JET PROPULSION LABORATORY

1979 Annual Report

(Cover) Io, one of Jupiter's largest moons, is the most active and complex volcanic body in our solar system and has a surface composed primarily of various forms of sulfur. In the center of this photograph is the circular pattern of a volcanic vent.

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A description of work accomplished under Contract NAS 7-100 between the California Institute of Technology and the National Aeronautics and Space Administration for the period January 1 to December 31, 1979.

JET PROPULSION LABORATORY
California Institute of Technology
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This was the year of Voyager, a landmark in scientific deep space exploration.

During two successive periods covering eight months, Voyagers 1 and 2 probed the Jovian system, dazzling the world with their discoveries and rewriting the book on Jupiter and its major satellites. The dramatic Voyager findings are greatly enriching our knowledge of the solar system and are an invaluable input to the relatively new science of comparative planetology.

With the Voyagers en route to Saturn, preparations are under way for new planetary observations that are expected to be as revealing and spectacular as the Jupiter encounters. The Vikings, which have been operating successfully at Mars for more than three years, continue to monitor the Martian seasons, and one of the Landers may return data for another decade. Processing and analyzing ocean surface data from the 1978 experimental Seasat mission continued through this year and will be an important contribution to an operational ocean-monitoring satellite system.

As the nation's principal center for deep space exploration, JPL is preparing two major flight projects—the Galileo Orbiter and atmospheric Probe to Jupiter and the International Solar Polar Mission (ISPM) to unobserved regions of the Sun. During the past year, the Galileo launch was delayed two years until 1984 due to Shuttle schedule delays and was divided into separate Orbiter and Probe launches.

The Laboratory manages Project Galileo and will develop the Orbiter. The Ames Research Center is responsible for the development of the Probe and its Carrier spacecraft. The ISPM, now scheduled to be launched by the Space Shuttle in 1985, consists of two spacecraft—one developed by the United States, the other by the 11-nation European Space Agency.

Two Earth satellite projects managed by the Laboratory will begin returning data from polar orbit in 1982. The Infrared Astronomical Satellite, an international cooperative endeavor involving the United States, the Netherlands, and Great Britain, will conduct a year-long infrared telescopic survey of the sky. The Solar Mesosphere Explorer will investigate the effects of solar radiation on the ozone layer surrounding Earth.

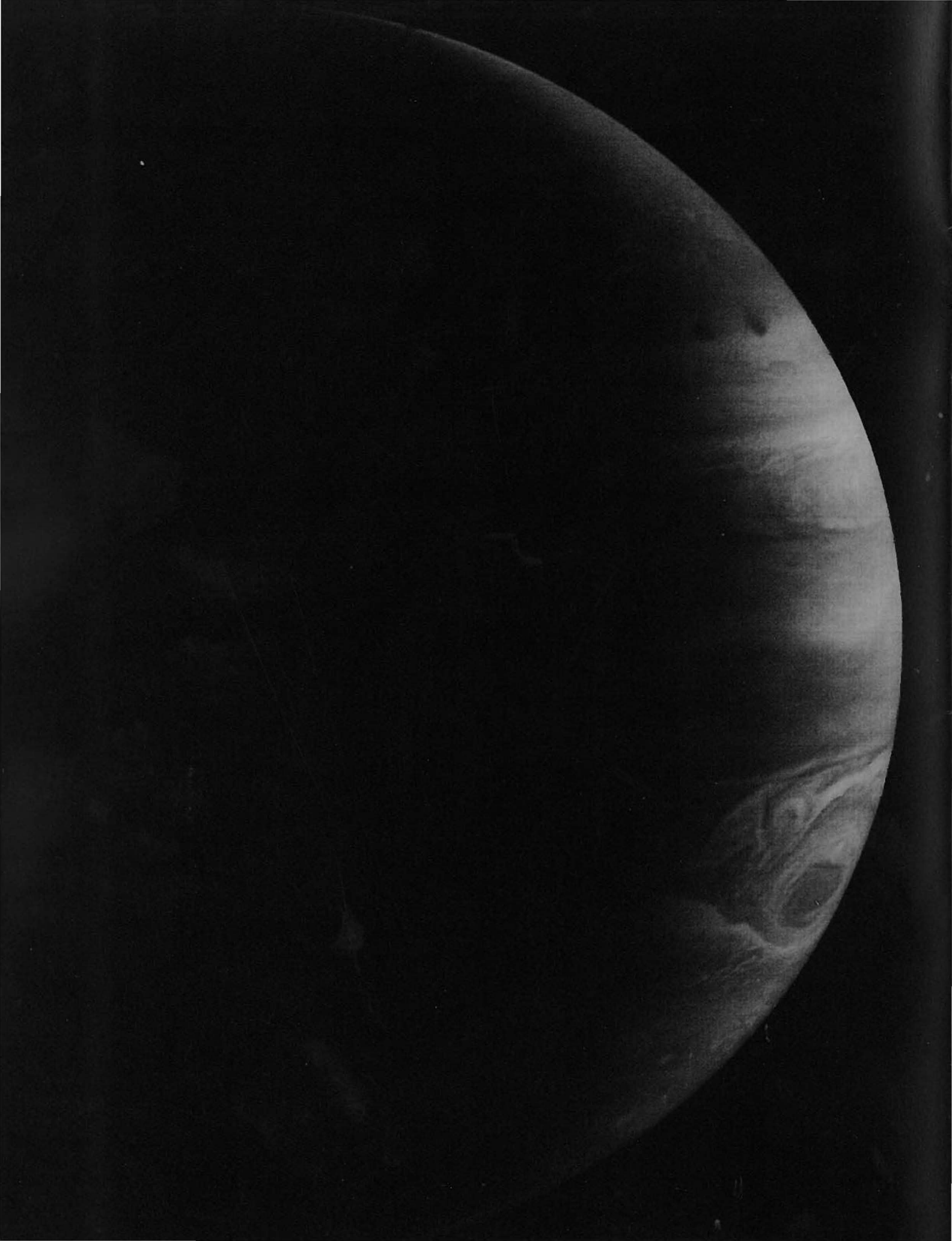
For the future, development is progressing on the Venus Orbiting Imaging Radar study to map the entire planet through its solid cloud cover. The remote-sensing capability was developed by JPL for Seasat ocean observations and provides radar mapping similar to high-resolution photography.

Completing its 35th year as a government-sponsored organization, the Laboratory has clearly evolved into an important national resource in the crucial area of alternative energy sources. Noteworthy accomplishments have been recorded in the solar energy program and in experimental energy-saving automotive systems.

As for our professional staff, it remains of the highest caliber, while changing to deal with the special needs of new assignments. We have a tradition of excellence at JPL, and that gives the people who work here a strong sense of pride, identity, and purpose.

I see the 1980's as a decade of real promise and challenging opportunity for the Jet Propulsion Laboratory, both in its primary space exploration mission for the National Aeronautics and Space Administration, and in its newer, expanding nonspace role for the Department of Energy and other government agencies.

Bruce Murray
Director



The highly successful Voyager flyby missions to Jupiter highlighted the 1979 deep space program at JPL. Mission operations plans have subsequently focused on the scheduled flybys of Saturn in late 1980 and mid-1981.

As the lead center for NASA's planetary programs, the Laboratory also gleaned further scientific data from the Viking Mars operation and continued developing two future missions—Galileo, a projected return to Jupiter and its major moons, and the International Solar Polar Mission, a joint effort by NASA and the European Space Agency to study the Sun.

Planning proceeded for possible Venus, Halley's Comet, and Sun-probe missions, as well as for many planetary science experiments to be carried out from space and Earth.

Tracking and data acquisition by the Deep Space Network, which JPL develops and operates for NASA, attained a new level of versatility. Besides supporting Voyager and Viking, the DSN monitored Pioneer 10 on its journey out of the solar system, Pioneer 11 at its Saturn encounter, and the Pioneer Venus Orbiter. (All Pioneer missions are managed by NASA's Ames Research Center.)

FLIGHT PROJECTS

Voyager

The historic Voyager encounters with Jupiter provided a wealth of new information on Jupiter's atmosphere, satellites, and magnetosphere. The most spectacular sighting was the observation of nine active volcanoes on the satellite Io, making it the most geologically active body known in our solar system. Additional discoveries included a ring around Jupiter, a new satellite just outside the edge of the ring, a torus of highly ionized sulfur and oxygen at Io's orbit, and extensive aurorae and lightning in Jupiter's atmosphere. Live television coverage in the United States and Mexico enabled millions of viewers to share in the excitement of exploring the Jovian system.

The two Voyager spacecraft were launched in the summer of 1977. The closest approach to Jupiter occurred on March 5, 1979, for Voyager 1 and on July 9, 1979, for Voyager 2. Voyager 1 spent 92 days and Voyager 2 spent 133 days observing the Jovian system. The integrated efforts of the Deep Space Network, the Mission Control and Computing Center, and the Voyager flight team resulted in the recovery and processing of over 250 billion bits of data returned during the encounters. During the flybys, Jupiter's gravity field and its motion in orbit accelerated the spacecraft toward their encounters with Saturn. Both spacecraft are now on excellent trajectories to Saturn, with Voyager 1's closest approach scheduled for November 12, 1980, and Voyager 2's for August 26, 1981.

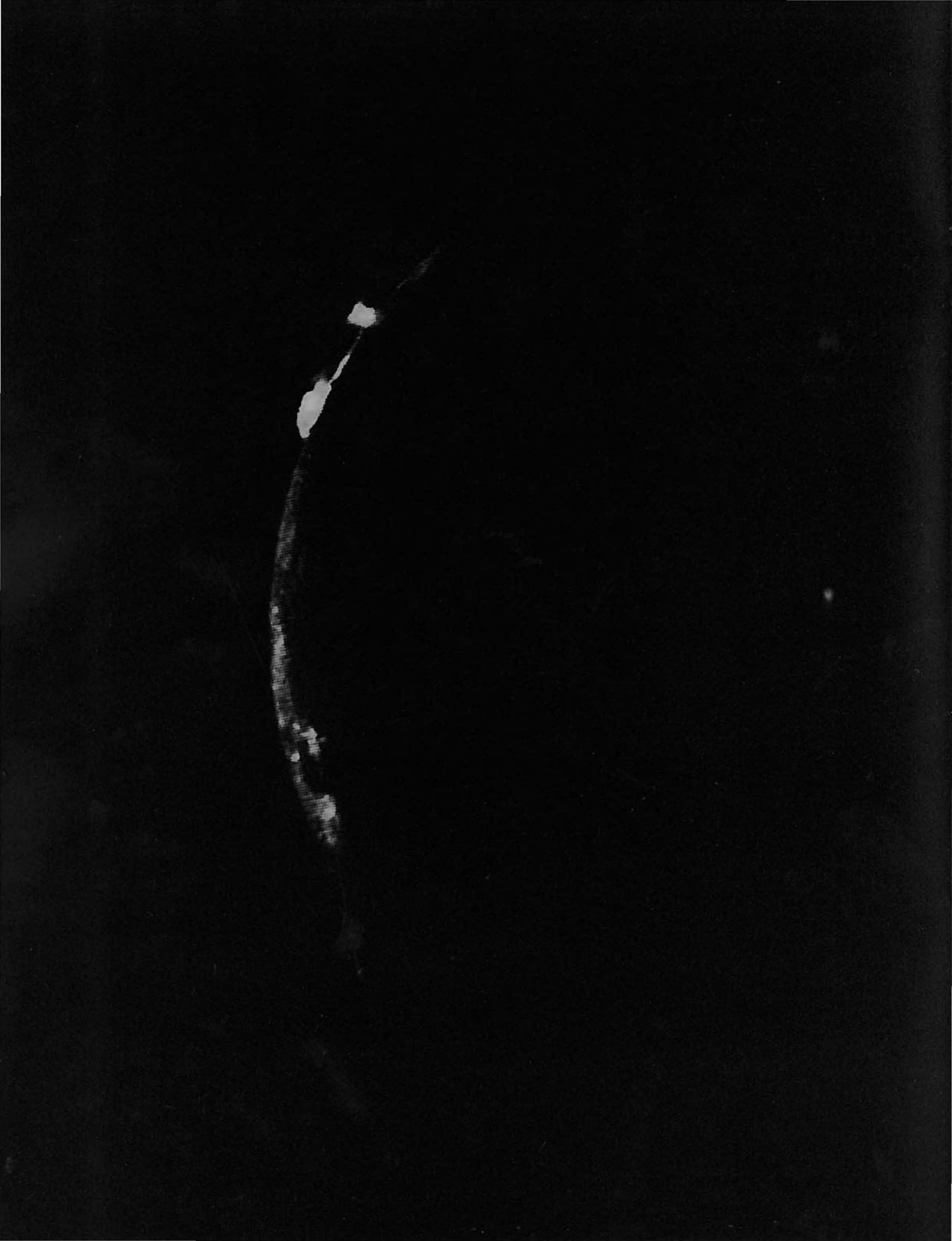
The scientific results of the Voyager encounters fall into four areas: magnetosphere, atmosphere, satellites, and ring system. Jupiter's magnetosphere extends a minimum of 3 million kilometers (several times larger than the Sun), and the four large Galilean moons are swept by magnetic field lines as they orbit Jupiter. A 5-million-ampere electrical current was observed to flow along the magnetic lines linking Io to Jupiter. The magnetosphere also appeared to have an abundance of ionized sulfur and oxygen, both as high-energy plasma and in a torus-shaped cloud at Io's orbit. The origin of this material became apparent when active volcanoes on Io, erupting sulfur and sulfur dioxide, were discovered. Charged particles spiraling into Jupiter's atmosphere along the magnetic field lines produce intense auroral activity in Jupiter's polar regions. In addition to the intense aurorae, extensive lightning activity was photographed. Lightning was also observed indirectly by onboard radio receivers.

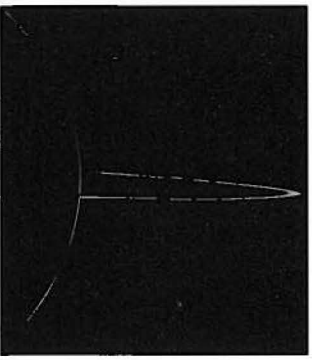
The planet's visible atmosphere is dominated by layers of colorful clouds near the top of a very deep atmosphere of hydrogen and helium. The atmosphere, much more turbulent than had been expected, has many rotational features, of which the Great Red Spot is the most obvious. The Great Red Spot, large enough to hold several Earths, appears to be a giant column of rotating gas extending deep into the atmosphere, with a slow upwelling of material that causes the unique red coloring.

With the discovery of a ring, Jupiter joins Saturn and Uranus as ringed planets. The thin ring's bright outer edge is 56,000 kilometers above the cloud tops. A small satellite was discovered buried within the ring, which may be responsible for the material in the ring.

Jupiter's four largest moons were surprisingly different in their appearances and apparent evolutionary histories. Starting with the outermost Galilean moon, Callisto appears to have the oldest surface, perhaps four billion years, with an extremely high meteoric impact crater density. Ganymede seems to have four basic terrain types, ranging from relatively young, smooth terrain to ancient, highly cratered terrain. Europa has a very

(Left) Moving out of the Jovian system, Voyager 1 photographed Jupiter from the dark side as the spacecraft proceeded on to Saturn.





(Above) A sequence of pictures taken of Jupiter's ring, combined into a mosaic, makes the ring appear fragmented. The ring and limb are backlighted by the eclipsed Sun.

(Right) The Galileo Orbiter, en route to Jupiter, will be released from the cargo bay of the Space Shuttle.

(Left) All of the volcanic plumes photographed on Io were so faint that special image-enhancement techniques were used to draw them out. These two plumes are estimated to have been active for at least four months.

smooth surface with few craters, and a uniformly bright, slightly mottled terrain with linear markings and low ridges criss-crossing it. All three of these moons show clear evidence of water ice on their surfaces. Io, however, appears to be devoid of water or water ice. The volcanism on Io seems to be constantly renewing the surface with deposition rates of about one millimeter per year. Nine active volcanoes were observed by the two spacecraft, with seven common to the two flybys. Another, inner Jovian moon, Amalthea, is a small dark body that appears faceted or diamond shaped.

Neither Voyager spacecraft was significantly affected by Jupiter's radiation. Both are operating well in the Jupiter–Saturn cruise phase. Cruise science observations are being made, and engineering and science calibrations are in process to prepare for the Saturn encounters. The data obtained at Jupiter have provided an excellent foundation for a comparative study of Jupiter and Saturn, which is the primary mission objective of Voyager. The encounters at Saturn are expected to be equally successful and spectacular.

Viking

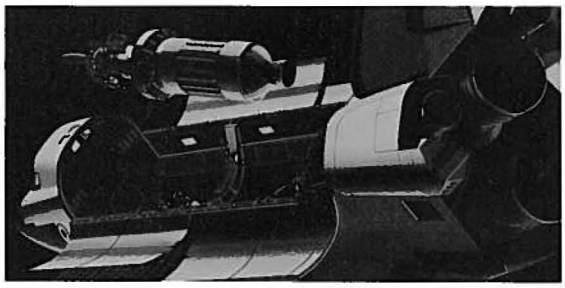
Extensions of the initially scheduled Viking operations at Mars were prompted by the nearly flawless operation of Orbiter 1 around Mars and the continued availability of attitude-control gas to maintain proper orientation. Orbiter 2 ceased operating in mid-1978. New and interesting data have been received almost daily from Orbiter 1 and intermittently from the Landers on the Martian surface. Lander 2 failed in early 1980.

The solar conjunction on January 20, 1979, provided another opportunity to use the radio communication link to probe the solar corona and measure the relativistic retardation of radio waves by the solar gravitational field. Full Orbiter 1 operation for three weeks in February produced very high resolution pictures of Mars from as low as 300 kilometers and made it possible to relay back to Earth data accumulated by the Landers since November 1978.

A hiatus of five months, while the Deep Space Network concentrated on the Voyager Jupiter encounters, precluded observations of anticipated dust storms during the Martian perihelion period. Nevertheless, indirect evidence of widespread dust accumulation was obtained. The Orbiter's infrared radiometer registered an increase in the upper atmosphere temperature in the far north, and the meteorology instruments on both Landers measured enhanced diurnal pressure variations, implying atmospheric heating. Photographs from Lander 2 documented a buildup of surface frost similar to that of the previous winter. These observations, taken in conjunction with 1977 data, suggest that the pre-perihelion and post-perihelion dust storms are generated by different mechanisms and are unrelated.

From July to November 1979 the Orbiter carried out a high-resolution photographic survey of a 5,000-kilometer strip of the Martian surface. Over 2,000 pictures were taken that included the polar caps and polar hoods in both hemispheres, as well as cloud formations. The survey included an area of ancient cratered terrain in the northern hemisphere, which appears promising for landing a sample-return spacecraft in the future. The final phase of the Orbiter mission, which began in November, will finish mapping the entire planet at medium resolution.

Both Viking Landers continued to acquire meteorology and imaging data. Lander 1 is in a preprogrammed automatic mode to set up data for a week and transmit it directly to Earth whenever a DSN station is available. It is programmed to continue doing this until February 1990.



Galileo

Originally scheduled as a single orbiter/probe mission to be launched in early 1982 as the scientific successor to the Voyager missions to Jupiter, Galileo has been rescheduled for a 1984 launch because of Space Shuttle delays. Due to the relative planet positions and the celestial mechanics involved, the slip in launch schedule has necessitated separate launchings for the Orbiter and Probe by Space Shuttle inertial upper stage vehicles. The Orbiter is now planned to be launched in February 1984 on a Mars flyby trajectory, supplemented by a large propulsion maneuver at Mars. The Probe, flying on a Probe Carrier spacecraft, is planned to be launched about a month later on a direct trajectory to Jupiter. The Orbiter will arrive in mid-1986, and the Probe in mid-1987. The

Orbiter is intended to complete 11 orbits of Jupiter while making a close flyby of one of the Galilean satellites—Callisto, Europa, Ganymede, or Io—on each orbit. The mission is expected to end about 20 months after orbit injection around Jupiter.

The Orbiter spacecraft, although similar to the original design based on a 1982 launch, will differ in that more propulsion capability must be provided for the maneuver past Mars. The Orbiter is planned to carry all 11 scientific experiments originally selected. At the time of mission realignment in November 1979, all subsystem preliminary designs were complete and all but one subsystem contract had been let prior to critical design review.

The Probe, carrying seven scientific instruments, will penetrate Jupiter's atmosphere after being released from the Carrier spacecraft. Data will be relayed back to Earth via the Carrier. The Probe injection into Jupiter's atmosphere will nominally take 60 minutes and will penetrate the atmosphere to a level of 10 bars. The Probe is being developed by Hughes Aircraft Company under the direction of the Ames Research Center. Its design was essentially unaffected by the change in launch date.

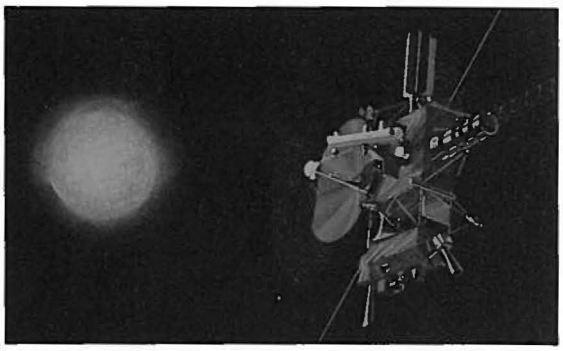
Project Galileo, named after the great Italian astronomer who first discovered the four large Jovian moons in January 1610, involves 114 investigators from 10 nations. JPL is the management center for the total project, and Ames Research Center is responsible for managing the systems contracts involved with the Probe and the Probe Carrier. JPL is developing the Orbiter spacecraft, and the Federal Republic of Germany is providing the retropropulsion module for the spacecraft.

International Solar Polar Mission

Two spacecraft are under development to carry out scientific investigations of the Sun and its effects on the solar system from a perspective above and below the ecliptic (the plane in which the Earth orbits the Sun). For this ambitious international mission, NASA will furnish one spacecraft and the European Space Agency (ESA) will provide a second. This joint venture marks the first planetary spacecraft mission for ESA, which is supported by 11 European nations.

Due to budget cuts, the launch date has been changed from 1983 to 1985. The two spacecraft will follow a trajectory that uses Jupiter's gravity to sling them back to the Sun's poles.

(Bottom) The Venus Orbiting Imaging Radar spacecraft will use Synthetic Aperture Radar to photograph the planet's surface through the thick cloud cover. This artist's rendering depicts spacecraft motion through the appreciable atmosphere before the spacecraft slows into a closer orbit.



Following injection into a trajectory toward Jupiter, the spacecraft will be separated from the Shuttle and will be independently controlled during their 4½ year flights. Initial maneuvers will direct one spacecraft roughly 30 degrees north of Jupiter's equator, and the other about 30 degrees south of Jupiter's equator. Both spacecraft will approach Jupiter at a high velocity, and the effects of the planet's gravity will redirect them on paths out of the ecliptic and nearly perpendicular to the plane of the solar system. One of the spacecraft will fly on a trajectory over the Sun's north pole and the other will be directed over the south pole. Following the first polar passages, the spacecraft will pass each other in opposite directions near the ecliptic plane and later make concurrent observations at opposite poles.

JPL has selected TRW, in California, to build the NASA spacecraft. ESA has selected Dornier Systems, in the Federal Republic of Germany, to build the ESA spacecraft. The scientific investigations supported by NASA have been confirmed and contracts have been awarded. JPL is responsible for managing five scientific investigations and developing part of a sixth on the ESA spacecraft, and will manage five investigations aboard the NASA spacecraft. The three remaining investigations on both spacecraft will be performed by West German teams.

An accord is being reached on detailed agreements concerning the operations to be conducted at JPL for both the NASA and ESA spacecraft. The JPL-operated Deep Space Network will be utilized for tracking support of both spacecraft.

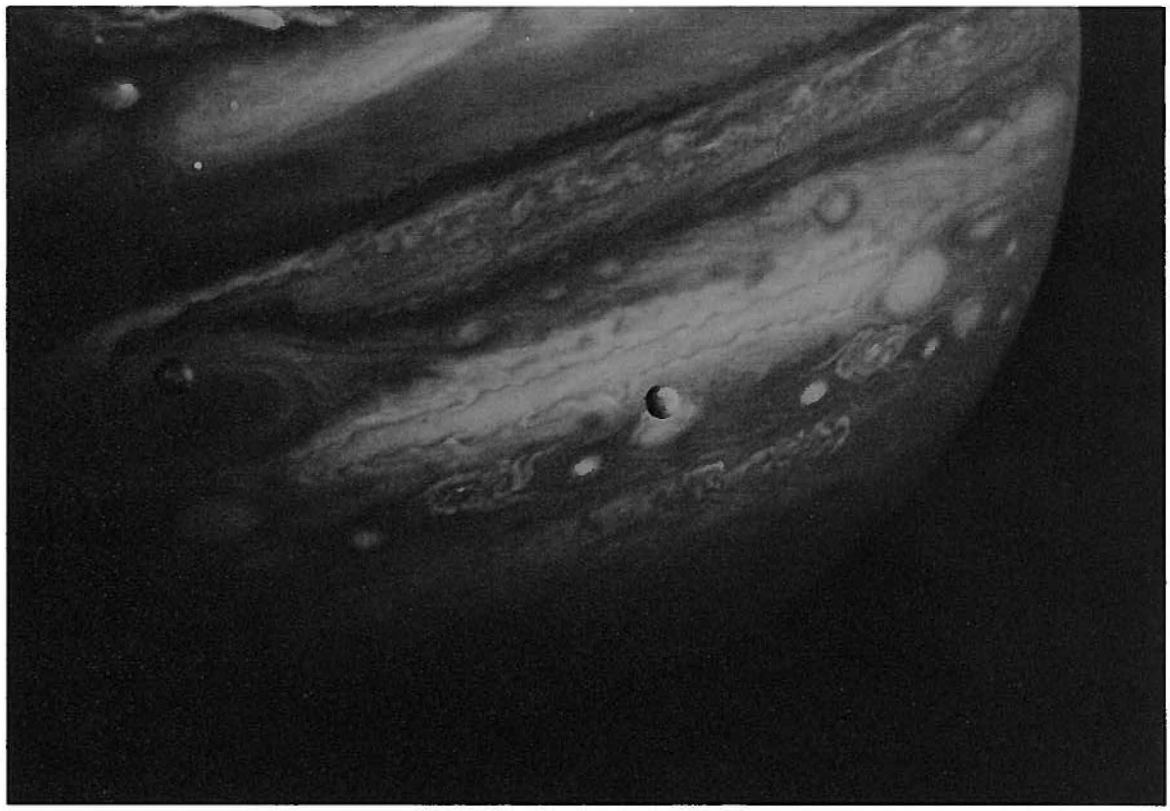
PLANETARY PROGRAM PLANNING

Venus Orbiting Imaging Radar

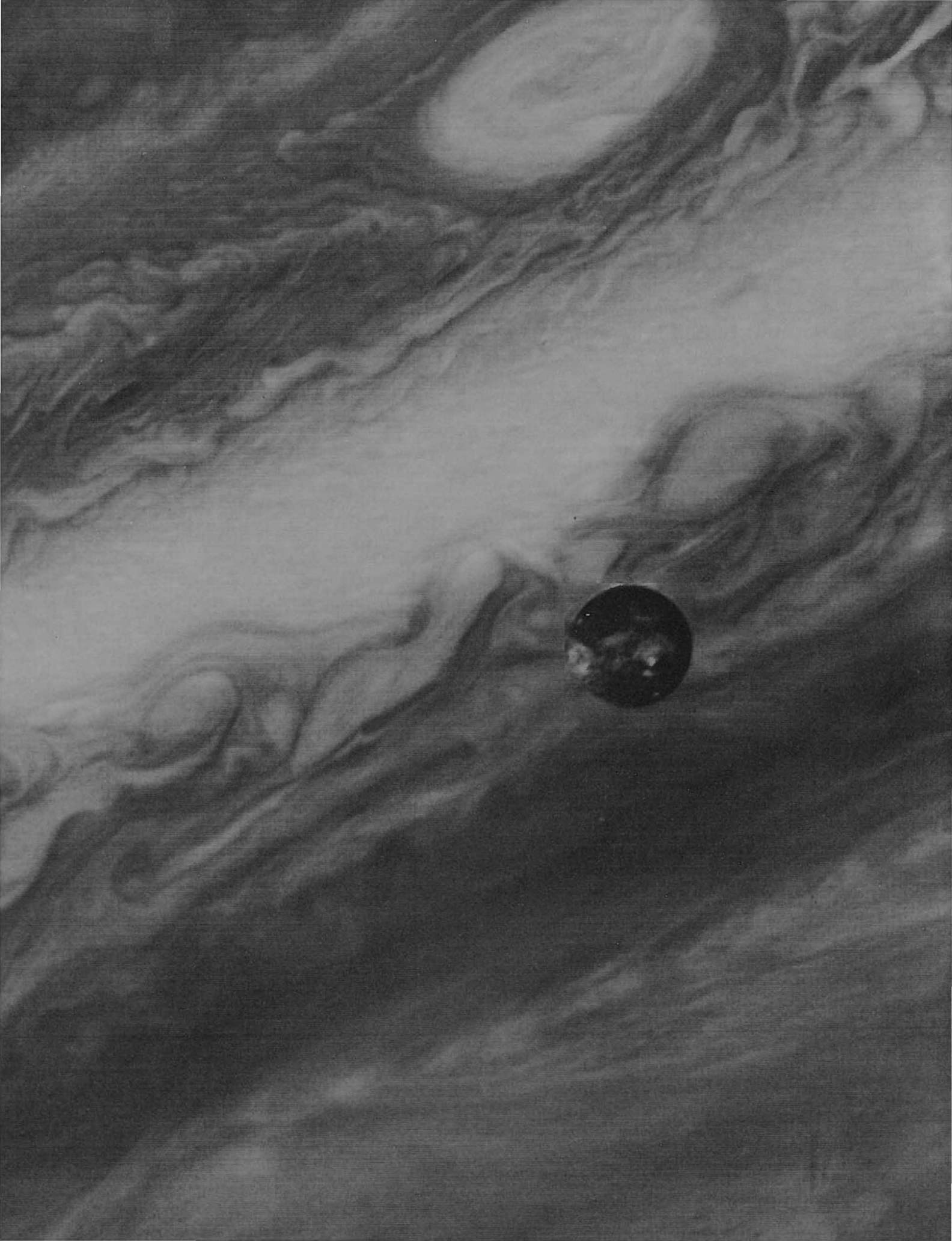
The Venus Orbiting Imaging Radar (VOIR) mission would increase the understanding of Venus by mapping at least 70 percent of the planet's surface. The images, gravimetry, and altimetry should be comparable to that

(Left) The International Solar Polar Mission will study the corona, flares, convection currents, and magnetic fields of the Sun from a distance of 320 million kilometers.

(Top) Two of Jupiter's 15 known satellites, Io (left) and Europa (right), are about the size of our Moon.

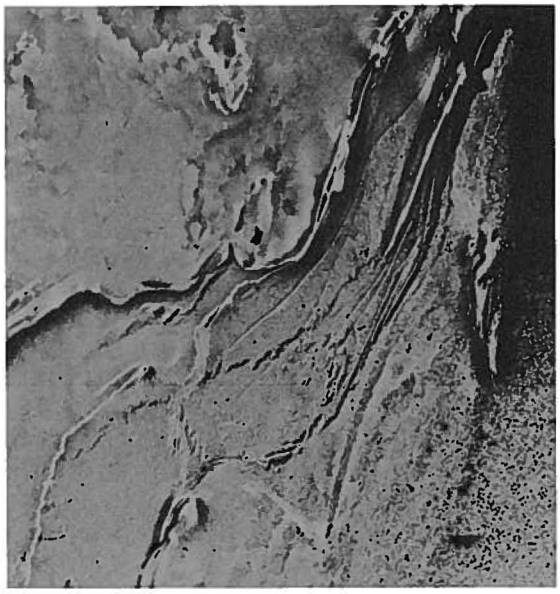


(Bottom) Jupiter's layered, gaseous atmosphere is composed of hydrogen, helium, ammonia, ammonium hydrosulfide, and possibly water-ice crystals. The turbulence shown in this picture is created by high-velocity east and west wind streams that interact with the rotational and convection currents in the Great Red Spot and the two smaller vortices beneath it.

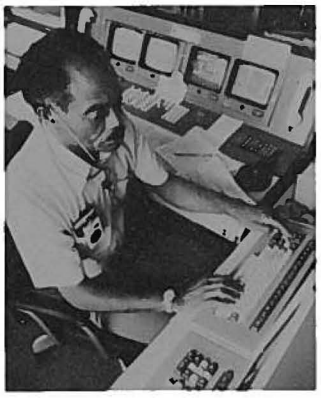


(Left) Io is superimposed on this high-resolution photograph of Jupiter, which shows the semipermanent atmospheric zones. The white oval is one of the many circulating cloud features that have been known to last for decades.

(Right) Only on Earth, Mars, and Io are there unique, irregularly shaped, erosional scarps. These features are caused by the flow of liquid sulfur dioxide on Io.



Neutral Atomic Carbon in Orion
The Radio Astronomy group, in a research program using the NASA Airborne Observatory (the Gerard Kuiper, based at Moffett Field, California), detected neutral atomic carbon gas in Orion and several other sources. Because atomic carbon gas is a common constituent of the molecular clouds from which new stars are born, this detection is important in tracing the evolution of interstellar gas. The method used to make the finding may also provide an improved technique for radio astronomers, especially when high-altitude and orbiting submillimeter telescopes become available. Bell Telephone Laboratories collaborated in the research.



TRACKING AND DATA ACQUISITION

The JPL Office of Tracking and Data Acquisition (TDA) manages the planning, development, and operation of the Deep Space Network (DSN) for the NASA Office of Space Tracking and Data Systems (OSTDS). The DSN's primary role is to provide tracking and two-way communication with spacecraft exploring the solar system. The basic elements of the DSN are three deep space communications complexes located at Goldstone, California; Madrid, Spain; and Canberra, Australia; a ground communications facility; and a Network control center at JPL.

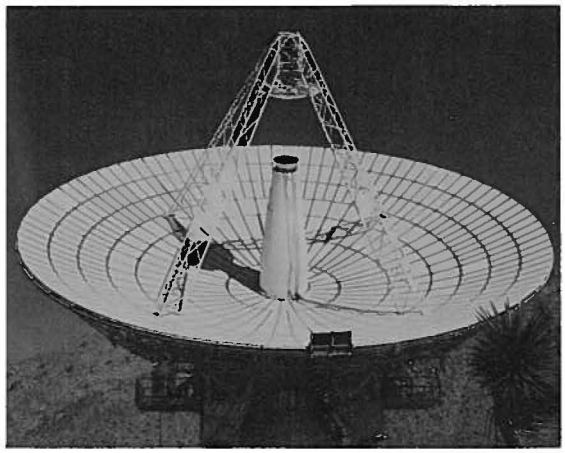
Operations
The major DSN operation during 1979 was support for the Voyager 1 and 2 encounters with Jupiter. During the highly active encounter periods, the DSN provided nearly continuous 24-hour command, telemetry, and tracking support. The operational highlight was the transmission to Earth of approximately 35,000 high-quality digital images of the giant planet and its moons from a distance of approximately four astronomical units (AU).* The imaging and other scientific data were transmitted at 115.2 kilobits per second and were received on the new high-rate X-band radio frequency link by the DSN's 64-meter antenna subnet. The spacecraft data were relayed to Pasadena and displayed almost instantaneously at the JPL Mission Control Center. An analysis of the X-band link performance reveals that out of a 1200-hour total of returned scientific data, only 4.7 hours (four-tenths of one percent) were unrecoverable.

Prior to the Voyager 2 encounter, the orbital motion of Earth and Jupiter had increased the distance between the two planets, causing a decrease in the spacecraft signal strength, which threatened the imaging data quality. To improve the margin, the 34- and 64-meter diameter antennas at Goldstone were arrayed to receive the spacecraft signal simultaneously. The two telemetry signals were electronically combined to provide the needed increase in signal strength (about 1 decibel) to ensure the data quality during the encounter.

The Pioneer Venus Orbiter spacecraft was inserted into orbit in December 1978 and completed its primary mission in August 1979, a period covering one Venusian orbit around the Sun (243 Earth days). The data returned included low-resolution radar mapping of most of the clouded planet's surface, optical imaging of the cloud blanket, upper atmosphere physics, and electrical fields and particles measurements. The spacecraft continues to orbit Venus once per Earth day, and DSN operational support for the extended mission is expected to continue through 1980.

During September 1979, the DSN supported the first close encounter with the planet Saturn by the Pioneer 11 spacecraft, following its encounter with Jupiter in December 1974. Precision navigation data, provided by the Network, guided Pioneer 11 on a 33-month extended mission to within 19,200 kilometers of Saturn's cloud layer and to a point less than 10,000 kilometers beneath the familiar rings. Twenty high-quality pictures were returned with better resolution than any taken from Earth. The reception of Saturn images and other scientific data from a spacecraft primarily designed for a Jupiter encounter was a challenge to the DSN. Advanced radio recep-

*An astronomical unit is the nominal distance between the Earth and the Sun, about 150 million kilometers (93 million miles).



(Above) The 64-meter antenna at Canberra, Australia.

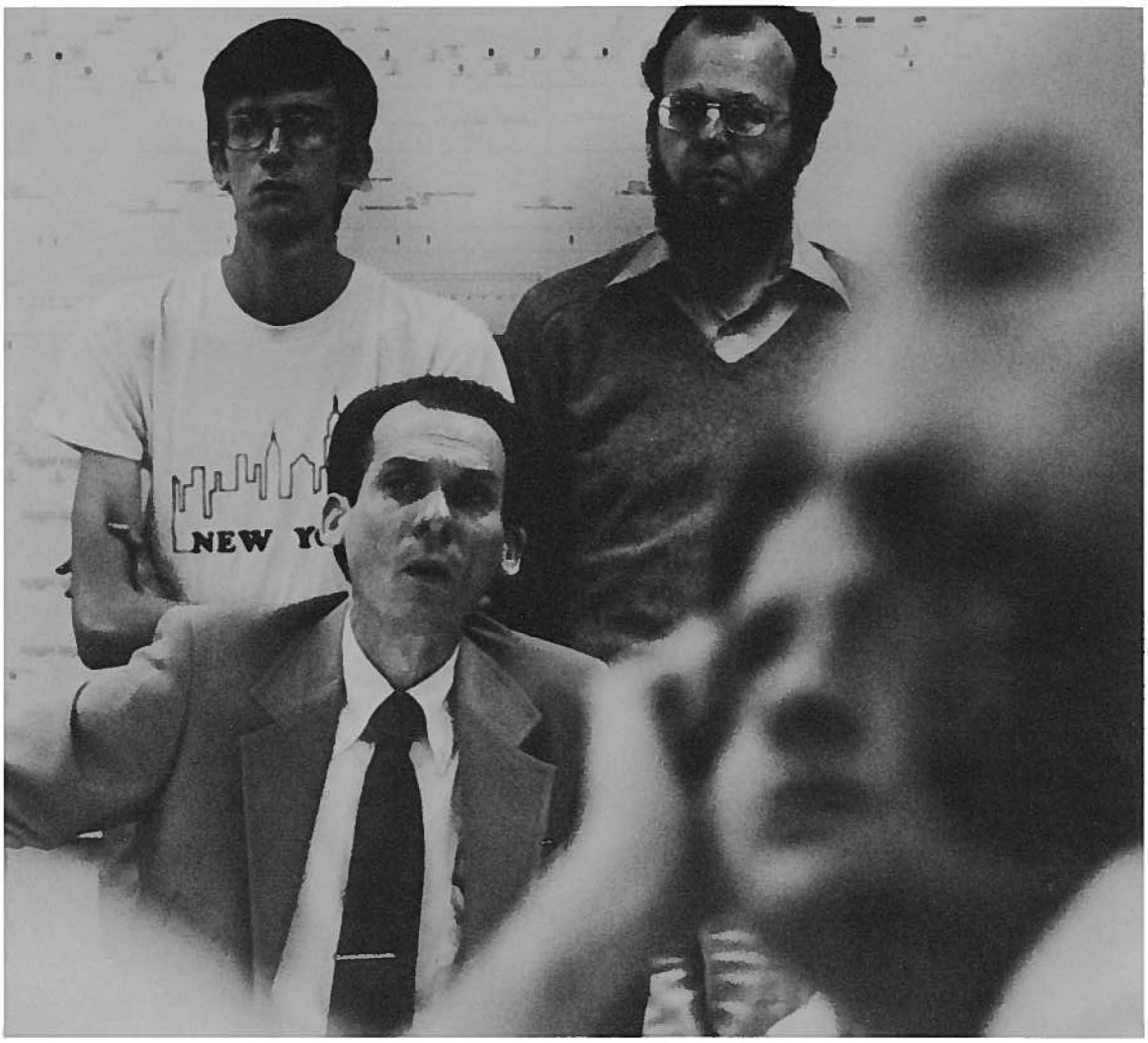
(Above right) There are two 26-meter antennas at Goldstone, California. This one is used for telecommunications research and development, while the other one is operational in spaceflight data acquisition.

tion techniques were employed, which included the use of ultra-low-noise maser amplifiers, dual station coverage during overlapping view periods, and increasing the signal level by arraying the Goldstone 34- and 64-meter stations.

DSN support for other Pioneer spacecraft continues to set communication records for both time and distance. Pioneer 6, a "space weather station" in orbit between Earth and Venus, has been tracked for 14 years—longer than any other spacecraft. Pioneer 10, which is on a trajectory that will take it beyond the solar system, is currently being tracked by the DSN over a distance of 20 AU (2.9 billion kilometers)—the longest communications link ever, and still increasing. Three other Pioneer space weather stations, all launched between 1966 and 1968, are also still part of the DSN's operational schedule.

Other spacecraft operations supported during 1979 were the continuing Viking Mars mission and Helios, the West German solar exploration mission.

The rapid rise in episodes of radio frequency interference with the highly sensitive DSN receivers at Goldstone has increasingly threatened the reliability of deep space com-



munications. The DSN and other government agencies concerned with radio transmission, including satellites, have been working together to find ways to control the problem. Radio interference monitoring equipment that can quickly identify the direction and signal characteristics of the interfering source has been installed at the Goldstone complex. More sophisticated automated equipment is currently being developed.

New Capabilities

The new DSN capabilities implemented during 1979 were primarily for the Voyager encounters with Jupiter, the Voyager encounters with Saturn in 1980 and 1981, and future outer-planet missions.

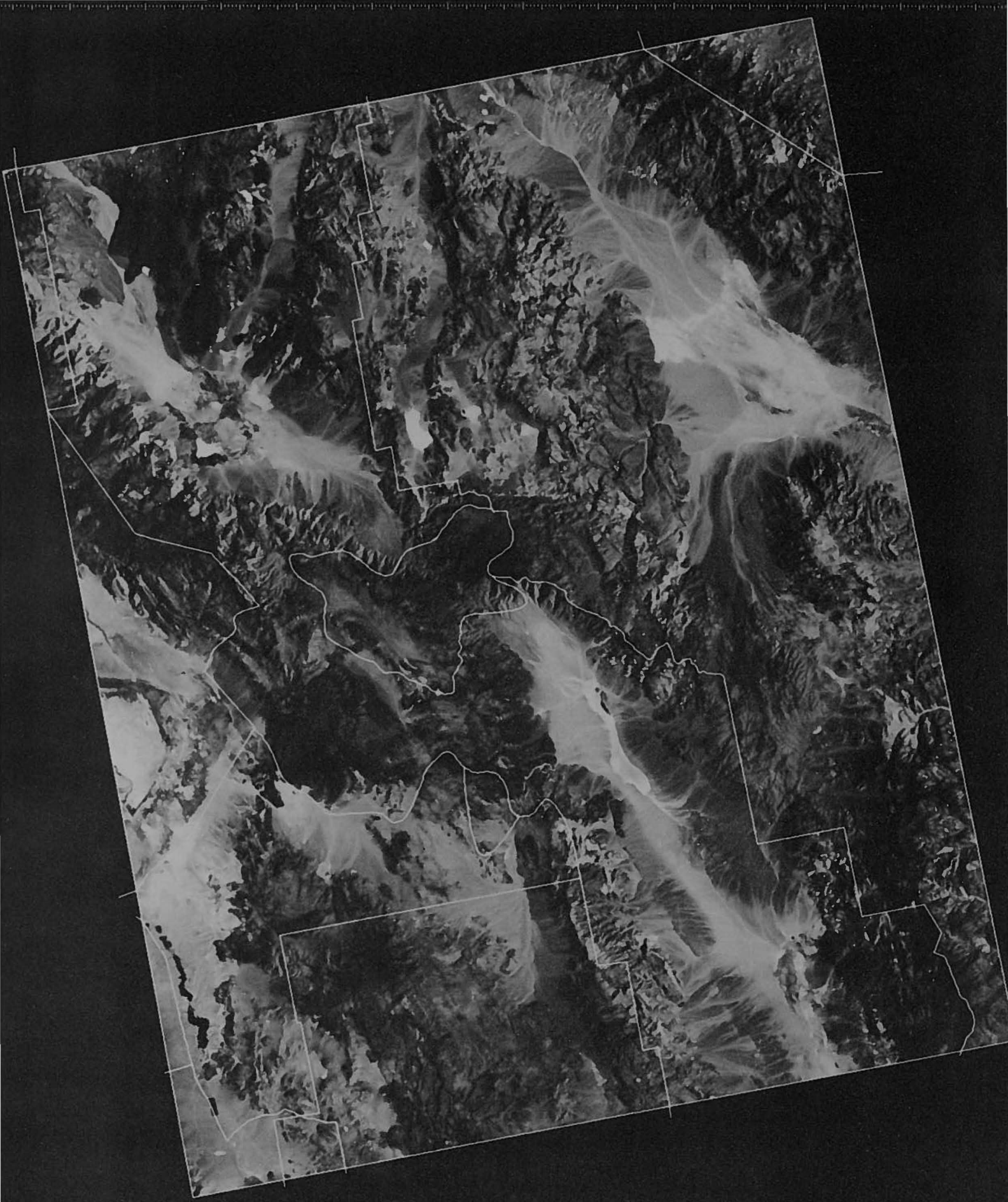
New data handling and receiving equipment was installed at the Madrid and Goldstone complexes to support Voyager radio science observations of the Jovian ionosphere and neutral atmosphere.

Ground transmission of spacecraft data from the deep space stations to the various spaceflight projects via the DSN's Ground Communications Facility was greatly improved by the installation of an automatic error-correction system. The new system retransmits incorrectly received data until it is received correctly.

In preparation for the Voyager encounters with Saturn, improved low-noise X-band maser amplifiers and modified antenna feed systems for receiving both X- and S-band frequencies are being installed to improve reception of the high-rate imaging telemetry data. The antenna arraying configuration, which will contribute greatly to the quality of the Saturn pictures, was successfully demonstrated during the Voyager 2 encounter. Based on this experience, improvements are being made in the arraying system and in the operational procedures for the Saturn encounter.

The planned shift to a new Tracking and Data Relay Satellite System (TDRSS), which will be managed and operated by NASA's Goddard Space Flight Center, has resulted in a reorganization of JPL and Goddard ground tracking responsibilities. At the request of NASA Headquarters , the JPL TDA Office and Goddard have collaborated in developing a plan for consolidating the Goddard tracking stations that are co-located at DSN sites into the DSN by 1985. The plan maintains Goddard's responsibility for TDRSS and most Earth-orbiter tracking, while JPL retains deep space tracking and assumes responsibility for the ground tracking of high Earth-orbiter satellites, which cannot be tracked by TDRSS.

(Right) This historic picture of Io was the first image returned by Voyager 1 in which volcanic action was detected. The two simultaneously erupting volcanoes are on the limb (lower right) and the terminator (shadow between day and night) where the volcanic cloud is lit by the Sun.



DEATH VALLEY WEST NJ11-11W
LAMBERT CONFORMAL CONIC MAP PROJECTION
GRAZING ALLOTMENTS AND ADMINISTRATIVE DISTRICTS

(Right) The effect of the Sun's ultraviolet radiation on the Earth's ozone layer will be studied by the Solar Mesosphere Explorer. This artist's rendering shows the spacecraft in its polar orbit around the Earth.

The JPL goal of implementing selected Earth-orbital projects and experiments for scientific and utilitarian purposes is being achieved through the Infrared Astronomical Satellite (IRAS), the Solar Mesosphere Explorer (SME), Seasat Data Utilization, and a wide variety of flight science experiments. Possible future missions under study include Stereosat, a complementary program to NASA's Landsat project, and the Ocean Topography Experiment (TOPEX), which will chart the Earth's ocean circulation via satellite.

FLIGHT PROJECTS

IRAS

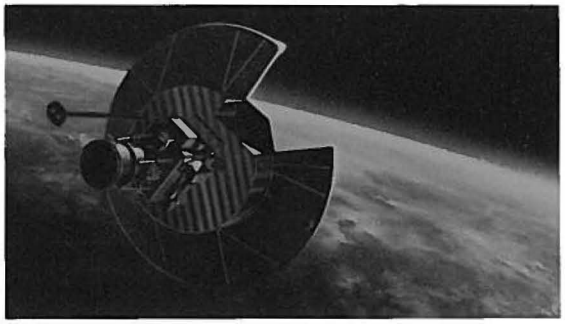
The Infrared Astronomical Satellite (IRAS), which has a planned 1982 launch date, will carry a cryogenically cooled, 57-centimeter-aperture infrared telescope into a 900-kilometer near-polar orbit. Before its cryogenic coolant is exhausted, after about one year, the international satellite will survey the sky at infrared wavelengths not observable from the Earth's surface to produce an infrared sky map and a catalog that may contain several hundred thousand new infrared sources.

JPL is responsible for project management, and the design and operation of the science data analysis facilities. The Ames Research Center is responsible for developing the telescope system. The spacecraft is being built in the Netherlands, and the mission control facilities will be in England. During the mission, scientists from the United States, the United Kingdom, and the Netherlands will gather at JPL to interpret the data.

After initial difficulties, equipment has been designed to operate reliably at cryogenic temperatures. The beryllium mirror, and the focal plane infrared detectors and preamplifiers, operate at 2.8 kelvins while the entire superfluid helium cryostat operates at 2.2 kelvins (colder than −400°F). Final assembly and testing of the telescope system, cryogenics, optics, and electronics will be completed in 1980 before these components are integrated with the spacecraft in the Netherlands.

IRAS will contribute to the understanding of such astronomical phenomena as the origin, constitution, and replenishment of interstellar and circumstellar matter and how molecular clouds and stars are formed. IRAS will also allow us to gain insight into the problem of energy balance in ionized hydrogen regions, normal galaxies, extragalactic sources, and quasi-stellar objects. IRAS should permit scientists to study infrared objects throughout our galaxy.

(Left) Landsat images such as this one of Death Valley and the Panamint Mountains were used to determine animal grazing capacity and soil erosion for the Bureau of Land Management.



Solar Mesosphere Explorer

The Solar Mesosphere Explorer (SME) is planned to be launched in September 1981 into a polar, Sun-synchronous orbit 535 kilometers above the Earth. The project is being managed by JPL and the spacecraft is being built by Ball Aerospace Systems in Colorado. The observation module will carry five science instruments that are being developed by the Laboratory for Atmospheric and Space Physics (LASP) at the University of Colorado. Mission operations will be conducted from the LASP facilities at Boulder through the Goddard Space Flight Center's satellite tracking system.

The primary mission objective is to measure the effect of the Sun's ultraviolet radiation on the Earth's ozone layer. Mesospheric temperature variations and resultant ozone changes will also be measured. The relationship and interactions between mesospheric ozone and water vapor and the stratospheric ozone and nitrogen dioxide will be studied. The mission is scheduled to last three to twelve months.

Seasat Data Utilization

This pioneering Seasat project, managed by JPL for NASA's Office of Space and Terrestrial Applications, involved a proof-of-concept oceanographic satellite launched in June 1978 and silenced in October 1978 by an on-board power failure. Despite its short 106-day life, Seasat proved successful in its primary goal—establishing the practicality of monitoring and measuring sea-surface conditions from Earth orbit in all kinds of weather, day or night.

An intensive year of data reduction and interpretation by the Seasat Data Utilization Project, aided by computer algorithmic innovations, has resulted in a thorough evaluation of sensor performance, and the provision of oceanographic and atmospheric information to the National Oceanic and Atmospheric Administration, the Navy, industrial users, and the scientific community at large.

The Seasat data evaluation is being accomplished through a series of workshops comparing the output of the four microwave sensors with surface observations made during the mission, particularly those in the Gulf of Alaska experiment.

FLIGHT SCIENCE EXPERIMENTS

The Laboratory continues to be involved in a wide variety of flight science experiments being carried out aboard flight missions under the overall control of other NASA centers. This includes participation by the staff as members of science investigation teams, as well as the development of instruments.

The Laboratory is furnishing the instrumentation for the Wide-Field Planetary Camera experiment being developed by Caltech for the Space Telescope Project. This camera, attached to a large telescope, will be launched into Earth's orbit in 1983 by the Space Shuttle.

A high-resolution gamma-ray spectrometer was designed and built by JPL for the HEAO-3 (High Energy Astronomical Observatory) satellite, which was successfully launched into orbit in September 1979. The instrument has performed an initial exploratory search for sources of nuclear gamma-ray line emissions from neutron stars, black holes, and supernovae, as well as from the galactic center region and the interstellar medium. The spectral resolution of this instrument, which has been improved by using high-purity germanium sensors, is expected to open new vistas in gamma-ray astronomy.

The Laboratory is managing the development of the Atmospheric Trace Molecular Spectroscopy Experiment planned to be carried aboard Spacelab 3. This experiment is intended to measure the molecular composition of the stratosphere to a height resolution of 2 kilometers or less and clarify the nature of the stratospheric infrared spectral background.

A number of future experiments planned to investigate the potentialities of space processing require the manipulation and control of weightless molten material. In this circumstance, the melt would be positioned and formed within a container without contacting the container walls. A novel acoustical method has been developed by JPL for controlling molten material without physical contact. The acoustic method can be used for both positioning and inducing oscillation and rotation of a melt. During the past year, a zero-gravity test of this technique was flown on the SPAR VI rocket flight. The liquid sample was successfully injected into the chamber. The data analysis has shown that the experiment proceeded flawlessly.

A series of increasingly accurate active cavity radiometers (ACR) has been developed over a period of 15 years at JPL for defining the radiation scale in the International System of Units and making flight measurements of the total solar irradiance to establish a long-term data base on the variability of solar luminosity. They are among a handful of instruments whose performance defines a new scale—the World Radiometric Reference. ACRs developed in the late 1970s demonstrated a change in solar luminosity of +0.4 percent (±0.1 percent) between June 1976 and November 1978. An ACR Irradiance Monitor containing three ACR sensors was launched in February 1980 as part of Goddard Space Flight Center's Solar Maximum Mission, a NASA project dedicated to studying the Sun. The third in a series of rocket experiments was scheduled for April 1980. Currently under development is an advanced ACR sensor system for a flight experiment on the Spacelab 1 Mission in 1982.

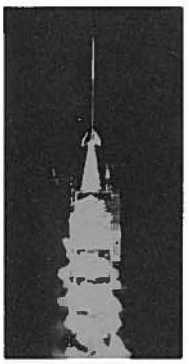
Other JPL instruments under development are the Shuttle Imaging Radar-A; the Shuttle Multispectral Infrared Radiometer; and a detector subsystem and components for a large and complex gamma-ray spectrometer for the planned Gamma Ray Observatory, a collaborative project with the University of California, San Diego.

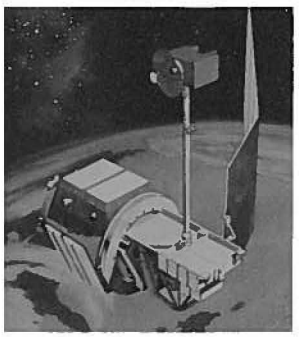
EARTH-ORBITING PROGRAM PLANNING

Stereosat

This proposed Earth-satellite project would provide a complementary capability to the Landsat program by imaging land masses in stereo for the benefit of geological research and for locating possible indicators of mineral and petroleum resources. The data could be used as well for improving topographic maps of the Earth. A preliminary mission description was published in 1979. A 1982 start would enable a 1985 launch.

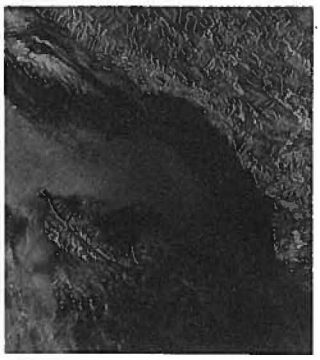
This project has been examined as a joint government–private sector venture and as a transition step toward a remote-sensing satellite system operated by industry. Studies of factors affecting the participation of the private sector, such as financing, management, ownership of data, and relevant laws and international treaties, were initiated in 1979. The appropriate role for NASA and JPL in this type of endeavor is also being examined.





(Top) JPL's containerless processing experiment was tested in a zero-gravity environment aboard Marshall Space Flight Center's Space Processing Applications Rocket (SPAR VI).

(Bottom) Mineral exploration, mapping, and general geological data acquisition would be performed by the proposed Stereosat mission. The spacecraft's antenna and solar array are shown deployed.



(Above) The surface observations obtained by Seasat have been digitally processed into valuable aerial photographs such as this one of the Channel Islands (center left) off the Southern California coast near Santa Barbara.

Ocean Topography Experiment
The success of oceanographers in correlating Seasat altimetry data with ocean current features measured by conventional surface techniques has lent impetus to ocean remote sensing. As a result, the Laboratory is studying a possible NASA research mission to measure and monitor global ocean circulation. This mission, the Ocean Topography Experiment (TOPEX), would employ radar altimetry in conjunction with precision orbit determination and geodesy to measure the height of the ocean surface on a global basis. The data would help oceanographers delineate ocean circulation and tidal action.

A 1982 project start would lead to a 1986 launch. Current mission concepts call for five years in Earth orbit.

EARTH OBSERVATION

Geologically Related Imaging
The rapidly expanding use of Landsat visible and near-infrared data by industry and government for geological applications, particularly mineral exploration, substantiates the value of data acquired from space. The use of remotely sensed mid-infrared data, while not yet exploited for these purposes, promises to be of comparable value.

Image enhancement techniques developed by JPL have proven valuable in producing rock-type maps in several Western states, principally Utah and Wyoming.

Under a NASA Geosat test case program, JPL analyses revealed possible new uranium deposits at Copper Mountain, Wyoming. The work, based on Landsat-equivalent, color-ratio composite aircraft multispectral scanner images, found distinctive iron oxidation patterns related to known uranium deposits. New areas were located by extrapolation. A Geosat member company's field study confirmed the presence of mineralization. This find appears to be the first recorded prediction of uranium mineralization using remote-sensing techniques.

Desert Land-Use Planning
The animal grazing capacity of marginal southern California desert areas has been computed by JPL image processing engineers for the U.S. Bureau of Land Management (BLM). Using the BLM's sampling of 500 low-altitude phototransects (750 × 2000 meters), JPL also digitized and overlaid maps of land ownership and grazing allotment leases on a Landsat mosaic to derive maps of soil erosion potential, total standing biomass, and edible biomass.

With these data, it was possible to derive monthly livestock grazing capacities for each allotment. Wildlife capacities can also be computed, as can some measures of recreational use. The BLM-sponsored project was another application of the Laboratory's VICAR–IBIS techniques.*

Stratosphere Measurements
Studies of minor and trace constituents of the stratosphere, using infrared interferometry, were continued by the Stratospheric Spectroscopy Group. Simultaneous concentration profiles were developed at both northern and southern mid-latitudes for carbon dioxide, carbon monoxide, methane, nitrogen oxide, ozone, hydrogen chloride, and hydrofluorine. A new version of the interferometer used in the measurements program, with significantly increased resolution and wavelength coverage, was successfully test-flown on a balloon-borne gondola. A third interferometer was designed for use on the Space Shuttle.

Submillimeter Spectroscopy
A JPL submillimeter spectrometer provided valuable measurements for astronomy, atmospheric chemistry, and submillimeter technology development. Transition frequencies and line shapes are measured for molecules in the spectral region from 50 to 1500 gigahertz (6-millimeter to 200-micrometer wavelengths). Sample cells can be used for transient, unstable molecular species as well as for stable ones. Measurements were made of the spectra of nitric oxide, chlorine monoxide, hydrogen peroxide, monodeuteromethane, phosphine, carbonyl sulfide, and bromine monoxide. The first three were especially vital to the interpretation of continuing stratospheric measurements.

*VICAR is an acronym for Video Image Communications and Retrieval, and IBIS stands for Image Based Information System.

The tempo of JPL activities in the energy sector was stepped up substantially in 1979. Under the aegis of JPL's Energy and Technology Applications Office (E&TA) and the U.S. Department of Energy (DOE), major research and development field sites were established in two solar technologies—solar photovoltaics and solar thermal systems. The DOE also sponsored coal handling projects and electric and hybrid vehicle development. Important advances were also made in freeway and tunnel studies for the U.S. Department of Transportation.

SOLAR ENERGY

Photovoltaics

As the DOE's lead center for technology development in photovoltaics, JPL expanded its role in cost-policy analysis and system integration while also coordinating the work of other laboratories on solar cell development and applications.

The nation's largest photovoltaic experiment to date—the 60-kilowatt power system at the Mount Laguna Air Force (Radar) Station near San Diego—involved the Laboratory in a dual role as program management coordinator and as supplier of the 2366 solar array modules used in the system, which is designed to provide a major system-level field test (supplying up to 10 percent of the station needs).

Studies delineating possible federal policy on photovoltaics were done for DOE and a multiyear management plan was drafted.

The Low-Cost Solar Array Project completed its fifth year of collaboration with a vigorously growing industry now involved in photovoltaic technology development and array production. Significant progress was achieved in key technologies. Notable advancements in the industrial sector included moving low-cost production of high-purity silicon into the pilot-plant stage and demonstrating the growth of multiple crystalline silicon ribbons 10 centimeters wide. Several production processes demonstrated good cell performance and it is possible that low-cost mass production can be achieved by 1982, an important project goal. Laboratories were opened for photovoltaic materials and device testing and for controlled evaluation of variations and innovations in individual steps of cell-processing production. Cost evaluation indicates that the project could meet a 1986 production price goal of 70 cents per peak watt in 1980 dollars.

The major part of the technical work on photovoltaics has been allocated to industrial firms and research laboratories. JPL's own work has included process analysis and evaluation, product testing and analysis, and research on alternative solar cell materials and designs.

Solar Thermal Power Systems

The Laboratory's second solar energy technology project, also sponsored by DOE, is developing point-focusing modules and systems capable of delivering either electricity (from a heat engine and generator mounted at the focus of each collector), or a high-quality process heat (manifolded from the focal-point receivers). This project is tripartite, with an applications effort utilizing current and near-term designs, a technology development activity aimed at low-cost systems, and an advanced technology effort.

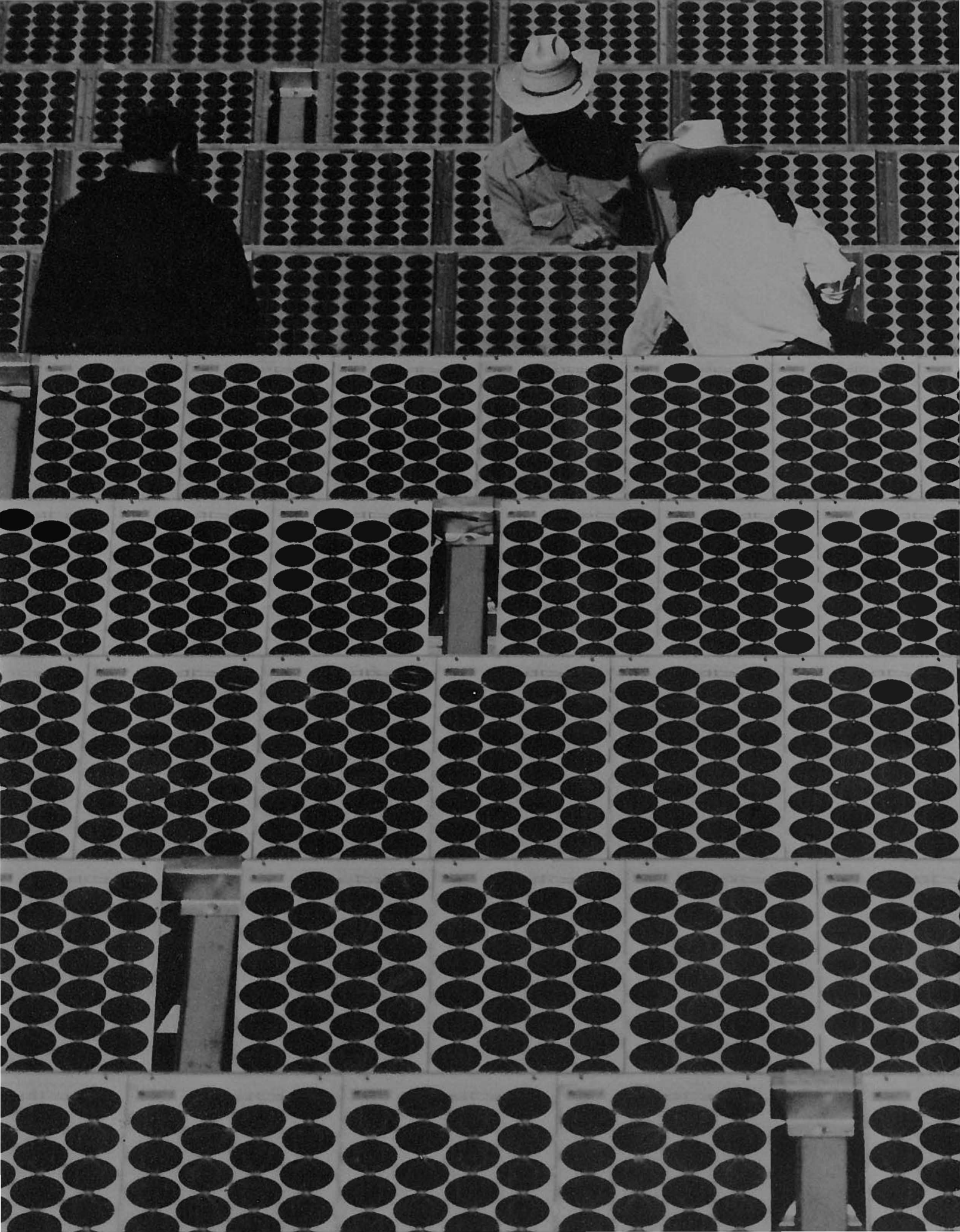
In the applications area, a manufacturing contractor was selected to run a small-community engineering experiment prior to soliciting candidate communities; joint planning was begun with the U.S. Navy's Civil Engineering Laboratory for a remote-site application experiment; and possible applications for an industrial heat experiment were studied.

For point-focusing technology development, contractors were selected for the low-cost concentrator and for heat receivers using air and steam. The major test equipment, installed at the Point-Focus Test Facility at Edwards Test Station, included a flux mapper to guide a sensor for measuring the fireball at a concentrator's focal point; the sensor itself; a wide-range modification of a JPL active cavity radiometer; and two test-bed concentrators.

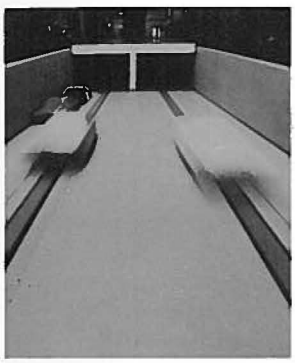
The concentrators are 11-meter-diameter tracking parabolic dishes modified from a radar antenna design. The reflecting surfaces are mosaics of 60 × 70-centimeter spherical reflectors that use inexpensive mirrors laminated to cellular-glass slabs. The test beds will evaluate focal-point subsystems (receivers and engine generators), now being fabricated, and advanced subsystems as they are developed.

The advanced technology activity included contracting for advanced hardware, concentrator design studies, and a preliminary study of advanced systems for fuels and chemicals production applications. NASA's Lewis Research Center is developing power conversion units for the project.

(Right) JPL has established several solar photovoltaic installations throughout the country as part of its Low-Cost Solar Array Project.



Right) JPL developed the solar concentrator's concave mirrors that are made by bonding mirrors of back-silvered glass to contoured cellular-glass slabs. The cellular glass, which resembles a rigid sponge, is often used as thermal insulation.



(Top) Solar concentrators collect the Sun's radiation and focus it into a small area. The resulting heat can then be converted into power.

(Middle) The Highway Intermittent Tunnel Simulator at JPL is used to study the complex air flow patterns in and around tunnels. The results may contribute to a new urban highway design.

(Bottom) The Electric Test Vehicle demonstrated that electric vehicles can be a viable and desirable transportation option.

UTILITY SYSTEMS

The utility systems program, sponsored by DOE, strives to develop a systems perspective and methodology for integrating new technologies into existing utilities. Part of the program concentrates on improved communications and control systems for use in future electric power systems. A NASA-backed project focuses specifically on applying NASA–JPL systems capability to these problems. Cooperative efforts were begun with the electric utilities of Pasadena, Glendale, and Burbank to explore possible application in these cities. An electronic simulator is being developed to examine electric utility operational problems on an interactive basis. Fifty JPL engineers and technicians completed an educational course on utility systems design and practice.

COAL SYSTEMS

The JPL coal program, sponsored by DOE, includes analysis of advanced underground mining systems and a study of new technologies. Environmental studies, a mining cost-analysis model, a baseline mine study, and a skills data base for new technical concepts were completed.

Two JPL innovations in coal processing, begun under NASA, are now sponsored by DOE: a coal pump for injecting plasticized coal into pressure vessels and a chemical desulfurization process based on chlorinolysis. The coal pump achieved regular, continuous spraying of coal, a requirement for gasification and other conversion processes. Improved pump-nozzle designs were also evaluated. The chlorinolysis group completed studies of process chemistry and engineering, using a 2-kilogram batch system, and constructed and tested a 2-kilogram-per-hour continuous-flow processor.

In another DOE task, JPL assessed candidate coal gasification processes for strengths and weaknesses. JPL also continued experiments in coal conversion and combustion, and combustion of other fossil fuels, seeking better fuel efficiency and emission control.

TRANSPORTATION SYSTEMS

Electric and Hybrid Vehicles

The first near-term advanced experimental electric passenger car was developed by General Electric Company with support from the Chrysler Corporation under a Department of Energy contract. The vehicle was completed and delivered to JPL for testing. The vehicle met its preliminary goals of a 75-mile driving range without recharging and a 0 to 30-mile-per-hour acceleration in 9 seconds. Another vehicle is being developed under a DOE contract to Garrett Corporation and is based on an innovative flywheel storage concept.

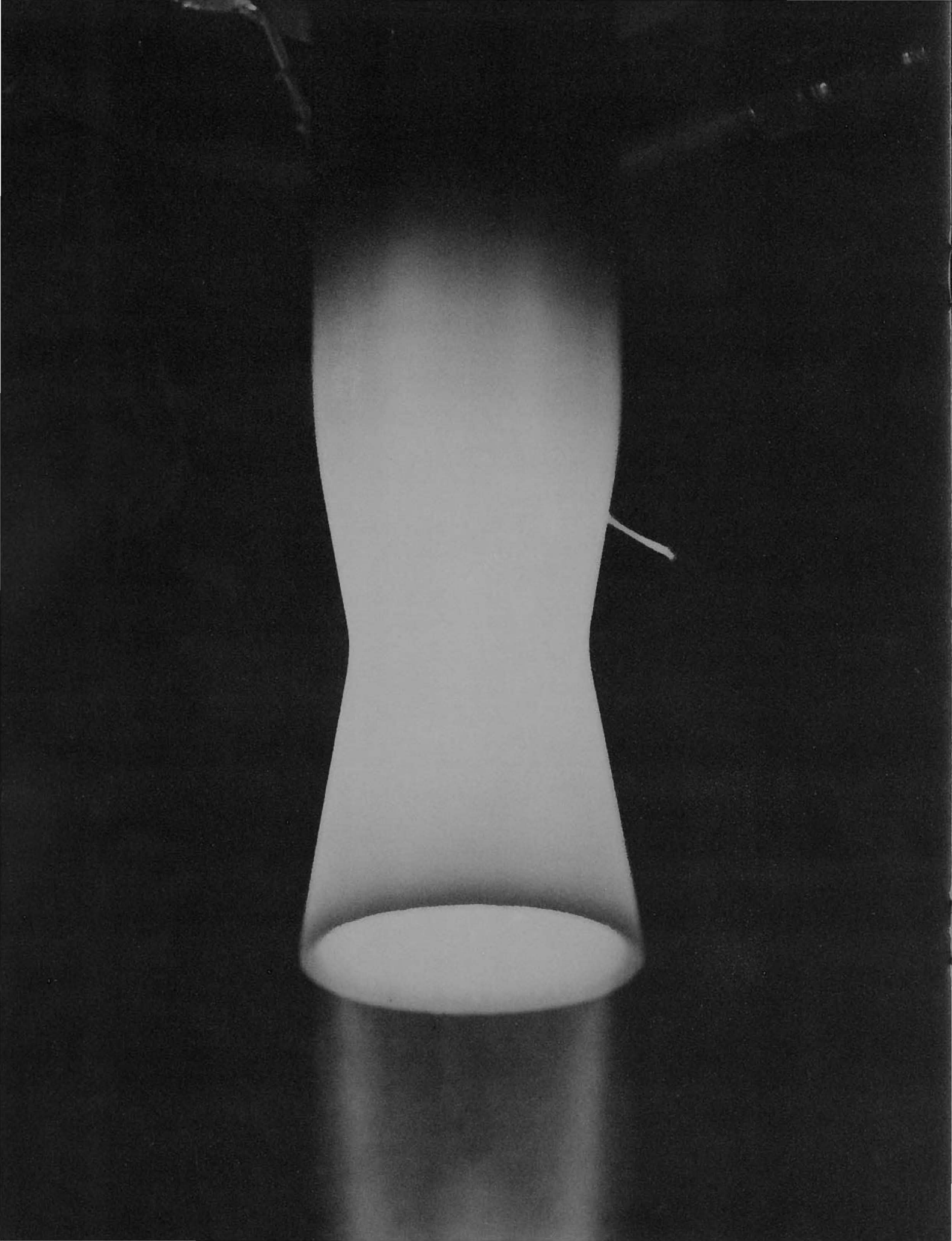
The Electric and Hybrid Vehicle project acquired and tested several vehicles adapted from conventional automobiles to electric propulsion by small private firms, and completed JPL's Vehicle Technology Test Bed, designed to road-test developed components. In-vehicle testing of advanced batteries began this year. All of the vehicles are tested both in JPL's dynamometer laboratory and on the road at the Edwards Test Station.

A comprehensive study of the potential for hybrid vehicles, showing a possible fuel savings of up to 40 percent, was completed. JPL selected General Electric to develop a near-term hybrid vehicle, which contains both an internal combustion engine and an electric motor.

Freeway and Tunnel Studies

Three significant transportation-related tasks were performed for the U.S. Department of Transportation. The SCAN (Sensor for Control of Arterials and Networks) traffic-monitoring system can show multilane traffic speeds, density, and volume by computer image data processing using a single television camera. This SCAN system, which operates in a medium-sized van, was successfully field-tested on Los Angeles freeways.

Two studies in tunnel aerodynamics—railway tunnel entry pressure and freeway tunnel ventilation—were pursued through scale-model experiments. The pressure-transient study showed that the addition of a perforated tapered collar at a tunnel entrance would obviate the need to slow trains on approach. The freeway tunnel model, relying on a series of open vents and covers, was validated in several tests on a full-scale Los Angeles tunnel. The project has yielded fundamental ideas for designing tunnels that have reduced air pollution.



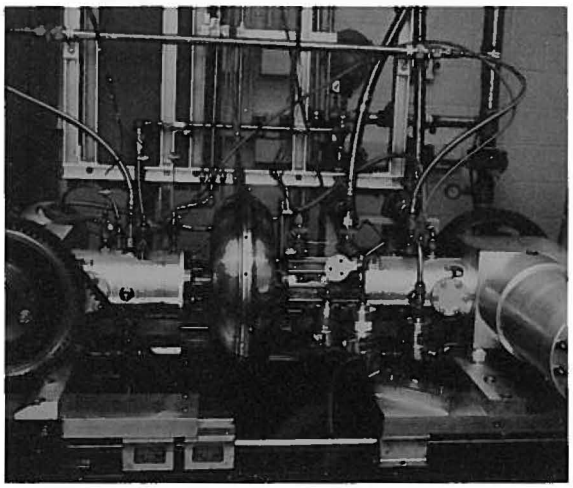
Research and development in both space and nonspace energy applications are vital concerns of JPL. New types of engines and energy conversion components are being sought and tested. A Stirling cycle research engine for Earth use and a space-storable propulsion module for future spacecraft were tested this year. Advances were also made in space solar cell and array technology.

ENERGY CONVERSION

Stirling Laboratory Research Engine

Stirling cycle engines, while used comparatively little now, have the potential to operate from a variety of external heat sources, including solar, nuclear, industrial waste, or any combustion device burning solid, liquid, or gaseous fuels. The Stirling engine appears well-suited for converting solar to electrical energy for stationary applications, for silent power-generation systems, and perhaps for automotive propulsion.

To accelerate U.S. Stirling engine development, NASA is sponsoring a JPL program intended to lead to a versatile Stirling laboratory research engine. The nearly completed first phase of this program included design, fabrication, and successful testing of a modular two-piston preprototype engine. It demonstrated self-sustaining operation for up to 13½ hours, using helium gas within a closed-cycle system heated by an external electrical source. The potential for a fully operational test engine was established.



(Right) The two-piston modular Stirling laboratory research engine could operate from a variety of external heat inputs. This JPL model has an electrical heater as the power source.

(Left) A new rocket engine, developed by JPL, uses liquid propellants that are space-storable because they do not need to be kept at room temperature like traditional propellants. This engine is also lighter because these propellants are more efficient, a factor that is especially important for future missions to the outer planets.

Solar Array Concentrator Development

Solar cell arrays using concentrators can provide significant electrical power for spacecraft operating at the outer planets, where limited sunlight makes conventional solar arrays ineffective. By employing accurately pointed large mirrors, the extremely low-intensity sunlight available at large solar distances (5 AU and beyond) can be collected and concentrated so that photovoltaic arrays can be used.

Concentrator-enhanced solar arrays have been evaluated for use on Solar Polar, Galileo, and other missions. With further development, concentrator-enhanced solar arrays will give mission planners another option for spacecraft power sources.

These solar arrays are also potentially less costly and have a higher power-to-mass capability than present power sources. The primary goal is to generate more than 20 watts per kilogram at Jupiter and 5 watts per kilogram at Saturn, a factor of 2 to 5 greater than the present power sources being used for these mission applications.

Space-Storable Propulsion

A more efficient spacecraft propulsion system is being developed at JPL for missions that require substantial velocity changes, such as planetary orbiters. This program, sponsored by NASA's Office of Aeronautics and Space Technology, is producing a 3560-newton (800-pound) thrust rocket engine using liquid fluorine and hydrazine as propellants. This results in a specific impulse 25 percent greater than that of the Viking Orbiters' propulsion system. The new engine was made possible by the development of lightweight carbon composite material for radiation-cooled thrust chambers.

Test runs of up to 1000 cumulative seconds, in thrust chambers using a thin rhenium liner to eliminate corrosion, were successfully completed. The nozzle throat temperatures are nominally 2,200 degrees Celsius, while engine head-end temperatures are below 200 degrees Celsius.

Final demonstration testing of this engine is expected in 1980 and will be followed by a demonstration using a full expansion ratio nozzle under vacuum conditions. This will lead to technology readiness of the full propulsion system by JPL in 1982.

Photovoltaic Space Systems

An ultrathin silicon solar cell was used to produce modules with the highest specific power (watts/unit mass) yet achieved, thus verifying JPL conceptual studies begun in 1972. In-flight arrays using these modules would have a specific power exceeding 100 watts per kilogram, over twice that of any array ever flown. The integrity of these modules was demonstrated by thermal cycling tests at JPL and other NASA centers.

A key step in the fabrication of a new gen-

eration of solar cells—the gallium arsenide cell—was taken with the completion of a chemical vapor deposition system which used organo-metallic sources to produce thin-film gallium arsenide layers.

Conversion efficiencies of over 16 percent were produced by another type of photovoltaic device, the antireflection coated-metal-oxide semiconductor (AMOS) cell. Radiation damage studies of gallium arsenide AMOS cells indicated that they are superior to the silicon solar cell now being used in space.

(Right) Ultrathin silicon solar cells have been successfully matched with solar panel technology to produce sample modules that have three to five times the power-to-mass value of any module flown in space.

INFORMATION SYSTEMS

Small, but reliable, computer systems are the heart of spacecraft used in planetary exploration. They decode and interpret the strings of commands sent from Earth to control the spacecraft and its scientific instruments. They assemble and organize the data acquired from these instruments for transmission. On Earth, large and complex computer systems help mission personnel prepare the command strings, sort through the wealth of data telemetered from the spacecraft, and send it on to scientists and engineers for further study and analysis.

Computer Replacement Project

The Computer Replacement Project was started in 1979 to implement a modern large-scale information and data processing system at JPL. This system will replace JPL's older large computers (three Univac 1108's and two IBM 360/75's) and will incorporate JPL's administrative computing, which is now done on the Caltech campus.

The new system includes Univac 1100/81 computers and a large mass-storage system. A facility for housing the system was completed at a nearby off-Laboratory site and testing was begun on the first two computers to be delivered. Completion of the system in 1980 should provide JPL with a computer processing facility adequate to support future activities.

End-to-End Information System

An Information Systems Program was established at JPL to design the End-to-End Information System used for solar system exploration. Among the important design questions being considered are: How can spacecraft be made more reliable and better able to cope with unpredictable events? How can the costs of mission support be reduced, while the useful information yielded by the mission is increased? How can the scientist, engineer, or mission analyst be given more convenient access to the information that is of primary interest to him or her?

Image Processing Laboratory

Image enhancement techniques employed in deep space exploration, particularly for Voyager, were also used in the Landsat data analyses of geologically related and desert land-use planning projects. However, the Image Processing Laboratory is also involved in a wide range of other programs. An operations research task was begun to help the FBI evaluate the automation of fingerprint identification, and technical studies were also made on promising automation approaches.

Studies in radar archaeology used digital processing of overflight radar images in a search for evidence of Mayan agriculture in forested and relatively inaccessible terrain in Guatemala. This work, sponsored by NASA's Office of Space and Terrestrial Applications, was carried out in collaboration with Churchill College, Cambridge University.

Remote Sensing of Air Pollution

Vertically swept microwave sensors, in the 53- to 57-gigahertz region, were used experimentally to construct temperature profiles charting the dimensions and movement of the inversion layer, both from the ground and from aircraft. This system is also promising as a real-time detector of clear-air turbulence, an aviation hazard.

The JPL Laser Absorption Spectrometer (LAS) was used to chart smog patterns in the Los Angeles basin. LAS utilizes two carbon dioxide lasers, aimed downward from an aircraft, to measure the ozone burden along the path from the aircraft to the ground. By taking a difference signal from the two reflected

(Far Right) This Landsat photograph of the Salton Sea (upper left) and the Imperial Valley, taken for JPL's desert land-use study, has been enhanced by the Image Processing Laboratory. The central area shows farmland, bordered by desert on either side and by mountains in the upper right.

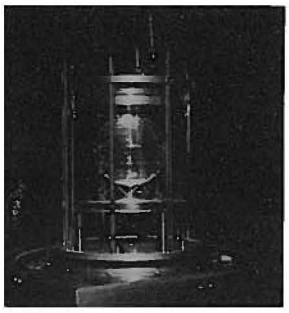
beams, ozone is detected in the 9.5-micron infrared band.

The Multispectral Observation of Pollutants System constructs an image from a linear array of ultraviolet detectors which can be filter-tuned to detect sulfur dioxide, nitrogen dioxide, or ozone. It was tested in flight this year after previous ground-based evaluation. The Laboratory is preparing to integrate the various instrumental approaches into a multispectral pollution mapping system.

Mobile Automated Field Instrumentation System
The U.S. Army Training and Doctrine Command Combined Arms Test Activity (TCATA) provides facilities for testing and training. An instrumentation system to monitor and evaluate field test activities was required by TCATA, and JPL will provide the system design and technical management. The Mobile Automated Field Instrumentation System (MAFIS) will consist of position location, communication, benign engagement systems, and a command and control center. The combat engagement area would be 50 kilometers square, with position location and communication coverage of that area.

A field element will be developed that could be carried by any "weapons platform" (man, tank, helicopter, etc.) and this element will report the position, the execution of engagement activities, and the assessment of results to the test control center, all in real time. A large exercise employing up to 2,000 platforms will be possible. This system is scheduled to go into operation in 1985.

Machine Intelligence
Building on artificial intelligence techniques, a general-purpose reasoning system was designed to deal with a broad range of automation problems. The first practical space application is to automate mission operation tasks on Earth and onboard spacecraft. The primary goal is to have a system produce spacecraft command sequences using a data base that incorporates operating constraints and conditions aboard a spacecraft. It is anticipated that the application of these techniques will significantly reduce the cost of mission operations.



(Above) A quartz bulb, which holds the hydrogen atoms in JPL's hydrogen maser clock, as part of a new, advanced, vibration-resistant design. This timing system is used in the frequency and timing subsystem of the 64-meter deep space stations and is crucial for navigation at the outer planets.

DEEP SPACE EXPLORATION SUPPORT

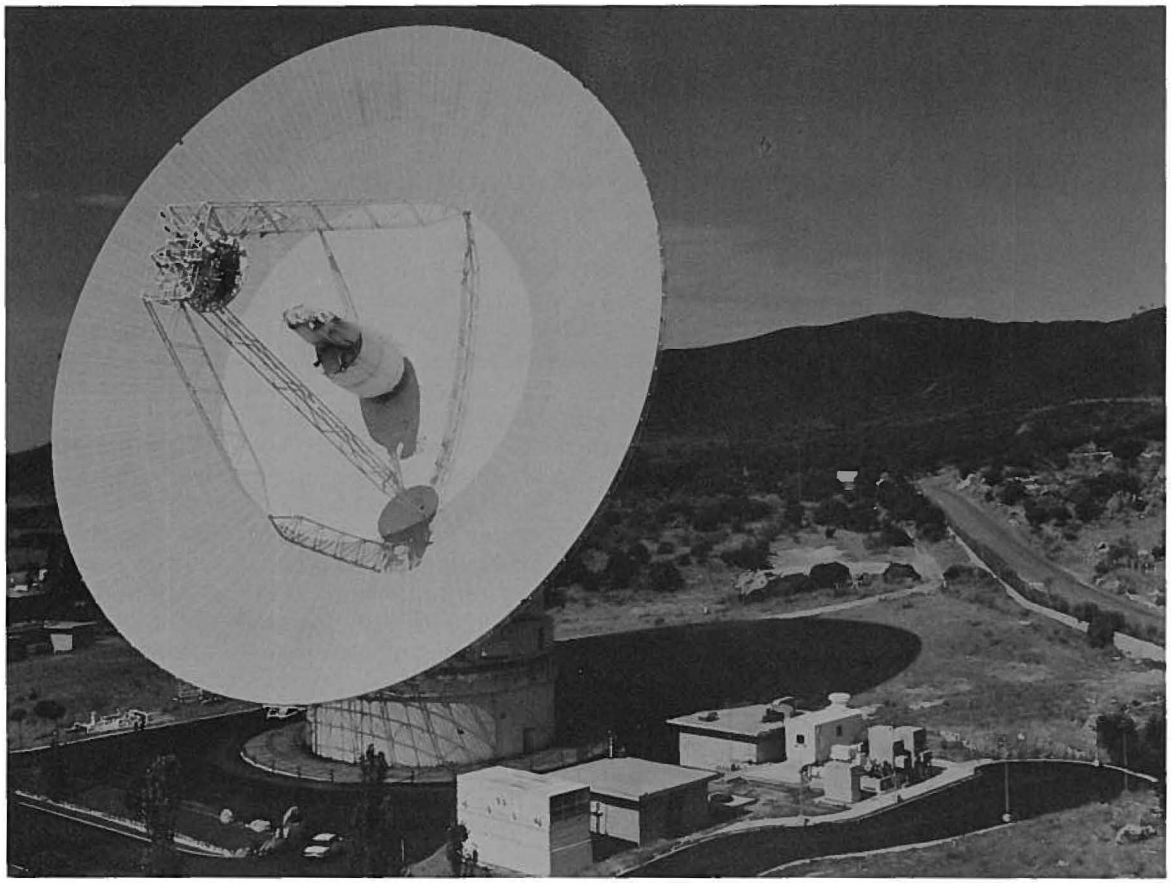
DSN Advanced Systems
The DSN Advanced Systems Program devises, develops, and demonstrates new technologies to meet future needs in spacecraft navigation and communication. Missions in the 1980's and beyond will require improved navigation accuracy and telemetry capability over greater distances and at reduced cost. Work is under way on new radio navigation concepts, improved communications elements, and on computer-based automatic operation, monitoring, and control of the DSN stations.

Very long baseline interferometry (VLBI) is being used in spacecraft navigation experiments to evaluate its potential for improved accuracy and lower operating cost. The VLBI technique involves the simultaneous reception of a radio signal from a radio star or spacecraft at two or more widely separated receiving stations. The minute difference in signal arrival time at each station is precisely measured and used to calculate the angular position of the signal source. A second technique, differential VLBI, is also under test. In differential VLBI, a radio star source at a precisely known position near the spacecraft is tracked nearly simultaneously to locate the spacecraft position relative to the radio star. This technique was demonstrated with the Viking Mars Orbiter to evaluate low circular orbit tracking, and was used during both Voyager encounters to evaluate flyby trajectory tracking.

Multistation radio interferometry requires extraordinarily accurate clocks at each station and a means to synchronize them. The timing accuracy needed for precision navigation at Jupiter and Saturn distances requires a time reference that doesn't vary more than one second in three million years. This kind of precision is obtained with ultrastable hydrogen maser oscillators, the vibration of their hydrogen atoms being analogous to the movement of a clock pendulum. The clock synchronization between stations is performed by reversing the VLBI function. The capability of VLBI to monitor the synchronization and stability of the remotely located hydrogen maser clocks was demonstrated in a series of experiments conducted between the deep space stations in Australia, Spain, and California. Over 10-day intervals, the measured stabilities of the clock systems were 1 to 3 parts in 10 trillion (10^{13}).

Developmental hydrogen maser clocks have been operating at all DSN complexes for more than a year. These early models require improvement, and the implementation of the next generation of ultrastable oscillators has been given high priority. One version of the latest hydrogen maser, developed by the Smithsonian Astrophysical Observatory at Harvard University, is being evaluated in a

(Right) The 64-meter antenna near Madrid, Spain, is as high as a 21-story building and weighs 8000 tons. It represents the latest design in sensitive tracking antennas and is capable of tracking spacecraft to the edge of the solar system.



JPL test facility that can compare the performance of up to five precision oscillators simultaneously. The facility's environmental control provides an overall temperature stability of ±0.5 degrees Celsius. During initial use of the facility, hydrogen maser frequency stabilities of better than a few parts in one quadrillion (10^{15}) were maintained for over 24 hours.

Innovative approaches are being used to improve the performance of communication elements and reduce costs. For example, recently developed analytical techniques are making new antenna reflector designs with 50 percent higher efficiencies possible. Improved antenna feed performance has been demonstrated on a 26-meter antenna, using a single concentric feed for simultaneous reception of both S- and X-band spacecraft frequencies. Broadband ultra-low-noise receiving systems promise enhanced deep space telemetry reception and reduced costs of multifrequency operation. An experimental low-noise system employing a cryogenic supercooled S-band frequency up-converter and a maser amplifier, operating at much higher K-band frequencies, was tested extensively during 1979 with good results. The objective is to up-convert both S- and X-band frequencies to the higher K-band frequencies, which are then amplified by a single K-band maser amplifier.

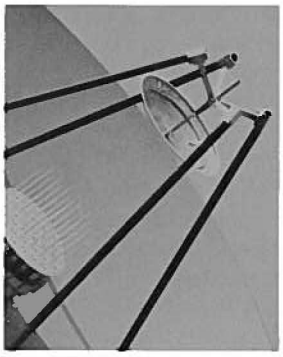
An automatically operated 20-kilowatt X-band transmitter is under development to improve command performance for future spacecraft, particularly near solar conjunction. The reduced sensitivity of X-band uplink frequencies to solar corona effects will permit the commanding of a spacecraft to continue within one degree of the Sun rather than terminating at five degrees, which is the limit for S-band frequencies. The command outage time during solar conjunction will be reduced from one month to one week.

An improved system for radio frequency interference detection and analysis has been developed by JPL engineers. The system is capable of frequency analysis in 75,000 channels over a 15-MHz bandwidth centered on the DSN S-band receiving frequency. This portable system will be demonstrated at Goldstone during 1980.

The operation of DSN stations currently requires some manual attention, and stations are unavailable for mission operations during necessary maintenance and calibration

(Top) A mobile 9-meter antenna of JPL's Earth-measuring system ARIES is used in conjunction with two stationary reference stations to take geophysical measurements.

(Bottom) JPL's experimental antenna-transmitter, which would be used on future spacecraft, consists of 32 independent transmitting elements that can vary the direction of the antenna beam back to Earth without reorienting the antenna itself. This preserves precious attitude control gas used in space flights.



checks. The development of equipment and techniques to increase mission operation time and reduce the station operating staff has been in progress for several years. During 1979, the quick response of a prototype, unattended, computer-controlled tracking station was demonstrated. With only 15 minutes notice, the unattended Advanced Systems 26-meter station at Goldstone interrupted its schedule, reconfigured for a different flight project, tracked and acquired telemetry, and delivered data. This was all remotely controlled from JPL in Pasadena.

Work continues on computer software technology. The second volume of an instructional text, Standardized Development of Computer Software, *has been published by Prentice Hall. The book was developed within the Advanced Systems Program for DSN use and is becoming a standard text in university software engineering courses.*

Geodynamics

The Astronomical Radio Interferometric Earth Surveying (ARIES) Project has continued to demonstrate the feasibility of determining three-dimensional Earth positions with an accuracy of a few centimeters over baselines of 180 to 500 kilometers. The ARIES technique employs VLBI and a quasar radio source reference frame. One of the interferometer stations in these experiments is portable, so that various sites may be surveyed. Caltech's Owens Valley Radio Astronomy Observatory and DSN stations at Goldstone were used with the ARIES portable station to establish distance vectors between the two stationary reference sites and a grid of remote points. A 19-month observation period ending in November 1979 revealed a possible change in the baseline vector across the San Andreas Fault, indicating that JPL may have moved westward nearly 11 centimeters.

Spacecraft Antenna Research

A technique was developed and verified experimentally for determining the performance of an antenna over great distances (the far-field performance) by measuring the fields on a plane near the antenna in polar coordinates. This method should be especially suitable for testing the 5-meter antenna of the Galileo spacecraft.

Very good agreement was observed for far-field patterns obtained in the far-field range for the right and left circularly polarized components of the Viking high-gain antennas when compared with the far-field patterns constructed from the plane-polar near-field data.

Precision Pointing and Tracking

A Precision Pointing and Tracking System (PPTS) for high-accuracy, ultrastable science scan-platform control for unmanned planetary spacecraft is under development at JPL. The platform-mounted science instruments will require pointing control that is beyond existing planetary spacecraft capabilities. The limiting factor in current pointing systems, such as on Voyager, has been their inability to directly measure the position of target bodies (like the moons of Jupiter) relative to the science instruments' line-of-sight. The PPTS will overcome this limitation by employing an optical charge-coupled device (CCD) target-body tracker mounted on the science platform. This sensor, combined with a platform-mounted gyroscope, stabilizes the science instruments' pointing to compensate for image motion and permit high-resolution photography with minimal image smear. The ongoing PPTS development will culminate in a breadboard demonstration of the system in fiscal 1982.

CCD Optical Tracker Technology

Work is continuing on the application of CCD imaging arrays in optical tracking systems. A CCD-based star-tracker has recently demonstrated an accuracy better than 1/50 of a picture element. With present arrays approaching 1000 × 1000 elements, this accuracy corresponds to one part in 50,000 of the total field-of-view, an improvement relative to conventional approaches of more than an order of magnitude. Similar techniques are being developed to track extended targets such as a satellite or comet nucleus. When used in conjunction with an appropriate control system, such as PPTS, error signals generated by the CCD tracker permit the platform to be stabilized relative to the target being observed. A third application of CCD technology involves the simultaneous measurement of a target image location and background stars for optical navigation. Once these measurements can be made entirely onboard the spacecraft, without the present requirement for ground-based image processing, real-time optical navigation can become a reality.

OTHER TECHNOLOGY DEVELOPMENTS

Biomedical Technology

A muscle biopsy analyzer, developed to aid in the diagnosis of neuromuscular diseases, has been licensed for manufacture. The system, which uses digital image-processing technology, is capable of discriminating

and assessing diseased and healthy muscle fibers from a biopsy specimen.

The system was developed at JPL in collaboration with the University of Southern California's Neurology Department under the sponsorship of NASA and the Muscular Dystrophy Association.

Another JPL innovation that is moving toward large-scale clinical testing, manufacture, and use is an aseptic fluid transfer system. Sponsored by NIH's National Heart and Lung Institute, this system provides for the sterile connection of blood or red-cell containers used in blood-bank and hospital processing. Harbor General Hospital in Torrance, California, is the medical collaborator. Polymer-sandwich envelopes, furnished on the sterile containers, are connected by a controlled heat sealer, which creates the flow aperture, seals the connection, and sterilizes the interface in a single operation.

The problem of rapid, low-cost diagnosis of cervical cancer is the subject of a JPL image-processing project sponsored by the National Cancer Institute. A mathematical model has been developed and, in 1979, a cell-image library and data base were compiled from 10,000 normal and abnormal cervical cells. These have been used to evaluate several automatic cell-classification steps and techniques, with the model giving estimates of performance and cost. JPL's collaborators in this effort are the UCLA Department of Cytology and the School of Public Health.

Kinesthetic Man-Machine Coupling

A control system for a remote mechanical hand was developed with a feedback capability that gives the human operator the same feeling he would get if his own hand were performing the task. Still to be tested, this kinesthetic man-machine coupling device, which incorporates a force-reflecting control system with proximity sensor systems, is expected to increase the human operator's sense of presence during remote manipulations. A minicomputer serves as the system's nerve center, performing the required complex computations in real time.

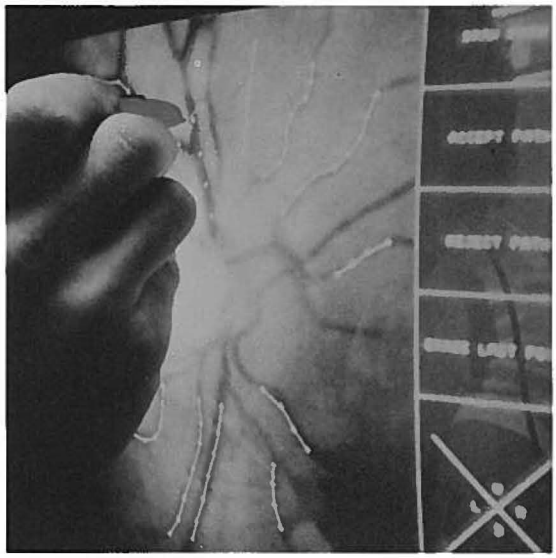
Ocean Chirp Sonar

A JPL-developed deep-ocean chirp sonar system to analyze ocean bottom and sub-bottom sediments and structure was successfully demonstrated at sea with both the U.S. Geological Survey and the National Oceanic and Atmospheric Administration (NOAA). The system is based on advanced concepts in signal processing, and the echo from a transmitted broad-band acoustic chirp is used to indicate the morphology and probable structural strength of the ocean floor.

A high-intensity sound projector is combined with a sensitive hydrophone-receiving array in a missile-shaped vehicle towed at depth from a surface ship. The vehicle is only 3 meters long and weighs about 114 kilograms in air, permitting it to be used on even small research vessels. Its maximum operating depth is over 7 kilometers, providing access to more than 90 percent of the ocean floor.

In a demonstration under joint NASA-NOAA sponsorship, JPL chirp sonar was the prime instrument used by the NOAA National Ocean Survey to track and delineate the San Andreas fault off the northern California coast.

(Above) One of the medical applications of space technology is the use of immunospheres, which are polymeric microspheres with specific antibodies. They attach themselves to specific cells, such as the cancerous white blood cell in the upper portion of the picture, and leave the normal cell, at the bottom, untouched. The background is a spongy material.



(Right) Shown here is a computer-digitized photograph of retinal vessels in the eyeball. The centerline of the vessel is demarcated by a sonic pen, whose points are picked up by the computer and integrated into the image. The computer can then determine the degree of constriction and twisting of the vessel, a symptom of diabetes. This image-processing technique has primarily been applied in coronary arterial analysis using X-rays.

PLANNING AND REVIEW

The Office of Planning and Review (OPR), in a staff and support role to the Director's Office, is responsible for a variety of administrative, planning, assessment, and review activities. Among these are administration of reliability and quality assurance of Laboratory programs, administration of the Director's Discretionary Fund, and JPL relations with the Caltech President's Fund.

A principal effort this year was the coordination, editing, and production of The 1979 JPL Long-Range Plan. This document, which will be updated annually, replaces the JPL Five-Year Plan. Recognizing the increasingly complex national environment, it expands the time horizon to 10 years or more. The plan's objectives are to facilitate internal communication, identify long-range goals and priorities, and provide a basis for systematic evaluation and decision making. The process of preparing the plan helped identify the major long-range challenges for JPL.

The OPR served as a catalyst in generating and monitoring the Laboratory's manpower plans, producing the semiannual Program Operating Plans required by NASA and negotiating the manpower ceiling for 1980 required by the NASA–Caltech contract.

Other efforts included assessing Caltech–JPL conformity with the Caltech–NASA Memorandum of Understanding; conducting a study to improve cost-estimating methods; initiating a task to generate a laboratory directory of administrative data; and developing an automated process for producing semiannual operating plans.

Quality assurance and reliability tasks were focused on several major flight instrument commitments and on plans for Shuttle-launched payloads. Efforts were made to improve communication between assurance personnel and project leaders at earlier stages in new projects.

DIRECTOR'S DISCRETIONARY FUND

This fund provides support for independent research and development in promising fields of science and engineering. It supports seed efforts and encourages collaborative work with faculty and students at Caltech and other universities. The fund will increase from $750,000 in 1979 to $1,000,000 in 1980. Grants vary from about $10,000 to $65,000 per task.

The work completed in 1979 included the following diverse tasks, some of which were collaborative projects:

1. *A study of the cell culture of the guayule plant (with the University of California, Irvine).*
2. *A magnetic resonance spectrometer system for a Mars Rover mission.*
3. *Design of bioelectronic controllers.*
4. *Photo-activated catalysts on polymeric supports for fixation of small molecules (with Caltech).*
5. *X-ray and gamma-ray fluxes from the Galilean satellites as a means of determining their surface composition (with the University of California, San Diego).*
6. *An artificial retina (with Caltech).*

Continuing studies or innovations initiated during the reporting period included:

1. *Gas extraction of coal by supercritical fluids (with Caltech).*
2. *Advanced applications of far-infrared lasers (with Caltech).*
3. *Memory-based manipulator control (with the Massachusetts Institute of Technology).*
4. *Hologram lenses for remote-sensing instruments (with the University of Arizona).*
5. *A new surgically implanted cardiac assist pump (with the State University of New York).*
6. *An exploratory investigation of ceramic composites for solar probe thermal shields.*

In all, 34 projects were supported by the Director's Discretionary Fund during 1979.

VISITING SCIENTISTS

A Distinguished Visiting Scientist Program, initiated by the Director in 1979, brought five eminent authorities to JPL for short-term consultation on important JPL projects. They are Professors Michael S. Longuet-Higgins, England; Jacques Blamont, France; Giuseppe Colombo, Italy; and Armand Delsemme and Richard Goody, U.S.A.

Under a Faculty Fellowship plan sponsored by the American Society for Engineering Education, 10 other professors from U.S. campuses spent the summer in residence at JPL. Arrangements were made to increase the number of faculty fellows to 22 in 1980.

PATENTS AND TECHNOLOGY TRANSFER

Through the Office of Patents and Technology Utilization, JPL-produced innovations are identified and evaluated in an effort to transfer technology into public use through patent licensing and dissemination of information.

During 1979, the Office of Patent Counsel reported 325 inventions to NASA, 249 of them by Caltech–JPL employees. Patent applications were completed by outside coun-

sel in 54 cases—37 on behalf of NASA and 17 on behalf of Caltech. Of about 300 patent properties acquired by Caltech in the last 30 years, over 110 have been licensed. At the end of 1979, 40 of these patent properties were still under active license, resulting in 16 commercial products currently being sold by industry, with several more under development.

The Technology Utilization Office promotes technology transfer by information dissemination, and in 1979 it mailed over 40,000 information packets to persons or firms seeking details about innovations created by JPL. Follow-up questionnaires indicate that many recipients are making use of the technology. The Technology Utilization Office also maintains a reference library of NASA–JPL technology.

ADMINISTRATION

Funding for JPL's ongoing tasks and new efforts in research and development during fiscal year 1979 amounted to $335,000,000, an increase of 20.9 percent over the previous year. Energy and Technology Applications tasks accounted for $60,000,000 or 18 percent of total Laboratory funding. Funding for facilities construction totaled $4,400,000 during this same period.

Procurement activities during fiscal year 1979 increased substantially over fiscal year 1978 with total obligations up 14 percent to a new high of $179,558,000. Reflected in this increase were small business transactions of $53,585,000, an increase of 24 percent, and a doubling of minority business activity to $6,287,000. A large part of the increased activity resulted from the implementation of Project Galileo subcontracts and the expansion of E&TA programs.

Despite an extremely competitive labor market, there was a steady increase in the number of minorities and women in the Laboratory workforce, including officials, managers, and professionals. The continuing Cooperative Education–Experience Program for undergraduates, involving alternating periods of work and university study, was expanded. A self-supporting Child Development Center for children of Laboratory employees was established at the nearby Oak Grove Elementary School, and now has an enrollment of 88 children in three classes.

JPL, together with three NASA centers, participated in an experiment designed to test the feasibility of remote library searching, combined with delivery of the full text of articles by facsimile transmitter, using the Communications Technology Satellite.

A slow-scan closed-circuit TV link between the Laboratory and NASA Headquarters was partially operational for Voyager picture transmission support. The system is expected to be in full operation by mid-1980.

The Laboratory intensified its energy conservation efforts in 1979 and, through a program of equipment inspections, repairs, adjustments, and modifications, was able to reduce consumption by 15 percent over 1978. This exceeded the Laboratory, and national, goal by 10 percent.

SPECIAL RECOGNITION

The NASA honor awards program provides special recognition annually for a number of outstanding individual and team contributions. The JPL honor awards recipients in 1979 were:

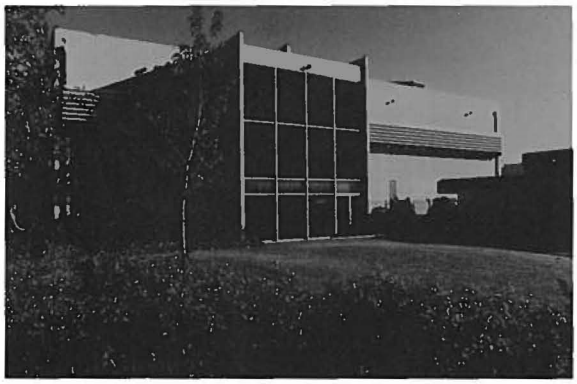
Mahlon F. Easterling,
NASA Outstanding Leadership Medal

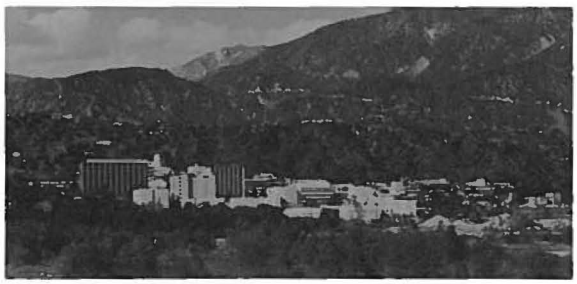
Richard T. Woo,
NASA Exceptional Scientific Achievement Medal

Lloyd H. Back, Donald E. Hayes, Rolando L. Jordan, Richard P. Mathison, Marvin K. Simon, Gerald M. Smith, and Anthony J. Spear,
NASA Exceptional Service Medals

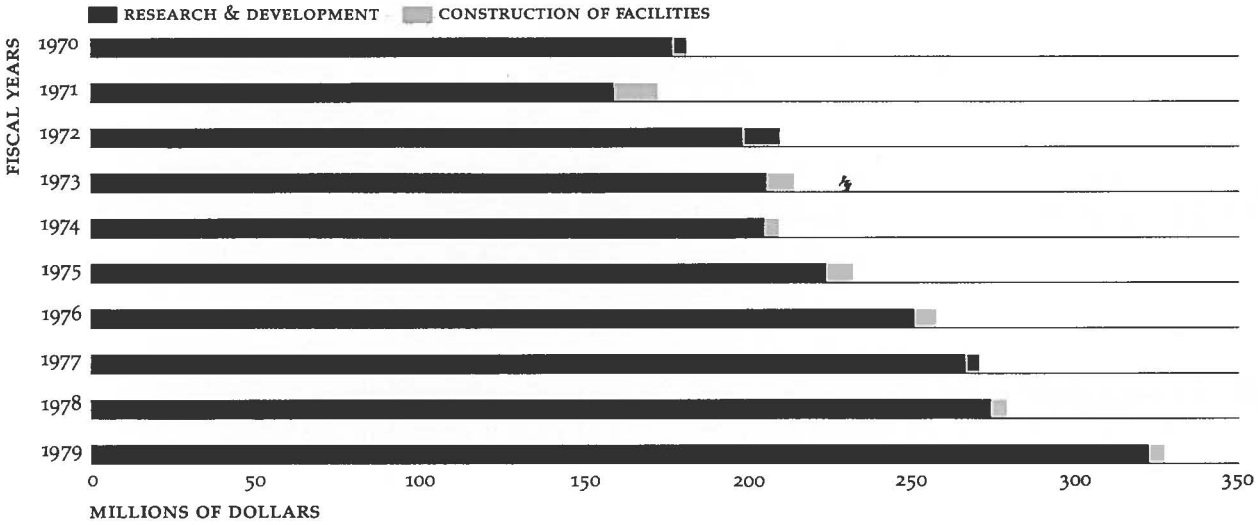
Kay H. Haines,
NASA Equal Employment Opportunity Medal

The Mission Control and Computing Center's MARK III Development Team, Planetary Ephemeris Development Team, and the **Seasat Synthetic Aperture Radar Team,** Group Achievement Awards

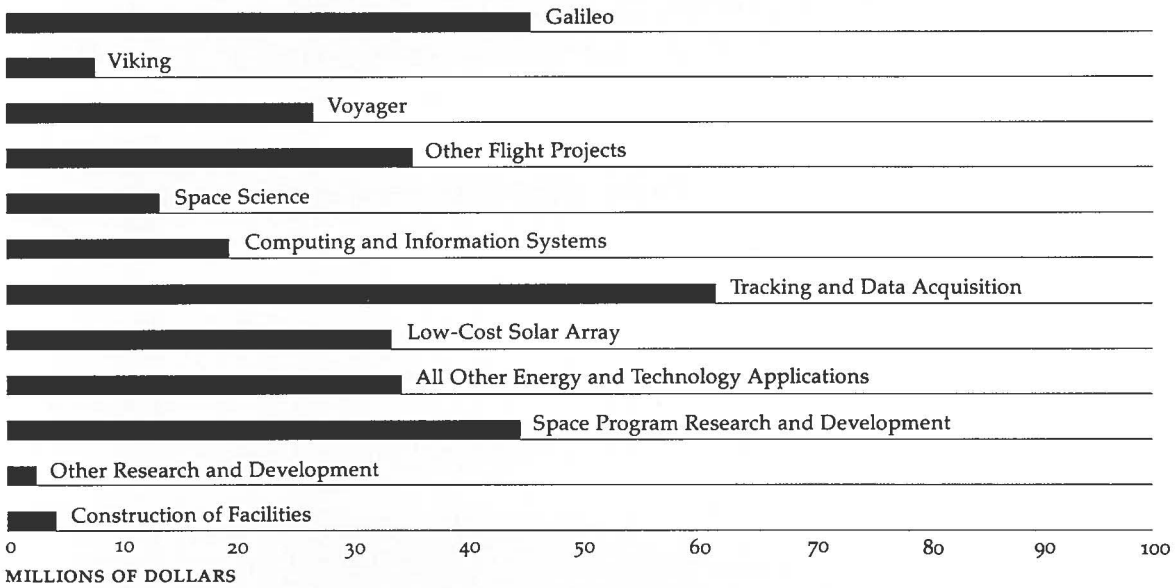




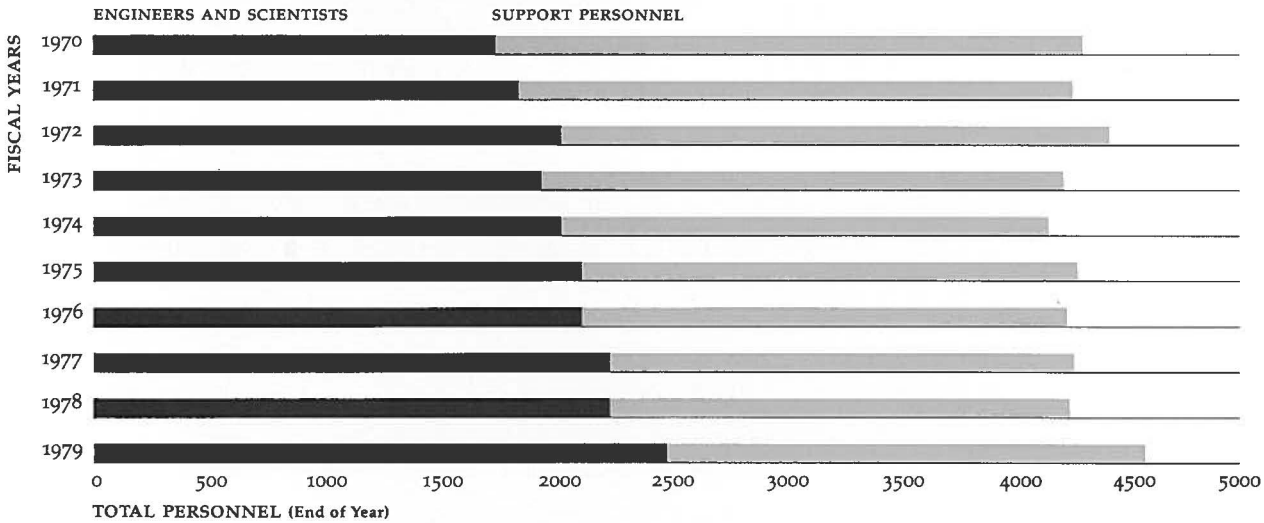
Total Costs



Fiscal Year 1979 Costs



Personnel



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