacecraft ever to be launched, HEAO 1 is the first in a series of three of its kind, designed to make significant contributions to knowledge in the disciplines of x-ray and gamma-ray astronomy, as well as cosmic-ray research. HEAO-B and C are scheduled for launch in 1978 and 1979.

Data from these satellites are expected to provide valuable information on the nature of some of the most recently discovered and most mysterious objects in the Universe, including pulsars, quasars, and, possibly, black holes. From such information could come better understanding of high-energy processes in the Universe and new theories of energy production by these objects.

All four experiments on HEAO 1 were operating and returning useful scientific data. During the first month of operation, a rare, transient x-ray nova was observed along with other sources in the scanned regions. Within days this previously unseen source became one of the brightest objects in the x-ray sky. HEAO 1's observations are being analyzed by the investigators and several scientific papers have already been submitted for publication. The spacecraft spent the first three months in

orbit in a celestial scanning mode, rotating slowly and mapping the sky for x-ray and low-energy gamma-ray sources; the next three months would be devoted to pinpoint observations of scientifically interesting x-ray sources. The four experiments, developed by six universities and Federal agencies, provide complementary data on the detected sources in terms of location, spectra, and time variations.

*Space Telescope.* After several years of study and refinement, the Space Telescope was approved as a new start in NASA's FY 1978 budget. It is conceived as a long-term program that will provide a capability in astronomy not achievable by any current or foreseeable ground-based telescope. The Space Telescope is a high-resolution, 2.4-meter instrument which, when placed in orbit in late 1983, will be able to observe objects at much greater distances in the Universe than can be reached by any ground-based telescope. It will differ from other unmanned satellites in that its design will permit in-orbit maintenance and repair by astronauts or pick-up by the Space Shuttle and return to Earth for refurbishment and relaunch. Any of the focal-plane instruments can be replaced in either of these situations, encouraging updating of the instrumentation and the broadest use of the Space Telescope to meet scientific requirements arising over its lifetime, which is expected to exceed a decade.

Contractors have been selected and contracts awarded for the detailed design and fabrication of the telescope and supporting systems. The first set of focal-plane instruments has been selected from among the proposals submitted by the scientific community. The European Space Agency has agreed to participate in the program by providing one of the scientific instruments—the Faint Object camera—as well as the solar array that will power the telescope system and personnel to man science operations.

*Explorer Satellites.* Explorer satellites are relatively low-cost payloads designed to explore new fields of scientific research, some of them targets of opportunity generated by inconclusive data from other satellites. In January 1978 the International Ultraviolet Explorer will be launched into a modified geosynchronous orbit to provide data on sources emitting energy in the ultraviolet portion of the spectrum; it will be very important in designing instruments and operational techniques for the Space Telescope. The IUE is another international space venture; the United Kingdom and the European Space Agency are contributing essential hardware and the operations and satellite observations will be conducted from one ground station in the U.S. and another in Europe. The

geosynchronous orbit will enable observations by guest observers at each of the ground stations in a manner similar to that in ground-based optical observatories.

Another international Explorer, the Infrared Astronomical Satellite, was begun in 1977 for launch in 1981. The U.S., the Netherlands, and the United Kingdom have designed this satellite to survey the infrared sky with a "first of its kind" cryogenically cooled telescope and focal-plane detectors. It should open up the infrared sky as did earlier Explorers in the x-ray part of the electromagnetic spectrum.

Of other Explorers designed to study select portions of the Universe, one that is still operating successfully is the Small Astronomy Observatory 3, which continues to provide unique data on recently discovered x-ray burst sources. An Explorer in the advanced study stage is the Cosmic Background Explorer, which could provide the first careful examination of radiation believed to be left over from the earliest stages of the expansion of the Universe.

*Orbiting Astronomical Observatories.* OAO 3, named Copernicus, is still operating successfully. The unanticipated long life of this satellite has provided a rich scientific harvest, with more than 200 scientific papers published in the field of ultraviolet astronomy.

*Suborbital Vehicles.* Sounding rockets, balloons, and aircraft continued to make their contributions to the development of technology and to the advancement of science. For example, one NASA sounding rocket flight, building on earlier observations, offered new insights into the nature of quasars; also it indirectly suggested that the Universe is finite in size. In the NASA balloon program, one flight carried aloft the prototype of a new, highly efficient cosmic ray detector. The airborne astronomy program has already been mentioned with the Kuiper Airborne Observatory confirming the discovery of rings around the planet Uranus.

### *Study of Life Sciences*

*U.S. Experiments on Soviet Spacecraft.* Cosmos 836 flew 7 U.S. biological experiments. The 19-day flight ended on August 22, 1977, and the U.S. experiments were received at NASA's Ames Research Center on September 25, 1977. Experiments included investigations with laboratory rats on the effects of weightlessness and normal gravity on the life span of red blood cells, on liver enzyme activity, on bone growth, and on muscle changes; as well as on dosages from high-energy particles and

investigation by electron microscope of the genetics and aging of fruit flies in zero gravity.

## **Space Transportation**

All operations in space, manned or unmanned, depend on some means of space transportation. Since the beginning of the space age, transportation has involved expensive, expendable launch vehicles. For six years a new Space Transportation System has been in stages of design, development, and testing. Pacing this effort is the Space Shuttle, which for the first time in the brief history of space exploration will be a space vehicle that is recoverable and reusable. The Space Shuttle is augmented by other components, developed and funded by other organizations: Spacelab, by the European Space Agency; the Inertial Upper Stage, by the Department of Defense; the Spinning Upper Stages, by private industry.

### *Space Shuttle*

The Space Shuttle is the keystone of the Space Transportation System, which will begin providing frequent access to low Earth orbit in the 1980s. The world's first reusable spacecraft, the Shuttle will offer cost savings and unique mission capabilities. Satellites can be serviced or repaired in orbit, or returned to Earth for refurbishment; scientific laboratories can be orbited and returned to Earth for examination. A crew of as many as seven persons can orbit in the Shuttle, exposed to much lower acceleration than on previous manned space systems, and can work in shirtsleeves in normal atmospheric pressure. Journey into space, for both people and payloads, should become routine and eliminate the need for costly expendable launch vehicles.

Development of the Shuttle is now far advanced, on schedule for the start of the orbital flight tests in 1979. Major milestones achieved in 1977 included successful completion of the approach and landing flight tests, the first firing of the solid rocket motor, delivery of the first external fuel tank, and firing of the main engine for over five minutes at the rated power level.

*Shuttle Orbiter.* The orbiter's approach and landing tests were conducted at Dryden Flight Research Center, California. Captive flights atop 747 carrier aircraft were conducted first and followed by free flights and landings of the orbiter, verifying its aerodynamic flight characteristics. This first orbiter, named the Enterprise, will be flown on the 747 to Marshall Space Flight Center in Alabama for use in full-scale vibration testing. The

second orbiter, which will be the first one to orbit the Earth, is now being assembled at the Rockwell International Space Division plant in Palmdale, California. After a final checkout, it will be ferried atop the 747 in late 1978 to the Kennedy Space Center, Florida, to prepare for the orbital flight tests in 1979.

The orbiter main propulsion test structure was completed in June 1977 and shipped to the National Space Technology Laboratory in Mississippi. It will be joined to an external fuel tank and three main engines for the main propulsion test. Also a structural-test version of the orbiter is now being completed at Palmdale. It will be moved to Lockheed's Palmdale plant for full-scale structural tests in 1978. Problems with avionics software and production of the external tiles providing thermal protection have largely been solved.

*Main Engine.* Three main engines are clustered to the aft section of the orbiter. They are the major technological advance over previous systems; as such, they have had technical problems. The basic requirement for a very-long-lifetime reusable engine was a new frontier for rocket engines; to this was added a requirement for a large increase in operating pressure to provide a substantially higher thrust-to-weight ratio than existed in previous systems. The main engine problems are mostly in the high-pressure turbo machinery. Many problems have been resolved and testing continues. All components have now been tested at the rated power level and all except the flight nozzle have been taken to the full power level (109 percent of rated power). Despite some delays, engine tests have accumulated over 13,000 seconds of test time; accelerated testing is planned for 1978, allowing NASA to move with confidence into orbital flight tests in 1979.

*External Tank.* This tank will contain in separate compartments the liquid hydrogen fuel and the liquid oxygen that drive the main engines. Since this is the one expendable component of the Space Shuttle, manufacturing and assembly of the tank have emphasized standard, low-cost techniques. The first tank, assembled by the Martin Marietta Corporation at NASA's Michoud Assembly Facility in Louisiana, was completed and shipped to the National Space Technology Laboratory in September 1977 for use in the main propulsion tests. Deliveries of structural test versions of the liquid-hydrogen and liquid-oxygen tanks will be completed early in 1978; a ground vibration test article will also be delivered early in 1978 for use in the full-scale, mated ground vibration test program.

*Solid Rocket Booster.* The first test firings of the solid-rocket booster were in July 1977 and were

performed on schedule by the Thiokol Corporation at Wasatch, Utah. Drop tests of the booster's recovery parachutes were also performed, and development of other systems proceeded on schedule.

*Launch and Landing Facilities.* Construction of launch and landing facilities at the Kennedy Space Center is on schedule. Facilities needed for the orbital flight tests include the orbiter landing facility; mate/demate device; orbiter processing facilities; hypergolic maintenance; booster retrieval, disassembly, and parachute facility; and modifications to the Vehicle Assembly Building, Launch Pad 39A, and the mobile launcher. The computerized launch processing system is largely complete and ground-support equipment is being installed. Construction has begun on the second line of ground processing stations needed for the Shuttle operational phase.

*Spacelab.* Spacelab is an orbital facility carried within the cargo bay of the Shuttle; its flexible components offer a pressurized, shirt-sleeve laboratory (the module), an unpressurized platform exposed to the space environment (the pallet), and standardized support services. Designed to be used 50 times over 10 years, each Spacelab can act as a short-stay space station that can remain in orbit for 30 days, though the normal mission lasts 7 days. Experiments can be operated by as many as four payload specialists; the intent is to provide ready access to space for a variety of experimenters in many fields and from many nations. Payload weights will range from 5500 to 9100 kilograms.

The European Space Agency (ESA), in its agreement with NASA, is responsible for the design, development, and manufacture of the first flight unit, an engineering model, two sets of ground-support equipment, and initial spares. The costs to ESA are now estimated at about \$575 million. NASA is responsible for operations and development of connective items, such as the tunnel between the Spacelab and the cabin of the Shuttle. NASA plans to buy at least one production unit of Spacelab from ESA.

In 1977 Spacelab moved past the halfway point in approved designs of components and systems, with the remainder expected to be ready for the overall critical design review in February 1978. Manufacture of many components for the first flight unit has begun. Developmental tests are proceeding well for all subsystems, with integration begun in April 1977. With assembly and test of the engineering model under way, delivery to NASA is scheduled in mid-1979. The first flight unit is scheduled to arrive at NASA in two increments, one in late 1979 and the other in early 1980. The first Shuttle mission that includes Spacelab is scheduled for December 1980.

In fulfilling NASA's obligation for operational support of the Spacelab, a contract was let in March 1977 for Spacelab integration. The contract provides for the design, development, and fabrication of most of the Spacelab equipment that NASA is responsible for, plus the system engineering and integration needed to provide an operational capability for Spacelab. Also, in September 1977 NASA began work to modify the Operations and Checkout building at the Kennedy Space Center so that it can support preparations for launch of Spacelab hardware. Construction should be completed in September 1978.

*Inertial Upper Stage.* The Inertial Upper Stage (IUS) (formerly the Interim Upper Stage) is designed to take Shuttle payloads out of low-Earth orbit and place them into orbits beyond the performance curve of the Space Shuttle. The solid-propellant IUS, with payload attached, will be carried into orbit in the cargo bay of the Shuttle orbiter, deployed, and the motor ignited. Two- and three-stage versions of the IUS will be available. Under development by DoD, the IUS will be used by both DoD and NASA, with NASA use confined primarily to missions requiring geosynchronous or planetary orbits. Validation is essentially completed, and full-scale development is expected to begin in the first quarter of 1978, working toward an operational date in 1980.

*Spinning Solid Upper Stages.* Complementary to the IUS, the spin-stabilized solid-propellant stage will be used to inject payloads into geosynchronous orbits that are beyond the capability of the orbiter but call for less energy than that of the Inertial Upper Stage. Designed primarily for the small commercial payload, it will be carried into orbit by the orbiter, spun up, and then deployed before ignition. The inherent simplicity of spin stabilization and solid propellant motor will make for easy, economical transition to the Space Shuttle of payloads now using expendable launch vehicles. Two configurations are being developed by private industry at no cost to the government: one in the Delta vehicle class, the other in the Centaur class. As many as four of the former or two of the latter can be accommodated in one Shuttle flight. First flight is planned for 1980.

*Space Transportation System Operations.* The Space Transportation System (STS), consisting of the Space Shuttle, Spacelab, and an upper stage, is intended to provide routine, less expensive access to space for a wide variety of payloads, including those accompanied by their scientist operators. With the Space Transportation System scheduled to be in operation by 1980, the organizational structure, development of the ground-support

equipment, and the operational planning are almost complete.

In addition to planning NASA and DoD missions, NASA has been negotiating launch agreements with such domestic and foreign commercial organizations as Comsat, Western Union, and Telesat/Canada to launch communications satellites. With these commitments and the government's own requirements, cargo manifests have been developed for the first few years of Shuttle operations. Shuttle flights are now fully booked for 1980-1981.

There has been an intensive preparation for operational flights, scheduled to begin in mid-1980. A user's handbook has been published; user charge policies have been issued, establishing firm fixed prices for DoD, civilian U.S. government, and commercial users, including price lists for both standard and optional services. All users are guaranteed a firm fixed price during the early years of STS operation, subject only to adjustments for inflation. The objective is to encourage maximum use of the system by all classes of users while ensuring that NASA recovers operating costs over a reasonable period of time. Within that framework, special discounts are offered users who are willing to share flights or to fly on a "standby" basis. DoD will be charged less because there will be an exchange of launch and support services between the NASA facility at Kennedy Space Center and the Air Force facility at Vandenberg Air Force Base in California.

Acting within the bilateral agreement signed in May 1977 by the U.S. and U.S.S.R. continuing space cooperation for another five years, NASA representatives met in Moscow in November with Soviet technical people to examine experiments that might fit the format of a long-duration mission featuring the U.S. Space Shuttle and the Soviet Salyut space station. Representatives of the two nations were to meet three more times in 1978 (in April, July, and October) to complete the evaluation of experiments and to develop a program to be recommended to their governments for consideration.

Particularly encouraging has been the enthusiastic response from American industry, educational institutions, and private individuals in response to NASA's offer to fly small, self-contained payloads on a space-available basis for \$10,000 or less. By the end of 1977 advance payments for more than 150 payloads had been received from industry, educational institutions, and individuals specifying their intentions to fly experiments on the Shuttle. It is hoped that many of these experiments will contain innovative ideas from small businesses and individual researchers who for the first time will

have the chance to test their ideas in the space environment at a cost they can afford.

Operations planning kept pace with the technical developments—technical and business management, procedures for integrated operations, and crew training. Since NASA's astronaut corps was not large enough to cope with the projected number of yearly Shuttle flights, NASA solicited applications for additional flight crew positions, including the new mission specialist categories. More than 20,000 persons requested forms and more than 8000 applications were received and processed for final selection in 1978.

*Space Shuttle Life Science.* A high-fidelity mock-up of the Space Shuttle/Spacelab combination was the scene of a demonstration test, conducted as a seven-day, single-shift Shuttle flight. The three-man crew performed 26 life-science experiments and 12 operational tests. Animals were used extensively in the tests. The crew, consisting of a mission specialist and two payload specialists, remained isolated in the mockup for the entire test, supported by "ground" flight control and payload operations staff. Six developmental flight laboratory items, produced and made available for this test, provided environmental control, waste management, animal handling, and feeding devices.

The first model of a new, higher pressure space-suit for astronaut use outside the Shuttle is now undergoing tests within NASA. Designed to afford greater mobility and to cost less to make, it offers adjustments in size for fitting of most people by modular selection of arms, legs, and torsos.

Preparing for Space Shuttle operations, NASA developed medical standards tailored to the individual crew and passenger responsibilities. Space medical standards for selection of Astronauts (Class I), Astronaut Mission Specialists (Class II), and Payload Specialists/Passengers (Class III) were published. These are the most concise and up-to-date occupational medical guidelines in existence.

### *Expendable Launch Vehicles*

During 1977 the expendable launch vehicles continued to provide transportation services to a variety of users, though marked by three launch failures, of which 1 had partial success, placing a satellite in elliptical rather than synchronous orbit. Of the total of 16 launches in the year, 12 were for the several categories of customers who reimburse NASA for the cost of the launch vehicle and the support and launch services.

*Scout.* The single launch of this vehicle system was of a Navy navigation satellite in October from the Western Test Range, California.

*Delta.* The most used of the vehicle systems, Delta had 10 launches this year, 8 of them successful: communications satellites for NATO, Japan, and Indonesia; a research communications satellite for Italy; a meteorological satellite for Japan and one for NOAA; three satellites for the European Space Agency; and a NASA scientific Explorer satellite. Of the two failures, the first was in April during the launch of the European Space Agency's GEOS mission, when the separation device between the second and third stages of the launch vehicle failed. This prevented the satellite from attaining synchronous orbit; it did go into a highly elliptical orbit, from which it is meeting about 70 percent of its mission objectives. After an investigation and corrective actions, the next three launches were successes.

The second Delta failure occurred on September 13, 1977, during another European Space Agency launch, this time an Orbital Test Satellite experimental communications satellite on a Delta 3914-series vehicle. The Delta had a catastrophic failure, exploding approximately 54 seconds after launch. The review board's investigation indicated that the probable cause was failure of one of the Castor IV strap-on solid motors. Since then, Deltas using smaller Castor II solid motors were given clearance to launch the NASA-European Space Agency scientific explorers ISEE-A and B, a European Space Agency meteorological satellite, and a communications satellite for Japan.

*Atlas-Centaur.* Three launches used Atlas-Centaur vehicles: two Intelsat communications satellites for the Comsat Corporation and a NASA scientific high-energy astronomy satellite (HEAO 1). On one of the Intelsat launches, conducted in September, the booster failed approximately 54 seconds after launch, causing the vehicle to tumble, the Atlas stage to explode just after separation from the Centaur stage, and the Centaur stage to be destroyed by the range safety officer. Probable cause of failure was a ruptured line in the hot gas generator that drives the turbopumps on the two Atlas outboard booster engines. This caused a fire in the engine section.

*Titan III-Centaur.* The largest of the vehicle systems successfully launched Voyager 1 and 2 on two boosters in August and September. These were the last missions now scheduled to be launched by this vehicle combination.

### *Advanced Studies*

NASA continued to conduct advanced studies on the feasibility and trade-offs between various new projects or program extensions, to provide both focus to long-range planning and a data base for

informed decision making. A major study looked at extended-duration missions of the Shuttle with Spacelab. Options which appeared feasible were:

- an evolutionary approach to large-scale space operations in which capabilities being developed in the Space Transportation System could be augmented by a small electric-power module (25 kilowatts) to supplement the Shuttle's power system. Later this module could be increased in size so that the Shuttle could support communications, materials processing, and assembly of large structures in orbit, leading eventually to a space construction base. Approaches were defined for fabricating and assembling large structures in space, for developing orbital operations, and for deploying large antennas. Also included was a study of reboosting and reusing Skylab, the space station that has been in orbit since 1973.
- future Space Transportation System requirements through the year 2000 included a capability for orbit transfer well in excess of what the Inertial Upper Stage could provide. For example, extending manned flight to geosynchronous orbit would call for a large orbit-transfer vehicle with payload capability from 5 to 10 times that of the Inertial Upper Stage. For unmanned cargo transfer, solar-electric ion propulsion was investigated.

For long-range planning purposes, an analysis is underway to set feasible goals and determine technology needs for future commercial use of the space environment, with emphasis on worthwhile objectives for space industrialization.

### **Space Research and Technology**

NASA's work in space research and technology provides advanced technology for future space missions. The principal areas of study include materials and structures; guidance, control, and information systems; space propulsion systems; and space energy systems. Although intended for use in space, some of the technology has applications on Earth as well.

#### *Materials and Structures*

Research in materials and structures provides technology advances for reliable, long-life, lightweight structural materials for building spacecraft and large orbiting space structures. These advances could save operational costs and increase payload capability for future space missions.

*Materials.* In thermal protection for re-entry spacecraft, a reusable insulation material has been

developed with improved strength, wear, and impact resistance. This material was selected for use on the Space Shuttle for those areas subject to wear, such as around doors and ports.

A new thermal control coating was developed in 1977. Known as "second surface mirror," the coating has a diffuse surface which, by eliminating glare, prevents secondary thermal buildup and improves temperature control; it also saves weight over previous materials used. Because of these advantages, it was selected for use on the thermal control radiators in the Space Shuttle, which are located inside the payload-bay doors. This type of coating will find many uses in spacecraft of the future.

*Structures.* As part of an effort to save weight in future space systems, composite structures made of a graphite-polyimide combination are being developed that can withstand temperatures 150°C higher than existing composites. During 1977, four polyimide materials were identified as having potential for use as structural materials at a temperature of 315°C for as many as 500 re-entry cycles. Techniques for fabricating structures made of these materials are being developed so that a typical control surface can be constructed and tested; if it verifies the predictions of structural integrity, the reduction in weight is estimated to be 28 percent.

#### *Guidance, Control, and Information Systems*

NASA's work in guidance, control, and information systems in 1977 was designed to develop a technology base that would permit a 1000-fold increase in availability to the user of space-derived information, and reduce by an order of magnitude the cost of mission operations by stepping up the level of autonomous operations in spacecraft systems.

*Sensing and Detection.* The first linear charge-coupled sensor array that can image in the near-infrared region of the spectrum has been designed for remote sensing of Earth's and other planets' environments. The device achieves signal processing in real time directly on the same chip as the imager and significantly reduces weight and size as well as power needs.

*Guidance and Control.* Pursuing the cost advantages of increased automation, NASA this year completed demonstration of a robot that combines and coordinates the functions of vision, locomotion, and manipulation. The speed at which this robot can process TV images was increased by more than an order of magnitude with improved computer techniques and the design of a unique visual memory system.



*Data Reduction and Distribution.* Work continued on the improvement of software tools and techniques that interface user software programs and applications computers. A breadboard for a compiler writer system that can translate a user's program into proven machine software in near-real time was developed this year. When operational, this system promises to reduce the cost of translation significantly.

### *Space Propulsion Systems*

NASA's work in space propulsion seeks to advance liquid, solid, and heat-electric propulsion so that future Earth-orbital missions and planetary explorations can have increased performance at reduced costs.

*Liquid Propulsion.* Testing of components for a small, reusable, high-performance engine burning oxygen and hydrogen—designed for use in future reusable orbital-transfer vehicles—was a notable milestone in 1977. A thrust-chamber assembly, with a 400-to-1 nozzle area ratio, was successfully tested under simulated vacuum conditions. The specific impulse measured 478 seconds, the highest known value ever recorded for these propellants.

*Solid Propulsion.* Significant progress was made in demonstrating heat-sterilizable propellants for solid rocket motors that could launch payloads from the surface of planets. Propellant charges as large as 71 centimeters in diameter (260 kilograms of propellant) survived the Viking sterilization requirement of 6 cycles of 54 hours each at 135°C. This capability is being extended to larger diameter motors.

*Electric Propulsion.* Substantial progress occurred in the development of ion thrusters for both low-energy-level applications—such as station-keeping of geosynchronous satellites—and the higher energy levels of primary propulsion for planetary exploration. The station-keeper version—4.5 millinewtons of thrust—successfully completed a 10-cycle thermal vacuum test and an accelerated-cycle life test (5000 cycles). The primary ion thruster (130 millinewtons of thrust) is targeted to a FY 1980 technology readiness standard to be applied to planetary exploration. One element is the development of the power processing systems that take raw power coming from the solar arrays and convert it into the currents and voltages needed to run the ion thrusters. Development versions of these power processors have been fabricated and tested.

### *Space Energy Systems*

NASA's research in space energy systems improves the longevity and efficiency of energy sys-

tems and tries to reduce their cost. The associated technology tries to meet the growing need for energy in space, with some spin-off for applications on Earth.

*Solar Cells and Arrays.* Solar cell technology achieved a major advance in 1977 with pilot production of a solar cell five times thinner and lighter than those now in use in space. Secondary benefits from these thin solar cells are reduced fragility and the potential for lower cost since less silicon material is needed. As for solar arrays, a large step toward demonstrating the feasibility of lightweight solar arrays was the successful zero-g testing, using a KC-135 aircraft, of the root section of a 66-watt-per-kilogram solar array.

*Chemical Energy Conversion and Storage.* A silver-hydrogen battery, a blend of the technologies of the silver-zinc battery and the hydrogen-oxygen fuel cell, has completed testing in simulated geosynchronous orbit. This prototype represents a potential for halving battery weight.

Having demonstrated the basic compatibility of the reactants—hydrogen and oxygen—in this new role, the technology offers promise that, since the same reactants are being used both for propulsion and power, the weight savings from elimination of redundant tankage and reserve fuel can be significant.

*Thermal-to-Electric Conversion.* Under a joint program with the Department of Energy, NASA has developed and delivered rotating units and recuperators for a 500–2000-watt Brayton power system powered by radioisotope. Longevity of the rotating machinery has been the major technical limitation of Brayton conversion systems. In addressing this concern, a larger (10 kilowatt) Brayton unit has logged over 30,000 hours of endurance testing and will continue toward a goal of 50,000 hours.

## **Tracking and Data Acquisition**

Tracking and data acquisition represent the crucial links that return data to Earth for analysis and exploitation. These activities include tracking space vehicles for position and trajectory, receiving and processing science and engineering telemetry, transmitting commands to automated spacecraft, and providing voice communications for manned mission.

The bulk of those services are provided by the facilities of NASA's two worldwide tracking networks. The Spaceflight Tracking and Data Network is specialized to support all Earth-orbital missions. The Deep Space Network is designed and engineered to support planetary and interplanetary

missions at great distances from Earth. A NASA Communications System, employing a variety of communications links from simple land telephone lines to satellite relays, connects these facilities to provide instantaneous information flow between the spacecraft, the ground stations, and the project control centers.

### *Operational Activities*

Throughout the year the networks continued to support more than 50 Earth-orbital spacecraft and some 14 interplanetary missions. This includes tracking and telemetry launch support that was provided to other government agencies, to commercial owners, and to a host of international cooperative and foreign missions, on a reimbursable basis. Sometimes post-launch support was provided as well.

### *Support of the International Community*

In 1977 telemetry and tracking support were provided to the European Space Agency's Meteosat weather spacecraft, several Japanese weather and communications satellites, and the Italian Sirio mission. Post-launch support normally involves maneuvering the spacecraft from its initial orbit into geosynchronous orbit and drifting the satellite to the desired geostationary position once in synchronous orbit. Then operational control is returned to the owner in a series of graduated steps for a smooth transition of the control function with little risk to continuing operational reliability.

### *Network Progress*

*Data Processing Improvements.* At the Goddard Space Flight Center, important improvements were made in 1977 to the large-scale, common-purpose data processing facilities and the mission control centers for automated Earth-orbital spacecraft. A new telemetry processing system eliminates tape recording of data received at each station; data now enter a mass storage system directly from communications lines. This eliminates the delay for recording and the delay involved in shipping the tapes from the stations to the control center. Also the data are cataloged automatically as they are stored, avoiding another tape recording. With these improvements, much greater volumes of data can be processed and delivery of data to the experimenter is quicker.

*Control Center Improvements.* A new capability in mission control will take effect early in 1978 when the control room for the International Ultraviolet Explorer is activated. For the first time the participating scientist will be able to manipulate

a spaceborne telescope just as if he were in a ground observatory. Now undergoing test and checkout, this unique facility enables the investigator to select the star he wishes to observe; a computer complex will generate commands, relay them to the spacecraft through the ground stations, and point the telescope to the desired star, all automatically. Not only is this popular with the scientist, but with him in the control loop, rapid, flexible response is possible when confronted with unexpected results or brief phenomena.

*Deep Space Network Improvement.* Capabilities of the Deep Space Network were improved by the completion of a number of modifications that reduced the noise generated by the antenna systems themselves. Antennas must be extremely sensitive to pick up spacecraft transmissions from hundreds of millions of miles away. In this situation the noise generated by the antennas themselves is a major component of the interference that must be overcome if we are to communicate with distant spacecraft and navigate them across vast distances. In addition the conversion of the 26-meter antennas to x-band frequencies began in 1977. X-band will enable satellites to transmit data at higher rates—and therefore return more data—than they can on S-band. The first of these dual-frequency antennas will be ready by late 1978 to assist in the simultaneous handling of the Pioneer Venus mission and the Jupiter encounters of the Voyager spacecraft.

## **NASA Energy Programs**

NASA support of research and development in the field of energy includes reimbursed support to the Department of Energy and other agencies, and definition and understanding of ways in which space technology may be used to help solve energy needs on Earth. The reimbursed activity in 1977 amounted to nearly \$100 million and 400 equivalent man-years of effort from several NASA centers. The definition activity was largely funded by NASA.

### *Solar Heating and Cooling*

NASA contributes to the development of systems for the National Solar Heating and Cooling Program and provides contract management and technical support for the commercial demonstration part of that program. NASA also participates in a joint program with the Department of Energy to install solar equipment on buildings in NASA centers.

Improved solar heating components and systems are now being integrated into 45 operational test sites throughout the U.S. to test capabilities and performance in a wide variety of climatic zones. Seventeen of the 45 systems were completed in 1977.

Prototypes of advanced cooling systems are being tested at three locations. These systems are a major step toward cost-effective solar cooling of single-family residences. The first of these Rankine-cycle systems will be installed in a test building by mid-1978. Also, 10 buildings at 6 NASA centers in California, Texas, Alabama, Florida, and Virginia will be equipped with solar heating systems by mid-1978.

### *Wind Turbine Generators*

The 100-kilowatt wind turbine (MOD-O) dedicated two years ago at NASA's Plum Brook Station near Sandusky, Ohio, has undergone extensive testing. Early technical difficulties were overcome in 1977 and the machine now operates automatically, delivering power to the local utility company whenever the wind exceeds 11 kilometers per hour.

Another machine, similar but rated at 200 kilowatts, will begin operation at Clayton, New Mexico, early in 1978. Two more of this model will be installed next year at Culebra, Puerto Rico, and Block Island, Rhode Island. Design and construction of two much larger machines was begun in 1977.

### *Photovoltaics (Solar Cells)*

As part of the Department of Energy's National Photovoltaic Conversion Program, work continued on the Low-Cost Silicon Solar Array Project at NASA's Jet Propulsion Laboratory and the Test and Applications Project at NASA's Lewis Research Laboratory. The first project develops technologies to reduce the cost and increase the lifetime of arrays. The Lewis project experiments with a variety of applications intended to stimulate near-term commercial use.

### *Satellite Power Systems*

A joint study by the Department of Energy and NASA is under way, to develop by the end of 1980 a first understanding of technical feasibility, economic viability, and social and environmental acceptability of the Satellite Power Systems concept. The Department of Energy will manage the effort and assess the economic, environmental, and social aspects in comparison with other energy alternatives. NASA will focus on technical issues, attempting to define the systems to the depth neces-

sary to assess technical feasibility and thereby provide a baseline for the studies by the Department of Energy.

## **Aeronautical Research and Technology**

NASA's aeronautical research is aimed at (1) improving the energy efficiency of aircraft, (2) reducing aircraft noise and emission pollution, (3) improving aviation safety and terminal-area operations, (4) advancing long-haul and short-haul aircraft, and (5) providing technical support to the military to maintain the performance superiority of military aircraft.

### *Improving the Energy Efficiency of Aircraft*

The Aircraft Energy Efficiency program, begun in 1976, has as its goal the development of new technology that can reduce fuel consumption of future transport aircraft by up to 50 percent through advances in engine systems, aerodynamics and active controls, and structures.

*Engine Systems.* By improving engine components in current engines, NASA intends not only to reduce fuel consumption but to minimize deterioration of performance in current and future derivative turbofan engines. During 1977 work was begun on redesign of fan blades and improving the high-pressure turbine seals; improvements in these components could reduce specific fuel consumption by about 2.5 percent. Research on seal flow effectiveness has led to design of a better seal configuration to reduce leakage and thereby reduce fuel consumption when the seals are used on components throughout the engine.

Components identified for further development in 1978 include incorporating new materials and manufacturing processes, more efficient cooling, reduced leakage, improved bearings, and improved component aerodynamics.

NASA also explored in 1977 the technology required for a next-generation turbofan engine that significantly reduces specific fuel consumption—by approximately 15 percent less than current high-bypass-ratio engines. Work has begun on the advanced components—fans, compressors, combustors, and turbines.

*Aerodynamics and Active Controls.* Testing in wind tunnels provided basic data on the aerodynamic performance of the supercritical wing for potential application to the design of future transport aircraft. Over 1000 hours in the wind tunnel were devoted to testing the effects of varying the wing aspect ratio, camber and sweep, and the configuration of the wing control surfaces. Items iden-

tified for additional wind-tunnel testing are wing-lets, propulsion system integration, and active controls for alleviating wing loading. Work has begun on applying active controls and aerodynamic improvement, singly or coupled, to future transport aircraft. Baseline flights were begun in 1977 with a Lockheed L1011 aircraft equipped with an active control system.

Work in laminar flow control has focused on achieving a practical wing structure of minimum structural weight by integrating the flow-suction system with the primary structure. Wind-tunnel tests of a full-scale wing model having a 6-meter chord and a supercritical cross-section confirmed that laminar flow could be achieved with a wing design representative of a future transport aircraft.

Research was conducted on the aerodynamic problem caused by the buildup of dead insects on the leading edge of an aircraft wing in flight. The results of the flight tests at locations throughout the U.S. demonstrated that a water spray on a Teflon-coated leading edge of a wing would eliminate boundary-layer transition from laminar to turbulent flow otherwise caused by the layer of insects.

*Structures.* So that performance predictions and manufacturing processes can be validated, NASA is developing and ground-testing six components of existing transport aircraft; these components have been made from advanced composite materials up to 30 percent lighter than metal. Ten upper aft rudders for the DC-10 were produced from composite materials in 1977. The second component, the vertical fin on the L1011 aircraft, completed its critical design review and entered design verification testing. Experience to date indicates that, when produced in sufficient quantities, the composite components will compare favorably in cost with their metal counterparts.

### *Reducing Undesirable Environmental Effects*

*Emissions Reduction.* Work on experimental clean combustors, seeking to reduce the exhaust emissions from large turbine engines during landing and takeoff, has been completed. Emission levels were significantly below those of conventional engine combustors and comparable to the emission standards set for 1979 by the Environmental Protection Agency. The experimental data are being used by the Environmental Protection Agency in evaluating emission-level standards for all future engine classes.

Work has begun on a program to reduce aircraft emission during stratospheric cruise. Concepts for fuel preparation and combustors are being sought which can reduce emissions of oxides of nitrogen at the power settings and atmospheric conditions

of high-altitude flight. Such a reduction would reduce the possibility of destruction of atmospheric ozone. Laboratory tests in other studies have indicated that enriching fuel with hydrogen during fuel preparation is a concept which permits leaner fuel/air burning and thus reduces the formation of oxides of nitrogen.

*Aircraft Noise Reduction.* One type of low-level nozzle being investigated is the inverted-velocity-profile nozzle. In this configuration the high velocity of the jet occurs in the outer region rather than at the center as in the conventional bypass exhaust systems. Combinations of inverted-velocity-profile nozzles and advanced multi-element mechanical suppressors were tested in wind tunnels in varying arrangements in 1977. Preliminary analysis of the data suggests that such sequences can prove fruitful in reducing high-velocity jet noise.

Significant progress was also made in understanding of sound attenuation, propagation, and radiation from the engine inlet ducts. A new technique was developed which will aid in the rapid, efficient design of acoustic liners for ducts. The method accurately describes the far-field sound radiation pattern from ducts with far greater simplicity than was previously thought possible. An advanced bulk linear material was demonstrated in an integrated engine nacelle; it provides high acoustic efficiency with savings in weight.

In the study of human response to aircraft noise, a major effort has been to improve the bases for relating laboratory findings to community responses. Several studies to improve the noise descriptor for specific types of aircraft have been completed. Critical aspects of the human stimuli in helicopter and supersonic aircraft noise have been identified. The data are being used in the development of national and international noise standards.

In structural acoustics, development was begun of improved prediction methods for the transmission, absorption, and reflection of noise in airframe materials and structural configurations. Recent results show that structural weight requirements for noise attenuation may be reduced by as much as 50 percent by advanced design techniques.

### *Improved Safety and Terminal-Area Operations*

*Safety.* Aircraft fires, either in-flight or post-crash, are among the serious threats to occupants of aircraft. NASA is exploring several ways of controlling the propagation and intensity of fires. Through thermochemical modeling, NASA researchers have provided a useful analytical tool for guiding materials designers in structuring panels and cabin liners in ways that will in-

hibit flammability, rapid spread of fire, and the amount of smoke and toxic gas. New materials have been developed which offer potential gains in resistance to fires. Fire-resistant polyimide foams are being examined for possible use in seat cushions, one of the main sources of smoke and flame in aircraft cabin fires.

In a crash, a major link between the ignition sources—hot parts of the engine, electrical shorts, friction sparks—and a fire is the fuel-mist cloud that is generated by rupture of fuel tanks and lines when the aircraft crashes. NASA is applying basic chemistry in the study of aircraft fuel treated with small amounts of high-molecular-weight polymer additives; test results indicate that these additives inhibit the formation of fuel mist in crash situations.

Aircraft safety can also be improved if the persons who work in or use the national aviation system feel responsible and secure in reporting threats to safety which they have observed. In an effort to provide a buffer between the regulatory agency and these individuals, NASA has for the last two years operated the Aviation Safety Reporting System, in which complaints are submitted to it, synthesized, and worthwhile data are passed on to the Federal Aviation Administration for appropriate action. The system continues to be well supported by the aviation community, with more than 8000 reports submitted. Many of the reports have identified immediate safety problems; over 400 bulletins have been forwarded to the Federal Aviation Administration for investigation and corrective action. This year the emphasis has been on developing a computerized data base, from which it will be possible to analyze in detail the more pervasive safety problems.

*Terminal-Area Operations.* All-weather use of helicopters can be a major factor in future transportation. To fit them into the total pattern of terminal-area operations, helicopters must be equipped with flight and navigation instruments that will enable them to fly precisely prescribed flight paths to small landing pads while maintaining the required separation from other aircraft in the traffic flow in and out of the airports. Since helicopters have vastly different flight characteristics than other aircraft and impose a greater workload on pilots, their equipment and operating techniques cannot be mere spinoffs from conventional aircraft systems. NASA has successfully demonstrated operating systems and piloting techniques for safe operation of helicopters in adverse weather and in congested terminal areas. These demonstrations include some 60 manual approaches to landing, using cockpit displays providing the pilot with informa-

tion that enables him to perform complex approach trajectories in low visibility; they also include 30 fully automatic (hands-off) landings.

In cooperation with the Federal Aviation Administration, NASA is developing technology for advanced airborne systems and flight procedures that can improve terminal operations through effective use of advanced navigation, guidance, and communications systems being developed by the Federal Aviation Administration. One such system is the Microwave Landing System, a precision guidance system designed to replace the 35-year-old Instrument Landing System. A 737 aircraft, with display, navigation, and flight control systems representing the first application of all-digital systems to conventional transport aircraft, has demonstrated coupled approaches and automatic landings with the Microwave Landing System. The purpose of these flights was to demonstrate to representatives of the Organization of American States the maturity and integrity of the U.S. Microwave Landing System as a candidate for the new international precision-guidance landing system.

#### *Advancing Long-Haul and Short-Haul Aircraft*

*Long-Haul.* Several significant advances have been made in identifying advanced technology for supersonic transport that are economically attractive and environmentally acceptable. The standard technique for tailoring the size of subsonic transports from a basic design to fit other range and payload demands was to lengthen or shorten the fuselage. This approach was found not to apply to supersonic transports with their highly integrated and blended wing/fuselage designs. This year the U.S. applied for a patent on a new concept which involves lateral fuselage changes to provide wider or narrower cross sections for the cabin area of supersonic transports. Also flight research with the YF-12 aircraft demonstrated for the first time that improved high-speed handling and ride qualities were achievable with a cooperative control system, which integrated aircraft, inlet, and engine controls. In ground-based research, structures made of superplastically formed titanium were tested, as were low-speed aerodynamic improvements for noise reduction and the verification of coannular-nozzle acoustic suppression for concepts of the variable-cycle engines.

*Quiet Propulsive-Lift Technology.* In August 1977 the inflight measurements on the Boeing YC-14 and the Douglas YC-15 aircraft were completed as part of the test and evaluation of the USAF Advanced Medium STOL Transport prototype aircraft. Now being compared with analytical estimates and ground-test data to develop improved

design techniques for future transports, these measurements included thermal and acoustic environment on the wing flap systems, interior and flyover noise, engine-inlet acoustics, and handling qualities.

The Quiet Short-Haul Research Aircraft made substantial progress in 1977 with the completion of fabrication, assembly, and installation of the new propulsive-lift wing, new engine nacelles, and fuselage modifications. Scheduled for delivery to NASA in 1978, this aircraft will be used to validate in flight the design and operational technology needed by the U.S. aviation industry to develop quiet short-takeoff-and-landing transports and by Federal regulatory agencies to establish appropriate certification standards.

#### *Technical Support to the Military*

The support by NASA of military programs advances broad-based technology for use by the military in developing future generations of military aircraft.

*Stall-Spin Research.* Investigation of stalls and spins has proceeded for several years because of the undesirable departure and spin characteristics of modern fighter aircraft. Losses from spin-related accidents have averaged 70 aircraft and 38 airmen per year. NASA's Langley Research Center, in cooperation with the USAF, has contributed to the reversal of this trend through its research in aerodynamics and control systems. The F-15, F-16, and F-17 aircraft are highly spin-resistant as a result of this research. Currently the aerodynamics and control systems of the F-18 are being tailored to provide a high degree of resistance to spin. Basic re-

search on nose shapes for aircraft is seeking design data on spin resistance to be used early in the design cycle of future fighter aircraft.

*Airframe/Propulsion System Interactions.* The very large turbofan engines being used in modern fighter aircraft have caused propulsion aerodynamics to react with the aerodynamics of the airframe for a larger effect on performance than in previous designs. NASA has used the F-15 in flight tests and models of the aircraft in wind-tunnel measurements to provide data for designers of future aircraft, enabling them to optimize performance by including the effects of propulsion-system aerodynamics in their basic design.

*NASA/Military Flight Programs.* The joint NASA/Air Force Highly Maneuverable Aircraft Technology program has moved to the point where the prime contractor has fabricated parts for the two flight vehicles and is now in final assembly, with delivery of the first vehicle planned for early in 1978. The NASA/Air Force Transonic Aircraft Technology program has been completed and its data are available to the industry, showing wind-tunnel-to-flight correlation for supercritical wings.

NASA and the Air Force have two joint helicopter-research programs: the Rotor Systems Research Aircraft and the Tilt Rotor Research Aircraft. The first of these has completed its initial operational checkout flights and is being readied for research flight testing, using both the rotor system and wings for lift. The Tilt Rotor Research Aircraft has finished its initial hover flight tests and is now in the ground-test program that precedes the full-scale wind-tunnel tests and the first transition flight.

# III



# Department of Defense

## Introduction

Department of Defense aeronautics and space developmental activities are fundamental to national security. Aeronautical activities support the national defense role in terms of tactical and strategic aircraft and cruise missiles, airborne early warning, ground and ocean surveillance, amphibious and ground/air assault mobility, and air mobile command, control, and communications. Space activities support the national defense role in terms of mission support for communications, navigation, weather and ocean forecasting, and surveillance.

## Space Activities

### *Space Systems and Programs*

*Military Satellite Communications Activities.* Defense requirements for satellite communications call for three categories of service: (1) high-capacity, long haul trunking (point-to-point communications), (2) moderate-capacity mobile-user service, and (3) strategic-force command and control. Military communication links, including those using satellites, must have an anti-jam capability which civil systems do not need, so that hostile enemy activity cannot degrade our military satellite communication systems. In the near term these services are satisfied by (1) the Defense Satellite Communications System, Phase II (DSCS II), (2) the Fleet Satellite Communications System (FLTSATCOM) plus leased services on the maritime satellite (Marisat), and (3) the Air Force Satellite Communications System (AFSATCOM), consisting of the Satellite Data System (SDS), FLTSATCOM, and other host satellites. At varying times in the future, these near-term systems will be replaced by (1) the DSCS III, (2) the General Purpose Satellite Communications System (GPSCS), and (3) the Strategic Satellite System (SSS). Each of these military satellite communications programs will be described in more detail.

**DEFENSE SATELLITE COMMUNICATIONS SYSTEM.** The primary mission of the Defense Satellite Communications System (DSCS) is to provide rapid, reliable, and secure satellite communications for the National Command Authorities and to contribute to the Worldwide Military Command and Control System. The system has provided exceptional communications support to the National Command Authorities.

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 deployed over the Atlantic and Western Pacific Oceans, DSCS II satellite (number 4) launched in December 1973 and recently moved from the western Pacific to the Indian Ocean, and NATO IIIB obtained on loan for temporary use over the eastern Pacific Ocean. A dual launch of DSCS II satellites (numbers 9 and 10) is scheduled for March 1978 to replace the Indian Ocean satellite and the NATO IIIB satellite, which must be returned to NATO in accordance with the temporary loan agreement. DSCS II satellite numbers 11 and 12 will be available for dual launch in November 1978. In addition, the Air Force has contracted for four additional, higher powered DSCS II satellites (number 13 through 16) to replenish the DSCS space segment in 1979-1980.

Ground terminals for DSCS are provided by the Army. During 1977, a total of seven new terminals with 19-meter antenna reflectors became available for operational use. Additional digital modulation equipment procured by the Army represents progress toward an all-digital system.

The next generation of DSCS satellites will be DSCS III models. A contract was awarded in 1977 for the development of one qualification model and two R&D flight models. The first R&D satellite (DSCS IIIA) is scheduled for launch in mid-1979 for about one year of R&D test and evaluation. The second R&D satellite (DSCS IIIB) is scheduled

for launch in mid-1980 for about a six-month test period. 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, the DCSC 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 controlling reconfigurations of communications channels. The satellite will conform to nuclear survivability guidelines and will have a design lifetime of about six 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.** Moderate capacity, mobile-user service will be provided by the Fleet Satellite Communications System (FLTSATCOM). Its objective is to develop, procure, and implement a satellite communications system to satisfy the most urgent, worldwide, tactical and strategic communications requirements of the U.S. Navy and U.S. Air Force. Production contracts for the first three FLTSATCOM spacecraft have been awarded. The first launch is scheduled for early 1978. Installation of fleet broadcast receivers is virtually complete, with shipboard transceivers and information exchange systems in over 200 ships and 40 submarines. The third leased Marisat spacecraft became operational in 1977, thereby providing virtually worldwide UHF satellite communications. The shipboard terminal equipment will be operated through both the Marisat and FLTSATCOM systems. Installation of secure voice shipboard terminals commenced in 1977.

In the future, this class of service will be satisfied by the General Purpose Satellite Communications System (GPSCS) to support mobile users of the Army, Navy, Air Force, and Marines. During 1977, a joint program office was established for the GPSCS.

**AIR FORCE SATELLITE COMMUNICATIONS SYSTEM.** The Air Force Satellite Communications (AFSATCOM) System will provide command and control communications for strategic forces. The space segment includes UHF transponders on several spacecraft types, including FLTSATCOM and the Satellite Data System (SDS).

The AFSATCOM terminal segment will consist of airborne, mobile, and fixed terminals. Terminal deployment will begin in 1978. Planning for the concept for a Strategic Satellite System (SSS) as a follow-on to AFSATCOM is under way.

**ARMY SATELLITE COMMUNICATIONS ACTIVITIES.** The Army Satellite Communications Ground Environment includes the development 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.

**DEFENSE SATELLITE COMMUNICATIONS SYSTEM SUPPORT.** The U.S. Army has completed the modification of all existing DSCS ground terminals to upgrade their reliability and communications capacity. Two AN/FSC-78 terminals have been installed and are operational at Fort Detrick, Maryland. Seventeen more have been procured to satisfy the needs of the DSCS and, by the end of 1977, were installed worldwide. The contract for 21 AN/MS-61 medium terminals is scheduled to be awarded by March 1, 1978. The AN/TSC-86 light transportable terminal contract was awarded September 30, 1977, for three terminals. A contract for an additional three terminals was awarded on October 30, 1977.

**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, those terminals will provide mobile, multi-channel communications for the ground mobile forces transmitting through the DSCS satellites from the field. Engineering development has begun on a UHF manpack terminal and for a UHF vehicular terminal.

The interim operational capability provided by the test models continues to support various contingencies and field exercises. Operational testing through the year has assisted in refining concepts for use of this significant transmission medium in support of combat readiness operations.

**INTERNATIONAL COOPERATION IN SPACE.** The United States and the United Kingdom continued to operate under an agreement whereby the U.S. and the U.K. would exchange an essentially equivalent amount of satellite capability between U.S. DSCS and U.K. Skynet satellites, and to interoperate with each other's Earth terminals.

The U.S., U.K., and NATO continued in agreement for a post-1975 communications satellite arrangement. The parties will exchange satellite



capacity during specified conditions and will 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, the U.S. has had the exclusive use of the NATO IIIB satellite during 1977. This arrangement will continue until spring 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.

Progress continues toward establishing the U.S.-U.S.S.R. Direct Communication Link, which uses satellite communication circuits via Intelsat and Molniya satellites. The link was created in accordance with the 1971 Strategic Arms Limitations Talks agreement between the U.S. and U.S.S.R. Since August 1976, the Molniya system has been usable 24 hours a day, and end-to-end testing continues, using both Intelsat and Molniya.

### *Navigation Satellite Activity*

The Navy Navigation Satellite System, referred to as Transit, achieved its twelfth year of operation in 1977. The purpose of developing Transit was to provide a worldwide, two-dimensional system for position fixing to an accuracy of better than one half of a kilometer—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 offshore oil exploration and measurement of the drift of ice over the poles. The six 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 Navy navigation satellite, was placed in orbit. In addition to navigation equipment, this Transit carries two specially instrumented transponders or radio relays called translators. These translators will be used to test a Trident Missile Tracking System (SATRACK) and to check out and calibrate range safety ground stations and equipment.

Since the early 1970s, a Transit improvement program has been under way. The improved satellites will provide greater survivability, as well as a disturbance 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) 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 satel-

lites in three orbital planes at 20,400 kilometers, 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. Six satellites will be launched by the end of 1978. Development models of all classes of user equipment, including high-accuracy, low-cost, and man-pack models, will be extensively field tested.

Navigation Technology Satellite Number 2 (NTS 2), developed by the Naval Research Laboratory, was launched in June 1977. NTS 2 is principally a test bed for advanced frequency standards which are the key to the precise positioning capability of the NAVSTAR system. NTS 2 carries a navigation payload identical to that to be launched in 1978 in support of the system validation program.

*Defense Meteorological Satellite Program.* The Defense Meteorological Satellite Program (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. During 1977, the first of the new generation Block 5D satellites became operational, providing visual and infrared cloud cover imagery of heretofore unequalled quality. The second Block 5D satellite was launched into a dawn-dusk orbit and was declared operational in July 1977. In addition to imagery, both of 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. Feasibility has

been demonstrated by measurements conducted in 1977 by the Naval Research Laboratory. Four of the sensors are planned for deployment on DMSP satellites in 1980-1984. DoD continued to cooperate with NASA and the National Oceanic and Atmospheric Administration in development of the Tiros-N domestic weather satellite. The Tiros-N satellite will use an adaption of the DMSP Block 5D spacecraft but with different sensors.

*Space Shuttle.* The Concept Validation Phase for the Inertial Upper Stage (IUS) (formerly the Interim Upper Stage) development for Space Shuttle use is planned to be completed in February 1978. This phase has defined four IUS configurations to meet the high-altitude mission requirements of the DoD and NASA. The Full Scale Development Phase of the IUS is planned to begin in March 1978.

The Air Force acquisition efforts for a Shuttle launch and landing capability at Vandenberg Air Force Base, California, continue with definition of the facilities and support equipment requirements planned for completion during 1978. Design efforts for the planned facility construction in FY 1979 are well under way. The environmental statement associated with the planned construction activities has been released for public comment.

*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 surplus ICBM Atlas E/F vehicles. These boosters launched 12 DoD space missions during 1977: 5 Titan IIIs, 1 SM-75 Thor, 4 Atlas, 1 Scout, and 1 Delta (the Scout and Delta being launched by NASA for DoD). To correct reliability deficiencies in the Titan III, an effort to integrate the Inertial Upper Stage and its redundant avionics into the Titan III family of launch vehicles was initiated in June 1977.

*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. The two payloads flown in 1977 were the Navy Navigation Technology Satellite (NTS 2) and a geodetic package (NAVPAC), the first of three such geodetic satellites being placed in orbit. The remaining two NAVPAC's are scheduled for FY 1978 launch.

Environmental experiments are to be flown on NASA's Long Duration Exposure Facility (LDEF). The LDEF is a reusable, gravity-gradient-stabilized, free-flying structure on which many experiments can be mounted. It will be placed in orbit by the Shuttle and remain there for at least six months

before being retrieved. This will allow the effects on materials to be tested. NASA agreed to assign at least four of the LDEF trays for DoD use on Orbital Flight Test No. 3.

### *Space Research and Technology*

Space-related research and technology by the Department of Defense includes effort defining the space environment and assessing its effect on the performance of DoD systems operating within it. One program is to measure atmospheric density and composition by means of rocket observations and accelerometers on satellites. Another continued interest is the measurement and monitoring of charged particles and electric fields in space. Data from an earlier satellite (S72-1) continue to be used for improving models of the particle population of the Earth's Van Allen radiation belts.

The Defense Advanced Research Projects Agency (DARPA) is developing concepts, designs, and technology for advanced strategic surveillance from space. New concepts in optics, detector arrays, and signal processing will provide a capability for a wider range of future mission options. The DARPA 301 gamma-ray spectroscopy project, to be launched in mid-1978, 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 1978. Progress in detector arrays has allowed DARPA to initiate the Teal Ruby experiment to demonstrate detection of strategic vehicles from space. Currently scheduled for launch in March 1981, this experiment will gather spectral and spatial scene-intensity data and provide a demonstration of advanced detector technology.

*Solar Radiation Monitoring Program.* The Navy solar monitoring program in 1977 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 prediction system under evaluation at the Naval Communications Station, Stockton, California. The Naval Research Laboratory pursued 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 propagation-environment prediction, 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 emissions. Working closely with NASA scientists, Air Force personnel are studying the variation of solar UV observed by spectrophotometers on Atmosphere Explorer C, D, and E satellites. Rocket flights designed to measure solar UV flares between 230 and 1220 Angstroms continue to be flown and, in conjunction with satellite measurements, used to develop models of the solar UV emission spectrum.

*Environmental Remote Sensing.* Significant Navy accomplishments in 1977 included the completion of the installation of the Satellite Data Processing Center at the Fleet Numerical Weather Central, Monterey, California. The center will process real-time data from the Defense Meteorological Satellites (DMSP), and will receive and process real-time satellite data from the NASA Seasat-A project after the satellite is launched in May 1978. Data from these satellites will provide global ocean data for inputs to atmospheric and oceanographic operational analysis and forecasts. Significant progress has been made in developing applications of infrared imagery from DMSP and NOAA satellite data in observing sea-surface thermal structures and locating oceanic fronts, eddies, and water masses. Several 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 capability also supports the National Climate Program.

The Air Force Geophysics Laboratory continues to monitor space environment-induced effects as observed at the surface of the Earth. Using transmissions from beacons on both orbiting and geostationary satellites, scientists are measuring ionospheric scintillation and signal time delay at a number of ground stations around the globe. These measurements indicate signal statistics (fade margins, message reliability) for satellite communications systems and positional accuracy for navigation satellite systems and Air Force surveillance radars.

The Air Force Space Technology program under overall management of the Space and Missile Sys-

tems Organization (SAMSO) is oriented toward development and orbital demonstration of advanced prime mission equipment and supporting subsystems. The primary objectives of these new developments are performance, survivability, and reliability.

In advanced space communications, the Lincoln Experimental Satellites (Les 8 and 9) concluded a highly successful test program which demonstrated spread-spectrum, jam-resistant EHF and UHF communications with aircraft, ships, and Earth terminals. Advanced electromagnetic and physical survivability techniques were tested. The Les 9 satellite was turned over to Air Force Communications Service in October 1977 for operational employment. Research and development tests continued using the Les 8 satellite.

The technology of satellite space power systems advanced with the fabrication and testing of high-efficiency silicon and gallium arsenide solar cells and the orbital demonstration of a nickel-hydrogen battery, intended to replace current nickel-cadmium spacecraft batteries.

In advanced early warning sensors for missiles, Space and Missiles Systems Office continued the development of critical components of a mosaic staring sensor. Such a sensor offers inherent performance and survivability advances over current line-scanning sensors. The objective is earlier, more precise detection of launches of hostile missiles.

### *Space Ground Support*

DoD space activities are principally supported by the Army's White Sands Missile Range; the Navy's Pacific Missile Test Center; and the Air Force's Eastern Test Range, Space and Missile Test Center, Satellite Control Facility, and Arnold Engineering Development Center. 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 (ETR).* The objective of the Air Force's ETR is to provide support to 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 1977, ETR provided support to Navy testing of Poseidon and Trident 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.

*Space and Missile Test Center (SAMTEC).* SAMTEC manages, operates, and maintains the Western Test Range (WTR) in support of DoD and NASA tests. WTR is a national range providing range tracking, data acquisition, and flight safety support for all ballistic missile, space launches, and aeronautical tests at Vandenberg Air Force Base, California. The number of launches remains at approximately 50 ballistic and space launches and 60 aeronautical flights per year. Major programs include Minuteman, Titan, F-15, E-3A, Bomarc, and Thor. SAMTEC is actively engaged in planning for Space Shuttle launches from Vandenberg AFB, which involves extensive construction of launch, maintenance, and logistic facilities.

*Satellite Control Facility (SCF).* The SCF continued to operate in a near flawless manner during 1977. Eighteen launches (13 DoD and NASA, 5 ballistic), 63,220 satellite contacts, and 51,551 network hours were supported during FY 1977. The major portion of the restoration of Guam Tracking Station was completed. Modifications to the network to provide essential support to the early NAVSTAR-Global Positioning Satellites were made, and various communications and data systems improvements were also completed. To reduce data processing at remote stations, a four-year program to centralize data processing at the Satellite Test Center was begun. By eliminating unnecessary equipment and associated manpower, this consolidation will produce significant savings by 1982. Development of SCF-compatible Timed Division Multiplex telemetry equipment was completed. Its procurement and network modification will begin in FY 1978. Studies of SCF support requirements generated by the DoD's transition to the Space Transportation System were continued.

*Arnold Engineering Development Center (AEDC).* AEDC is the Free World's most comprehensive complex of technical and support facilities designed to simulate flight environments on the ground. AEDC's work ranges from basic research and development associated with environmental testing to full-scale flight-hardware testing. In 1977, AEDC provided over 45,000 test hours in support of programs such as B-1 and F-16 aircraft, Air Launched Cruise Missile, Sea Launched Cruise Missile, and support to the Energy Research and Development Administration.

AEDC is acquiring the Aero Propulsion Systems Test Facility (ASTF), which will be capable of simulating the severe flight environments experi-

enced 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 possible costly modifications to completed propulsion systems.

*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 and Air Force programs include the Space Shuttle, Astrobee rocket, Aerospace Sounding Rocket Vehicle, and the Atmospheric Measurement Balloon Program. NASA programs that were supported included the calibration rocket program, upper atmospheric rocket sounding program using the Aerobee rocket, numerous smaller rocket systems, and a variety of astronomical test programs.

*Pacific Missile Test Center.* The Pacific Missile 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 1977 supported the DoD Global Positioning System, providing radar tracking, telemetry, and command destruct capability for the launch sequence, and using the NASA Advanced Technology Satellites (ATS 1, 3, and 6) for data relay. The Center is also engaged in planning support of the NASA Space Shuttle Orbiter.

*Kwajalein Missile Range (KMR).* The Army's Kwajalein Missile Range continued to provide, maintain, and operate a national range to support technological advances in both offensive and defensive strategic weapon test programs. KMR is our only range with the technical capability to obtain critical data associated with terminal ballistics of intercontinental ballistic missiles and support defensive testing technology. KMR radars have also provided backup tracking data for the NASA space program.

*National Parachute Test Range.* During 1977 the National Parachute Test Range continued support of NASA and DoD space programs, primarily for programs requiring an application of parachute subsystems. Principal programs supported were: the Air Force aerial retrieval system, NASA Space Shuttle booster recovery system, and the NAVSTAR Global Positioning System.

## Aeronautical Activities

### *Aircraft and Airborne Systems*

**F-16 Multimission Fighter.** After an extensive review of all aspects of the F-16 program, full production was approved; the first of the programmed 1388 aircraft will be delivered in August 1978. The full-scale development test program continued on schedule, with five aircraft currently flying and three more scheduled for 1978 delivery. The F-16 European partners—Belgium, Norway, The Netherlands, and Denmark—signed formal agreements in May 1977 for 348 aircraft. With almost \$2 billion of F-16 contracts in Europe, this is the largest co-production program ever initiated and a significant step toward standardization of NATO weapon systems. Iran became the first official Foreign Military Sales customer by signing an agreement to purchase 160 aircraft.

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

Three research, development, test, and evaluation aircraft are currently flying in the test program at Edwards AFB, California, to measure overall performance, gather data on structural air loads, and evaluate the offensive avionics subsystem. Primary emphasis has been placed upon low-altitude terrain-following penetration equipment, weapons delivery capabilities, navigation, communications, and overall system performance.

**A-10 Close-Air-Support Aircraft.** The Air Force plans to procure 733 A-10s to provide a specialized close-air-support aircraft. The A-10's research and development is complete, except for new systems being added to improve effectiveness. Of the 339 aircraft approved for production, approximately 75 have been delivered to Tactical Air Command. The first operational squadron was activated in June 1977; the planned initial operational capability was accomplished in October 1977, approximately three months ahead of schedule. Favorable reliability and maintainability have continued, so the anticipated low operating costs should be realized.

**F-15 Air Superiority Fighter.** The last of the F-15 development program milestones was successfully passed early in 1977. A limited development effort will continue to complete threat updates to the electronic countermeasures equipment and various other component improvements.

Production deliveries of the F-15 continued at the rate of nine aircraft per month throughout the year and a total of more than 250 aircraft had been

delivered to the Tactical Air Command and United States Air Forces in Europe by the year's end. The second and third of a planned six combat wings were activated during the year at Bitburg AB, Germany, and Holloman AFB, New Mexico.

**F-18 Carrier-Based Strike Fighter.** The Navy's McDonnell Douglas/Northrop F-18 aircraft will become the replacement for the remaining Navy and Marine F-4 Phantom fighters as they reach the end of their service life. An attack version of the same aircraft will begin replacing 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 defeating the projected air threat and surviving over hostile territory. The F-18, though not as sophisticated as the F-14 Tomcat, will complement the F-14 in maintaining maritime air superiority. The Secretary of Defense has approved full-scale development of this aircraft, with first flight planned for October 1978.

**F-14A Carrier-Based Tactical Fighter.** F-14A Tomcat squadrons are now routinely making extended deployments on carriers of the Atlantic and Pacific Fleets. Twelve operational and two training squadrons have completed transition to this aircraft and two additional squadrons are programmed to receive the Tomcat in 1978. The F-14A continues to prove its versatility as a highly maneuverable and agile fighter.

**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 much more capable AV-8B.

The AV-8B is an improved, vectored-thrust V/STOL aircraft based on the AV-8A concept and the current Pegasus 11 engine. The airplane incorporates a supercritical composite wing, redesigned inlets, and lift improvement devices. The AV-8B, produced by McDonnell-Douglas Corporation with Hawker Siddeley of the United Kingdom as the principal subcontractor, will be equipped with angle-rate bombing systems for improved accuracy in weapon delivery.

The AV-8B program has completed the initial phase of full-scale wind tunnel testing 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 with McDonnell Douglas Corp.

**Advanced Medium STOL Transport (AMST).** The AMST completed Phase I prototype program in 1977. Objectives of the advanced development program were to demonstrate STOL technology,

evaluate operational utility, and provide an option for modernization of our aging tactical airlift force. The AMST prototypes demonstrated these objectives. However, the projected production and operating costs of this sophisticated aircraft design are not sufficiently offset by its operational utility to justify continuing the program.

The Boeing YC-14 and McDonnell Douglas YC-15 prototypes completed their flight testing in August 1977. These four aircraft accumulated 1397 flight hours and demonstrated satisfactory performance against all goals of the Phase I flight test program.

*UH-60A Black Hawk.* The Army requires a helicopter that provides combat support and combat service support necessary to sustain ground forces engaged in land warfare.

Air frame engineering development contracts were awarded to Boeing Vertol and Sikorsky in August 1972, with a contract to General Electric for development of the T-700 engine preceding the air frame awards in March 1972. During the competitive development phase, each airframe contractor built three flying prototypes and flew over 600 flight test hours. The government flew over 700 hours during the "fly-off" evaluation. The T-700 engine experienced over 30,000 hours of development and field testing.

Sikorsky was awarded an \$83.4-million production contract on December 23, 1976, for 15 aircraft, with options for 353 additional Black Hawks over the next three years. First production delivery is scheduled for August 1978. General Electric was simultaneously awarded a \$38.3-million engine production contract.

*Advanced Attack Helicopter.* After a prime airframe contractor was selected in December 1976 to continue development, Phase II—full engineering development—continued during 1977. The primary emphasis is the total systems integration of the armament and fire control. Competitive contracts were awarded in March 1977 for development of the target-acquisition-designation and pilot-night-vision subsystems, which are parts of the fire control system. Aircraft efforts were directed toward design and testing of the airframe modifications stemming from evaluation of the Phase I aircraft in 1976. Fabrication of the additional flying prototype aircraft was deferred until 1978 because of fiscal restructuring of the program.

*Cobra/Tow.* The Cobra/Tow program, including a retrofit of 290 of the existing Cobra helicopters and purchase of 324 new aircraft with the highly effective Tube Launched Optically Tracked Wire Guided (Tow) Missile, was continued in 1977. Deliveries of the retrofitted Cobra helicopters began in June 1975 and were completed in October

1977. Testing the upgraded engine, transmission, and dynamic components—Improve Cobra Agility and Maneuverability (ICAM)—was completed in May 1975. These ICAM components are incorporated in the 297 new aircraft on which deliveries began in March 1977. The Army's plans include the retrofit of an additional 400 Cobra helicopters and a modernization program of the Cobra/Tow fleet. The modernization program will substantially increase secondary armament capability; survivability; and the reliability, availability, and maintainability. The modernization program also includes a new main rotor blade of composite materials now in final demonstration in the technology base that will increase survivability and double the blade life.

*CH-47 Modernization.* The CH-47 modernization program is designed to increase the life of the CH-47A, B, and C models and improve the performance of the A and B models. The intent is to modify three prototypes through development and testing of seven modernized systems; rotor, drive, hydraulic, electrical, advanced flight control, cargo handling, and auxiliary power unit. Integration of these systems will improve reliability, availability, maintainability, safety, and survivability.

*E-3A Airborne Warning and Control System (AWACS).* The first E-3A AWACS was delivered to the Tactical Air Command at Tinker AFB, Oklahoma, on March 24, 1977. This delivery culminated a successful program to develop a high powered airborne surveillance system capable of detecting and tracking aircraft at all altitudes and over all terrains.

*EF-111A Tactical Jamming System.* The EF-111A is being designed to provide ground and airborne radar jamming in support of all tactical air missions. The peacetime mission will be to provide training in electronic countermeasures for our own air defense and tactical forces. Flight testing of the two prototypes was initiated in March 1977 and May 1977, respectively. All contractor flight testing was completed in September 1977. Government Development Test and Evaluation (DT&E) and Initial Operational Test and Evaluation (IOT&E) are scheduled from October 1977 through April 1978.

*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 antiship version and a nuclear-armed land attack version.

The antiship Tomahawk is essential to Navy general-purpose forces in a sea-control offensive/

defensive role. Tomahawk will provide an important complement to carrier-based air in extending the Navy's antiship capability over a broad ocean area. If they are to have a flexible sea control capability, 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 on 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 survivability make it particularly suitable for use in limited nuclear attacks.

Tomahawk is planned for installation on attack submarines, cruisers, and Spruance-class destroyers. A ground-launched version of Tomahawk is being developed for the Air Force.

*Pave Low III.* The Air Force's prototype H-3 combat rescue helicopter equipped with Pave Low III completed initial flight testing in 1977. Using forward-looking infrared devices, terrain-avoidance/following radar, and inertial/Doppler navigation, the system permits low-level penetration of unfriendly territory and aircrew recovery under conditions of total darkness and adverse weather. An invaluable addition to the military rescue fleet, Pave Low III blends the latest, state-of-the-art electronics with a time-tested, long-range rescue vehicle to provide the only system of its type capable of surviving the intense hostile environment predicted for tomorrow's combat situation.

*Joint Tactical Information Distribution System (JTIDS).* The JTIDS program objective is to develop a highly flexible data network to satisfy multiple tactical operational users. When deployed it will provide high-capacity, jam-resistant, low-probability-of-intercept communications to interconnect all participants in an area of tactical military operations. JTIDS employs modern spread-spectrum and time-division multiple-access technology to provide multi-access, jam resistant communications as well as accurate relative navigation with other cochannel transmissions such as IFF and Tacan.

With the Air Force acting as lead service, all services are participating in this program, and a joint program office has been established. Initial operational application of the early phase of JTIDS will be in the Air Warning and Control (AWACS) aircraft. When fully deployed, it is anticipated that JTIDS will afford the means for close coordination of forces of all services.

## *Aeronautical Research and Development*

*Aircraft Structures and Materials Technology.* Each of the services has research and development programs directed toward its needs for improved structures and materials for aeronautical and space applications. Among these is the Navy's engineering development program initiated to develop a fiberglass composite rotor blade as a replacement for the CH-46 metal rotor blade. The fiberglass rotor blade is designed to be corrosion resistant, provide no environmental degradation, be insensitive to small defects, have slow failure propagation with a change in stiffness warning, require only visual pre-flight inspections, and increase mean time between repairs by 500 percent. This blade will significantly increase the effectiveness of the CH-46 helicopter fleet.

The Navy's composite aircraft structures program continues to demonstrate significant progress. Components which have completed laboratory static and fatigue tests include the S-3 spoiler, F-14 overwing fairing, F-14 main landing gear door, and a wing for BQM-34E supersonic target vehicle. Additional components are being fabricated to be placed on operational aircraft and monitored over an extended period to answer critical technical questions as well as increase confidence in graphite composites. This program will provide the Navy with long-term experience in composite structures in an operational environment, extend design and fabrication technology to large primary structures, and establish greater confidence in acquisition/life cycle cost projections.

After several years of development work, composite structures began to accelerate into the Army inventory in 1977. Both the Black Hawk and the Advanced Attack Helicopter began flying in 1977 with composite aerodynamic surfaces and fuselage structural components. The AH-1 Cobra gunship received new composite main rotor blades and the CH-47 cargo helicopter got the composite rotor blades portion of its overall modification/improvement program. A plan to retrofit composite rotor blades onto the UH-1 and OH-58 fleets was developed to reduce the life cycle costs of these operational aircraft. In 1977, research and development efforts continued toward producing from composite materials safer, lighter, and more durable rotor hubs, crashworthy landing gear, and less vulnerable fuselage structures, with savings in weight and cost.

*Advanced Helo Rotor System.* The Advanced Helo Rotor System's objective is to prove the flight feasibility of the Circulation Control Rotor (CCR) concept with a full-scale system in which design-to-cost goals and trade-off parameters will be established for the rotor system. The CCR system is to

be capable of replacing all existing helicopter rotor systems without any inherent operational limitation. Operating on the basic principle of a trailing-edge boundary-layer blowing system, the rotor blade is provided cyclic control by air modulation, eliminating conventional rotor head complexities (swashplate, lead-lag hinges, and flapping hinges), improving aircraft maneuverability, reliability, maintainability, and reducing overall vibration levels. The first full-scale CCR blade was fabricated during April and the first full-scale whirl test of the complete CCR system will begin in February 1978. The X-wing concept utilizes CCR technology and high-speed rotor technology (Reverse Velocity Rotor). The X-wing program will demonstrate the feasibility of the high-speed rotor and X-wing concept in parallel with the CCR program; both programs are scheduled for completion in FY 1979.

*Helicopter Acoustic Research.* Experience gained by correlation of in-flight and wind-tunnel acoustic data has accumulated and a "quiet" rotor blade design has been initiated. Instrumentation for a permanent measurement system of in-flight far-field noise has been completed. A hover test facility is being calibrated, and an experiment to provide acoustic data for a parametric variation of rotor geometry is being initiated. These efforts are all aimed at reduction of acoustic detectability.

*Advancing Blade Concept (ABC) Demonstrator Aircraft.* Helicopter technology has progressed to the point where many of the unsolved problems are concerned with high-speed maneuvering flight. One design concept which promises to alleviate some of these problems incorporates co-axial, counterrotating rotors. In December 1971, the Army contracted with Sikorsky Aircraft to design, construct, and flight-test this concept; the resulting aircraft is called the Advancing Blade Concept (ABC). The ABC completed its flight tests in the pure helicopter mode in the spring of 1977, attaining speeds up to 320 kilometers per hour. In a program just getting underway, the Army, Navy, and NASA have joined forces to fund high-speed (up to 550 kilometers per hour) tests of this concept. The test aircraft has been fitted with thrusting engines (loaned by the Air Force) and is now preparing for further tests.

*Helicopter Rotor Aerodynamics.* Both civil and military helicopters suffer from high vibratory loads. These vibratory loads increase operating costs by causing frequent replacement of components and contribute to pilot fatigue and passenger discomfort. A number of investigations are underway to understand the basic aerodynamic mechanisms causing these loads and to develop design techniques to alleviate them while improving or maintaining aerodynamic performance.

The effect of the shape of the tip of the blades on noise and vibration is being studied. As a consequence of this program, the rotor tip on a test UH-1 was modified into an ogee shape, reducing noise and vibratory loads, and, for this particular rotor, increasing aerodynamic performance. A rotor with an ogee tip shape is presently being fabricated for testing next year on the AS-15 Cobra.

The French and the U.S. Army are pursuing a joint program to understand the role of transonic aerodynamics in vibratory loads. The French have completed experiments on a non-lifting rotor with both square and swept rotor tip shapes. The Army has found good agreement between these experiments and analysis for the square rotor tip and is now performing the analysis on the swept tip shape.

An investigation of a high-energy rotor system resulted in the demonstration of an OH-58 modified to provide high rotor inertia that could autorotate safely from any altitude and speed. This investigation will continue next year to define the design constraints of such a rotor system.

*Helicopter Aerodynamic Launch Environment.* Attack helicopters experience a number of launch transients, such as vibration, rotor downwash, and rotation/translation of the aircraft. Because these factors affect the first few meters of a missile's trajectory, the resultant errors cause impact dispersion at the weapon's potential target. Model testing on the AH-1G utilizing laser techniques, flow visualization, and rotor wake theory has aided mapping of the rotor flow field. In addition, low-air-speed sensors have been tested and strategically located on the aircraft to provide the pilot with previously unavailable airspeed readings. Investigations by the Army are continuing to utilize these data for fire-control augmentation which should ultimately improve weapon accuracy.

*Remotely Piloted Vehicles (RPV).* The Army is conducting a system technology program to demonstrate that a small airborne RPV can obtain reconnaissance and target acquisition information beyond the forward edge of the battle area. Its application is for those high-threat situations where probability of survival of manned systems is unacceptably low. The full-scale RPV, including a TV sensor and laser range finder/designator, has a wingspan of 3.7 meters and weighs 66 kilograms. It flies at speeds under 180 kilometers per hour, yet will be extremely difficult to shoot down. A contractor validation program consisting of 65 flights was completed in July 1977. The Air Force and Navy have limited RPV programs which complement this Army program.

*Helicopter Avionics.* After a successful competitive, design-to-cost engineering development program, the AN/ASN-128 Doppler navigation sub-



system entered production. The AN/ASN-128 will provide Army helicopters a self-contained tactical navigation capability. Range and bearing to ten checkpoints, as well as present position, are provided to the crew. First applications will be to the Black Hawk and the AH-1S.

Competitive, design-to-cost engineering development contracts were awarded 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.) and save cockpit space and improve the man-machine interface. Prototypes will be delivered during FY 1978.

*Electronics For Aviation.* The pervasive role of electronics in aeronautics and space continues to grow. The current generation of large-scale integrated circuits and techniques today is making many electronic functions that were promised by the transistor generation affordable and reliable. The greatest impact has been in the area of microprocessors for control, guidance, and built-in test. The advances in electro-optics and microwaves have also been impressive in their impact on the sensor capabilities of modern aircraft.

The direction of advanced electronics for aeronautics can best be shown by examining three technologies—electro-optics, microwaves, and computers—and by how each affects a variety of systems.

**ELECTRO-OPTICS TECHNOLOGY.** Electro-optics is still an emergent and rapidly growing technology. The revolutionary development of the laser and the evolutionary development of low-cost, compact television cameras have led to TV homing and laser designated precision weapons. However, electro-optics technology is also incorporated in many other devices, such as infrared imaging devices, charge-coupled imagers and signal processors, ring laser gyros, fiber optics, and displays. Recent significant applications are:

- Laser designators have progressed farthest toward operational systems in the form of lightweight target designators and range finders. The PAVE SPIKE system, when integrated with the F-4's avionics, permits daytime delivery of laser-designated ordnance by the designating or other aircraft. The PAVE TACK infrared imaging system will provide F-4Es and F-111Fs with a day/night capability for ranging, tracking, and designation. The PAVE PENNY compact laser search-and-track system will allow various close-air-support aircraft, such as the A-10, to pick up targets illuminated by either an airborne or ground-based forward air controller.
- Infrared imaging devices provide a night operation capability for optical search and track

systems in addition to improved vision in inclement weather. One major emphasis has been the application of technology for cost reduction in the modular FLIR (Forward Looking Infrared) program, which will enable widespread employment of infrared imaging devices. A major thrust for the future is the development of two-dimensional arrays of infrared detectors to provide increased sensitivity, resolution, compactness, and reliability.

- A major advance in visible sensors has been achieved in the development of a miniature solid-state TV camera using charge coupled devices (CCD). This provides self scanning of the scene, thereby eliminating the vacuum tube, electron beams, high voltage supply, and filament. Apart from its size and reliability advantage, the camera has exceptional dynamic range (500 to one), greater sensitivity than vidicon tubes for low-light level viewing, 10-megahertz data rates, and digital system compatibility with sampled data outputs. Current technology efforts are directed toward larger arrays for increased resolution and techniques to extend the long-wave length response into the infrared.
- Fiber optics research has led to fibers with very low loss and to military quality connectors and transmitter-receiver modules. Fiber optics installed on the A-7 aircraft demonstrated the potential for lower weight and volume by factors of 20, increased reliability, lower initial and life-cycle costs, elimination of radio frequency interference problems, and reduced vulnerability to battle damage.
- Ring laser gyros are the subject of a coordinated Air Force, Navy, and Army program from exploratory through advanced development. The ring laser gyro has no moving parts in the conventional sense; instead, the measurement of frequency change of the laser beam is used to detect attitude changes. This offers great potential for higher reliability and reduced support costs. In addition, the laser gyro will be more resistant to shock, vibration, acceleration, and other requirements of a quick-response aircraft or missile environment. An experimental laser inertial navigator has demonstrated an accuracy of better than two kilometers per hour of flight time in actual flight test, which is about ten times better than previous laser gyro systems. Plans call for a completed navigation system in 1978 with production units available as early as 1980.
- Electro-optic displays using liquid crystals and light-emitting diodes are replacing cathode ray tubes and incandescent lamps for those applica-

tions where weight, volume, and ruggedness are at a premium. Current development efforts are aimed at cost-effective fabrication of larger area displays.

**RF AND MICROWAVE TECHNOLOGY.** Microwave technology for radar and communications is considerably more mature than electro-optics, but continues to show surprisingly vigorous evolution. First, for the signal generation function, solid-state devices satisfying the low power and low noise requirements at frequencies from UHF to millimeter waves have seen a decade of discovery and development. Second, there have been major advances in our ability to carry out sophisticated signal processing in ever shrinking package sizes.

- Gunn effect solid-state sources have completely displaced low-power klystrons for local oscillator and test generator applications from 5 GHz (gigahertz) to 35 GHz because of their low AM and FM noise and convenient operating voltages, typically 12 volts and less. Reliable operation for over 100,000 hours is now commonplace.
- Impatt diodes have shown impressive efficiencies and power output in the range above 6 GHz, where bipolar transistors have performance deficiencies. Combining the power outputs of several 30%-efficiency diodes has produced over 50 watts at 10 GHz, offering a new potential for medium-power solid-state transmitters. The advances have been achieved by increased understanding of the technology of gallium arsenide material.
- Gallium arsenide is also important for the latest solid-state power source, the Field Effect Transistor (FET). This device has recently demonstrated an output of more than one watt at 10 GHz, complementing its previously demonstrated low noise characteristics for signal detection. Its wide band-width and efficiency are of significance for electronic countermeasures where a single jammer must handle many threats at diverse frequencies. Current development efforts are directed toward increased yield to enable large scale integration of very-high-speed FET logic circuits.
- For fundamental reasons, vacuum tubes continue to supply the high-power transmitter sources needed for search, acquisition, and tracking radars. The emphasis here has been an increased reliability and lower life cycle costs. Combining pulse and carrier-wave performance in the same tube package is being pursued to achieve capability for electronic countermeasures with reduced volume.

- A major technological thrust is in signal processing to sort out target returns from cluttered backgrounds and to identify threat radars in a dense electromagnetic signal environment. Charge-coupled devices, surface acoustic wave filters, and microprocessors have all played a role here.
- An emerging interest is that of millimeter (mm) waves, which refers to wavelengths of one to ten millimeters, or corresponding frequencies of 30 to 300 GHz. Potential applications for mm waves include target designation, air-to-ground imaging, guidance for beam-riding missiles, low-angle tracking of surface-hugging missiles and aircraft, and short-range communications. Radiometric area correlators, which are airborne passive wave radiometers, are demonstrating the ability to navigate by using the natural radiation from surface features on the ground. If successful, the system will be very difficult to countermeasure and will operate in moderate rain and cloudy weather, where current infrared radiometer systems have difficulty.

**COMPUTER TECHNOLOGY.** Exploitation of the phenomenal growth of computer science is a major area of technological emphasis within DoD. Given the rapidly decreasing cost of hardware, a number of computer-based research areas offer the potential of providing a major impact on the aeronautical systems of the 1980s and 1990s. Major advances in hardware and software are occurring.

- Low cost, compact, and reliable microcomputers will revolutionize a variety of functions in missiles and aircraft. Air-to-ground missile target acquisition has been improved by adaptive threshold gating to enable the missile to distinguish a target from the ground clutter and noise. Computer correlation of terrain features, sensed by radar or passive radiometers, with previously stored mapping information can now be used to update the gyro controls for precise navigation over long distances.
- Present aircraft contain as many as a dozen minicomputers, handling functions such as navigation, altimetry, fire control, weapon delivery, search, and flight control. The Air Force's Digital Avionics Information System (DAIS) is a test bed to evaluate new systems architecture, in which information is transferred rapidly between the various parts with data processing at each sensor and data management via similar executive processors. Increased flexibility and modularity are the potential benefits.

- In addition to research aimed at developing better computer hardware, DoD is also placing increasing emphasis on using hardware capabilities more effectively, primarily through software improvements. The objective is cost reduction of the estimated \$3 billion DoD spends annually on software-related problems. The approach is to develop better tools for the software designer and to standardize on a minimum number of higher order languages.

*Synthetic Flight Training Systems (SFTS).* Two major events have occurred during 1977. First, the CH-47 Flight Simulator (FS), using a closed-circuit television camera which roves across a three-dimensional terrain model in response to the pilot's control inputs, was completed. The significance of this first Army visual simulator is the ability to perform various flight maneuvers, emergency procedures, and instrument flight at less cost and in complete safety.

Second, the Army will complete its acceptance for testing of the AH-1 Flight and Weapons Simulator (FWS). Using a camera model board similar to the CH-47 FS, but with a wider field-of-view, the AH-1 simulator is the first to incorporate weapons engagement along with the 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 complete the evolution from the UH-1 FS instrument training system to a full "combat mission simulator" with the capability to produce the sound and fury of the battlefield. Development will begin in 1979 with testing to be conducted in 1982.

*Research in Aircraft Propulsion Systems.* The Advanced Turbine Engine Gas Generator (ATEGG) 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 1977 include several successful demonstrations of variable-area turbines, lower cost design concepts and manufacturing methods, and burners with increased durability. Also realistic structural test methodologies have been completed 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 consumption by matching the engine cycle to changing flight conditions. The JTDE efforts are progressing toward demonstrations in FY 1978 and 1979.

*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.

*Research in Helicopter Propulsion.* The helicopter drive train and power plant have been significant contributors to high acquisition and high operating costs. A number of programs are underway to reduce that cost by developing design techniques that permit a gas turbine to achieve high performance while maintaining a simple, durable design. An advanced centrifugal compressor program is underway to develop a high-pressure-ratio compressor with a single centrifugal stage to replace existing designs that have from two to five axial compressor stages in addition to the centrifugal stage. The Army entered into contracts with Allison Division, General Motors, and AVCO Lycoming Division for a four-year program to develop advanced technology demonstrator engines (ATDE) rated at 800 shaft horsepower. The ATDE will reduce fuel consumption by approximately 20 percent while improving the power-to-weight ratio and reducing the installed vulnerable area by approximately 50 percent relative to current production engines. The ATDE program utilizes the results of previous Army component research to provide a significantly more durable engine at an affordable cost.

The drive-train program has focused on the potential for significant weight reductions with increased reliability. An advanced coupling program was completed this year that promises to provide a 14-kilogram weight reduction in the UH-60A. There are three active transmission programs to build and evaluate critical transmission compo-

nents. If these components are successful, transmission weight could be reduced by as much as 20 percent, while cost could be reduced by 20 percent and mean time between transmission removals could be increased by up to 100 percent.

*Airdrop.* The Airdrop Development Program has solved the age-old problem of inversion-type malfunctions of the main personnel parachute. The anti-inversion net is a basketball-type nylon net added around the circumference of the parachute canopy at the bottom and extending 46 centimeters down the suspension lines. The net prevents panels of the parachute from blowing through opposite suspension lines during parachute deployment. The anti-inversion net has not only eliminated the inversion malfunctions, but has produced a bonus effect of practically no malfunctions of any type. In over 90,000 jumps with net-equipped parachutes, only two malfunctions occurred. This achieves reduced personnel injuries and reduced parachute maintenance previously caused by inversion burns. The modification program to add the anti-inversion net to field stocks was completed in 1977. All new main parachutes are equipped with the net.

## Relationship with NASA

### *Aeronautics and Astronautics Coordinating Board*

The Aeronautics and Astronautics Coordinating Board (AACB) is the principal formal coordination mechanism between DoD and NASA. Major policy issues of mutual interest in aeronautics and space are addressed.

*Reimbursement for Shuttle Services.* In June 1976 NASA offered for comment a preliminary proposed policy on reimbursement for Shuttle services to DoD. This initial policy proposed considering all direct and indirect costs as a basis for establishing a price to DoD for a dedicated Shuttle flight. At the October 13, 1976, AACB meeting the Co-Chairmen agreed to explore simpler approaches to developing a fair, reasonable price for such services to DoD. An approach has now been agreed upon which is simple and encourages efficient operations, early transition from expendable launch vehicles to the Space Shuttle, provides pricing stability, and establishes a mutually acceptable price. The DoD reimbursement to NASA will be based on the costs of materials and services, to be mutually agreed upon. The DoD will provide the Vandenberg Shuttle launch support for all non-DoD users in return for provision by NASA of all Shuttle launch support from Kennedy Space Center and Shuttle flight operations support for all DoD flights. These services are projected to be of approximately equal value to each agency. DoD will

be charged a fixed price for the first six years based on realistic average projected materials and services costs. For launches after the first six years, the price will be adjusted annually, based on forecasts of annual costs for that year for materials and services. Details of the policy based on this approach will be negotiated.

*FY 1978 DoD/NASA Facilities Coordination.* Preliminary coordination was begun between NASA and the Air Force for examination of facility programs most likely to be of mutual interest or with high potential for duplication. The normal budgetary review process within each agency reduced the number of proposals. The early start and detailed nature of the review, as well as the desire to make most effective use of resources, all contribute to assuring elimination of unwarranted duplication early in the process. The final DoD and NASA review involved 14 DoD projects estimated to cost \$70 million, and 22 NASA projects totaling \$162 million. These facilities were included in the President' budget.

*National Aeronautical Facilities Program.* Three facilities constitute the National Aeronautical Facilities Program:

- The Air Force Aeropropulsion Systems Test Facility design is complete, construction bidding is in progress, and the facility is proceeding within costs toward beginning operation in 1981. Congress appropriated the full \$437 million for ASTF in FY 1977.
- Modifications to the NASA 40-x-80-foot low speed wind tunnel are now in the preliminary design stage. Congress appropriated \$6 million in FY 1977. The facility is scheduled for completion in 1982 at a total cost of \$85 million.
- The NASA National Transonic Facility is in the site-preparation stage. Congress appropriated \$25 million in FY 1977 and the facility is scheduled to operate in 1982.

Higher-than-expected bids on the transonic-tunnel shell and motor caused NASA to institute a joint DoD/NASA reexamination of the tunnel configuration. It was concluded that while the basic tunnel design is still valid, insulation and model angular travel capability need to be increased, so the total cost will be about \$85 million. The increase is primarily in higher-than-estimated bids (inflation) although some is attributed to necessary design changes. DoD requirements have not been compromised either during design or as a result of cost increases.

*Shuttle Orbiter Fleet Size.* The timely availability of an adequate national fleet of orbiters to support military as well as civil users of the Shuttle is essential if the full capabilities of the Shuttle are

to be realized. The fleet size must be based on total national traffic—foreign and domestic, civil and military—projected for the Shuttle. Extensive studies conducted by NASA, with Air Force support, over the past two years plus detailed reviews within the Administration have led to the decision that NASA should proceed with the production of four Space Shuttle orbiters.

*Use of Johnson Mission Control Center.* Present DoD planning for its Shuttle launches is predicated on the use of NASA's Johnson Mission Control Center (JMCC) for simulation, training, and Shuttle flight control for all DoD missions. However, as currently designed, JMCC cannot handle payload data for classified missions. A number of options for accommodating classified DoD launches in the JMCC have been evaluated over the past year by both DoD and NASA. Recently a low-cost approach has been defined to modifying JMCC which will adequately protect classified payload launches on the Shuttle with minimum disruption to civil users. The validation of this approach, the "controlled mode" concept, has been started.

### *Joint Programs*

*Rotor Systems Research Aircraft (RSRA).* A joint Army-NASA contract for the design and fabrication of two Rotor Systems Research Aircraft has produced two research aircraft which will serve as "flying wind tunnels" for helicopter research. The aircraft design will permit in-flight testing of full-scale main rotor systems having from two to six blades. The design also permits the addition of fixed wings and thrusting engines that will permit rotor testing at flight speeds up to 450 kilometers per hour. These two aircraft will provide data that will help solve aerodynamic problems that are currently mathematically intractable and cannot be solved without the aid of precise flight research results. The Rotor Systems Research Aircraft, with its first set of rotor blades, has completed its first phase of flight testing as a pure helicopter; it is presently being fitted with wings and thrusting engines to enter further flight testing in high-speed maneuvering flight. After establishing the basic capabilities of the research aircraft, they will be used to test and optimize the performance of various candidate rotor designs and to obtain data for improvement in rotorcraft prediction methodology.

*Tilt Rotor Research Aircraft (XV-15).* Under a joint Army/NASA contract awarded in 1973, Bell Helicopter Textron completed the fabrication of two Tilt Rotor Research Aircraft (XV-15) during the past year. The first of the two aircraft has been extensively ground tested on a tiedown test facility; its new design transmissions and vertical/horizontal

running engines have now been operated for approximately 60 hours. The first aircraft has also flown three hours of hover and low-speed tests since its new-design transmissions and vertical/horizontal XV-15 is completing operational tests under remote control in preparation for full-scale wind tunnel testing in the NASA-Ames 40-x-80-foot wind tunnel, to be initiated in early 1978. The second XV-15 is being prepared for limited ground testing prior to entering contractor flight tests early in 1978 to establish the basic flight characteristics for both helicopter and airplane modes of operation.

*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 is preparing 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 instrumented to measure energetic electrons in the range 110 MeV. These measurements are needed to determine the dosage rates that satellite micro-components will be subjected to under operational scenarios.

*Seasat-A Data Processing.* NASA and the Navy have agreed to a cooperative effort for Seasat-A data processing. The Navy will do real time processing of the NASA Seasat-A satellite data at the Fleet Numerical Weather Central, and make the processed data available to NASA for distribution to the user community. The Navy will also demonstrate the utility of the Seasat data as inputs to global atmospheric and oceanographic analyses and forecasts. This NASA/Navy effort capitalizes on the significant Navy programs to develop oceanographic applications for infrared imagery from the satellite data, and to use the data in analysis of sea-surface thermal structures such as locating oceanic fronts, eddies, and water masses. The surface temperature measurement and analysis capability supports the objectives of the National Climate Program. Several fleet exercises conducted in 1977

demonstrated the potential of utilizing satellite-collected sea-surface temperatures for tactical applications in undersea warfare.

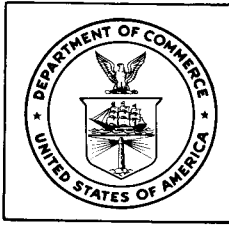
*Standard Atmosphere.* The joint effort between National Oceanic and Atmospheric Administration (NOAA), NASA, and USAF which produced the U.S. Standard Atmosphere (1976) continues. The joint publication has disseminated the wealth of knowledge of the upper atmosphere obtained during the past solar cycle. 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.

*Astronaut Selection.* DoD is fully cooperating with NASA in their selection of astronaut candi-

dates for the Space Shuttle Program. The selections from over 8000 applicants would be announced in 1978. At present (1977) DoD has eleven officers assigned as astronauts, many of whom have prior space flight experience.

*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 total number of detailees under the program in FY 1978 is 59 (45 from Air Force, 8 from Navy, and 6 from Army). They 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.

# IV



# Department of Commerce

## Introduction

The Department of Commerce agencies contributing directly to the nation's aeronautics and space programs include 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.

The long-range goals of these organizations are to ensure wise use of the environment and its resources; to provide standards and related services for uniform and reliable physical measurements, standard reference materials, and data to commerce, industry, and government; to improve ship communications, navigation, safety, and management techniques; to provide specialized engineering, management, and advisory assistance on national telecommunications issues to other Federal agencies; and to provide information on population trends, urban growth, and internal structure of national land areas.

These goals are accomplished by operating and improving the nation's operational environmental satellite systems; by providing data to assess the impact of natural and man-induced factors on such things as global food supplies, national energy problems, and environmental quality; by conducting fundamental research to improve man's understanding of the environment; by using satellite data and aerial photography for charting, coastal mapping, and geodetic research; by improving weather services through the automation of forecast and observation stations, better radar systems, and continued atmospheric research; by improving the assessment and conservation of all living marine resources; by conducting telecommunications and information policy analyses, and navigation, telecommunication, and remote sensing studies to support communications services; by providing basic measurement and calibration methods for operating technical systems and engineering data for the design and construction of sophisticated space and aeronautics equipment; by using satellites to im-

prove navigation, communication, and surveillance of commercial ship operations; and by using satellite data for demographic studies and population estimates.

## Space Systems

### *Satellite Operations*

*Polar-Orbiting Satellites.* During 1977, the National Environmental Satellite Service (NESS) of the National Oceanic and Atmospheric Administration (NOAA) operated two satellites, NOAA 4 and NOAA 5, of the Improved Tiros Operational Satellite (ITOS) series. NOAA 5 is the primary operational satellite and NOAA 4 is the in-orbit backup.

Development of the Tiros-N series, the third generation of operational polar-orbiting satellites, is continuing. This series of satellites will replace the present ITOS series beginning in late 1978. Tiros-N, the NASA prototype, will be launched in mid-1978; NOAA A, NOAA's first operational satellite of this series, is scheduled for launch in late 1978.

Installation of the Tiros-N series ground equipment began at the NESS Satellite Operations Control Center in Suitland, Maryland, in September 1977. The major components of the ground system are the Data Acquisition and Control Subsystem (DACS) and the Data Processing and Services Subsystem (DPSS). The DACS equipment will be located at Wallops, Virginia; Gilmore Creek, Alaska; San Francisco, California; Suitland, Maryland; and Lannion, France. This system will acquire environmental and engineering data and facilitate complete operational control of the entire ground system and satellite. The data processing equipment will be located at the NESS computer facility and be integrated with the acquisition system and a wideband communication network. The acquired data then will be preprocessed and conditioned for storage and products developed and distributed to the users. The data also will be retained for archive by the Environmental Data Service.

*Geostationary Satellites.* Geostationary Operational Environmental Satellite Goes 2 was launched

June 16, 1977. On August 15, Goes 2 was positioned over the equator at 75° West longitude to replace Goes 1 as the eastern operational satellite. Goes 1 was placed on standby in an orbit centered at 105° West longitude. Synchronous Meteorological Satellite SMS 2 remained at 135° West longitude as the western operational satellite.

In February 1977, NESS increased to 72 the daily number of Weather Facsimile broadcasts from the two geostationary satellites. Each broadcast lasts 7 minutes and transmits both processed images from the polar-orbiting satellites and unprocessed sectors from the two geostationary satellites. Plain-language operational messages related to the schedules and planning activities are broadcast twice each day from the eastern satellite and once each day from the western satellite. These data are received and used by a growing number of Department of Defense and foreign meteorological agencies. In October 1977, a limited number of National Meteorological Center conventional weather charts were broadcast daily from the eastern satellite at times other than the normal weather facsimile broadcasts. These broadcasts and routine imaging operations were made simultaneously.

#### *Satellite Data Uses*

*Determining Winds and Temperatures.* During 1977, research continued on the automatic computation of winds from cloud motions observed by geostationary satellites. One study compared simultaneous wind vectors from identical clouds tracked by both Goes 1 and SMS 2. Results showed that the objective geographic registration of the infrared images was accurate within 8 kilometers. Median wind vector differences were 1.2 and 1.5 meters per second for computer-derived winds and for manually computed winds respectively.

In another study, an objective analysis procedure for editing low-level picture-pair winds derived from geostationary satellite images has been tested with satisfactory results. The object is to eliminate inaccurate data. This technique will reduce the amount of manual editing by 12 percent. Also, the temperature slicing technique used to calculate low-level cloud motions has been modified by increasing the array size used in the calculations. This reduces the amount of inaccurate data and presents a more coherent wind.

A technique is being developed to define the low-level wind field around a hurricane. The components are cloud motion wind vectors from high resolution visible images, the location of the hurricane center, and a hurricane intensity index. When applied to data from Hurricane Belle (Au-

gust 1976), it produced results corresponding to an actual wind field.

Research was continued to determine why the subtropical jet stream acts as a southern boundary to severe weather. An examination of five case studies was made to see if cold air in the high troposphere north of the jet is a contributing factor to deep instability. Detailed 200-millibar temperature analyses showed a wedge of cold air between the subtropical and polar jet streams. Severe storms occurred where the 200-millibar cold tongue was superimposed over the surface warm tongue and in areas of weak calculated divergence at upper levels.

Work was continued to improve methods for extracting meteorological information from the High Resolution Infrared Sounder data from the Nimbus 6 experimental meteorological satellite. Processing of data was completed for the Global Atmospheric Research Program (GARP) Nimbus 6 Data Systems Test periods 5 and 6. These data will be used to provide specifications for the First GARP Global Experiment in 1978.

Research was conducted using Scanning Microwave Spectrometer data from Nimbus 6. Results showed that the data would be adequate as a lower resolution back-up system to Tiros-N for deriving temperature soundings. These data also were used to estimate 700-millibar wind speeds in large typhoons and precipitable water amounts over tropical areas. The results showed fair agreement with conventional radiosonde measurements.

*Monitoring Global Radiation.* Time averaged global heat budget data from NOAA Scanning Radiometers continued to be archived and compiled in 1977 and were used in many studies. In one case, radiative heating data for the 1975 and 1976 Southeast Asia summer monsoons were studied. The 1975 monsoon had greater intensity than the one in 1976, and there were differences in radiative heating in Southern and Central Asia during the two spring and summer seasons. Also, snow cover over Soviet Central Asia was greater in the spring of 1976 when the monsoon was weaker. Substantial changes in radiative heating, likely related to monsoon development, were observed over much of the central and eastern tropical Pacific. Earth Radiation Budget data from Nimbus 6 continued to be used for monitoring global incoming solar and outgoing terrestrial radiation and as a measure of the solar constant. These data will be valuable tools in conducting climate-related studies.

Knowledge of the Earth's radiation budget is an integral part of the nation's total climate program. In 1977, NESS established a group of researchers to work with NASA on the development of an Earth Radiation Budget Satellite System (ERBSS).



The object of the ERBSS is to acquire radiation budget data for understanding and predicting climatic change. The instrument designed to meet these objectives will measure reflected and emitted radiation over a broad range of spectral intervals. The ERBSS will derive radiation data from instruments to be carried on future NOAA-Tiros-N satellites and a NASA Applications Explorer Mission satellite.

*Environmental Warning Services.* Throughout 1977, the GOES Data Collection System (DCS) continued to grow in size and variety of uses. There are now 22 national and international users participating in this program which incorporates nearly 600 Data Collection Platforms (DCP). Some of the new applications included deployment of 25 magnetometer platforms for the International Magnetospheric Study Program, relaying hurricane data from a C-130 reconnaissance aircraft, and implementation of the first Aircraft-to-Satellite Data Acquisition and Relay platform on a commercial jet. Importance of the GOES DCS was realized in areas of the country where the National Weather Service (NWS) had DCPs located to detect flooding. NWS and NESS developed procedures to collect data hourly whenever a flood threat arises. These procedures were used several times in Pennsylvania, Colorado, Oregon, and Texas. Demonstrations of the GOES DCS also were presented to government officials in Santiago, Chile, and to participants in the World Meteorological Organization's regional association meeting in Mexico City, Mexico.

A major milestone in the development of the GOES DCS was reached when a second generation ground processing system became operational on June 15, 1977. The new ground system consists of computers located at the World Weather Building and the Wallops Command and Data Acquisition station, communication equipment between the computers, expanded channel capacity, real-time dissemination of collected data, and redundant equipment for emergencies.

The GOES-Tap system, inaugurated in 1975 to provide sector-by-sector weather images from Goes satellites, was expanded during 1977 to serve 20 Federal and 16 nonfederal users. The NWS also provided Tap service to users located near their Weather Service Forecast Offices (WSFO). During 1977, WSFO Tap service was increased to 72 subscribers. Lanica Airlines of Nicaragua became the first commercial airline to use the GOES-Tap. During 1977, Lanica, along with eight other Miami-based Latin American Airlines, used GOES-Tap images for aircraft routing over the Gulf of Mexico and the Caribbean. Sectorized images were pro-

vided every half hour by the Miami Satellite Field Services Station.

During the 1976-1977 winter, NWS forecasters received GOES enhanced infrared images that were used to display surface temperatures critical to frost predictions. The forecasting technique was tested operationally in support of the Florida citrus industry. In the 1977-1978 winter season GOES infrared data will be displayed in digital rather than image form. Digital temperature data are expected to be more timely, accurate, and economical.

Using GOES infrared temperature data, NESS is developing a digital cloud-top height display to detect the position, movement, and growth of thunderstorms. This technique will be further refined using the NWS Automation of Field Operations and Services system. This will allow forecasters to monitor more objectively local thunderstorm development from satellite data. Also under development is a set of digital satellite products that show hurricane intensity, rainfall amounts, and solar insolation.

A quantitative method for analyzing tropical storm intensity uses GOES enhanced infrared images. The procedure involves contouring the coldest cloud tops to show certain temperature patterns that are related to the storm's wind speed, central pressure, and center location. This technique enables forecasters to estimate hurricane intensities at night when visible images are unavailable.

GOES enhanced infrared images are used to detect high concentrations of low-level moisture. When skies are clear in the early evening, moist air in the boundary layer will cause the land beneath it to appear darker than land under dryer air. This is because land under moist air cools at a slower rate. It is in these areas where fog is most likely to form later in the night. Thus areas with a high probability of fog formation can be predicted several hours in advance.

During 1977, specially enhanced visible images were used to locate fog areas and forecast the time of fog dissipation. Early morning images were analyzed for fog brightness. Brightness is related to fog dissipation time.

Work continued on the detection of haze and air pollution from satellite images. Early morning and late afternoon visible pictures, taken when the sun angle is low, show these hazy, polluted areas particularly well. The haze often restricts visibility and can be a hazard to low-level aircraft operations. Thus satellite images aid in making short-range forecasts of restrictions to visibility.

*Search and Rescue Support.* In 1977 NESS continued to provide satellite data to support the U.S. Air Force and U.S. Coast Guard Search and Rescue

operations. The California Wing of the Civil Air Patrol has been using satellite images for Search and Rescue missions since 1974. Satellite pictures show weather conditions at the time the pilots were in distress. Up to 40-percent reduction in mission flying hours has been achieved by using satellite data.

The Coast Guard used satellite data in its Search and Rescue missions to determine sea surface temperatures and ocean current boundaries. Sea surface temperatures are important to mission planning, especially in the winter when temperature differences between the Gulf Stream and adjacent shelf waters can be more than 17°C. This can mean a difference in life expectancy, as affected by exposure, of several hours to several days and a radically different drift rate and direction.

*Determining Ocean Conditions.* Seasat-A is a NASA oceanographic satellite scheduled for launch in 1978. It is designed to provide all-weather global monitoring of oceanographic conditions using an array of microwave instruments and one visible-infrared instrument. NOAA will participate in a research and demonstration program using Seasat-A data as they apply to NOAA requirements. Thirty-five experiments are planned in the open ocean and coastal zone on winds and waves, currents and circulation dynamics, surface temperatures, geodesy, and sea ice. Demonstration activities will involve meteorology, oceanography, geodesy, and living marine resources. In addition plans are under way to sponsor a few experiments by non-government organizations.

Ocean color research continues in support of the Coastal Zone Color Scanner to be carried on Nimbus-G, scheduled for launch in 1978. The capability to acquire *in situ* optical measurements simultaneously with remotely-sensed radiance data was demonstrated by experiments conducted in late 1975. A more extensive ship and aircraft field program was carried out in the Gulf of Mexico in October 1977, by scientists from NOAA, NASA, the Scripps Institution of Oceanography, and Texas A&M University. The objectives were to provide a prelaunch *in-situ* data base for development of chlorophyll and total suspended sediment models, to standardize measurement procedures for these parameters, and to test instruments for acquisition of spectral irradiance data.

The Scripps Institution of Oceanography, supported by NESS, completed development on the bio-optical state of the ocean which can be characterized by determining certain optical parameters as a function of wavelength. Then bio-optical state can be related to chlorophyll concentrations, which further can be linked to other important biological features of the ocean. Satellite optical measure-

ments, like those expected from the color scanner, can provide otherwise virtually unobtainable information on the detection, growth, and decay of plankton. Such information can provide a better understanding of marine ecosystems.

Mean monthly sea surface temperature fields, derived from satellite infrared measurements, were compiled for the past several years. These data were used to construct annual-change and anomaly charts for possible use in long-range weather forecasting and climate dynamics studies. One interesting feature was a large cold-water anomaly that developed in the North Pacific in the autumn of 1976 and reached peak intensity in February 1977. A similar anomaly appeared to be developing in the same general area in late summer 1977.

NESS is using GOES visible and infrared digital data to produce composite sea surface-temperature gradient maps. By using GOES images at various times of the day, a cloud-free composite of the sea surface-thermal structure is displayed. During 1977, this daily composite was used to determine the position of the Gulf Stream and the Gulf of Mexico Loop Current. The Satellite Field Services Stations have provided this information to commercial and sports fishermen, recreational boaters, and the merchant marine.

In March 1977, work began on preparing maps showing ice conditions in the Labrador Sea and Davis Strait. These maps, derived from NOAA 5 and Goes 1 satellite images, were disseminated three times a week to the Coast Guard as an aid to navigation. Also, the Coast Guard was briefed on cloud conditions over its International Ice Patrol area, based on satellite images. This information saves aircraft time and reduces operating costs. NESS also continued to prepare and distribute ice maps of Alaskan Coastal waters for shipping interests for the fifth consecutive year.

High-resolution images from Landsat 1 and 2 were used by NOAA's Pacific Marine Environmental Laboratory to compile an atlas of underwater internal waves off the North American east coast, the first large-scale view of this phenomenon. The data were used to prepare two oceanographic investigations of internal waves.

Scientists from NOAA's Outer Continental Shelf Environmental Assessment Program used sea surface temperature data from NOAA satellites in conjunction with hydrographic data to map surface currents in the Gulf of Alaska. This program supports the University of Alaska in acquiring and cataloging remote sensing data from satellites and aircraft and distributing these data to scientists involved in Alaskan studies.

NOAA's Wave Propagation Laboratory developed a method of using satellite radar altimeter

data to determine sea state. This method has been applied to a limited amount of Geos 3 altimeter data, producing estimates of significant wave height to 0.6 meters accuracy over 70 kilometer-square areas.

*Determining Lake Conditions.* Analysis of satellite infrared data over the Great Lakes during November 1976 showed the lake surface temperatures to be an average of 5°C cooler than on the same date in 1975. These low temperatures preceded one of the heaviest ice years on record. On February 7, 1977, NOAA 5 satellite data showed Lake Michigan was completely frozen over for the first time in 20 years.

NOAA's Great Lakes Environmental Research Laboratory and NESS used satellite multispectral images to map reflectance patterns from calcium carbonate precipitation in the Great Lakes. This milky-water phenomenon, called a whiting, was examined over a 4-year period. Results showed that whittings occur regularly during the summer and fall in Lakes Ontario, Erie, and Michigan.

*Determining Hydrological Conditions.* NESS continued to produce satellite maps of snowcover in about two dozen United States and Canadian river basins. Nearly 500 snowcover maps were compiled between November 1976 and June 1977. Users were the National Weather Service, U.S. Geological Survey, Corps of Engineers, Soil Conservation Service, and Bureau of Reclamation. These maps were used to help assess the extent of the 1977 drought in the western United States. Snowpacks in the high elevations of Wyoming, Colorado, Idaho, California, and Oregon, were found to be the lowest or near the lowest on record. Using NOAA 5 VHRR images, mid-April areal snowcover for California's Sierra Nevada Mountain Range was determined to be only one third of what it had been on the same date in 1975. Satellite derived snow and ice cover maps were transmitted daily to NWS hydrologists in the middle Atlantic and northeastern states. This information was used to prepare river and flood forecasts. Regional hydrologists found the information to be especially useful because this section of the country experienced one of the most severe winters in history.

A technique for estimating hourly rainfall from convective clouds using enhanced infrared and high resolution visible satellite images was field tested in 1977. Field tests were conducted by hydrologists at the Weather Service offices at Phoenix, Arizona, and Lubbock, Texas; the Kansas City, Missouri, Satellite Field Services Station; and the Division of Hydrology in Caracas, Venezuela. Preliminary results show successful identification of areas of no significant rainfall and reasonable estimates of total rainfall in heavy precipitation areas. This tech-

nique will aid in monitoring areas of convective rainfall for agricultural uses and flash flood warnings. It is especially useful for areas where no reporting stations are present, or where surface reports are delayed by poor communications.

Also, GOES visible and infrared images were used to develop a digital enhancement technique for estimating rainfall rates and potential rainfall for tropical storms. The National Hurricane and Experimental Laboratory used this technique to prepare rainfall estimates for the National Hurricane Center's warning services. The NWS River Forecast Center at San Antonio, Texas, used this information to monitor heavy rainfall continuously as Hurricane Anita crossed the Texas-Mexico coast in September 1977.

The NWS collected rainfall data from 61 unmanned sites in its Automatic Hydrologic Observing System. These data were transmitted to River Forecast Centers via the GOES Data Collection System and were used in the river and flood forecasting program.

NESS completed a series of satellite-derived snowcover maps and graphs of North America and Eurasia for the period November 1966 to September 1977. The maps showed the monthly variation of snowcover, and the graphs showed the monthly, seasonal, and annual variation of snowcover on each continent. A 12-month running mean of monthly values showed no significant fluctuations or trends for North America, but two large increases in snowcover were observed for Eurasia. One of these occurred in the 1971-1972 winter and the other in the 1976-1977 winter.

A study was made of near-infrared reflectance from snow using Skylab multispectral scanner data. Results showed that reflectance over uniform snowpack is significantly lower in the near-infrared than in the visible red part of the spectrum, and that the near-infrared can be used to distinguish objectively between snow and clouds. More data are needed to clearly distinguish between snow reflectance measurements made in the laboratory and those obtained from spacecraft and aircraft.

*Monitoring Agricultural Conditions.* In cooperation with the Great Plains Agricultural Council and the U.S. Department of Agriculture, NESS joined in an effort to develop a technique for estimating solar insolation over the Great Plains using GOES digital data. The parameters measured were surface brightness, cloud brightness, cloud cover, precipitable water, and surface pressure. The first three parameters were determined from satellite data and the last two from surface measurements. These data are presently being correlated with surface truth pyranometer data provided by the Great Plains Council. Eventually, the insolation data may

be incorporated into yield models for sorghum and wheat crops.

*Fisheries Monitoring.* During 1977, NESS continued to produce charts showing ocean thermal fronts, observed from high-resolution satellite data, along the California coast. The Ocean Services Unit at Seattle began issuing similar information for the offshore waters of Oregon and Washington. It is known that nutrients and plankton important to the food chain for fish are concentrated along these fronts as a result of seasonal upwelling. For the past three years, these charts have been used by West Coast tuna and salmon fishermen to locate productive fishing areas. In spite of increasing fuel costs and more stringent fishing regulations, the commercial fishermen have improved their efficiency and reduced overfishing of small areas. In 1977, this service was expanded to the northwest Atlantic and Gulf of Mexico. The swordfish industry is being provided weekly Gulf Stream analyses, and some fishing companies are purchasing satellite images for direct use in their fishing operations.

The National Marine Fisheries Service, in cooperation with other Federal and private agencies, initiated research to use satellites for tracking porpoise migration in the eastern tropical Pacific. A preliminary study was conducted by fitting trained porpoises with small transmitters capable of operating a year and relaying position data via the Nimbus 6 Remote Access Management System. Data can be received for up to 200 platforms within the satellite's view and from 1000 platforms per orbit.

The Fisheries Service also participated in Seasat-A prelaunch studies conducted off the coast of California during the spring of 1977 to determine if a scatterometer system would provide accurate measurements of wind stress for use in estimating water movement. Test results will be available early in 1978. The objective is to evaluate the potential of space-borne scatterometer measurements for improved yield predictions for certain estuarine-dependent fish. The survival of these species is dependent on the egg and larval stages being transported by surface water currents to estuarine nursery grounds.

The National Fisheries Engineering Laboratory, in cooperation with NASA and the Coast Guard, investigated the use of space-borne Synthetic Aperture Radar systems for fishery management and fishing vessel surveillance. Preliminary results were published this year describing tests of vessel surveillance conducted over concentrations of foreign vessels in the Bering Sea. Detection of a broad range of fishing vessels seems certain, but questions remain concerning additional information such as vessel speed, direction, activity, and size.

## Other Uses of Satellites and Space

### *International Cooperation*

*Sharing Data.* More than 120 countries receive low-resolution Automatic Picture Transmission (APT) images, and a dozen countries also receive high-resolution images from NOAA polar-orbiting satellites. Another 20 high-resolution stations are planned, including one at McMurdo Sound, Antarctica. Ten countries in the Caribbean and in Central and South America also receive Weather Facsimile (WEFAX) images from geostationary satellites, and new stations soon will be operating in Western Europe, Africa, and some Pacific Ocean sites.

The National Weather Service, under the Voluntary Assistance Program for the World Meteorological Organization, established combination APT/WEFAX stations with improved satellite video capability in Costa Rica, Honduras, and Guatemala in November and December 1977. These stations can receive data from polar orbiting and geostationary satellites and will be the prototypes for eventual replacement of older APT equipment. The capability of the satellite to relay environmental data to ground stations within the satellite's transmission range has improved the observation and prediction efforts of many nations.

These data recently have been used by the U.N. Food and Agricultural Organization to suppress locust emergence and migration in northern Africa. They have been used to support exploratory oil drilling activities in the North Sea and Canadian Archipelago; to estimate snowfall in Norway for hydro-electric power generation; and to improve flight forecasting, flood control efforts, marine transportation, and research in weather modification in many countries. Much international good will has derived from cooperation and coordination among nations using this form of space technology.

The United States and the Soviet Union continued to exchange satellite cloud pictures during 1977. During the year the Soviets launched a new series of satellite called Meteor 2. The visible and infrared radiometers on this satellite appear to have environmental monitoring capability close to our ITOS series. Photographs received from the satellite have a resolution of about 2 kilometers. In addition the United States received data from Meteors 24 through 28 and sent data from NOAA 4 and 5 to Russia.

During 1977, the Department of State, Agency for International Development (AID), was provided with cloudcover data over the sub-Saharan part of Africa and the Caribbean area for use in determining the probability of precipitation. As part of

the tropical storm surveillance program, high winds and potential flooding in tropical areas of the world also were monitored.

*Demographic Studies.* The Bureau of the Census, supported by AID, demonstrated the use of Landsat data in demographic studies. Studies for Bolivia and Kenya were completed in 1977, and the results documented the use of satellite images in preparing Population and Housing Census operational maps. The reports also noted the relation of land cover to population density.

The Census Bureau also continues to study the use of Landsat data in domestic census activities. An Applications System Verification and Transfer agreement was signed with NASA. The experiment will test the utility and cost effectiveness of using computer-processed Landsat data for delineating urban fringe zones around the nation's major metropolitan areas. Urban land cover, recorded by Landsat, is being compared with photographs from high-altitude aircraft and other cartographically prepared products. If Landsat proves useful and cost-effective for monitoring the geographic expansion of urban areas, a larger sample will be tested.

#### *Weather Modification*

NOAA's National Hurricane and Experimental Meteorology Laboratory used satellite data for its research into the development and modification of convective cloud systems. Studies were initiated to apply rainfall estimates from satellite images to the analysis of cumulus modification experiments over an extended area. Satellite data promise to be important for diagnosing larger-scale effects of weather modification.

The Laboratory also used satellite data in hurricane research. Data collected with satellites, aircraft, and radar from Hurricane Anita (September 1977) are being analyzed to determine if systematic oscillations of cloud growth occur, if satellites can track cloud elements at speeds corresponding to observed wind speeds, and if characteristic cloud developments occur that can be related to present storm strength and potential for future development.

#### *Determination of the Earth's Shape and Gravity Field*

NOAA's National Ocean Survey and the Joint Institute for Laboratory Astrophysics made computer simulations of observations on the Lageos satellite by laser stations and determined geodetic station positions on the Earth with mean errors less than 5 centimeters. This method was limited in obtaining the desired accuracy because of limited knowledge of the Earth's gravitational field. Im-

proved Doppler data and more refined data processing have reduced positional errors to less than 90 centimeters for 40 stations and 10 to 25 centimeters for differenced positions. Comparison with the external standards of Very Long Baseline Interferometry position determinations and the High Precision Transcontinental Traverse yielded comparable accuracies. A high-quality aerial camera is being developed and tested to provide higher density geodetic control more quickly and economically.

The altimeter data base set up for the Geos 3 satellite now contains more than 1500 passes. These data have been enhanced through improved analysis techniques and have produced more accurate solutions for the Earth's gravitational field. The Ocean Survey continued to work with NASA in setting up methods and programs for using altimeter data from Seasat-A for geodetic purposes.

Analysis of Geos 3 and a Navy navigational satellite data for determination of ocean tidal amplitudes has confirmed that standard published ocean tide models are in error by a factor of one-third. As a result, a value for the acceleration of the Moon has been determined. This supports recent analysis of long-term astronomical observations.

On January 10, 1977, the Survey, the Defense Mapping Agency, and the Groupe de Recherches de Geodesie, France, started making Doppler observations at the Ukiah California Latitude Observatory, to support the French experiment to determine polar motion by Doppler tracking of artificial satellites. The Survey started a new project, Polar Motion Analysis by Radio Interferometric Surveying (POLARIS), to monitor polar motion and Earth rotation with improved spatial and temporal resolution using radio interferometry techniques. The POLARIS data will have wide application in deep-space navigation, celestial mechanics, relativity, and Earth evolution studies.

The National Bureau of Standards has investigated the use of a single photo-electron laser ranging technique to reduce the cost and increase the accuracy of satellite ranging stations. Preliminary studies indicate a 1.5-centimeter accuracy in ranging to the Lageos satellite. Under development is a 3-wavelength ground-to-ground laser distance measuring system with a 50-kilometer range and an accuracy of one part in 20 million. The system is intended to provide accurate geodetic ties to a surrounding network of markers from a site whose location is determined by satellite or lunar laser ranging stations or long baseline interferometry stations.

The use of high-accuracy range measurements to an orbiter around the planet Mercury for testing gravitational physics was studied. A check on a possible change in the gravitational constant with

time may be possible. Much improved checks on a number of other aspects of present gravitational theory also could be performed with such a mission.

### *Satellite Communications*

*Communications Studies.* The Office of Telecommunications published a study comparing the reliability of submarine cable and satellite communications. Data from the American Telephone and Telegraph Company's overseas message telephone circuits from 1970–1975 were used. Comparisons for each of the six years provided summaries of causes of cable outages and ways in which service was restored. Satellite communications were found to be more reliable.

A study was published on the aspects of direct voice communications from a satellite to individual homes for natural disaster warnings. The use of home radios and television sets for receiving these signals appeared remote.

Three computer programs were developed and published that will automatically check the compliance of fixed Earth stations with international power and antenna beam pointing restrictions; help engineers maximize satellite antenna coverage over particular portions of the Earth, while minimizing the effects of interference to other telecommunication systems; and calculate contours of power density measured at geostationary orbit.

*Commercial Satellite Service.* The Maritime Administration continued to expand its program of commercial satellite communications. In 1977 the Maritime Satellite (MARISAT) consortium announced commercial services from the Indian Ocean. The number of U.S.-owned vessels equipped with MARISAT terminals tripled, and the world fleet doubled in 1977. The MARISAT satellite communications system has opened 24-hour telephone and teleprinter service to ships at sea. Luxury liner passengers can now make ship-to-shore telephone calls directly from their staterooms. Cargo ships can avoid ports shut down by strikes, pick up new orders, and shift cargoes from one ship to another enroute. Oil tankers operating between Alaska and other U.S. ports can keep in contact with the home office. Canadian ice-breakers, whose mission it is to keep Canada's far-north sea lanes open for the shipping of supplies and equipment for resource development, can maintain constant communication with the Ministry of Transportation. Underway oil drilling rigs located in the Gulf of Alaska can communicate with their headquarters on shore. Satellite communications mean more efficient cost-cutting traffic management.

*Satellite Antennas.* The National Bureau of Standards extended the development of near-field

theory and measurement techniques for microwave antennas. It is now possible to perform accurate near-field measurements in the laboratory. Accurate gain, pattern, and polarization data are obtained for prelaunch testing of complicated multiantenna satellite systems and the terrestrial evaluation of ground stations.

*Orbiting Standards.* Test and measurement methods for the Orbiting Standards Platform are being defined. The Bureau of Standards will provide the required standards and carry out the satellite post-launch verification program. The platform will be accessible to virtually all users of satellite systems and will provide more reliable calibrations than can be achieved by other techniques.

*Time Services.* During 1977, time code transmissions on the 468-MHz frequency were continued from both GOES satellites. Improved satellite position prediction techniques resulted in time code performance of better than 25 microseconds. A commercial version of the GOES satellite clock system now is available. The GOES time code is in use or being considered for use in scientific data monitoring and correlation, navigation, communication systems, and electric power networks.

The Bureau of Standards has developed an extremely accurate atomic clock for satellite use. The device uses atomic hydrogen and has design features that are adapted to remote control in space. Other atomic clocks, based on cesium and rubidium resonances, were tested in a simulated space environment. These atomic clocks are critical components in world-wide, satellite-based navigation systems intended for space, air, sea, and ground position location.

## **Space Support Activities**

### *Weather Support*

*Launching Activities.* During 1977, the National Weather Service provided meteorological support to the Space Shuttle, Landsat, Voyager, Seasat, and the Rocketsonde and Atmospheric Ozone Measurement Programs. For the Space Shuttle, support was principally background and planning studies of atmospheric conditions at launch and landing sites. Landsat support required forecasts of cloud-free areas under the orbital path of the satellites. For the Voyager mission, forecasts were used to develop programs to maximize return signals from the spacecraft. Seasat support consisted of obtaining surface truth data for evaluation of the radar altimeter on Geos 3. Meteorological support was provided to the Wallops Flight Center for its rocketsonde and atmospheric ozone projects.

## *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. Alerts and measurements of these disturbances are provided to scientists in space physics and geophysics for planning scientific studies and experiments. The largest of these, the International Magnetospheric Study (IMS), is an international cooperative scientific program (1976–1979) designed to provide a better understanding of the dynamics of the Earth's external magnetic field. The Center supported the IMS with data collection and dissemination, and predictions, that were used to schedule satellite operations, rocket launches, and ground-based experiments. Similar information was provided to both military and civilian communication satellites and military reconnaissance systems. The primary data systems used were the Space Environment Monitor and Solar Proton Monitor on the GOES and ITOS satellites, the Global Solar Flare Patrol operated by NOAA and the Air Force, and data collected from the International Ursigram and World Days Service.

The Environmental Data Service operates the World Data Center-A for Solar-Terrestrial Physics. Last year World Data Center-A established a temporary IMS Central Information Exchange Office. This office is responsible for informing satellite, rocket, balloon, and ground-based experimenters about accomplishments, programs in progress, and future program plans for the duration of IMS. Opportunities for program coordination are stressed and have resulted in satellite experiment reconfigurations, rocket launch schedule changes, and repositioning of experiments from the surface to satellite altitudes. Prompt notification of special data collection opportunities based on multiple satellite configurations has been provided weekly to scientists. An address list of participating scientists was prepared and distributed to 2000 persons to facilitate direct contact between scientists. Monthly IMS newsletters carry the bulk of program information, maps, and news of preliminary scientific results.

## *Space Processing Research*

New research efforts were started by the Bureau of Standards to support NASA's program of using the Space Shuttle as an orbital workshop for materials science. The advantages of low gravity conditions in materials processing and thermochemical measurements on reactive oxides were evaluated. In addition, measurements and calculations were in-

itiated to determine the effects of gravity on liquid flow and flame propagation and inhibition.

## **Space and Atmospheric Research**

### *Space Physics*

*Interplanetary Physics.* The NOAA Space Environment Laboratory made dynamic, multidimensional computer simulations of solar flares using Skylab observations as a guide. This work, performed in collaboration with the University of Alabama in Huntsville, enables simulation of disturbances that travel from the Sun to the Earth.

Several models of the chemical composition (protons, electrons, and ionized helium) of the steady solar wind have been studied. One model considers nonradial flow near the Sun while another considers radial flow from the Sun to any point in space. Recent work has suggested that the period from 1645–1715, when there was visible absence of solar activity, showed a steady, magnetically featureless, low velocity, solar wind flow around the Earth's magnetosphere.

Hydrogen cyanide has been observed in the Jovian atmosphere in quantities greater than expected. Seeking to explain this, the Bureau of Standards has developed a mechanism to measure the rate constant for hydrogen cyanide formation. Improved thermodynamic values obtained through infrared absorption and mass spectrometric studies have been obtained for methyl and methylene radicals. These species are important in the chemistry of Jupiter and are derived from the decomposition of methane by solar radiation.

Techniques to analyze ultraviolet spectra are being developed using chromospheric models for solar active regions, and the study of wave modes in the solar chromosphere and transition region is under way, using Oso 8 observations. Spectroheliograms obtained from the Naval Research Laboratory's Skylab experiment have been used to study the formation of neutral and ionized helium lines in the solar atmosphere. Observations of cool stars have been analyzed to derive chromospheric models and estimates of the gravity-dependence of non-radiative heating in these stars. The first extreme-ultraviolet observations of a flare star, Proxima Centauri, obtained from an experiment on Apollo-Soyuz, were analyzed in terms of coronal properties of this star. This information will be useful to radio astronomers all over the world.

### *Atmospheric Physics*

*Ionospheric Physics.* Space Environment Laboratory scientists used solar x-ray measurements from the GOES satellites to detect solar flares. Research

was started to detect these explosions on the Sun before their x-ray and extreme ultraviolet flux intensity increased enough to significantly affect the ionosphere. One use of early flare-detection systems will be high time-resolution measurements to determine the ionospheric effects of solar flares.

*Magnetospheric Physics.* Analysis of energetic ion data in the interplanetary medium outside the Earth's magnetosphere shows these particles have originated from the magnetosphere. The Earth thus joins the Sun and Jupiter as a source, within the solar system, of the energetic particles and low-energy cosmic rays found in the interplanetary medium. Scientists have concluded that the extra-terrestrial ring current is not composed of solar wind protons, but of heavier ions of helium or oxygen. The theory, proposed last year, that the ionosphere rather than the solar wind is the major source of energetic radiation-belt ions, has been confirmed by observations that show ions of ionospheric origin jetting upward toward the outer magnetosphere where they are trapped and produce the ring current. Evidence is mounting that the process which energizes ionospheric ions and injects them into the magnetosphere is the same process which jets electrons from the magnetosphere into the atmosphere to produce auroral displays. An auroral theory has been developed that the ionosphere's demand for electrical current from the magnetosphere leads to the creation of electric potential difference along the geomagnetic field line. The existence of such a potential difference would lead directly to the acceleration of electrons downward to produce the aurora and ions upward to produce the ring current.

Data from GOES magnetometers were used to begin development of techniques to predict geomagnetic disturbances called substorms. This effort will help the Space Environment Services Center to predict disturbed communication conditions and predict conditions which lead to electrical malfunctions onboard communication satellites.

*Stratospheric Physics.* The NOAA Aeronomy Laboratory has obtained comprehensive measurements of nitrogen dioxide distribution in the stratosphere using ground and airborne spectroscopic techniques. Global measurements of stratospheric concentrations of fluorocarbons F-11 and F-12 and nitrous oxide also have been obtained using balloon-grab sampling methods. The nitrous oxide measurements yielded improved vertical transport coefficients that will allow better predictions of stratospheric ozone loss from manmade causes. Laboratory reaction rate measurements have substantially lowered the predicted stratospheric ozone destruction by supersonic aircraft and substantially

raised the predicted stratospheric ozone destruction by chlorofluorocarbon release.

A new Bureau of Standards instrument was used to measure calibration standards for a NASA satellite dedicated to mapping atmospheric ozone. Radiometric calibrations performed for NASA are important to NASA programs for monitoring solar radiation.

### *Atmospheric Chemistry*

*Photochemistry.* The Bureau of Standards has demonstrated for the first time in laboratory experiments a possible method of sunlight destroying chloromethanes in the troposphere. Solar radiation reaching the troposphere can break down chloromethanes if the chemicals are first adsorbed to the surfaces of sand or quartz particles. The extent to which these chemical pollutants may be removed from the troposphere is being assessed.

The Bureau is participating in an interagency program to predict the effects of halocarbons and nitrogen oxides on the ozone concentration in the stratosphere. The possible buildup of halocarbons, their global distribution, and fate requires analytical measurements at extremely low concentrations.

Rate constants have been determined for the reactions of chlorine and oxygen atoms with chlorine nitrate over the temperature range 225° to 273°K. The rates indicate that the chlorine reaction is not important, but the oxygen atom reaction competes with solar photodissociation above 30 kilometers. Nitric acid is an important molecule that connects the hydrogen and nitrogen oxide reaction cycles in the Earth's stratosphere. The details of its decomposition by solar radiation are necessary to understand the reaction cycles of ozone production and depletion.

## **Data Programs**

### *Environmental Data*

*Oil Storage.* The Environmental Data Service's Center for Experiment Design and Data Analysis uses the GOES Data Collection System to obtain hourly observations of ocean circulation patterns from a prototype Salt Dome Environmental Monitoring System in the Gulf of Mexico. Under the Strategic Petroleum Program, salt domes or caverns are used for oil storage. The enlargement of these caverns by leaching presents a problem of brine disposal in the coastal waters. The monitoring of potential salt brine disposal areas provides the data needed to characterize and predict brine disposal patterns.

*World Food Assessments.* The Large Area Crop Inventory Experiment (LACIE), a cooperative ef-



fort of NOAA, NASA, and the Department of Agriculture, has demonstrated technology to monitor global weather patterns, identify current anomalous weather situations, and make quantified estimates of the weather's influence on potential crop yields. Statistical climate crop yield models developed by the Center for Climatic and Environmental Assessment support this experiment. LACIE also is provided periodic assessments of the effects of weather and climate on crop production over the major agricultural regions of the world. These assessments utilize environmental satellite data to supplement information available from the limited network of ground based weather stations. Research leading to operational precipitation estimates from satellite data was initiated with NESS in August 1977, to enhance the global assessment capability.

### **Aeronautical Programs**

#### *Aeronautical Charts*

The National Ocean Survey, in response to a request from the Federal Aviation Administration (FAA), will certify obstacle and terrain data for 72 air terminal sites in the United States. This is 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. Fifteen major sites were analyzed in 1977.

The FAA and the Ocean Survey also have developed product requirements and specifications for an Airport Facility Directory for the coterminous United States. It will be comprised of 7 volumes to be phased in over a period of 6 months beginning in late 1977. The Directory will be made available through subscription and will be updated every 8 weeks.

As air traffic and the complexity of regulations and control procedures increase, more specialized

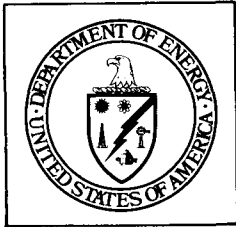
aeronautical charts are needed more quickly. To keep pace with this demand, the Ocean Survey organized an Aeronautical Chart Automation Project. The automated approach to aeronautical chart production was demonstrated this year when Radar Video Maps, generated by this system, were rated by the FAA as superior to those produced manually. This project is expected to make more efficient use of personnel and increase responsiveness to chart preparation deadlines.

#### *Use of Sensor Data from Aircraft*

*Safety Services.* The NOAA Atmospheric Physics and Chemistry Laboratory continued to conduct tests of a prototype clear-air turbulence detector and alarm system using NASA's C-141A, Learjet, and Convair 990 aircraft. The infrared radiometer detects anomalies in the water vapor ahead of the aircraft and gives 2 to 5 minutes advance warning of clear-air turbulence.

The NOAA National Severe Storm Laboratory used aircraft, conventional and dual-Doppler radars, a 444-meter weather-instrumented tower, and a mesonetwork of surface stations to investigate the Doppler radar's potential to locate and depict thunderstorm turbulence by measuring wind variations. Doppler radar capabilities in optically clear air were studied for depiction of wind shear associated with thunderstorm gust fronts which endanger aircraft during airport landings and takeoffs.

*Pollution Monitoring.* The Ocean Survey's Ocean Dumping Program Office conducted an experiment in the Gulf of Mexico during July and August 1977, to characterize the physical and chemical oceanographic conditions at an industrial waste disposal site. NASA aircraft acquired multispectral scanner and aerial photographic data over an organic sludge so as to track the distribution of waste. A similar experiment followed in December 1977, at a Deepwater Dumpsite in the Atlantic Ocean.



# 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 life of nuclear isotope power supplies have been essential to mission success. A continuing primary goal is to support the nation's civilian space exploration efforts with particular orientation toward NASA 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 can foresee the possible adaptation of today's spacecraft and satellites to the needs of tomorrow's world. New space technologies and spin-offs from today's technologies will undoubtedly play an important role in resolving our energy problems.

## Space Applications of Nuclear Power

### *Program Objectives*

In supporting NASA and DoD, DOE applies its various resources with the following intent:

- to exploit fully the results of prior research in nuclear fuel and special materials, thermoelectric elements, and candidate engine systems;
- to develop, analyze, and design toward the specific performance and environmental requirements established for the mission;
- to deliver environmentally acceptable, operationally safe, and technically qualified nuclear energy systems to the user agencies;
- to develop power systems technology for future requirements directed toward increased power, improved conversion efficiency and safety, and lower cost per electrical watt;

- to ensure the effectiveness of safety and environmental requirements for space nuclear systems operations;
- to perform data reduction analyses on launched or deployed nuclear power systems for comparison with predictions and for guidance toward future design alternatives;
- to initiate studies on the technology of alternative power sources, such as reactors, for potential high-power-demand applications.

In support of these objectives, the expertise at government-owned, contractor-operated laboratories is critical. DOE has recently completed construction of new plutonium-238 fuel fabrication laboratories and plant facilities at the Savannah River Plant site. Supporting research in fuel and advanced heat source design is conducted at the new Los Alamos Scientific Laboratory Plutonium Facility. Continuing research and improvement in containment capsule materials is pursued at Oak Ridge National Laboratory and at the Mound Facility where heat source assembly functions are also performed.

### *Program Abstract*

DOE's Office of Space Applications is the keystone in the structure linking nuclear materials and their technology with the space power requirements of other government agencies. The Atomic Energy Commission, fulfilling its historic role in the development of special nuclear materials for peaceful uses, provided the technical base for production of plutonium-238 in suitable quantities for space applications. This radioisotope has become the workhorse heat source for the majority of systems past, present, or future. Its 87.7-year half-life and its alpha-emission decay scheme combine to enable design and development of space power supplies with light weight, little shielding and long-term operational reliability.

In one of its essential roles, the Office of Space Applications seeks to effectively couple its expertise in nuclear technology with the skills of commercial contractors. These contractors provide the develop-

ment, fabrication, and support functions needed to deliver safe and efficient systems to convert the radioisotope decay heat into electrical energy. The so-called static conversion systems use solid state thermoelectric couples providing up to 500 watts of stable direct current to the spacecraft. Development of static converters is continuing, pointed toward higher efficiency and greater modularity. Dynamic conversion systems transfer the isotopic decay heat to a working fluid, which actuates a generator through either a piston or turbine system. Two such systems are currently under development, with expected efficiencies in the range of 18–30 percent, suitable to power requirements in excess of 1000 watts.

In its corollary role, the Office of Space Applications maintains liaison with NASA and DoD to explore and fulfill their needs for space nuclear power. The instrument of liaison is the coordinating committee; the vehicle of implementation is an

interagency agreement supported by appropriately funded procurement requests. Mutual fulfillment is evident at launch or deployment; mission support for these culminating events also is provided to ensure complete nuclear safety coverage, where required, and to assist in data review on a post-launch basis.

Studies of trends and national needs of the future have indicated a potential requirement for reactor-based power systems to provide 10–100 kilowatts of electrical power for specialized applications. Advanced dynamic conversion systems are expected to be used with these reactors as schedules develop.

#### Program Progress

The following table provides a brief recapitulation of space nuclear power systems (radioisotope thermoelectric generators (RTGs) or reactors) supporting the indicated successful NASA or DoD missions:

Summary of U.S. Space Nuclear Power Systems (1961–1977)

System	Mission	Launch Date	Status
Snap-3A RTG	Transit 4A	6/29/61	Achieved orbit
Snap-3A RTG	Transit 4B	11/16/61	Achieved orbit
Snap-9A RTG	Transit 5BN-1	9/28/63	Achieved orbit
Snap-9A RTG	Transit 5BN-2	12/05/63	Achieved orbit
Snap-10A Reactor	Snapshot	4/03/65	Achieved orbit
Snap-19B3 RTG	Nimbus	4/14/69	Achieved orbit
Snap-27 RTG	Apollo 12	11/14/69	Placed on lunar surface
Snap-27 RTG	Apollo 14	1/31/71	Placed on lunar surface
Snap-27 RTG	Apollo 15	7/26/71	Placed on lunar surface
Snap-19 RTG	Pioneer 10	3/02/72	Operated to Jupiter
Snap-27 RTG	Apollo 16	4/16/72	Placed on lunar surface
Triad-RTG	Transit	9/02/72	Achieved orbit
Snap-27 RTG	Apollo 17	12/07/72	Placed on lunar surface
Snap-19 RTG	Pioneer 11	4/05/73	Operated to Jupiter; on way to Saturn
Snap-19 RTG	Viking 1 & 2	8/20/75 & 9/09/75	Landed on Mars
MHW RTG	Les 8/9	3/14/76	Achieved orbit
MHW RTG	Voyager 1 & 2	8/20/77 & 9/05/77	Launched on way to outer planets

#### Current Status. As of the end of 1977

- The Transit, Snapshot, and Nimbus systems are in up to 4000-year-lifetime orbits after fulfilling numerous program objectives and in certain cases indicating areas for design improvements.
- The Apollo Lunar Surface Experiments Package (ALSEP) units were established by the Apollo explorers in five different locations on the Moon. Specifications called for a one-year operating life for the first four ALSEPs and two years for the Apollo 17 station; all have exceeded this requirement by delivering power up to the official termination date of September 30, 1977. As a consequence of the reliable performance of both the power supplies and

the scientific instrumentation, NASA has accumulated evidence of approximately 10,000 moonquakes and 2000 meteorite impacts, in addition to obtaining data on charged particles in the Moon's atmosphere and on the magnetic environment and interior lunar structure.

- Twenty trajectory months after its launch in March 1972, Pioneer 10 encountered Jupiter, performed close-up studies of the planet, its moons, and its environment, and transmitted these data to eager scientists on Earth. The four radioisotope thermoelectric generators on this spacecraft continue to report their own power output and scientific data after 5.6 years of service and from a distance exceeding 1.9

billion kilometers from both the Earth and the Sun. System performance is following an expected trend, while the spacecraft follows a solar system escape trajectory.

Pioneer 11, technologically a twin but programmatically different, performed a Jupiter fly-by maneuver and then was targeted for Saturn encounter in 1979. Power system performance data, reported in flight from a distance of 1 billion kilometers from Earth, again indicate a stable, predictable output after 4.5 years of operation.

- The Viking landers were successfully positioned at two selected sites on the planet Mars on July 20 and September 3, 1976 after launch on August 20 and September 9, 1975, respectively. The soil sampling apparatus, the complex sensors and analytical laboratories on board the landers, and the telemetry and television equipment transmitting information to Earth were dependent upon the radioisotope thermoelectric generators (RTGs) for continuing power supply. These units remained viable throughout the diurnal and seasonal temperature variations characteristic of the Mars weather patterns. In fact, some heat from the generators also was diverted periodically to keep certain lander equipment warm during the colder periods. Latest reports from the lander telemetry system indicate stable performance at a predictable power output level, after more than a year on the Martian surface.
- The Lincoln Experimental Satellites (Les 8/9) were launched in March 1976 as communications satellites. The radioisotope generators on board not only provide necessary operating power but also are to demonstrate the dependability and survivability of a satellite powered in this manner for long-term operation in a hostile environment. At last check, the nuclear power supplies were delivering power slightly in excess of expectations, and performance was very satisfactory. The record of Les 8/9 generator performance lends encouragement to use of the Multi-Hundred Watt (MHW) units in other applications where Earth-orbital power supplies are required.
- The two Voyager spacecraft (formerly designated Mariner Jupiter/Saturn) were launched from the Kennedy Space Center on August 20 and September 5, 1977, respectively. Each was powered for its scientific mission studies by three MHW generators. Their combined output was on the order of 475 watts per spacecraft. The total nuclear power allocated for this mission essentially equals the total of all previous missions currently in

space. Reports telemetered from the Voyagers indicate stable operation of the MHW generators and favorable prognosis for data retrieval at Jupiter encounter in 1979 and Saturn encounter in 1980–1981. It is anticipated that the generator lifetime will be adequate to return information from the approach to Uranus in 1986 and possibly from Neptune in 1989.

*Trends in Technology.* Materials technology and generator design have shown a steady evolutionary improvement as the space nuclear power program advanced to meet the challenges of ever more stringent mission requirements. Selection of fuel material was limited initially to plutonium-238 metal or an alloy with zirconium; these materials yielded 6–7 thermal watts per cubic centimeter of fuel, but were not compatible with typical capsule metals at elevated temperatures. Plutonium-238 oxide microspheres, fused to high density with a plasma torch, were much more stable in contact with containment metals at elevated temperatures, but suffered from a low power density of 2.5–3.0 watts per cubic centimeter. Significant improvement was achieved with molybdenum-coated particles, hot-pressed into a disk. This fuel form was much more stable toward its environment and showed a power density in excess of 4.0 watts per cubic centimeter. Further advantages were achieved with a hot-pressed sphere of plutonium-238 oxide, welded into an iridium capsule, and cushioned in a protective fibrous graphite impact shell. This fueled unit not only operates at high temperatures but is designed to withstand reentry heat and impact and to resist corrosive action in any environment.

Throughout the design history of space nuclear power systems, severely competitive trends in specification are evident. Increasing power demands have been tempered by constraints on payload weight; as a consequence, engineers used beryllium and specialized graphites to reduce power system weight. Increasing safety requirements for launch and possible reentry situations result in multiple encapsulation with resistant metals; in response, fuel specialists developed fuel forms with higher power density and improved mechanical and chemical stability.

Similarly, the development of thermoelectric converter materials has been responsive to the demands for additional power without weight penalties. The lead telluride modules of earlier systems were improved in efficiency by use of a tellurium-antimony-germanium-silver leg; by this expedient, the conversion factor rose from 5.0 to 6.3 percent. An additional increment in efficiency was achieved by

adoption of silicon-germanium couples; conversion rose to 6.7 percent, and the higher operating temperature enabled greater wattage output.

Representative materials and their performance parameters are tabulated to show the steady progress to date:

<i>Generator</i>	<i>Snap-3</i>	<i>Snap-27</i>	<i>Snap-19</i>	<i>MHW</i>
Mission	Transit 4	Apollo	Pioneer	Les 8/9
Fuel Form	Pu-metal	PuO <sub>2</sub> microspheres	PuO <sub>2</sub> Mo cermet	Pressed PuO <sub>2</sub>
Thermoelement	PbTe	PbSnTe	PbTe-TAGS	SiGe
Specific Power, w/lb	0.67	1.06	1.36	1.90
Conversion efficiency, percent	5.0	5.0	6.3	6.7

*Trends in Systems.* To date, the static thermoelectric conversion systems have satisfied requirements for up to 500 watts of electrical power, delivered reliably for mission durations of up to ten years. Conversion efficiencies in the range of 5 to 7 percent, however, may limit payload weights and therefore scientific opportunities may not be realized. Research has proceeded on a class of selenide thermoelement materials which have shown 8.5 percent conversion factors in the laboratory, and appear to be capable of development toward 10–15 percent efficiency. When achieved, the synergistic benefits of nuclear power and optimal conversion factor will provide striking advantages in retrieval of scientific data from outer-planetary missions.

In anticipation of near-term requirements for nuclear electric power supplies capable of delivering 500–2000 watts, DOE has coupled its nuclear expertise with industry in the development of both a Brayton cycle engine and an organic Rankine cycle engine. It is expected that either of these systems, when chosen for flight development, will have efficiencies approaching 30 percent.

The trends in technology and systems, pursued with adequate and well-managed resources, will lead toward continuing progress and new outreach, as suggested by the charts.

### Program Planning

In the summer of 1977, Congress approved and began funding the Jupiter Orbiter/Probe, a NASA mission scheduled for launch in 1982. Its objective is to further explore the environment, atmosphere, topography, and structure of that fascinating planet. In support of this endeavor, DOE has undertaken to develop the selenide isotope generator, incorporating the higher efficiency selenide conversion materials and the flight-qualified MHW heat source. Two generators delivering 240 watts each comprise the nuclear power complement.

Additional NASA missions proposed as FY 1979 "new starts" include the solar-polar mission for launch in 1983; this mission is sponsored jointly by NASA and the European Space Agency. In antic-

ipation of this requirement, DOE has initiated design and materials studies on a general purpose heat source, which would be coupled with a selenide thermoelectric converter. Improved performance and safety benefits are expected from this combination.

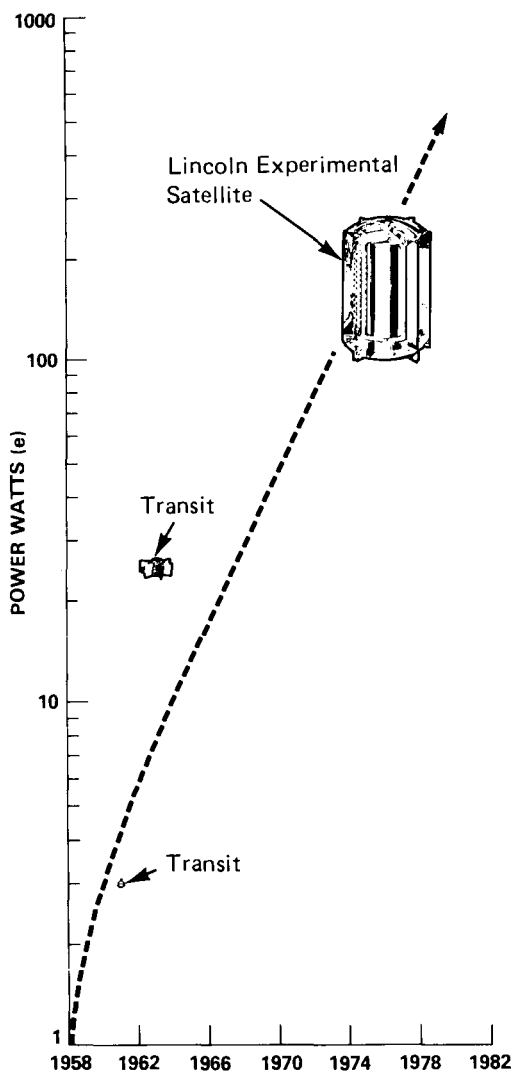
On the horizon are DoD requirements which indicate a need for (a) systems supplying electrical power in the 1–2 kilowatt range, and (b) considerably more substantial systems delivering 10–100 kilowatts. To support the indicated near-term need for the lower power levels, DOE is actively exploring the relative merits of two candidate dynamic systems, the Brayton isotope power system and the kilowatt isotope power system. The latter system employs an organic Rankine cycle engine. Development and engineering are progressing in each area; ground demonstration tests are scheduled for early 1978 and detailed evaluation will be pursued to enable selection of that system best fulfilling its functional specifications and best suited to the conditions of Shuttle launch. A demonstration flight test in 1982–1983 is contemplated as part of the DoD space test program. Affirmative results from that demonstration flight test would be significant input to the selection of the power system for the global positioning satellite, deep space surveillance systems, and general purpose satellite communications system.

For the higher kilowatt range, isotope power converters are not viable candidates; rather, spaceborne reactors are appropriate. Numerous ground-based reactor systems already have shown promise and studies leading to development of their specific utility for space applications are planned as a continuing element of the DOE space power program.

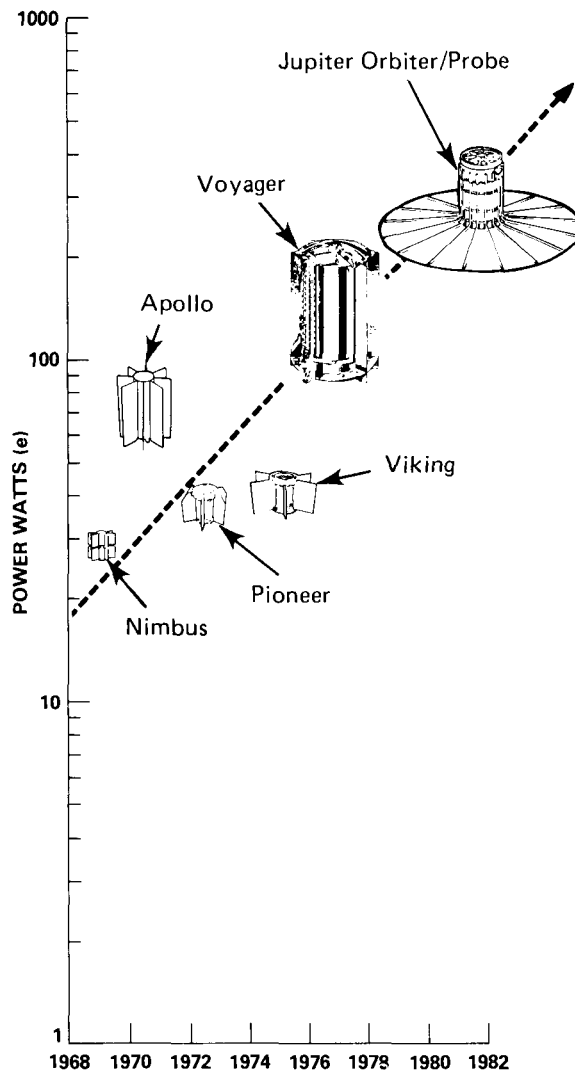
### Space Disposal of Nuclear Wastes

A cooperative study with NASA/Lewis Research Center in FY 1972 investigated the feasibility of nuclear waste disposal in space. It was determined that space disposal could reduce but not eliminate the need for terrestrial disposal methods. It was also concluded that additional processing would

**Progress in Space Nuclear Power:  
DOD Missions**



**Progress in Space Nuclear Power:  
NASA Missions**



be required to concentrate the long-lived radioactivity fraction for transport to space. During the past year, DOE provided further information to NASA to support a study to more specifically identify the possible applications of the use of the Space Shuttle for such disposal. The NASA study is scheduled for completion in 1979.

**Satellite Power Stations**

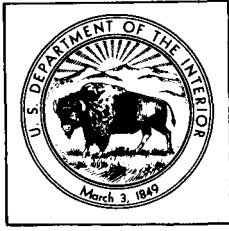
Satellite Power Stations (SPS) in geostationary orbit, which would convert solar energy to microwave energy for transmission to Earth and ultimate use as a terrestrial energy source, were first sug-

gested in 1968 and in recent years were under study by NASA. In 1976 the lead management responsibility for the SPS endeavor was transferred from NASA to DOE.

During 1976 a DOE task group studied the SPS concept, including the NASA activity, and concluded that, while no obvious or clearly unsurmountable problems were identified, insufficient information was available for any significant program decisions. The task group recommended a three-year program of studies leading, in 1980, to a recommendation regarding the advisability of continued development efforts. In recognition of the technical

breadth of the recommended study, an SPS panel of a DOE/NASA coordinating committee was established in late 1976. This panel prepared, in May 1977, a program plan for the development and evaluation of the SPS concept. In this plan, NASA is responsible for systems definition; DOE is respon-

sible for health, safety, and environmental factors, socio-economic issues, and comparative evaluations with terrestrial alternatives. During 1977 joint efforts by NASA and DOE in implementing this plan were accelerated.



## 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 more than one level of observation and 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 the department 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 some bureaus of the department are incorporating this new technology into their activities.

## Earth Resources Observation Systems Program

The purpose of the Interior Department's Earth Resources Observation Systems (EROS) program is to develop, demonstrate, and encourage applications of remotely-sensed data acquired from aircraft and spacecraft which are relevant to functional responsibilities of the department. The primary areas of activity are:

- applications demonstration and research
- user assistance and training
- data reproduction and distribution

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) aircraft, by National Aeronautics and Space Administration (NASA) research aircraft, and by Landsat, Skylab, Apollo, and Gemini spacecraft. Training and user assistance in applying remotely-sensed data are also major functions of EDC.

To facilitate regional applications, the EROS program operates three Applications Assistance Facilities where the public may view microfilm of imagery available at the EROS Data Center and receive assistance in searching and ordering data via computer terminal link to the central computer complex at Sioux Falls.

## *Application Demonstrations and Research*

EROS program scientists seek new applications of remote sensing to significant resource and environmental problems, commonly in cooperation with other organizations. One example is the Pacific Northwest Land Resources Inventory Demonstration Project, sponsored by the Pacific Northwest Regional Commission in cooperation with the EROS program, the Geography program of USGS, and NASA. This project has demonstrated the utility of Landsat data from these programs for resource management in the states of Idaho, Oregon, and Washington. It is estimated that use of Landsat data will permit a forest inventory of western Washington (40,500 square kilometers) to be completed in one half the time and at one tenth the cost of standard methods. A survey monitoring urban change was done with 98 percent accuracy in 1 man-month using Landsat data from these programs versus 15 man-years using standard methods. Because of the useful results already achieved, an operational resource inventory system in the Pacific Northwest based on the use of Landsat data from these programs is planned.

Other current application demonstrations include:

- Delineation of glacial moraines in the northern midwest by visual analysis of subtle terrain features on a mosaic of 54 Landsat images acquired during spring 1972-1976.



- Experimentation with optical and digital enhancement techniques on Landsat images of the Santa Barbara Channel to facilitate detection of oil in coastal waters.
- Application of the Australian concept of land systems mapping to the California Desert Conservation Area. The Bureau of Land Management and EROS are cooperating in this study, using aerial photographs, Landsat data, and interactive computer analysis to classify the soil, vegetation, landform, and other surface properties.
- Use of Landsat imagery of the Trust Territories in the Pacific to aid in delineating shallow bottom features. Through special arrangements with NASA, band 4 of the multispectral scanner was operated in the high-gain mode, thereby enhancing the underwater features in the shallow seas.
- Use of Landsat data in Project 143 of the United Nations Educational and Scientific and Cultural Organization (UNESCO)-sponsored International Geological Correlation Programme.
- Training and consultation for a Landsat inventory of natural resources of five Central American countries, to be performed by the EROS program and Purdue University with funds from the InterAmerican Development Bank.
- Use of Geostationary Operational Environmental Satellite (GOES) and Landsat data collection platforms to monitor stream flow, water levels, snow pack, weather, and volcanic events in Chile and Bolivia. Performed cooperatively with those two countries by the EROS program and the Water Resources Division of USGS.

#### *Data Reproduction and Distribution*

Since its establishment in 1972, EDC has distributed approximately 1.8 million reproductions from the nearly 6 million images in the data base. Half of the reproductions were from Landsat imagery, and in addition to images, nearly 6000 computer-compatible tapes of Landsat data have been supplied to users.

Dollar volume of all products sold in 1977 amounted to about \$2,500,000. Landsat products, while comprising only 18 percent of the data base, accounted for \$1,674,000 or 62 percent of the total sales. Of that total, digitally enhanced scenes amounted to \$137,000, and computer-compatible tapes \$374,000 or more than 30 percent of total Landsat sales, reflecting the increasing trend toward digital processing of Landsat data. Foreign users

and industry are the principal purchasers of Landsat data, accounting for approximately 32 and 27 percent respectively, of the total sales. The Federal government is the next largest category, at about 24 percent.

A digital image processing system is being readied by NASA and EDC to provide products from Landsat-C data, expected in 1978, which will be superior to those from Landsats 1 and 2. During 1977, about 175 Landsat images were computer-enhanced for special orders, approximating the image quality that will be routinely available with the new system.

#### **National Cartographic Information Center**

EDC also supports the National Cartographic Information Center, a facility of USGS which provides cartographic data and information on aerial photographs from Federal, state, and private organizations as well as data collection plans of those organizations. To facilitate the purchase of imagery from satellites and aircraft by the public, a number of NCIC offices located throughout the country are connected by remote terminals to the central computer complex at EDC.

#### **Monitoring the Environment**

##### *Alaska*

To provide data with which to analyze the environmental impact of oil exploration on the National Petroleum Reserve in Alaska, the USGS Geography program made a digital classification of the land cover and vegetation on ten Landsat images covering the area.

Changes in the Gulf of Alaska shoreline since 1941 were analyzed from various sets of aerial photographs to assess a potential staging area for offshore oil and gas development.

During two months of Alaska's dry summer, more than 500 fires burned about 8100 square kilometers of forests. The state used a Landsat rangeland inventory to decide where to concentrate fire protection.

##### *Mining Activities*

Because of the increase in surface mining activities, Conservation Division of USGS is using aerial photographs and satellite imagery to delineate various categories of surface mining operations and stages of reclamation in the Powder River basin of Montana and Wyoming and in southeastern Idaho. Aerial photographs and Skylab and Landsat images are being evaluated for use in mapping land use,

vegetation, and drainage in preparing environmental analyses and impact statements.

Bureau of Mines has funded four new remote sensing projects as part of its State Liaison Program. In New Mexico, the Navajo and McKinley coal mines, Grants uranium district, and potash mining areas are being monitored from Landsat imagery. Digital analysis of Landsat data is being used for monitoring phosphate mines in Florida and kaolin mines in Georgia and South Carolina.

The Mining Enforcement and Safety Administration is using aerial photographs and satellite multispectral imagery to identify linear features that may be related to fault and fracture systems, to evaluate mine ground stability, and to locate and monitor leakage and movement of mine embankments in surface and underground mines. These efforts to identify potentially hazardous ground in mine areas have been applied to over 100 sites in 26 states.

### *Indian Lands*

The Bureau of Indian Affairs, NASA, and USGS cooperated to obtain high-altitude aerial photographs of all Indian lands. The project was extended to include orthophotoquads, which will be used in a census of Indians in 1980 by the Bureau of the Census.

### *Data Collection Systems*

The Satellite Data Relay Project of the USGS Water Resources Division coordinated the installation of field radios (Data Collection Platforms) at 100 hydrologic sites in the United States for testing the GOES telemetry system. Field installation of 11 Comsat General platforms has begun in preparation for a 1978 demonstration of the commercial system.

USGS Geologic Division is cooperating with NOAA in a study of the Earth's magnetic field. The GOES system is used to relay information from 25 strategically placed magnetometers to the NOAA facility at Boulder, Colorado, where quick access is available to researchers via computers.

USGS geologists are also using the GOES system to monitor variations in the abundance of helium in the soil in remote Nevada locations. The information is used in earthquake prediction research.

## **Research**

### *Geology*

*Planetary studies.* The USGS provided scientific leadership and technical support in planning the Viking mission, in orbiter and lander imaging, and

in geochemical analysis of the materials on the surface of Mars. Large-scale maps were made of the landing sites, and uniform scale mosaics were made of large areas of the planet photographed by the orbiter. These will serve as a basis for a new planet-wide map series for Mars.

*USGS Minerals Land Assessment Program.* Methods developed for discrimination of hydrothermally altered rocks by ratioing and contrast stretching and mapping of major structural lineaments with Landsat data are being applied in a new exploration model for southern Arizona.

In the Powder River Basin, Wyoming, Landsat images are being used in developing techniques for detecting subtle changes in vegetation cover, which may indicate the presence of altered rocks and mineralized areas. Data beyond the spectral range of the Landsat multispectral scanner were acquired by an airborne scanner.

### *Hydrology*

USGS hydrologists are studying sea ice in Arctic and Antarctic regions as part of the Arctic Ice Dynamics Joint Experiment, using data from aircraft and from the scanning microwave radiometer on Nimbus 5. These data indicated that there was only a 50-percent concentration of ice in 100,000 square kilometers of the Arctic ice pack. Four years of data show that the morphology and dynamics of the ice are far more complex than was hitherto realized.

Landsat and NOAA satellite imagery were used in USGS research on sea ice dynamics and zonation in the Beaufort Sea and their relation to bottom morphology and geologic processes. The use of artificial islands, placed to modify the ice zonation, was proposed to make the offshore environment less hostile.

Bureau of Reclamation uses imagery of clouds from GOES to analyze storm systems in a research study of harsh winter climate in the Sierra Nevada Mountains and to forecast and control experimental events in Project Skywater, a weather modification program. Aircraft are used for data collection and cloud seeding in these experiments.

### *Land Use*

The Geography program devised efficient computer techniques to produce a land cover map of the Washington, D.C., metropolitan area compiled from October and April 1973 Landsat data. Part of a six-map folio at a scale of 1:1,000,000, the map is overprinted with place names and landmarks as well as census tracts on the Universal Transverse Mercator rectangular coordinate system.

In 1977, NASA and the USGS started a three-year cooperative Application Systems Verification and Transfer project to test the feasibility of the operational use of Landsat digital data for change detection and updating land use and land cover maps being produced by the USGS Geography program.

### **International Activities**

In addition to the remote sensing workshops conducted for foreign participants by the EROS Data Center, USGS cooperated with the Department of State and various international organizations in offering technical assistance, consultations, and briefings on the applications of remote sensing data to 60 other countries.

USGS with the U.S. Agency for International Development (AID) sponsored the Fourth CENTO Workshop in Turkey, and contributed to the development of remote sensing in Iran, Pakistan, and Turkey. Iran is also being assisted in starting a Landsat data center as an adjunct to their planned ground receiving station.

Also in cooperation with AID, USGS scientists participated in discussions about applications of Landsat data in a series of television programs (AIDSAT) relayed to 26 countries by the ATS 6 communications satellite. A program with Thailand establishing a remote sensing center for reproducing data and training staff has been extended for another year. A photomosaic was prepared for a Philippines land reform program. New faults were discovered on Landsat images of Jordan in a geologic mapping program.

In USGS bilateral agreements, Landsat data were among the tools used in selecting a site for Nigeria's new Federal capital city; a Landsat applications office was established in Saudi Arabia to aid in assessing the petroleum and mineral resources and preparing base maps of that country.

Scientists from Iceland, Iran, Japan, Lesotho, Poland, Spain, and Thailand spent all or part of 1977 working in USGS facilities on remote sensing projects.



## Introduction

The Department of Transportation manages a significant aeronautical research and system development program through its aviation component, the Federal Aviation Administration (FAA). This program supports FAA's major missions of assuring the safe and efficient use of the national airspace, fostering civil aeronautics and air commerce at home and abroad, and promoting air safety.

## Air Safety

### *Minimum Safe Altitude Warning (MSAW)*

The Federal Aviation Administration initiated this program in 1973 in response to a National Transportation Safety Board recommendation. The initial effort concentrated on enhancing automation in the terminal area of air traffic control by introducing new computer software for the Automated Radar Terminal System (ARTS-III) at major airports. The altitude warning system receives surveillance and altitude data from properly equipped aircraft that are being tracked by the air traffic control system. These data are compared with highest-points-of-ground-elevation data contained in a terrain map stored in the terminal computer memory. Whenever an aircraft is flying too low to the ground, the system provides the controller with both an aural and a visual alert; the controller in turn issues a radio warning to the pilot that he has descended below a minimum safe altitude.

The altitude warning system was successfully developed in an experimental environment in late 1974 and given a field evaluation in 1975; by late 1976, the program was fully operational at three major terminals: Los Angeles, Washington National, and Dulles International. In 1977, this warning system became operational at the remaining 60 ARTS-III terminals.

FAA has also validated the requirement for altitude warning in the en route air traffic control system. Like its terminal counterpart, En Route Minimum Safe Altitude Warning will be a ground-based aircraft altitude monitoring system tied to

the large central computer complex installed in each of the 20 Air Route Traffic Control Centers (ARTCCs) in the contiguous 48 states. Demonstration of this safety feature to the operating services is planned for the fall of 1978.

### *Wind Shear*

Since 1971 there have been seven air carrier accidents in which wind shear—abrupt change in wind speed or direction in the approach/departure zone—was a major contributing factor. During 1977, FAA sponsored research and development in three areas in its search for solutions to this problem:

- Development of a ground-based hazardous wind shear detection and tracking system;
- Development of avionics to assist pilots in coping with wind shear encounters;
- The testing of improved techniques for forecasting low-level wind shear associated with frontal zones. Ground-based sensor testing was conducted at six airports using additional anemometers mounted in the approach/departure zones to detect wind shear; airborne simulation studies were also employed. Techniques for displaying aircraft ground speed versus indicated airspeed were developed for airborne evaluation in late 1977. Improved forecasts of wind shear are still being pursued.

### *Conflict Alert*

During the last two calendar years, FAA has been actively engaged in installing and bringing into operational use a conflict alert system at Air Route Traffic Control Centers and at congested airport terminal areas. By the summer of 1977, the agency had successfully implemented conflict alert in nearly all en route ATC airspace and had begun concentrating on a parallel program for terminal areas. Terminal conflict alert functions with the Automated Radar Terminal System; it is similar operationally to the system in use in the en route airspace. The computer software “looks ahead”

along the flight paths of controlled aircraft. If two or more planes are predicted to approach unsafe separations within 40 seconds, the terminal controller is alerted to the potential conflict by a buzzer and the flashing of "CA" on the screen of his display consoles. The controller then takes the necessary action with the pilot to assure safe separation.

In early 1977, the terminal conflict alert computer program began undergoing system test at FAA's National Aviation Facilities Experimental Center, at Atlantic City, New Jersey. Field testing and evaluation in an operational environment were successfully completed at the Houston International Airport control tower in the fall of 1977.

### *Transport Safety*

New technology is emerging that has a high probability of being used in the next generation of jet transport aircraft. Examples of this emerging technology are composite structures, active control systems, digital avionics, and digital flight control systems. While these advances will lead to more efficient transports that will produce a higher rate of return on investment by reason of improved productivity and lower operating costs, they pose safety and certification problems that FAA has never before encountered.

Composite structures are stronger and lighter than conventional aluminum structures; at the same time, their lack of yielding deformation before failure makes their behavior under crash loads uncertain. Similarly, active control systems and airborne digital computers introduce different airworthiness concerns from those of the past. These include software validation, reliability assessment verification, lightning and electromagnetic interference effects, and failure detection.

Accordingly, in concert with the National Aeronautics and Space Administration, FAA embarked in 1977 on a broad program to examine the research and development areas pertinent to the certification implications of these technological advances.

### *Fire Safety*

FAA research and development activities during the reporting period in reducing the hazard of post-crash fires included:

- Initiating a two-year effort to develop a method for ranking a transport cabin's interior material for its collective combustion hazards. This approach to improving the postcrash fire safety of cabin interiors is novel because it relates the combustion properties of a cabin

material to physiological tolerances within the emergency-evacuation environment found during postcrash fires.

- Conducting full-scale cabin-fire tests in a simulated wide-body air carrier cabin at FAA's National Aviation Facilities Experimental Center. The tests were designed to assess hazards caused by burning cabin-interior materials and by the byproducts of burning fuel entering the cabin. These tests are expected to quantify hazard sources.
- Performing tests with the U.S. Navy using an antimisting additive in the fuel to minimize the crash fireball. The test results proved promising. Efforts will continue to assess and evaluate the additive's compatibility with existing fuel systems.

### *Aviation Security*

The goals of FAA's civil aviation security program are to deter acts of terrorism or sabotage aboard aircraft and at airports. Research and development programs in this area are designed to develop new deterrent systems as well as evaluate existing systems that may be used in the security program. These activities are coordinated with other U.S. agencies active in bomb detection and counterterrorism. In calendar 1977, FAA

- Demonstrated an experimental automated radiation contrast system to detect bombs in luggage. Tests at three airports using normal passenger luggage with and without simulated bombs produced excellent detection rates and low false-alarm rates. Procurement of the system for operational use at airports is under way.
- Identified locations aboard commercial aircraft where bombs discovered during flight might be placed with least risk to passengers and aircraft. In all tests with live explosives that followed these least-risk procedures, damage was reduced to levels that would have permitted the aircraft to land safely.
- Developed and demonstrated low-cost barriers and locker modifications that significantly reduce the potential death, injury, or damage from explosions in airport lockers. These straightforward design techniques limit damage to the immediate vicinity of the explosion.
- Completed an air-cargo bomb security study that included procedures to prevent bombs from being brought aboard aircraft with cargo.
- Evaluated all commercially available explosive-vapor detectors. None met FAA's requirements for aviation security.

- Started development of an experimental bomb detector system using thermal neutrons, after successfully demonstrating the concept in the laboratory.
- Successfully tested an experimental nuclear magnetic resonance explosive detection system in the laboratory. The development of preproduction prototypes was started.

### *Aviation Medicine*

FAA medical research activities during the reporting period focused on certain areas of high relevance to air safety—namely, occupant survival in air transport accidents and aircrew medical characteristics affecting flight performance.

Among the more significant studies undertaken in this area was an examination of the relative toxic hazards of 75 aircraft-cabin materials when these materials are subjected to fire. The materials included urethanes, polyvinyl chlorides, and various natural products, including wool. The findings of this study, when combined with other available information and applied to aircraft manufacture, will help to improve survivability in future aircraft accidents involving fire.

An investigation was also undertaken of the potential problems related to the emergency evacuation of handicapped passengers from aircraft. The study included an analysis of the movement of handicapped individuals within the cabin and the results of evacuation tests (using an emergency evacuation simulator), in which a portion of the test subjects either were handicapped or simulated handicaps. Data were generated on assistance required by handicapped passengers, effects on evacuation time of a group of such passengers, including seating location, floor slope, and exit design. An FAA report on these findings included suggestions by handicapped subjects and a summary of recent accidents involving evacuation of handicapped passengers.

When aircrew members approach middle age, correction for near vision often becomes necessary, especially for dim light conditions, as found in night flying. The traditional correction has been for reading, particularly with regard to aeronautical charts. During flight activities, however, precise vision at the intermediate distance, where the instruments are located, is also highly significant, so that many crewmembers require trifocal lenses—a relatively unusual lens combination among the non-flying public. For this reason a special study was conducted of intermediate visual correction, and a report made available for aviation medicine personnel and others concerned with pilot-vision factors.

In another vision study, it was found that pilots dependent on visual cues alone during night operations may make approaches that are too low—a tendency produced by visual illusions. An FAA report detailing these findings warns pilots that they must be aware of this tendency to approach runways at excessively shallow angles under night conditions. This information will be of importance to pilot training and safety education programs.

In view of periodic questions that arise concerning an FAA rule making mandatory the retirement of airline pilots at age 60, FAA's Office of Aviation Medicine undertook an intensive review of the scientific literature on the effects of aging. It was concluded that there is no sound basis for predicting the extent to which the aging process will degrade pilot performance. Until reliable criteria—based on a valid psychophysiological age index—are established, the current medical data support the continued use of age 60 as the age beyond which pilots should discontinue serving as airline pilots.

### **Air Traffic Control and Air Navigation**

#### *Microwave Landing System (MLS)*

The present instrument landing system (ILS), a product of the 1940s, has a number of disadvantages: terrain, structures, and aircraft interfere with its signals; it can provide flight path information for only one approach path; its limited number of frequency channels cannot meet future growth demands. None of these drawbacks is a feature of the Microwave Landing System, a system under development by FAA since the early 1970s and now in its third phase—prototype development and evaluation.

In mid-1976, FAA took delivery of two prototype Small Community systems and two prototype Basic Systems. These prototypes are now undergoing test and evaluation at the National Aviation Facilities Experimental Center and at Crow's Landing, California, by FAA, NASA, and the military services.

Meanwhile, the system developed by FAA, the Time Reference Scanning Beam system, was submitted to the International Civil Aviation Organization (ICAO) as the U.S. candidate for international standardization. After an assessment of all proposals by ICAO's All Weather Operations Panel, the U.S. system was selected and recommended to the Air Navigation Commission. This recommendation has been placed on the agenda for discussion and possible selection as an international standard at a world-wide ICAO/All Weather Operation meeting scheduled for April 1978.

### *Flight Service Station Modernization*

The mission of FAA's Flight Service Stations (FSS) is to promote safety in flight by (1) providing preflight and inflight weather briefings; (2) accepting and processing both instrument flight rule (IFR) and visual flight rule (VFR) flight plans; (3) providing inflight emergency assistance; (4) performing search and rescue operations; and (5) preparing and distributing notices to airmen (NOTAMs).

Current FSS operations are highly labor-intensive. The flight service specialist has to search through voluminous papers to retrieve the necessary data for pilot briefings and flight plan handling—a slow, error-prone, and expensive process. Although eighty percent of the current annual \$150-million operating expense for the system represents personnel staff costs, the demand for flight services is forecast to triple by the year 1995. If FAA met this demand by expanding the manual system, the annual operating cost would approach \$360 million. Rejecting that alternative, FAA has undertaken to modernize the flight service station system.

The following modernization efforts were completed during 1977:

- A master plan, concentrating on specialist automation and direct user access to the system for weather briefing and flight plan filing, was devised. The objective was to meet the present and projected long-term demand for flight services without a proportional increase in staff and commensurate operating costs.
- Extensive system configuration analysis and design work were performed and a procurement specification written for acquisition of the automation system required by the master plan.
- Field testing and evaluation of the Aviation Weather and NOTAM System (AWANS), a prototype automation system originally installed in 1975, were completed at Atlanta, Georgia.
- Demonstration of the operational concept of co-locating a flight service station with an Air Route Traffic Control Center and of performing the functions of several flight service facilities at a single site was completed at Leesburg, Virginia.
- Experiments with Pilot Self-Briefing Terminals were conducted at 14 locations throughout the United States involving over 1450 pilots.
- An experimental Voice Response System was completed and is expected to be operationally demonstrated in early 1978.

- A mass weather dissemination engineering model was assembled at NAFEC for demonstration in early 1978.
- A successful operational evaluation of an improved method of pilot briefing by telephone, without flight service specialist assistance, was completed at New York's La Guardia Airport. The method permits segment updating of data and eliminates the common rotary message and the participation of the flight service specialist.

### *Central Flow Control*

A major step to reduce "inflight time" and conserve fuel has been taken by the FAA through upgrading the automation capability of the Central Flow Control Facility in the Air Traffic Control System Command Center. Established within FAA headquarters in 1970, the Control Center exercises control and coordination of air traffic flow in the National Airspace System.

After program approval early in 1976, a series of acquisition-related activities followed in 1977:

- A contract was awarded for computer software development.
- The installation of a dedicated computer system in the flow control area of the Jacksonville Air Route Traffic Control Center. Computer checkout was completed in late summer.
- The start of system integration, leading to an initial system test by the end of calendar year 1977.

### **OST Research Support**

In addition to the R&D efforts undertaken by FAA, the Office of the Secretary of Transportation (OST) pursues research and analysis in areas affecting the nation's air transportation system. The principal OST aeronautical research activities during 1977 involved noise abatement, advanced telecommunications systems, advanced aviation transportation concepts, and fundamental studies in intermodal relations and demand forecasting. The prime objective of this work is to augment FAA efforts and ensure that the department fulfills its responsibility in providing timely national leadership in the evolution of the nation's aviation transportation system.

During 1977, OST complemented FAA's environmental efforts by reviewing Concorde noise data collected by FAA and by preparing rulemaking guidelines that led to the Secretary's decision, in September 1977, to open up on a trial basis specified U.S. airports to the existing Concorde fleet. In another action in the noise-abatement area, the Of-

Office assisted FAA in implementing its December 1976 noise rules on engine retrofit by providing support during the negotiations that produced legislative proposals on such key issues as planning and financing of required airport noise abatement programs.

Telecommunications play an increasingly important role in modern transportation by providing more efficient and safer operation. Because of the pervasive nature of telecommunication, cooperative arrangements and close liaison with other agencies are a major concern; OST serves as a focal point for DOT coordination. This was clearly evidenced by the extensive efforts in 1977 in the revision of DOT's National Plan for Navigation, which lays the groundwork for U.S. policy on navigational systems, including airspace coverage.

Innovative airport networks, advanced system

concepts, and actual aircraft technologies are often identified and studied by Office special task force groups. Many advanced concepts in civil aeronautics systems were evaluated during 1977 at its Transportation Systems Center. In addition to work on new system concepts, OST personnel participated in hearings and multigovernmental study groups on topics such as advanced V/STOL evaluation.

OST often functions as the focal point for transportation intermodal studies and analyses. In 1977, continuing studies analyzing aviation's evolving role in the nation's transportation system were conducted and long-range forecasts made in an attempt to identify transportation trends and determine how aviation systems will affect and be affected by future technical developments and service demands.



# 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	1967	78	4	10	0
1958	5	8	0	4	1968	61	15	3	0
1959	9	9	1	2	1969	58	1	8	1
1960	16	12	1	2	1970	36	1	3	0
1961	35	12	0	2	1971	45	2	8	1
1962	55	12	4	1	1972	33	2	8	0
1963	62	11	0	0	1973	23	2	3	0
1964	69	8	4	0	1974	27	2	1	0
1965	93	7	4	1	1975	30	4	4	0
1966	94	12	7	<sup>1</sup> 1	1976	33	0	1	0
					1977	27	2	2	0
					Total	889	127	72	15

<sup>1</sup> 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	<sup>1</sup> 1	1	1		
1971	30	83	1	<sup>1</sup> 2	2	1		1
1972	30	74		<sup>1</sup> 1	1			
1973	23	86						
1974	22	81		<sup>1</sup> 2	1			
1975	27	89	3	1	2	3		
1976	26	99			1	2		
1977	24	98			2			
Total	695	1075	10	8	10	7	1	1

<sup>1</sup> 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—1977

Launch date (G.m.t.) Spacecraft name Cospas designation Launch vehicle	Spacecraft data	Apogee and perigee (kilometers) Period Inclination to equator (degrees)	Remarks
Jan. 28 NATO III B 5A Delta	Objective: To launch spacecraft into synchronous orbit over equator for use by NATO. Spacecraft: Drum-shaped 2.2-m in diameter, 2.23-m long, with overall length of 3.1-m including antennas. Weight at launch: 670 kg. Weight after apogee motor fire: 310 kg.	35,962 35,463 1432.3 2.8	Second of three planned NATO communication satellites launched by NASA for NATO. Apogee boost motor fired Jan. 30 and satellite stationed at 15° west longitude above the equator.
Feb. 6 Defense 7A Titan IIIC	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	35,755 35,532 1436.0 0.1	Still in orbit.
Mar. 10 Palapa 2 18A Delta	Objective: To launch satellite into synchronous transfer orbit. Satellite to provide transmission of television, voice, and other data throughout Indonesia. Spacecraft: Cylindrical 1.8-m in diameter and 3.3-m high; spin stabilized; Earth oriented antenna assembly affixed on top of spacecraft. Provides 12 RF channels, two of which will be protected channels for the 10 traffic carrying channels; 23,000 solar cells mounted on spacecraft exterior. Weight at launch: 574 kg. Weight after apogee motor fire: 281 kg.	36,250 35,915 1451.2 0.1	Launched for Indonesia's satellite communication system. Successfully placed into transfer orbit. Apogee boost motor fired Mar. 12 and spacecraft placed in stationary equatorial synchronous orbit at 77° east longitude, just south of India. Became operational Apr. 15.
Mar. 13 Defense 19A Titan IIIB	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced	329 141 89.1 96.4	Decayed from orbit May 26, 1977.
Apr. 20 Geos 29A Delta	Objective: To launch satellite into synchronous transfer orbit. Spacecraft to provide data on magnetic and electric fields 36,000 k above Earth. Spacecraft: Cylindrical shape, 132-cm long and 162-cm in diameter; eight booms extend from spacecraft—four radial and four axial—with length between 1.5 and 20 m; carries seven primary experiments. Weight at launch: 574 kg.	11,710 241 227.8 26.0 Final: 38,270 2106 718.2 26.4	Launched by NASA for the European Space Agency. A malfunction of the booster placed spacecraft in unsatisfactory transfer orbit, from which geostationary position could not be attained. Apogee boost motor fired Apr. 27, placing satellite in the most desirable orbit. All experiments are returning useful data. Based on NASA criteria, mission adjudged unsuccessful.
May 12 DSCS II-7 34A Titan IIIC	Objective: Communications. Spacecraft: Not announced.	35,762 35,438 1426.7 2.4	Still in orbit.
May 12 DSCS II-8 34B Titan IIIC	Objective: Communications. Spacecraft: Not announced.	35,792 35,781 1436.1 2.4	Still in orbit.
May 23 Defense 38A Atlas-Agena D	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	35,855 35,679 1435.1 0.2	Still in orbit.

## Successful U.S. Launches-1977

Launch date (G.m.t.) Spacecraft name Cospas designation Launch vehicle	Spacecraft data	Apogee and perigee (kilometers) Period Inclination to equator (degrees)	Remarks
May 26 Intelsat IV-A F-4 41A 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 communications 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 subsystem; despun Earth-oriented platform atop rotating cylinder contains 20 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.	35,755 35,346 1425.0 0.3	Third 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 kick motor fired May 27 and satellite placed on station at 34.5° west longitude over Atlantic Ocean. To serve as backup for Intelsat IV-A F-1 launched Sept. 25, 1975, and F-2 launched Jan. 29, 1976.
June 5 AMS 2 44A Thor-Burner 2	Objective: To support the Defense Meteorological Satellite Program. Spacecraft: Similar to the NASA Tiros-N (to be launched in 1978).	864 817 101.7 99.2	Still in orbit.
June 16 Goes 2 48A Delta	Objective: To launch spacecraft into a synchronous orbit of sufficient accuracy to enable it to provide the capability for continuous observations of the atmosphere on an operational basis. Spacecraft: Cylindrical 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. Thrust tube located in center of satellite supports radiometer/telescope instrument. Scanning mirrors look out through an opening in cylindrical solar array whose panels cover spacecraft exterior walls. Instruments include a visible and infrared spin scan radiometer (VISSR) to provide day/night cloud cover data, a meteorological data collection and transmission system, and a space environmental 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. Spin stabilized. Weight at launch: 635 kg. Weight in orbit: 293 kg.	36,304 35,267 1436.0 0.9	Second operational spacecraft of a series of Geostationary Operational Environmental Satellites; launched by NASA for NOAA. Spacecraft placed in successful transfer orbit, and apogee boost motor fired June 16 and satellite placed in synchronous orbit at 75° west longitude replacing Goes 1. Satellite turned over to NOAA for operational use on July 29. Goes 2 will provide coverage of most of North and South America and the Atlantic Ocean. Goes 1 moved to 105° west longitude as a backup spacecraft.
June 23 NTS 2 53A Atlas F	Objective: To test technology for the Global Positioning System (Navstar). Spacecraft: Carries cesium clocks for precise time-standard testing, and a solar array to test 14 Navy experiments on solar cells.	20,187 19,545 705.2 63.3	Still in orbit.
June 27 Defense 56A Titan IIID	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	227 173 88.3 97.0	Decayed from orbit Dec. 23, 1977.

## Successful U.S. Launches—1977

Launch date (G.m.t.) Spacecraft name Cospas designation Launch vehicle	Spacecraft data	Apogee and perigee (kilometers) Period Inclination to equator (degrees)	Remarks
July 14 GMS (Himawari) 65A Delta	Objective: To launch satellite into a synchronous transfer orbit accurate enough to allow the spacecraft to enter a stationary synchronous orbit; day/night meteorological observation on nearly continuous basis, collection and transmission of data, monitor solar activities, and improve Japanese as well as international meteorological services. Spacecraft: Cylindrical 3.1-m long and 2.1-m in diameter. Solar panels on satellite outer surface. Visible and infrared spin scan radiometer (VISSR) instrument provides images of clouds and Earth's surface, and measures temperature of both surface and cloud tops; collection and transmission system; measurement of solar protons, alpha particles, and electrons. Spin stabilized. Weight at launch: 670 kg. Weight in orbit: 280 kg.	35,779 35,531 1429.4 1.2	Launched by NASA for the National Space Development Agency of Japan (NASDA) as part of World Weather Watch program. Apogee boost motor fired July 15 and satellite was placed in synchronous orbit at 140° east longitude above equator due south of Tokyo.
Aug. 12 HEAO 1 75A Atlas-Centaur	Objective: To obtain high resolution, experimental data on astrophysical phenomena by surveying the x-ray and gamma ray sky over the range from 150 electron volts to 10 million electron volts, measure size and location of x-ray sources in the range of 1 thousand to 15 thousand electron volts, determine the contribution of discrete sources to the x-ray background, and determine temporal behavior of x-ray sources; to demonstrate spacecraft capability of supporting the onboard experiments for six months. Spacecraft: Irregular hexagon 4.1-m long and 2.4-m in diameter. Satellite equipment module (SEM) contains all functional subsystems necessary to operate and control the observatory and experiments. Solar cells mounted on exterior panels. Experiment module (EM) contains four scientific instruments, the large x-ray survey, cosmic x-ray, scanning modulation collimator, and hard x-ray and low gamma ray. Six-sided configuration provides maximum experiment aperture area while minimizing overall observatory length. Weight: 2560 kg, including 1220 kg of experiments.	455 435 93.5 22.8	First in a series of three NASA High Energy Astronomical Observatories. Launched successfully into orbit, all experiments operational and returning excellent data. Largest Earth-oriented unmanned scientific satellite ever launched. Observatory configuration based on modular concept maximizing commonality among the three planned missions. During first 100 days of operation 15 previously unknown x-ray sources located. First six months to be spent mapping the sky.
Aug. 20 Voyager 2 76A Titan IIIE-Centaur	Objective: To investigate the Jupiter and Saturn planetary systems and the interplanetary medium. Scientific objectives: To conduct comparative studies of the Jupiter and Saturn systems, including the environment, atmosphere, surface and body characteristics of the planets; one or more of their satellites; and the nature of Saturn's rings. Spacecraft: Consists of a mission module and a propulsion module which is ejected after boosting mission module into Jupiter transfer trajectory. Mission module a 10-sided framework with 10 electronics packaging compartments, 47-cm high and 1.78-m across from flat to flat; 3.66-m diameter high-gain parabolic antenna supported by tubular trusswork; three radioisotope thermoelectric generators (RTG) in tandem on deployable boom; twin 10-m whip antennas; four magnetometers mounted on 13-m deployable boom. Weight at launch: 2080 kg. Weight after propulsion module separation: 822 kg. Weight at end of mission: 722 kg.	Trans-Jupiter trajectory; later may rendezvous with Uranus and escape from the solar system	First in twin Voyager series, following July 1979 Jupiter flyby, spacecraft will use gravitational assist of planet to change course to Saturn for projected 1981 rendezvous. Spacecraft may fly by Uranus in 1986. Voyager functioning normally and all instruments are operational. By Jan. 1, 1978, spacecraft was 162 million km from Earth. Named Voyager 2 though launched first because it will be overtaken by Voyager 1 before they reach Jupiter.

## Successful U.S. Launches—1977

Launch date (G.m.t.) Spacecraft name Cospas designation Launch vehicle	Spacecraft data	Apogee and perigee (kilometers) Period Inclination to equator (degrees)	Remarks
Aug. 25 Sirio 80A Delta	Objective: To launch spacecraft into synchronous transfer orbit. Satellite to conduct various communications experiments. Spacecraft: Cylindrical 1.438-m in diameter and 0.954-m in height, 2.0-m in length with apogee boost motor nozzle and Super-High Frequency (SHF) antenna. Despun telecommunication antenna, pointed to Earth, made of aluminum-honeycomb and polyester fiberglass. Satellite spin stabilized. Weight at launch: 398 kg, including the 200-kg apogee boost motor.	36,327 34,210 1409.7 0.2	Launched by NASA for the Consiglio Nazionale delle Ricerche—National Research Council of Italy (CNR)—into successful transfer orbit. Apogee boost motor fired Aug. 27 and spacecraft placed in stationary orbit over the South Atlantic at 15° west longitude above the equator. Satellite turned over to Italy Sept. 24. Spacecraft operating satisfactorily.
Sept. 5 Voyager 1 84A Titan IIIE—Centaur	Objective: To investigate the Jupiter and Saturn planetary systems and the interplanetary medium. Scientific objectives: To conduct comparative studies of the Jupiter and Saturn systems, including the environment, atmosphere, surface and body characteristics of the planets; one or more of their satellites; and the nature of Saturn's rings. Spacecraft: Consists of a mission module and a propulsion module which is ejected after boosting mission module into Jupiter transfer trajectory. Mission module a 10-sided framework with 10 electronics packaging compartments, 47-cm high and 1.78-m across from flat to flat; 3.66-m diameter high-gain parabolic antenna supported by tubular trusswork; three radioisotope thermoelectric generators (RTG) in tandem on deployable boom; twin 10-m whip antennas; four magnetometers mounted on a 13-m deployable boom. Weight at launch: 2080 kg. Weight after propulsion module separation: 822 kg. Weight at end of mission: 722 kg.	Trans-Jupiter trajectory; after passing Saturn may pass beyond solar system	Second in dual Voyager series. Following a Mar. 1979 flyby of Jupiter, spacecraft will alter course for a Nov. 1980 rendezvous with Saturn. Voyager 1, on a faster trajectory, passed its sister spacecraft on Dec. 15. By Jan. 1, 1978, spacecraft was 164 million km from Earth. Interplanetary explorer functioning normally and all instruments are operational and returning useful data.
Sep. 23 Defense 1 94A Titan IIIB	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	335 134 89.1 96.5	Decayed from orbit Dec. 8, 1977.
Oct. 22 ISEE 1 102A Delta	Objective: To measure the structure of the magnetosphere boundaries and their fluctuations from space and to obtain sample near-Earth measurements of the solar wind. Spacecraft: 16-sided cylinder 173-cm across flats by 161-cm high; main body of one aluminum honeycomb equipment shelf supported by eight struts on a 84-cm-long thrust tube; one solar array located forward of equipment section and second approximately 25-cm below the shelf. 13 scientific instruments on board. Spin stabilized. Weight at launch: 328.95 kg, including 93.50 kg of scientific instrumentation.	138,124 280 3446.8 28.7	Launched successfully as part of twin payload to make scientific measurements from two points in space. Separation of spacecraft successfully accomplished. All experiments, except one U.S. instrument, turned on and returning data.

## Successful U.S. Launches—1977

Launch date (G.m.t.) Spacecraft name Cospas designation Launch vehicle	Spacecraft data	Apogee and perigee (kilometers) Period Inclination to equator (degrees)	Remarks
Oct. 22 ISEE 2 102B Delta	Objective: To measure the structure of the magnetosphere boundaries and their fluctuations from space and to obtain sample near-Earth measurements of the solar wind. Spacecraft: Cylindrical 1.14-m high with a diameter of 1.27-m; single equipment platform with solar array covering spacecraft exterior, except at bottom where scientific instrument parts and protrusions are located; S-band antenna on spacecraft top, supported by three struts; three hinged booms, each about 2.25-m long, a pair of radially extending wire booms each 15-m long which serve as antennas for onboard experiments and a deployable experiment antenna parallel to the spacecraft spin axis. Eight scientific instruments. Spin stabilized. Weight: 157.72 kg.	138,330 279 3453.8 28.7	Built for the European Space Agency by the STAR consortium, launched by NASA as a secondary payload. Scientific instruments returning valuable data.
Oct. 28 Transit 106A Scout	Objective: To place satellite into an orbit which will enable the Navy to provide a worldwide, two-dimensional system for position fixing to an accuracy of better than .5 k. Spacecraft: Eight-sided cylinder with four deployable solar panels; two specially instrumented transponders or radio relays called translators. Weight: 94 kg.	1106 1067 107.0 89.9	Launched by NASA for the Navy. The Navy Navigation Satellite System, referred to as Transit, provides an opportunity for the user to take a position fix every two hours or less, depending upon the latitude. The satellite will be used to test a Trident Missile Tracking System (SATRACK) and to check out and calibrate range safety ground stations and equipment. Spacecraft placed in desired orbit and returning data.
Nov. 23 Meteosat 1 108A Delta	Objective: To launch satellite into synchronous transfer orbit of sufficient accuracy to allow the spacecraft to achieve a stationary synchronous orbit. European contribution to the World Meteorological Organization's World Weather Watch program. Spacecraft: Cylindrical 2.1-m in diameter and 4.3-m high; payload consists of telescope radiometer for observation of the Earth and cloud masses, and a system for data relay and transmission of the meteorological information. Spin stabilized. Weight at launch: 697 kg. Weight after apogee motor fire: 345 kg.	35,692 34,913 1411.5 0.7	Launched into successful transfer orbit by NASA for ESA. Apogee motor fired Nov. 23 and spacecraft placed in geostationary orbit above the Gulf of Guinea at 0° longitude. Satellite serves as part of ESA's contribution to the Global Atmospheric Research Program (GARP). Experiments to become fully operational May 1978.
Dec. 8 Defense 112A Atlas F	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	1169 1054 107.5 63.4	Still in orbit.
Dec. 8 Defense 112D Atlas F	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	1169 1054 107.5 63.4	Still in orbit.
Dec. 8 Defense 112E Atlas F	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	1168 1055 107.5 63.4	Still in orbit.
Dec. 11 Defense 114A Atlas-Agena D	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	35,855 35,679 1435.1 0.2	Still in orbit.

## Successful U.S. Launches—1977

Launch date (G.m.t.) Spacecraft name Cospas designation Launch vehicle	Spacecraft data	Apogee and perigee (kilometers) Period Inclination to equator (degrees)	Remarks
Dec. 15 CS (Sakura) 118A Delta	Objective: To place satellite into a successful synchronous transfer orbit; development of a domestic communications satellite system for Japan; experimentation with K-band and C-band. Spacecraft: Cylindrical 2.18-m in diameter and 3.48-m high; spin stabilized; solar cells mounted on spacecraft exterior; antenna horn reflector mounted on outer despun section of the Drive Motor Assembly, extends 128.8-cm above the upper edge of the solar array; six K-band channels and two C-band channels provide communications link. Weight at launch: 677 kg. Weight after apogee boost motor fire: 340 kg.	36,157 35,568 1440.0 0.1	Japanese National Space Development Agency (NASDA) satellite launched into synchronous transfer orbit by NASA. Apogee boost motor fired Dec. 16 and spacecraft placed in synchronous orbit above equator at 135° east longitude above New Guinea and due south of Japan.

## U.S. Applications Satellites 1973-1977

Date	Name	Launch Vehicle	Remarks
COMMUNICATIONS			
Apr. 20, 1973	Anik 2 (Telesat 2)	Thor-Delta (TAT)	Launched for Canada.
Aug. 24, 1973	Intelsat IV (F-7)	Atlas-Centaur	Fifth in high-capacity series. Positioned over Atlantic.
Dec. 13, 1973	DSCS 2-3,4	Titan IIC	Follow-on to DSCS 2-1,2.
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 IIC	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	Symphonic 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	Symphonic 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 IIC	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 11-7,8	Titan IIC	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.



## U.S. Applications Satellites 1973-1977

Date	Name	Launch Vehicle	Remarks
<b>WEATHER OBSERVATION*</b>			
Nov. 6, 1973	NOAA-3 (ITOS F)	Thor-Delta	Second generation operational meteorological satellite.
May 17, 1974	SMS-1	Thor-Delta	First full-time weather satellite in synchronous orbit.
Nov. 15, 1974	NOAA-4 (ITOS G)	Thor-Delta	Second generation operational meteorological satellite.
Feb. 6, 1975	SMS-2	Thor-Delta	Second full-time weather satellite in synchronous orbit.
June 12, 1975	Nimbus 6	Thor-Delta	To build numerical models for Global Atmospheric Research Program.
Oct. 16, 1975	Goes 1	Thor-Delta	First fully operational synchronous weather satellite.
July 29, 1976	NOAA-5 (ITOS H)	Thor-Delta	Second generation operational satellite.
June 16, 1977	Goes 2	Thor-Delta	Second of this series.
July 14, 1977	Himawari	Thor-Delta	Japanese geosynchronous satellite.
Nov. 23, 1977	Meteosat	Thor-Delta	European Space Agency geosynchronous satellite.
<b>EARTH OBSERVATION</b>			
Jan. 22, 1975	Landsat 2	Thor-Delta	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.
<b>GEODESY</b>			
Apr. 9, 1975	Geos 3	Thor-Delta	To measure geometry and topography of ocean surface.
May 4, 1976	Lageos	Thor-Delta	Laser geodynamic satellite.
<b>NAVIGATION</b>			
Oct. 30, 1973	NavSat O-20	Scout	
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.

\* Does not include Department of Defense weather satellites which are not individually identified by launch.

## U.S.-Launched Scientific Payloads 1973-1977

Date	Name	Launch Vehicle	Remarks
June 10, 1973	Radio Astronomy 2 (Explorer 49)	Thor-Delta	Measure galactic and solar radio noise shielded from Earth by the Moon, by use of lunar orbit.
Oct. 26, 1973	IMP 10 (Explorer 50)	Thor-Delta	Study of interplanetary environment particle and fuel interactions in the distant magneto tail.
Dec. 16, 1973	Atmosphere (Explorer 51)	Thor-Delta	Photochemical processes in absorption of solar UV.
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	Acros 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	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	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 IIC	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	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	Magnetosphere and solar wind measurements (for NASA and European Space Agency respectively).

## U.S.-Launched Space Probes 1973-1977

Date	Name	Launch Vehicle	Remarks
Apr. 6, 1973	Pioneer 11	Atlas-Centaur	Jupiter flyby mission. Passed Jupiter on Dec. 2, 1974, returning pictures and data and headed for a similar pass by Saturn before accelerating out of the solar system.
Nov. 3, 1973	Mariner 10	Atlas-Centaur	Venus and Mercury flyby mission. Passed Venus on Feb. 5, 1974, returning good quality pictures. Passed Mercury again on Sep. 21, 1974, returning 500-600 good quality pictures. Passed Mercury again on Mar. 16, 1975. Other data were also returned.
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.

## 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 S. 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 long U.S. flight.
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 Gorbatko	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 Viktor Ivanovich Patsayev	570 h 22 min.	Docked with Salyut 1 and Soyuz 11 crew occupied space station for 22 days. Crew perished during final phase of Soyuz 11 capsule recovery on June 30, 1971.
Apollo 15	July 26, 1971	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	Vasily 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 continuing long duration mission.
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	Aleksey 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 Sevastiyarov	1511 h 20 min.	Docked with Salyut 4 and occupied station during a 63-day mission.
Soyuz 19	July 15, 1975	Aleksey 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	Sep. 15, 1976	Valeriy Bykoyskiy 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.
Soyuz 25	Oct. 9, 1977	Vladimir Kovalenok Valeriy Rymunin	48 h 46 min.	Failed to achieve hard dock with Salyut 6 station.
Soyuz 26	Dec. 10, 1977	Yuriy Romanenko Georgiy Grecho	— —	Docked with Salyut 6; flight continued into 1978.

## U.S. Space Launch Vehicles

Vehicle	Stages	Propellant <sup>3</sup>	Thrust (in kilo- newtons)	Max. dia. (m)	Max. Payload (kg)			First launch
					Height (m)	550-km orbit	Escape	
Scout	1. Algol IIIA	Solid	481.7	1.12	22	185 <sup>4</sup>	38.6 <sup>4</sup>	1972(60) <sup>1</sup>
	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 TX 354-5	LOX/RP-1 Solid	911.9 440.4 <sup>2</sup>	2.44	35	1750 <sup>4</sup>	476 <sup>4</sup>	1973(60) <sup>1</sup>
	2. Delta (DSV-3)	N <sub>2</sub> O <sub>4</sub> /Aerozine	45.8					
	3. TE 364-4	Solid	66.7					
Atlas F/TE 364-4	1. Atlas booster & sustainer	LOX/RP-1	1970.6	3.05	2	1500 <sup>4</sup>		1977(60) <sup>1</sup>
	2. TE 364-4	Solid	66.7					
Atlas-Agena	1. Atlas booster & (SLV/3A)	LOX/RP-1	2237.5	3.05	40	2720 <sup>4</sup>	454 <sup>4</sup>	1968(60) <sup>1</sup>
	2. Agena	IRFNA/UDMH	71.2					
Titan IIIB-Agena	1. LR-87	N <sub>2</sub> O <sub>4</sub> /Aerozine	2353.1	3.05	48	3630 <sup>5</sup>		1966
	2. LR-91	N <sub>2</sub> O <sub>4</sub> /Aerozine	444.8					
	3. Agena	IRFNA/UDMH	71.2					
Titan IIIC	1. Two 5-segment 3.05- m dia	Solid	11,565.4	3.05	40	—	1461 <sup>7</sup>	1965
	2. LR-87	N <sub>2</sub> O <sub>4</sub> /Aerozine	2353.1					
	3. LR-91	N <sub>2</sub> O <sub>4</sub> /Aerozine	444.8					
	4. Transtage	N <sub>2</sub> O <sub>4</sub> /Aerozine	71.2					
Titan IIID	1. Two 5-segment 3.05- m dia	Solid	11,565.4	3.05	4	11,100 <sup>6</sup>		1971
	2. LR-87	N <sub>2</sub> O <sub>4</sub> /Aerozine	2353.1					
	3. LR-91	N <sub>2</sub> O <sub>4</sub> /Aerozine	444.8					
Titan III(34)D	1. Two 5½-segment 3.05-m dia	Solid	11,540.4	3.05	48	12,750 <sup>8</sup>		1981
	2. LR-87	N <sub>2</sub> O <sub>4</sub> /Aerozine	2353.1					
	3. LR-91	N <sub>2</sub> O <sub>4</sub> /Aerozine	444.8					
Titan III(34)D/IUS	1. Two 5½-segment	Solid	11,540.4	3.05	48	1905 <sup>9</sup>	1905 <sup>9</sup>	1980
	2. LR-87	N <sub>2</sub> O <sub>4</sub> /Aerozine	2353.1					
	3. LR-91	N <sub>2</sub> O <sub>4</sub> /Aerozine	444.8					
	4. IUS 1st Stage	Solid	191.3					
Thor LV-2F	1. Thor	LOX/RP-1	756.2	2.44	2	512 <sup>10</sup>		1976(66) <sup>1</sup>
	2. TE 364-4	Solid	66.7					
	3. TE 364-15	Solid	44.5					
Thor SLV-2A/Block 5D-2	1. Thor plus 3 TX 364-5	LOX/RJ-1 Solid	756.2 689.5 <sup>2</sup>	2.44	24	653 <sup>10</sup>		1980(63) <sup>1</sup>
	2. TE 364-4	Solid	66.7					
	3. TE 364-15	Solid	44.5					

<sup>1</sup> The date of first launch applies to this latest modification with a date in parentheses for the initial version.

<sup>2</sup> Set of 3.

<sup>3</sup> Propellant abbreviations used are as follows: Liquid Oxygen and a modified Kerosene-LOX/RP; Solid propellant combining in a single mixture both fuel and oxidizer-Solid; Inhibited Red Fuming Nitric Acid and Unsymmetrical Dimethylhydrazine-IRFNA/UDMH; Nitrogen Tetroxide and

UDMH/N<sub>2</sub>H<sub>4</sub>-N<sub>2</sub>O<sub>4</sub>/Aerozine; Liquid Oxygen and Liquid Hydrogen-LOX/LH.

<sup>4</sup> Due east launch.

<sup>5</sup> Polar launch.

<sup>6</sup> Polar 115 km (nominal).

<sup>7</sup> Synchronous equatorial (nominal).

<sup>8</sup> Polar 115 km (current estimate).

<sup>9</sup> Synchronous equatorial (current estimate)

<sup>10</sup> Polar 520 km (from WTR).

## Space Activities of the U.S. Government

21-YEAR BUDGET SUMMARY—BUDGET AUTHORITY  
(In millions of dollars)

	NASA		Defense	Energy	Com- merce	Interior	Agricul- ture	NSF	Total Space
	Total	Space <sup>1</sup>							
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. <sup>2</sup>	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 Est.	4062.8	3621.7	2713.8	34.4	93.8	9.7	7.7	2.4	6483.5
1979 Est.	4370.3	3848.5	3364.9	43.0	97.8	9.7	7.9	2.4	7374.2

<sup>1</sup> Excludes amounts for air transportation.

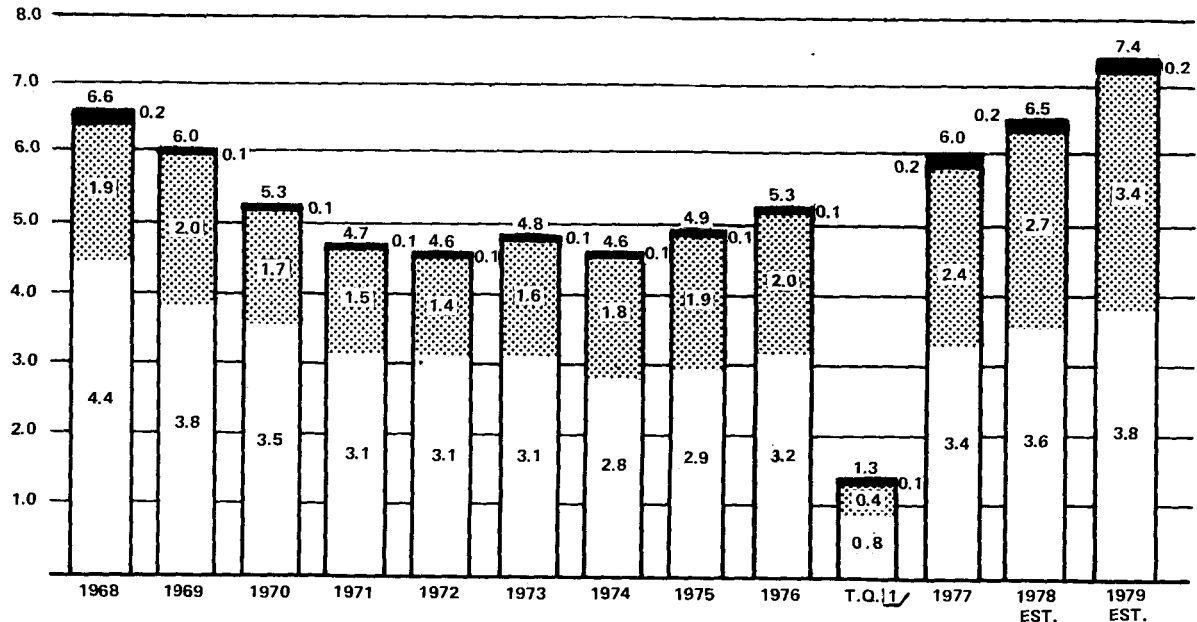
<sup>2</sup> T.Q.—Transitional Quarter.

Source: Office of Management and Budget.

### U.S. Space Budget - Budget Authority 1968-1979

BILLIONS OF DOLLARS

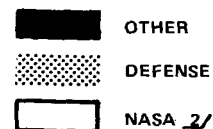
(May not add due to rounding)



1/ T.Q. - TRANSITIONAL QUARTER

2/ EXCLUDES AMOUNTS FOR AIR TRANSPORTATION

SOURCE: OFFICE OF MANAGEMENT AND BUDGET



## Space Activities Budget

(In millions of dollars)

	Budget Authority			Outlays		
	1977 Actual	1978 Estimate	1979 Estimate	1977 Actual	1978 Estimate	1979 Estimate
<b>Federal space programs:</b>						
NASA <sup>1</sup> .....	3440.2	3621.7	3848.5	3599.5	3567.4	3802.9
Defense .....	2411.9	2713.8	3364.9	1832.7	2443.6	3104.3
Energy .....	21.7	34.4	43.0	22.2	28.4	40.0
Commerce .....	90.8	93.8	97.8	86.9	93.4	96.0
Interior .....	9.5	9.7	9.7	9.1	9.6	9.6
NSF .....	2.4	2.4	2.4	2.4	2.4	2.4
Agriculture .....	6.3	7.7	7.9	6.3	7.7	7.9
<b>Total</b> .....	<b>5982.8</b>	<b>6483.5</b>	<b>7374.2</b>	<b>5559.1</b>	<b>6152.5</b>	<b>7063.1</b>
<b>NASA:</b>						
Space flight .....	2137.9	2198.0	2247.2	2251.7	2191.9	2264.2
Space science, applications and technology .....	963.9	1055.6	1209.7	1006.1	1018.3	1150.3
Air transportation .....	377.6	441.1	521.8	344.3	415.0	465.9
Supporting operations <sup>2</sup> .....	341.3	369.4	392.9	344.6	358.4	389.7
Less receipts <sup>2</sup> .....	-2.9	-1.3	-1.3	-2.9	-1.3	-1.3
<b>Total NASA</b> .....	<b>3817.8</b>	<b>4062.8</b>	<b>4370.3</b>	<b>3943.8</b>	<b>3982.3</b>	<b>4268.8</b>

<sup>1</sup> Excludes amounts for air transportation.

Source: Office of Management and Budget.

<sup>2</sup> Includes amounts for Trust Funds.

## Aeronautics Budget

(In millions of dollars)

	Budget Authority		
	1977 Actual	1978 Estimate	1979 Estimate
<b>Federal aeronautics programs:</b>			
NASA <sup>1</sup> .....	377.6	441.1	521.8
Department of Defense <sup>2</sup> .....	2256.0	2572.4	2118.0
Department of Transportation <sup>3</sup> .....	93.5	97.6	93.6
<b>Total</b> .....	<b>2727.1</b>	<b>3111.1</b>	<b>2733.4</b>

<sup>1</sup> Research and Development, Construction of Facilities, Research and Program Management.<sup>2</sup> Office of Secretary of Transportation and Federal Aviation Administration Research and Development.<sup>3</sup> Research, Development, Testing, and Evaluation of Aircraft and related equipment.

Source: Office of Management and Budget.