Jet Propulsion Laboratory **1978 Annual Report**

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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 through December 31, 1978.

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COVER
This photo of Jupiter and three of its satellites (Io, Europa, and Callisto) was taken February 5, 1979, while Voyager 1 was 28.4 million kilometers (17.5 million miles) from the planet. Io can be seen against Jupiter's disk; Europa is found to the right of the planet; Callisto (barely visible) lies at the lower left of the picture.

Director's Message

As 1978 ended, Voyager 1 was poised for a dramatic and surprise-packed excursion through the Jovian system. Although many important scientific discoveries will be reported next year, it seems appropriate to mention a few early results, such as the ring of particles around Jupiter, lightning within the turbulent atmosphere, the immense aurora, and active volcanic eruptions on Io.

The Voyager Jupiter adventure is rekindling the nation's imagination and interest in space. We're proud to be the institution that unites the National Aeronautics and Space Administration and the California Institute of Technology in fostering unique contributions to science which can so renew the national spirit.

Last year's flight project activities included continued preparation for the two major NASA deep space missions set for launch from the Space Shuttle during the first half of the 1980's—the Galileo mission to Jupiter and the Solar Polar mission, a joint effort with the multinational European Space Agency.

A logical next step beyond Voyager, Galileo will reach Jupiter in 1985, releasing an instrumented probe to penetrate the Jovian atmosphere while the Galileo orbiter begins a year-long examination of the planet and its satellites. The probe is under development by the NASA Ames Research Center.

We also are progressing with the Solar Polar mission, in which we will be joined by the Europeans in the flight of two spacecraft, one by NASA and one by ESA, for the first observations of the Sun from over its poles.

The flight portion of the pioneering Seasat mission began and ended during the reporting period. Despite a premature failure in the satellite's power system, Seasat delivered a wealth of high-quality data on the surface characteristics of the world's oceans. Ongoing data processing and analysis are demonstrating that the satellite and its unique sensor package indeed met the proof-of-concept objectives of the mission and established the basis for an operational system of ocean satellites.

The Deep Space Network, besides supporting Voyager, continued its multimission role throughout the year and closed 1978 with a space communications task of unprecedented complexity. During a brief period on a day in December, the DSN's tracking and data acquisition specialists sought out, locked up with and recorded radio signals simultaneously from six Pioneer Venus spacecraft, an orbiter, probe bus, and four atmospheric entry probes. All this was further complicated by entry blackout periods and rapidly shifting radio frequencies.

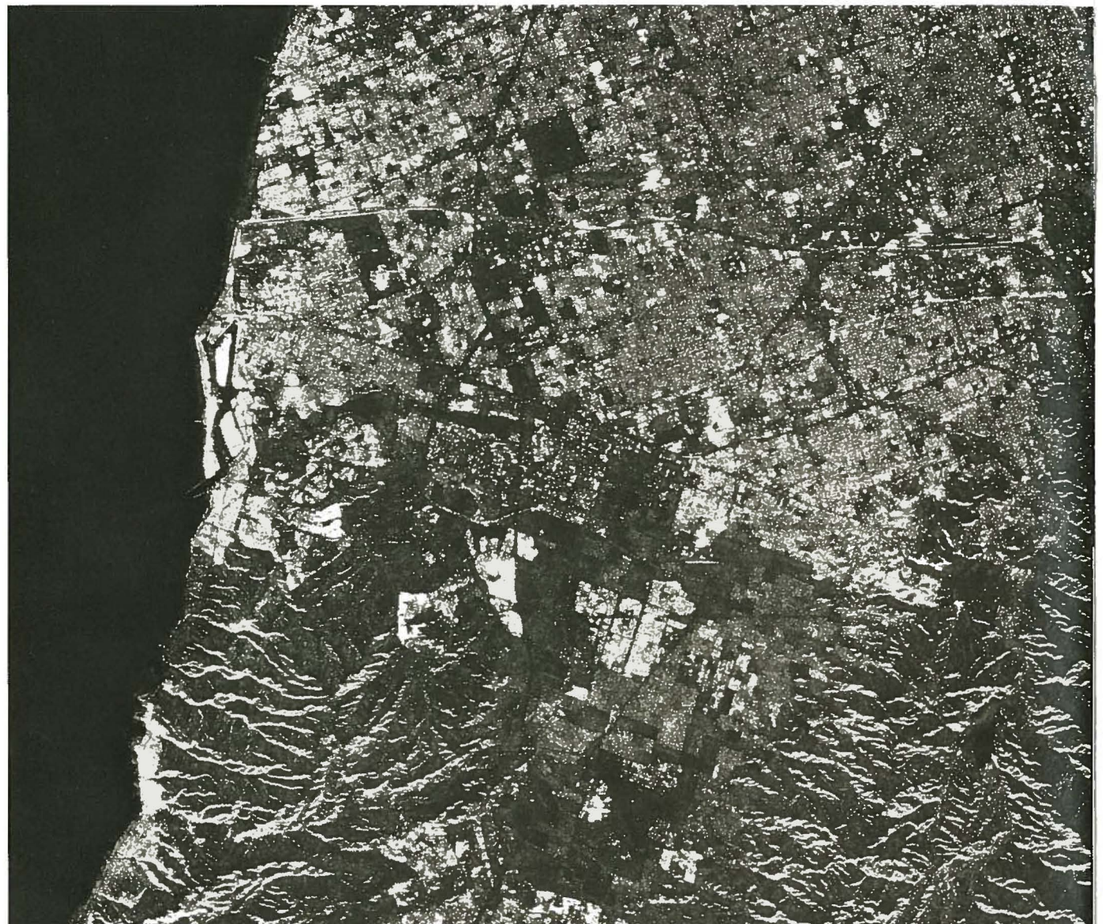
Space exploration shares our attention with a growing program in nonspace activities. The recently reorganized Office of Energy and Technology Applications is spearheaded by the Solar Energy Program. The U.S. Department of Energy has assigned the Laboratory as the lead center for the national photovoltaic program with the responsibility of developing solar cell arrays at a cost competitive with other energy sources.

The year also marked the inauguration of a new President of the California Institute of Technology. Dr. Marvin L. Goldberger succeeded Dr. Harold Brown, now Secretary of Defense. The NASA-Caltech contract for research and development at JPL was renewed for five years. Supplementing the contract is a revised memorandum of understanding establishing principles for the purpose, character, and management of the Laboratory.

The selection and implementation of the most challenging tasks dominated our thinking and interests this past year, and we intend to emphasize certain future efforts and plans more vigorously. We have consciously trimmed some lower priority or disconnected efforts in order to free staff and facilities for high-potential new endeavors, such as the development of design and fabrication techniques for large-scale integrated circuits, which is planned as a major collaboration with the Campus.

Looking ahead, we are entering a period in which we will be able to devote more effort to shaping programs and technologies of lasting benefit to science and mankind.

Bruce Murray
Director



(Above) The Newport Beach-Santa Ana area of California taken by the Seasat Synthetic Aperture Radar (SAR) on September 24, 1978, at 11:00 p.m. Newport Harbor and Balboa Island are at left center; Anaheim Stadium (right center, near the intersection of the Santa Ana and Orange-Garden Grove Freeways) appears as a dark-ringed area.

(Right) An image of the Beaufort Sea ice pack west of Banks Island, Canada (right), obtained by Seasat shows numerous ice, water, and land features. The dark zone adjacent to the island is shore-fast ice, primarily first-year sea ice, three to six feet thick.

Flight Projects

Major flight project activities at the Laboratory during the 1978 calendar year included:

1 Launching of the ocean observation satellite, Seasat; its intensive 105-day operation yielded much new data before a power failure terminated the mission.
2 Navigation of two Voyager spacecraft launched in 1977 on flyby missions to Jupiter and Saturn; early Jupiter photographs from Voyager 1 presaged important 1979 scientific discoveries.
3 Assumption of overall Viking mission operations, analysis, and reduction of data from the Mars Landers and Orbiters, pointing toward mission conclusion.
4 Establishing the Galileo Project as a Voyager follow-on mission to explore Jupiter's atmosphere and the Galilean moons.
5 Initiation of an International Solar Polar Mission involving NASA and the 11-nation European Space Agency.
6 Continuation of another international project, the Infrared Astronomical Satellite (IRAS), with the Netherlands and the United Kingdom.
7 Starting the Solar Mesospheric Explorer Project, a scientific satellite to measure the effects of solar radiation on ozone in Earth's atmosphere.

JPL also provided important flight operations support to Pioneers 10 and 11 and the Venus Pioneer Probe mission managed by Ames Research Center for NASA. Mission operations support also was afforded the joint West German–United States Helios missions investigating the Sun to within 0.30 astronomical unit (AU) of the surface.

Seasat

Seasat was launched on June 26, 1978, marking the first use of a satellite for microwave remote sensing of the ocean surface on a global scale. This pioneering project, managed by JPL for NASA's Office of Space and Terrestrial Applications, involved numerous government agencies, universities, and maritime industries.

Following 105 days of successful orbital operations, the satellite lost power and failed on October 9, 1978. Intensive investigations to determine the cause of the failure were undertaken by JPL, Lockheed Missiles and Space Company, and a NASA-appointed Failure Review Board. They found the failure was due to a massive, progressive short circuit in one of the two slip-ring assemblies that connect the rotating solar arrays to the spacecraft power subsystem. The most likely cause of this short was an arc between adjacent slip-ring brush assemblies, initiated either by contact between adjacent components in the slip-ring assembly or by a contaminant that momentarily bridged internal components of opposite polarity.

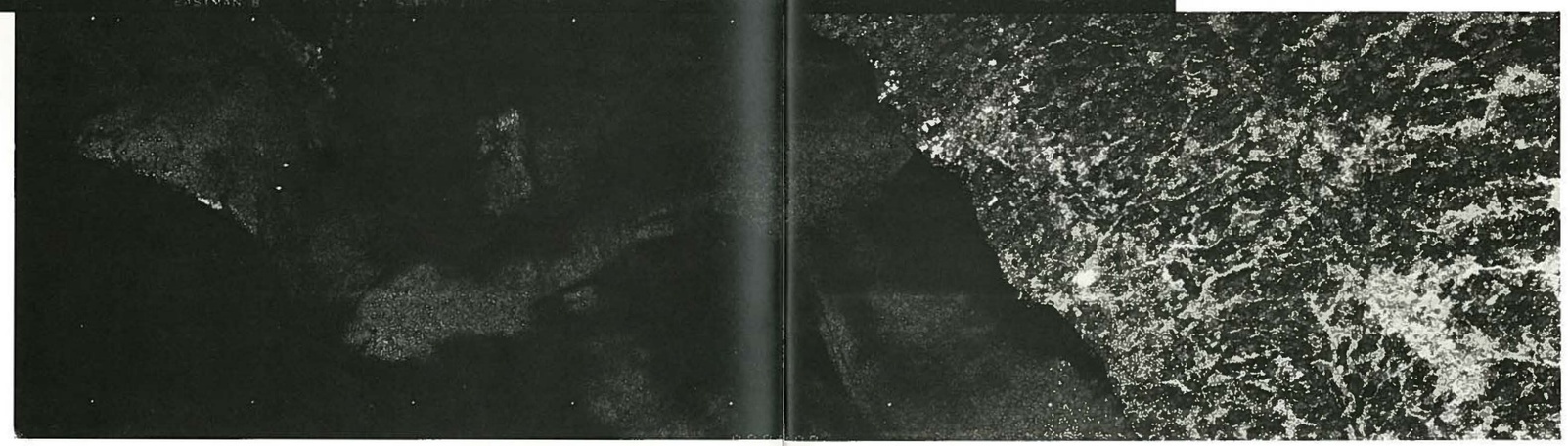
The basic goal of the Seasat Project was to demonstrate the practicality of using spaceborne microwave sensors to monitor and measure sea-surface conditions. Seasat sensors provided data on wave height and direction, surface wind speed and direction, ocean-surface topography and temperature, and atmospheric moisture content. A synthetic aperture radar (SAR) system provided high-resolution images of sea ice, ocean waves, and coastal features. All sensors provided data under day-night and all-weather conditions.

The satellite's sensors provided a wealth of oceanographic data not only of calm-sea conditions, but also during hurricanes, typhoons, and tropical storms in the Atlantic and Pacific oceans and in the Gulf of Mexico. Otherwise unobtainable data were derived of wave generation and propagation in cyclonic storms.

The microwave scatterometer and the scanning multichannel microwave radiometer operated continuously. The visual and infrared radiometer failed some 50 days into the mission, while the radar altimeter data collection was interrupted for two nine-day periods because of satellite thermal control and power problems. Both instruments, however, yielded substantial data sets of excellent quality. Virtually complete coverage was achieved over the North American Continent, Alaska, and adjacent waters. Critical experiment areas were covered in the North Atlantic, Canada, the United Kingdom, Iceland, and the Mediterranean.

A substantial body of surface truth data was acquired to support the geophysical evaluation of the sensors. The Navy's Fleet Numerical Weather Central provided all surface reports and selected field data in the form of a computer-compatible tape. This invaluable data base includes hundreds of daily wind, sea-state, sea, and air-temperature reports during the mission period. The National Environmental Satel-

Formerly designated Jupiter Orbiter Probe.



(Left) The Ohio River and Parkersburg, West Virginia, taken by Seasat (SAR) at 11 p.m. EDT on August 26, 1978, as the spacecraft moved from north to south. The scale is 25 km across the swath between the small cross-marks.

(Below) Some lake surface roughness caused by local winds and currents can be seen in this SAR image of Lake Ontario near Toronto, Canada, on August 26, 1978.

lite Service (NESS) provided important support through observations from surface vessels at satellite overpassage times, plus a complete set of daily meteorological satellite visible and infrared imagery.

The project cooperated in and conducted two major surface experiments during August and September. The first was the multinational Joint Air-Sea Interaction Experiment (JASIN) conducted in the Eastern Atlantic near Scotland, during which an intensive study of the marine boundary layer and air-sea energy transfer was performed by a group of European and American scientists. JASIN provided a source of high-quality surface truth data. Some 200 Seasat passes were obtained over the JASIN area during the experiment period. A NASA C-130 aircraft, carrying a Seasat underflight scatterometer built by Langley Research Center, was one of several participating research aircraft.

In September, the Gulf of Alaska Seasat Experiment (GOASEX) was conducted by the National Oceanic and Atmospheric Administration (NOAA). The principal research facility deployed was NOAA's research vessel Oceanographer. The Canadian weather ships Quadra and Vancouver also obtained data at satellite overpass times. Participating aircraft included the Ames Research Center's CV-990 equipped with a scanning microwave radiometer, the Johnson Space Center's MC-130B with the Seasat underflight scatterometer, the Naval Research Laboratory's RP-3A equipped with meteorological and microwave radiometer instrumentation, and the Canadian CV-580A aircraft carrying the Environmental Research Institute of Michigan's synthetic aperture radar system. A comprehensive data set was collected, corresponding to some 60 satellite overpasses. An intensive, coordinated study of this data set is under way.

The large volume of satellite data acquired during Seasat's 105-day lifetime, correlated with the substantial body of high-quality surface truth data, will make it possible to achieve the project's principal objective: determining the capabilities of microwave instruments to measure geophysical parameters. Further tests of monitoring systems based on the Seasat sensor technology should not be required. Future oceanographic survey systems can now be developed and used to expand the remote sensing data base for practical applications and scientific purposes.

Voyager

One of history's most dramatic encounters with another planet loomed large in JPL thinking as 1978 ended. The Voyager Project team was busy preparing the first of the two Voyager spacecraft for its March 1979 rendezvous with awesome Jupiter. Spectacular photographs of the huge, turbulent planet and several of its moons were received in December from Voyager 1, over 600 million kilometers from Earth and 80 million kilometers from Jupiter.

A preliminary near-encounter test went off smoothly prior to the start of the two-month Jupiter observatory phase in January. All scientific instruments, responsible for 11 experiments in all, appeared as ready as the telescopic television cameras for the historic flyby.

The twin Voyagers, launched late in the summer of 1977, are expected to produce a bonanza of scientific data during their scheduled flybys of Jupiter March 5 and July 9, 1979, and subsequently at Saturn in November 1980, and August 1981.

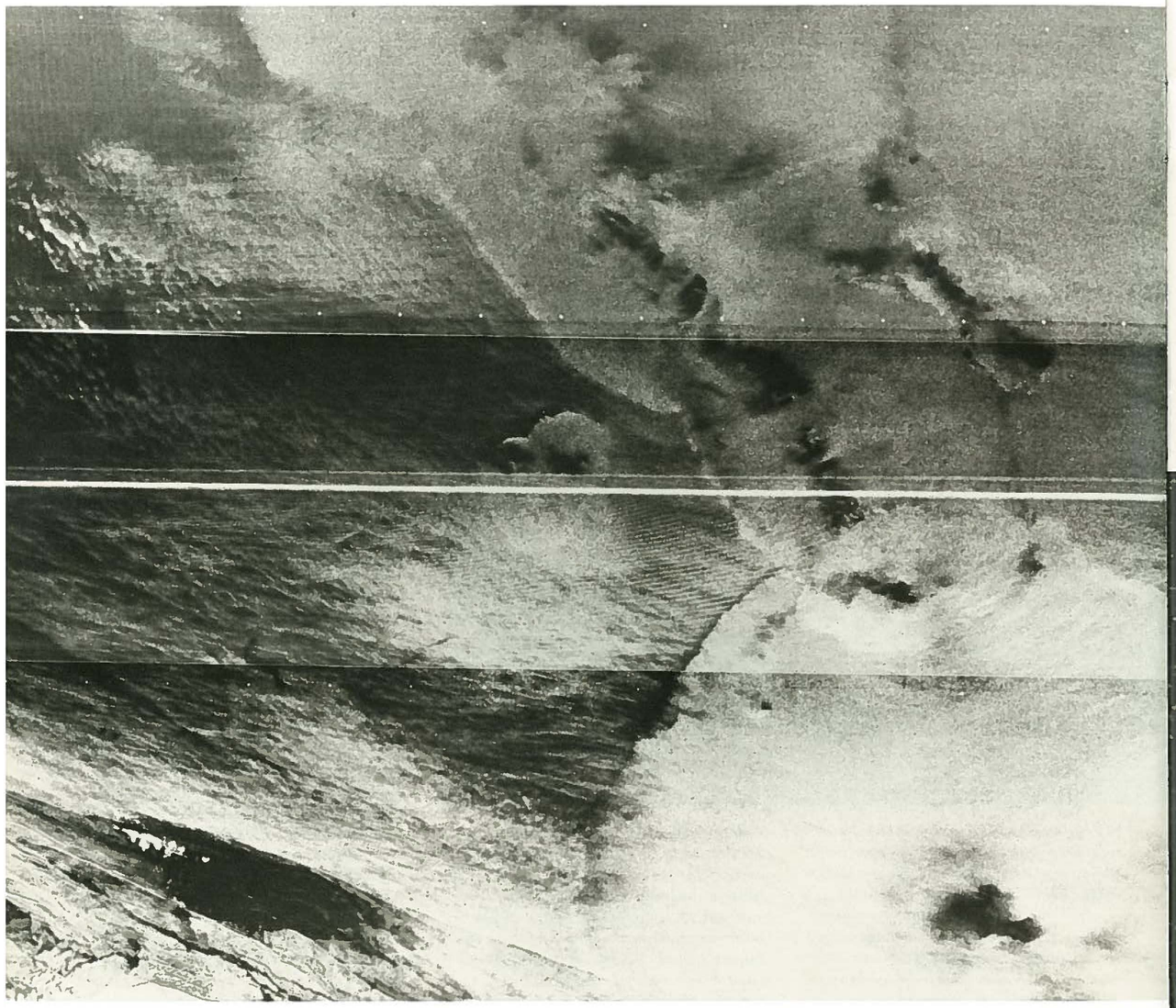
If all scientific objectives are met at Saturn and its satellites, Voyager 2 may be directed on to explore Uranus and its newly-found rings in January 1986. Both spacecraft eventually will sail out of the solar system. Valuable data should be returned to about 30 astronomical units (AU) (over 4 billion kilometers) from Earth, more than 8 years after launch. (An AU is the Sun-Earth distance, 150 million kilometers or 93 million miles.)

Each Voyager will conduct complementary investigations of the planets and their satellites, and the characteristics of interplanetary space in the outer regions of the solar system. Besides a pair of telescopic, slow-scan TV cameras, each craft has a cosmic ray detector, infrared radiometer-spectrometer, a charged-particle detector, magnetometer, photopolarimeter, plasma detector, plasma wave instrument, ultraviolet spectrometer, and a radio astronomy receiver.

The science experiment teams number 106 scientists, 21 of them on the Imaging Science team interpreting the thousands of pictures that will be beamed back to Earth during 1979 and subsequent years. As many as 50,000 pictures of the planets and their satellites may be sent back by the Voyagers.

Jupiter and Saturn are by far the largest planets, and together hold in their regimes more than two-thirds of all the moons in the solar system. With 13 known moons—four (Io, Europa, Ganymede and Callisto) the size of small planets—Jupiter qualifies as a miniature solar system. Saturn has 10 satellites, and its celebrated rings appear to be made up of tiny pieces of ice, snow, and perhaps rock.

An extension of the Mariner spacecraft family, Voyager has been augmented to meet the outer planet requirement of 4 to 9 years of operational life. Each Voyager has longer-range communications using X- and S-band frequencies, a large directional antenna permitting high data-rate return, radioisotope thermoelectric generators for prolonged operational power, and advanced on-board computer subsystems to sequence data acquisition requirements during the many phases of the mission.



During the early months of the flight, each spacecraft encountered several problems, but these were resolved without serious compromises of basic objectives. Voyager 2, the first spacecraft launched, had some trouble with science boom deployment and attitude control software. The problems were worked out, however, and changes were applied to Voyager 1 to avoid a repetition. A temporary hang-up of one axis of Voyager 1's instrument scan platform likewise was corrected. Receiver degradation problems aboard Voyager 2 have been alleviated by a slight change in the signal frequency transmitted by Deep Space Network stations to the second craft.

At year's end, Voyager 1 was 60 million kilometers from Jupiter, heading for a closest approach of 277,477 kilometers (172,424 miles). At that time it will be traveling at a speed of about 65,000 miles per hour, or 29 kilometers per second. Voyager 2 was 110 million kilometers from Jupiter, awaiting its turn to add to our planetary knowledge. Periodic instrument calibration tests have indicated it will be as reliable as its sister ship. Voyager 2 seems to have responded well to its longer and slower cruise route, which was designed to make it the first spaceship with the potential to visit three planets.

Viking

Knowledge of the geology and meteorology of Mars was substantially increased by the data continuing to flow from the two Viking Landers on the surface and from Orbiter 1 still circling the Red Planet. Orbiter 2's contributions terminated in July when it ran out of attitude control gas.

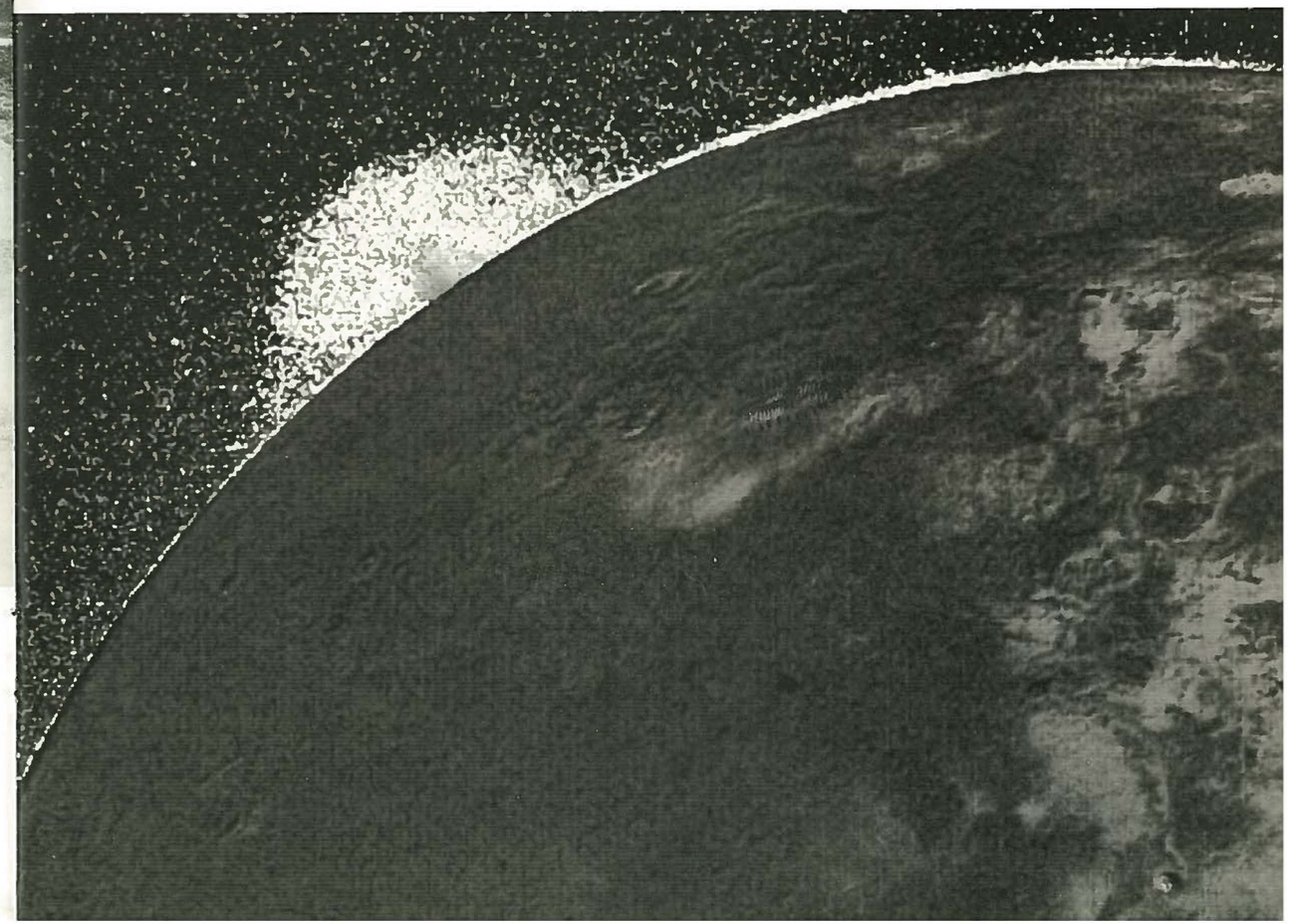
Scientists from more than 25 universities and 15 other research institutions have played major roles in interpreting the data since the 1976 landings on Mars. Overall responsibility for the completion of the Viking Extended Mission was turned over from Langley Research Center to JPL April 1.

During 1978, more than 80 percent of the Martian surface was photographed at resolutions between 150 and 250 meters. This Medium Resolution Mapping, as the process is called, will be invaluable for analysis of Martian geology and tectonics as it provides much greater clarity and detail than the global maps produced by Mariner 9 in 1971.

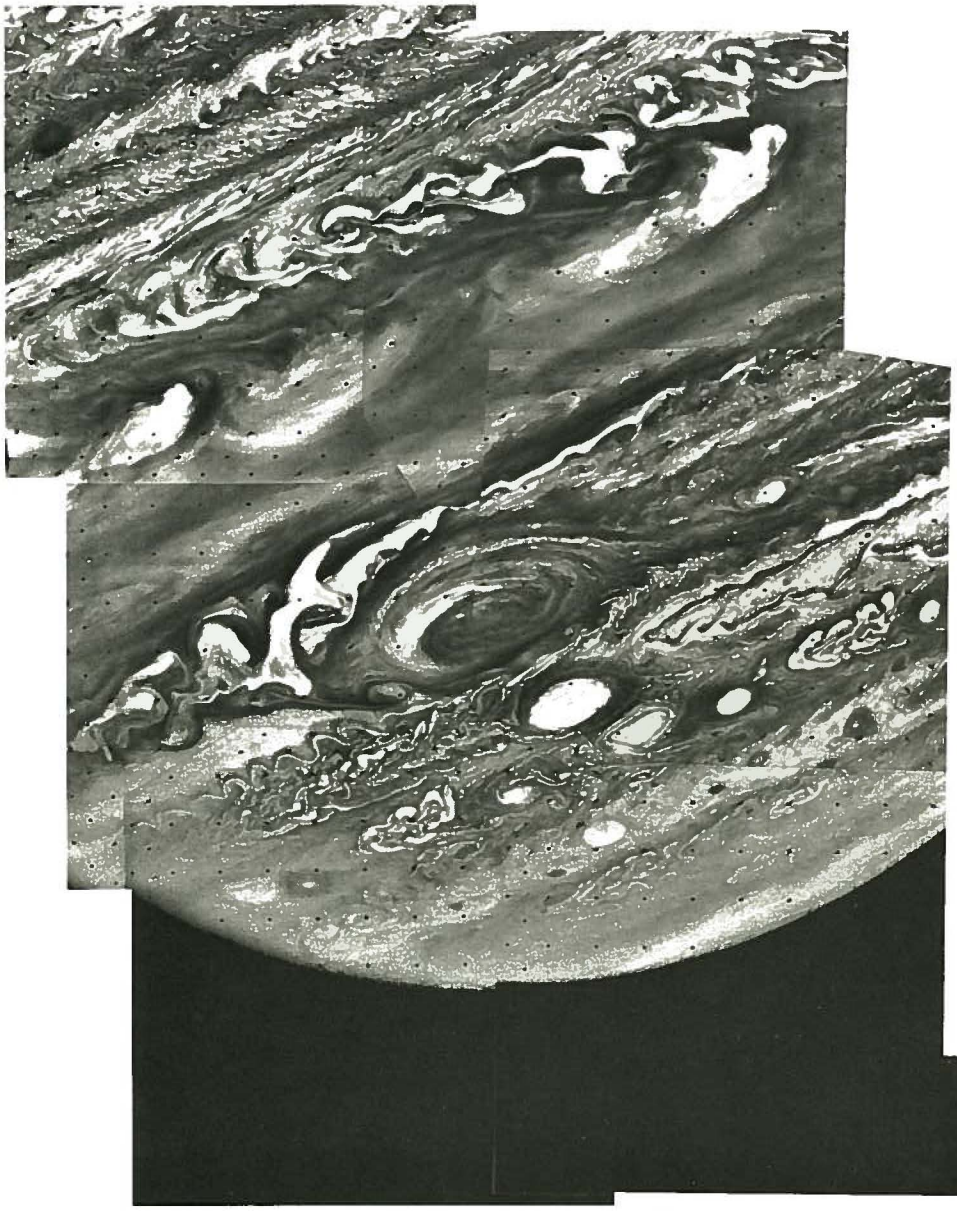
The Viking Mission has produced more than 41,000 photographs by the Orbiters and 4,400 by the Landers.

Viking images reveal much structure in the southern hemisphere's intercrater plains. This region retains the early evolutionary history of Mars—including the time when the planet's atmosphere was much denser—and may hold clues as to what happened to the atmosphere. The images show volcanic flows, mare ridges, cliff-like tectonic features, and exposed layers of strata.

This historic picture of Io was taken by Voyager 1 on March 4, 1979, at a distance of 490,000 kilometers (304,000 miles). An enormous volcanic explosion—the first ever viewed outside of Earth—is silhouetted against dark space over Io's bright limb, with solid material rising about 100 miles.



This Seasat SAR view includes a portion of the Atlantic Gulf Stream off the Florida coast northeast of Miami and north of Grand Bahama Island. While this photo appears to show clouds, the SAR sees through the atmosphere and records only reflections from the surface.



it is believed to have been formed by cycles of climatic change. These changes, in turn, are believed to reflect periodic wobbling of the planet's axis similar to that thought to have caused periodic climatic changes, such as ice ages, on Earth.

The great volcanoes of the Tharsis Ridge and Olympus Mons produced much more lava than disclosed in earlier pictures, several flows extending hundreds of kilometers. Accurate crater counting now can be done to determine ages of the volcanoes.

A technique has been developed, using Viking pictures, to determine something about the chemical and physical properties of lavas. The technique relates these properties to the thickness of lava flows and to flow width.

The very low periapsis altitude (300 kilometers) of the orbiters in the extended mission has permitted very much more detailed and precise investigations of the gravity field of Mars by radio tracking than ever before. Among other interesting results, the data reveal one mass concentration (mascon) in the Isidis Planitia basin that is comparable to those found on the Moon; it may be the only one on Mars.

As for meteorology, analysis of small local dust storms indicates that they precede and trigger the large Martian dust storms. About half these small storms occurred near the edge of the south polar cap, where surface winds presumably are enhanced by marked temperature gradients.

High-resolution pictures taken at altitudes between 300 and 500 kilometers—with a resolution from about eight to fifteen meters—reveal some selected areas to be saturated with craters as small as can be detected.

Significant observations have been made of the polar regions. The north polar layered terrain has very few craters, indicating it is one of the youngest regions. What appears to be the largest known field of sand dunes surrounds the north polar cap. The layered terrain is a prime subject for comparative planetological studies because

The atmospheric water vapor was found to be distributed fairly uniformly through the lower 10 kilometers, rather than concentrated near the surface, as had usually been assumed.

A significant discovery was the detection of the regular eastward passage of a sequence of cyclones and anticyclones somewhat north of the Lander 2 site. This phenomenon is present through the northern spring and autumn seasons.

A propulsive maneuver provided Orbiter 2 with five close encounters with Mars' outer moon, Deimos. One approach—28 kilometers from the surface—was the closest fly-by of any astronomical body yet achieved.

The resulting pictures revealed that bright patches observed earlier are deposits of fine-grained material partially filling impact craters and presumably ejected from the craters. Investigators are puzzled over how such a small body can hold so much ejecta. Some Deimos craters have "tails" resembling those of Mars, and ascribed to wind action. The tiny satellite could generate no wind, so the ejecta must have originated from impacts.

There were also surprises in high-resolution pictures of Phobos, the other Martian moon. Several parallel lines of grooves radiate from Stickney, the largest impact crater on the satellite, and converge at its antipode. The configuration indicates the grooves are from fractures caused by the impact that produced the crater. Many of the grooves are pricked with craters whose raised rims imply degassing; it was not known that this could occur in so small a body.

Galileo

A scientific successor to the Voyager Mission, this NASA project will send, in 1985, a spacecraft to Jupiter to release an instrumented probe into the atmosphere and then go into orbit around the giant planet. During 20 months of orbiting lifetime, up to eleven close encounters of Jupiter's four largest moons will be made.

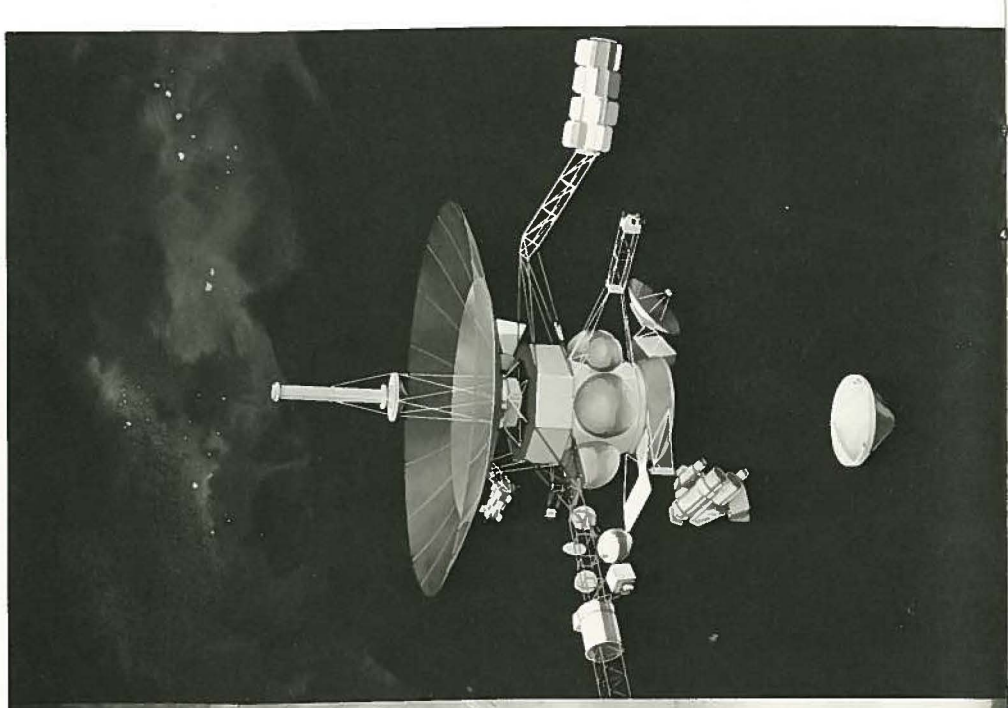
Project Galileo is expected to provide further insights into the phenomena revealed by Voyager and shed further light on the evolution of the solar system. JPL has managerial responsibility, and will design and build the spacecraft to orbit and carry the probe to Jupiter. Ames Research Center is developing the probe. The Federal Republic of Germany will supply the retro-propulsion module to insert the spacecraft into orbit, plus some scientific instrumentation.

The project was named for the great Italian astronomer who first discovered the four great moons—Io, Europa, Ganymede, and Callisto—in January 1610. Scientific interest in the venture has drawn 114 investigators from ten nations for the Galileo team.

The project plan is to launch one spacecraft from the Space Shuttle in January 1982, with a leisurely 3.5-year flight to Jupiter to permit the probe to enter the atmosphere on the sunlit side of the planet. The spacecraft will fly past Mars to use that planet's gravity to assist it on the desired path to Jupiter.

About 150 days before Galileo arrives at Jupiter in July 1985, the probe will be released. The instrument-laden probe, providing the first direct sampling of the heavy Jovian atmosphere, is expected to operate for at least 30 minutes, radioing its scientific findings to the orbiter for relay to Earth.

The orbiter's closest approach to Jupiter will be about 320,000 kilometers (200,000 miles). For the next 20 months the spacecraft will follow a series of elliptical paths to



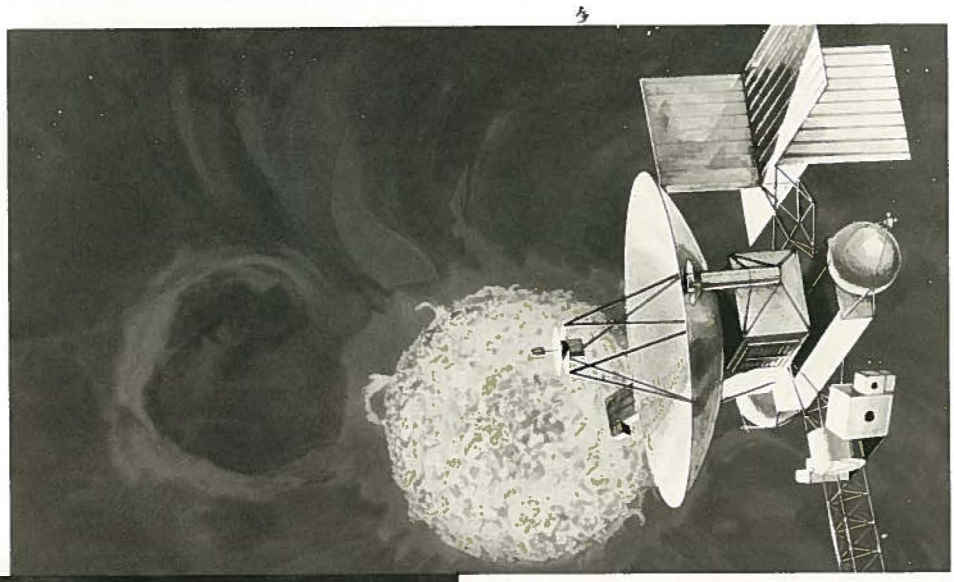
(Top) Artist's concept depicts the Galileo spacecraft releasing a probe to penetrate deep into Jupiter's atmosphere. The spacecraft will orbit Jupiter for 20 months to study the planet and some of its moons in the mid-1980s.

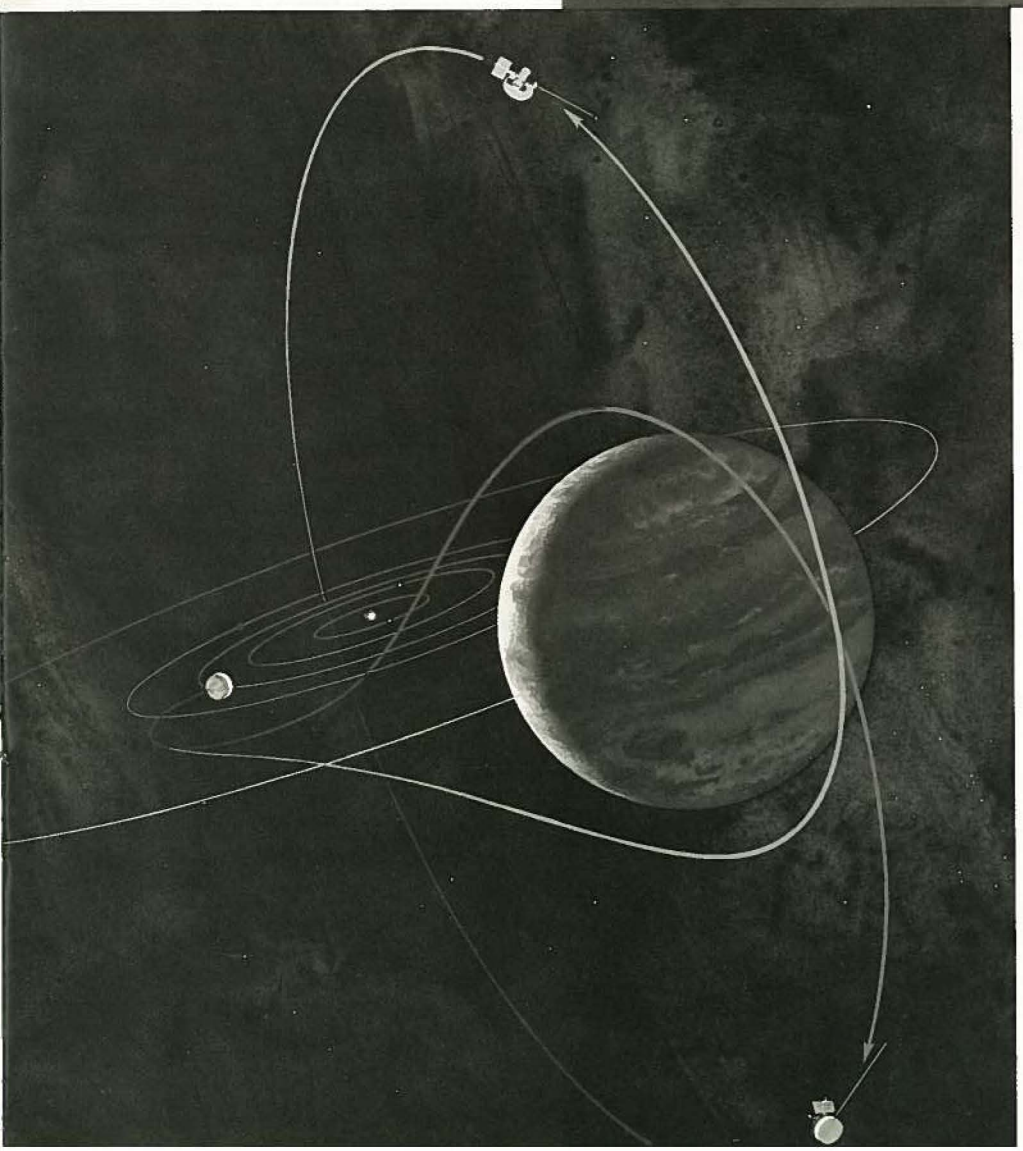
(Bottom) Red-hot nose cone separates from the probe portion of the Galileo spacecraft as it "hangs on the shrouds" and samples the atmosphere of Jupiter.

study the Galilean moons, particularly Ganymede and Callisto.

The spacecraft will employ a dual-spin design; part of the craft will be three-axis stabilized, the other spin-stabilized. A new camera system with a 1.5-meter (4.9-foot) focal length lens will employ solid-state charge-coupled devices (CCDs) instead of vidicon tubes flown on previous planetary missions. The CCD system will provide broader spectral response and higher resolution than previous cameras. Encounters with the larger moons could yield pictures with a best resolution of 30 to 50 meters (98 to 165 feet). Eleven other instruments will make scientific measurements on the orbiter.

The probe will carry seven scientific instruments into the Jovian atmosphere; a helium interferometer to measure the ratio of hydrogen to helium; a mass spectrometer to analyze atmospheric composition; lightning detectors; a radiometer to measure energy radiated and received by Jupiter; a nephelometer to study clouds and particles; an atmosphere structure instrument; and an energy particle detector. The general atmospheric structure will be determined by measuring the temperature, pressure, and deceleration of the probe itself as it descends.





(Above) A Solar Polar spacecraft draws near the Sun on its flight over the pole in this painting. The Sun and its corona are shown as seen by instruments aboard the spacecraft, one of two proposed in an international mission managed by JPL.

(Left) The trajectories of two Solar Polar spacecraft are shown here. After launch from the Space Shuttle, the two unmanned craft will fly to Jupiter and use the giant planet's gravity to boost them out of the ecliptic plane and back toward the Sun.

International Solar Polar Mission

This double-spacecraft mission to chart the Sun and previously unexplored areas of the solar system is the most ambitious international space venture yet projected. Cosponsored by NASA and the 11-nation European Space Agency, the International Solar Polar Mission will launch two spacecraft from the Space Shuttle in February 1983 to explore from a new perspective

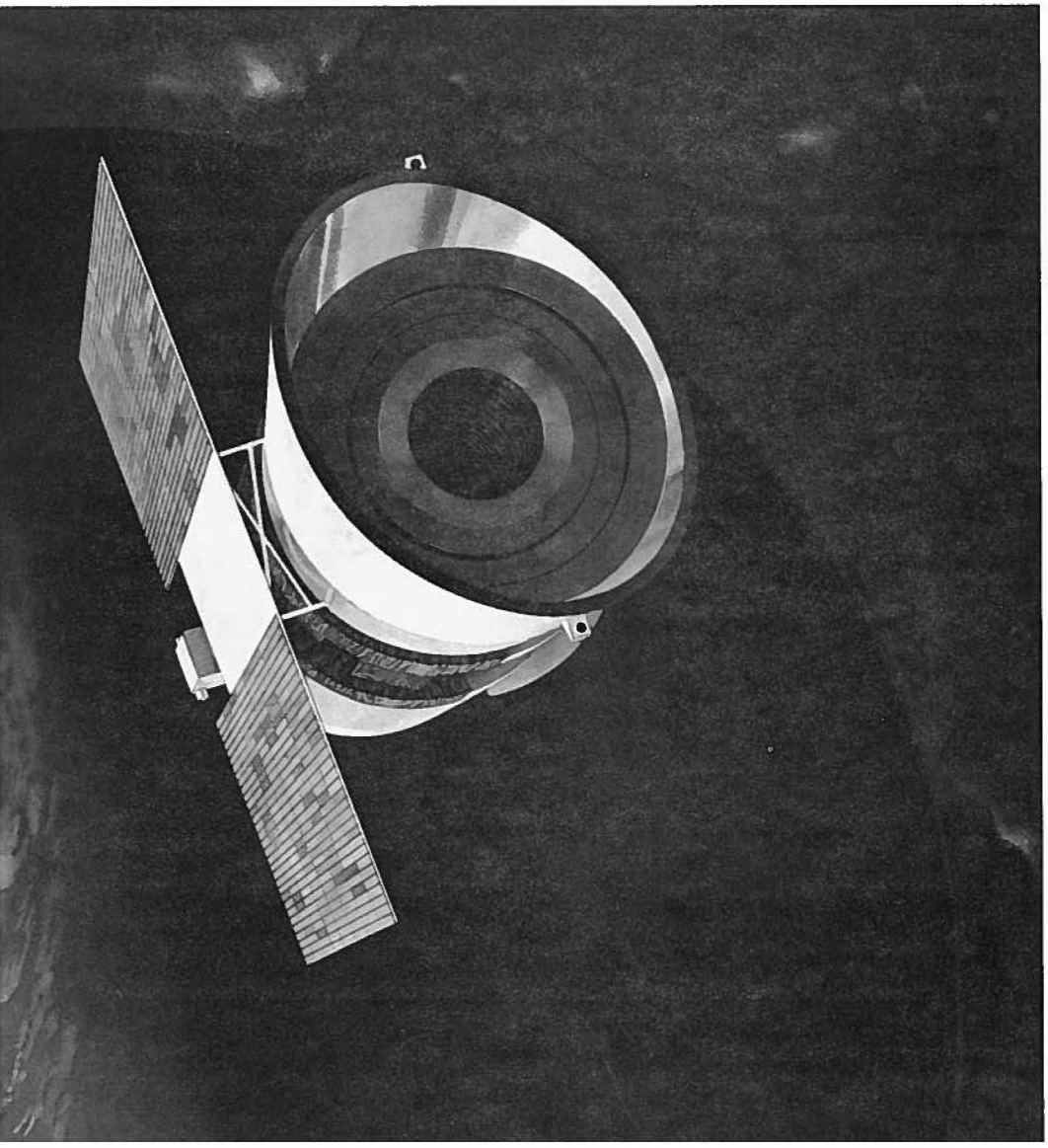
above and below the plane (called the ecliptic) in which the planets orbit the Sun.

The two craft will be sent on trajectories to Jupiter and use that planet's gravity to achieve orbits nearly perpendicular to the ecliptic and then swing back to the Sun. One spacecraft will go below the south pole, the other above the north pole of the Sun—hence the name, Solar Polar Mission. Subsequently, the two craft will reverse poles for comparative studies.

The four-year mission calls for Jupiter encounter in May, 1984, and the first arrival near the Sun's poles in September 1986. One spacecraft is being built for NASA by JPL, the other by ESA. Members of ESA are Belgium, Denmark, France, West Germany, Ireland, Italy, the Netherlands, Spain, Sweden, Switzerland, and the United Kingdom.

More than a dozen scientific experiments, to be conducted by European and American investigators, have been proposed for the mission. Selected experiments will be designed to expand our knowledge of the solar surface, radiation, magnetic fields, the heliosphere, cosmic dust, solar wind, and interstellar gas.

The Infrared Astronomical Satellite probes the sky in search of new stars and galaxies. A liquid-helium-chilled telescope, to be launched in 1981, is expected to provide much new fundamental knowledge about the universe during its one-year mission.



IRAS

The Infrared Astronomical Satellite (IRAS) Project is an international endeavor involving the United States, the Netherlands, and the United Kingdom. Managed jointly by JPL and the Netherlands Aerospace Agency (NIRV), the IRAS Project is designed to provide a one-year infrared telescopic survey of the celestial sphere from an Earth-orbiting satellite.

Using four broad-band photometry channels operating at 10, 20, 50, and 100 micrometers, the all-sky survey is expected to achieve a thousand-fold more sensitivity than any existing infrared astronomical system. Astrophysicists anticipate that they may witness the birth or death of a star; IRAS will give them their most potent tool to date for observing the maternity wards and graveyards of the universe.

The U.S. telescope and Dutch spacecraft will be launched February 1981, into a Sun-synchronous, near-polar orbit 900 kilometers high. The United Kingdom is furnishing the tracking station, whence data will be returned every 12 hours. Overall U.S. management, data reduction, and production of infrared source catalogues are JPL responsibilities. Ames Research Center and Goddard Space Flight Center are responsible, respectively, for supplying the telescope system and the Delta launch vehicle.

About 500 scientists and engineers of the three nations are involved in the project, which for the first time will survey the entire sky at infrared wavelengths that are ineffective in ground-based observations because of atmospheric interference. The cryogenically-cooled telescope reduces background radiation to a minimum, affording a sensitivity that could lead to a better understanding of the structure and evolution of the Universe.

It is expected that IRAS will detect as many as 2 million infrared sources at wavelengths beyond 8 micrometers, compared to the present total of slightly more than 1,000. Spiral galaxies like the Milky Way may be seen to distances of 200 million light years, and brighter quasi-stellar objects to distances of 10 billion light years.

Solar Mesosphere Explorer

An atmospheric science satellite named the Solar Mesosphere Explorer (SME) will be launched in July 1981 into a polar, Sun-synchronous orbit 500 kilometers above Earth. As project manager for NASA's Office of Space Science, JPL will procure the spacecraft module through contractor bidding.

The five science instruments are being developed by the University of Colorado Laboratory for Atmospheric and Space Physics (LASP) to measure ozone density and altitude distribution, monitor incoming solar radiation, and measure other atmospheric constituents that affect ozone. The Colorado laboratory will reduce, analyze, and publicize the data.

The SME satellite will be operated from the LASP campus facilities at Boulder through the Goddard Space Flight Center's satellite tracking system.

Other Project Activities

To assist NASA's continuing effort to reduce the cost of future missions through the use of standard subsystems, JPL has developed a standard radio frequency transponder, transponder test set, and inertial reference unit. Standard transponders have been delivered to the following projects: Stratospheric Aerosol and Gas Experiment, Seasat, Infrared Astronomical Satellite, Magnetic Field Satellite, and Solar Maximum Mission. Complete parts sets have been provided for the Space Telescope, Dynamic Explorer, and Landsat-D Projects. The standard inertial reference unit has been delivered to the Solar Maximum Mission Project, and future deliveries are scheduled for the Annular Pointing Suspension System and Landsat-D Projects.

The Laboratory also participates in a wide range of science experiments, and furnishes a variety of science instruments in support of missions not under direct JPL cognizance. Recent disciplines that have been involved include remote and active sensing devices (e.g., active cavity radiometers, synthetic aperture radars, infrared radiometers, spectroscopes, and imaging telescopes) as well as physics and chemistry experiments (PACE) of various types. Missions on which JPL is represented include Pioneer Venus, International Sun-Earth Explorer, Nimbus, Tiros, Solar Maximum, Long Duration Exposure Facility, Space Telescope, and Spacelabs I, II, and III.

The objectives of Technology and Space Program Development are to foster challenging space projects for the future to be implemented by the JPL program offices and technical divisions, and to provide programmatic leadership in developing and maintaining scientific and technological projects deemed important for the future.

Strategic Planning and Studies

Through study workshops, conferences, and advisory groups, Strategic Planning and Studies is developing several advanced mission concepts, including the following:

Solar Probe Mission

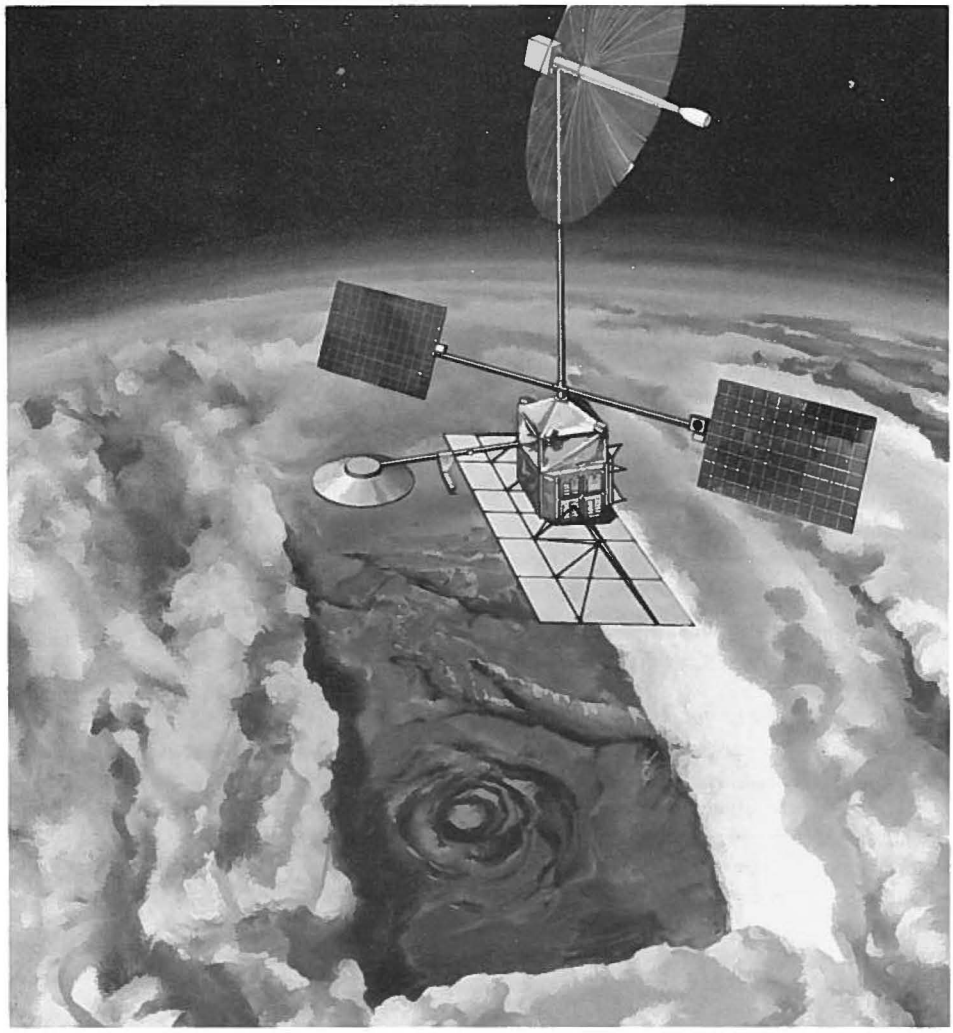
Advancing technology and a complex interplanetary trajectory make it possible to send an instrumented probe close to the Sun—only three solar radii from its surface. A 1987 launch for the Solar Probe from the Space Shuttle would require gravitational boosts from flybys of both Earth and Jupiter.

A Solar Probe mission would provide an unparalleled opportunity to measure the solar corona and study solar wind sources, magnetic field structure, and energetic particles. Television and X-ray observations would show details of the solar surface.

Spacecraft design must compensate for solar light pressure, use dual frequency telecommunications to permit sensitive tests including general relativity, and include special shielding against the intense heat.

The mission would take six years between launch and the first close pass of the

The Venus Orbiting Imaging Radar spacecraft will peel away the clouds, figuratively, to produce images of the surface of Venus. The Orbiter could also drop a lander to perform scientific tests on the hot Venusian surface.



Sun. On that close pass, the probe would whip by the Sun at a relative speed of 300 kilometers per second, fast enough to go from Earth to the Moon in 20 minutes. It would complete solar observations in about half a day of intense activities before shooting off into deep space like a Sungrazing comet, steadily slowing until it reached its most distant point beyond Jupiter's orbit. Subsequent close passes would recur every 4.2 years and, depending on the spacecraft's longevity, observations could be repeated.

Asteroid Exploration

An Asteroid Multiple Rendezvous mission would rely on an ion drive (solar electric) spacecraft to visit a series of asteroids over a period of several years. The asteroid tour concept calls for rendezvous with six to eight asteroids of several types, mainly in the asteroid belt.

The spacecraft, which could be launched in the late 1980s, would spiral into an adjustable orbit around each asteroid for about 50 days of scientific investigations, including mapping studies to determine morphology, chemical composition, and mineralogy. Novel schemes for direct measurement of asteroid samples also are being considered.

Asteroids to be explored have yet to be specified, but several tours of asteroids with known scientific interest have been computed. With the anticipated solar electric propulsion system, tour possibilities are so plentiful that mission strategists could select targets after launch.

Space Program Development

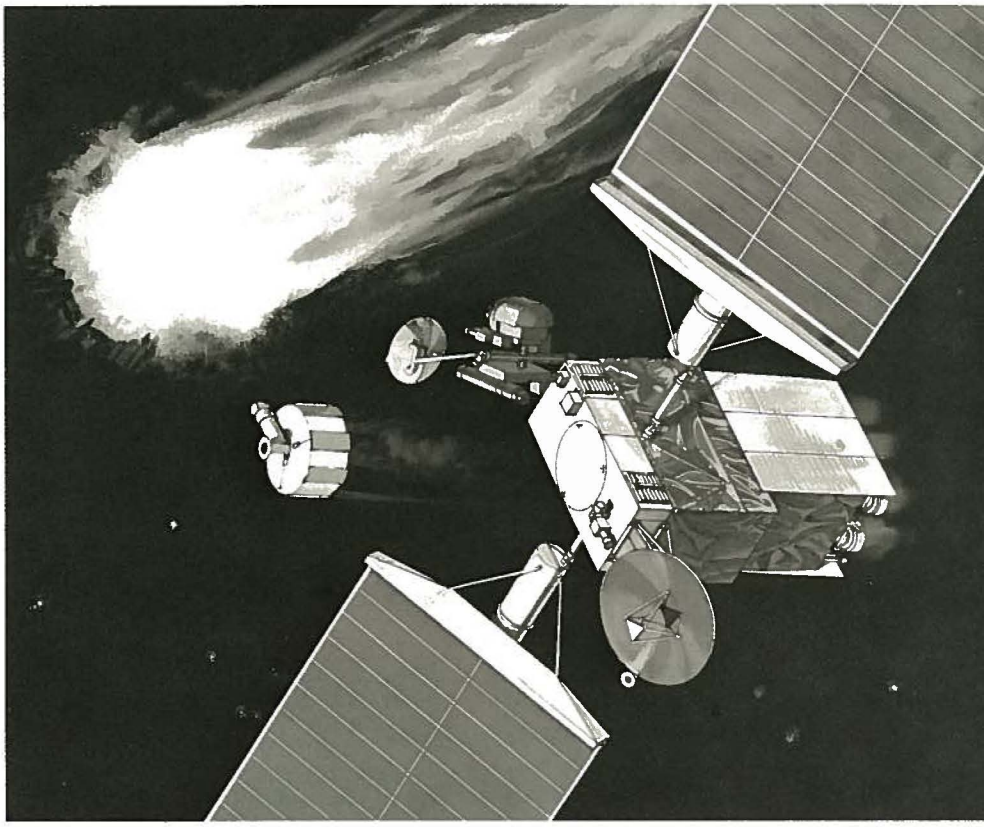
Space Program Development is responsible for developing new flight mission concepts to the point where they can be approved by NASA as new starts.

Venus Orbiting Imaging Radar

The Venus Orbiting Imaging Radar (VOIR) mission, designed to map at least 90 percent of the surface of the cloud-shrouded planet using synthetic-aperture radar, is under development for a fiscal 1981 start.

Other scientific objectives of VOIR include studies of the planet's surface and interior, and the density distribution and dynamics of its upper and lower atmosphere.

The synthetic-aperture radar, supplemented by radar altimetry, would furnish a topographical map that might yield clues to the forces that have shaped the Venusian surface.



A solar electric propulsion spacecraft ejects an instrumented probe toward Halley's comet for a proposed flyby in 1986. The craft would continue on to a rendezvous with another comet, Tempel 2.

The VOIR mission calls for a single spacecraft to be launched via the Space Shuttle in December 1984. After a five-month cruise, the spacecraft would go into circular polar orbit 300 kilometers above Venus. Mapping would commence in June 1985.

Comet Rendezvous/Ion Drive

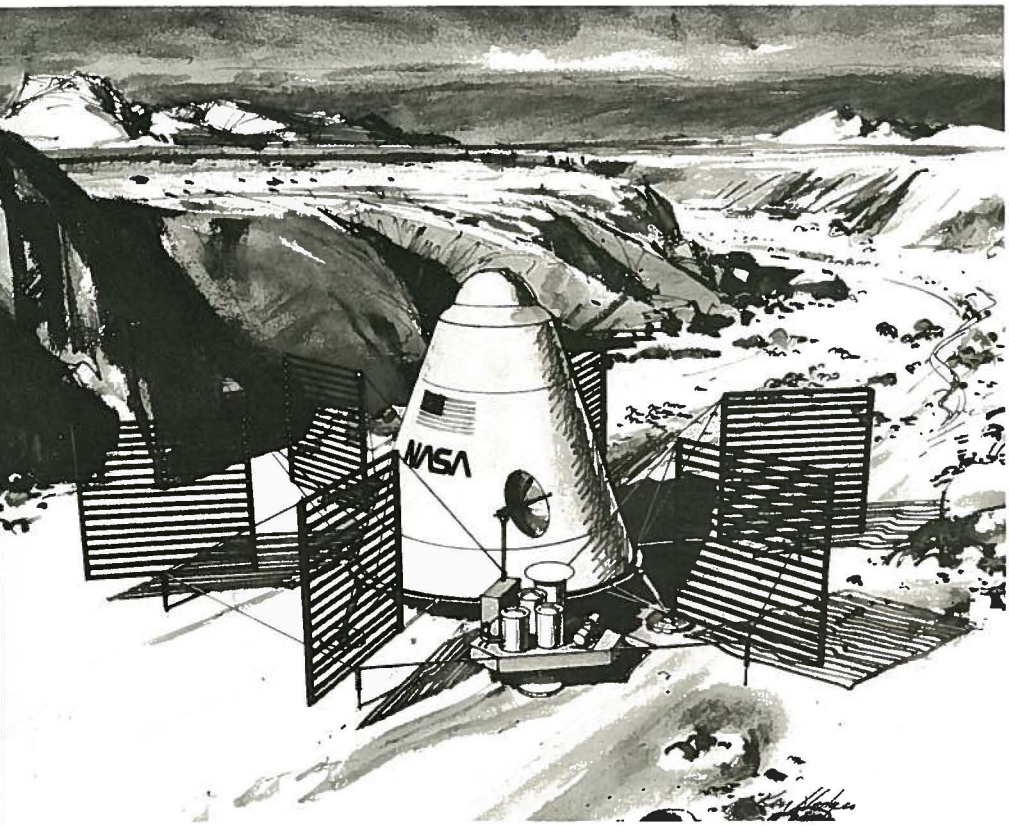
A unique dual-comet flight for the mid-1980s is being studied for a possible ion drive—solar electric propulsion—mission. As proposed to NASA, the JPL-managed project would launch an ion drive spacecraft (propelled by a solar electric stage) from the Space Shuttle in July 1985 to fly by Halley's Comet about four months later and to rendezvous with another comet, Tempel 2, in 1988 for a long-term investigation.

The solar electric propulsion stage, which is the responsibility of the Marshall Space Flight Center, will employ large, lightweight solar arrays to feed electric energy to a cluster of mercury ion engines. The ionization of mercury vapor provides sustained low thrust plus high-voltage acceleration to achieve rocket exhaust speeds of 240,000 kilometers (150,000 miles) per hour. This will enable the spacecraft to keep up with a comet. During 1985 through 1986, Halley's Comet will be making its closest approach to Earth in 76 years.

Mars Sample Return Mission

A preproject study group, after reviewing vehicle and mission options for the continued exploration of Mars, presented recommendations to the NASA Planetary Office for the next Mars mission.

Vehicle options included orbiters, hard and soft landers, penetrators, entry vehicles, airplanes, balloons, rolling balls, and rovers. Two sample return missions were designed, one utilizing Mars orbital rendezvous and sample transfer, the other landing the entire return vehicle on Mars for a direct return to Earth. Various options for increased intelli-



The Mars Oxygen Processor shown resting on the martian surface. This device is designed to return to Earth with samples of the planet's soil, which have been gathere by a robot rover. Oxygen to power the return flight could be generated by the Processor from carbon dioxide taken from Mar's atmosphere.

gence in sampling, mobility, and complementary science were analyzed.

The Mars group was directed to pursue further studies, including a possible adaptation of VOIR for a low-cost aeroscience/geoscience orbiter. Fiscal constraints, however, are limiting the follow-on studies.

National Oceanic Satellite System

The Laboratory has been assisting NASA in the definition of a National Oceanic Satellite System (NOSS) for the 1980s. The NOSS Project, a follow on of Seasat, is cosponsored by NASA, the National Oceanic and Atmospheric Administration, and the Department of Defense. The NOSS objective is to provide a limited operational demonstration of global sea-surface observation by remote sensing from space. The project calls for two satellites to be launched in 1984 and 1985. Management of the project has been assigned to the Goddard Space Flight Center. Negotiations are underway to determine JPL's supporting role.

Stereosat

This proposed Earth-satellite project would provide a follow on to the Landsat program, photographing land masses of the Earth in stereo for the benefit of mineral and petroleum exploration. The data in conjunction with Landsat images would provide three-dimensional capability for improved topographic maps. A 1981 start would enable a 1984 launch.

User requirements have been established by NASA's Office of Space and Terrestrial Applications after consultation with Geosat Committee, Inc., representing 100 resource exploration firms.

Technology and User Program Development

The Technology Program aims to determine technological themes of future value and to develop Laboratory leadership in these fields, both in space and Earth applications. The User Program implements the advancing technology wherever feasible.

New Astronomical Tool

Astronomical observatories are using digital imaging techniques evolved at JPL to support exploration of the planets. The process transforms a photograph into an array of numbers, each number representing a shade of gray.

The resulting "numbers picture" is fed into a computer, along with instructions for manipulating the picture to emphasize desired features. Fuzzy images may be sharpened, faint ones intensified, and obscuring sky brightness or extraneous objects can be removed by the computer. Color differences may be enhanced to emphasize features or the chemical composition of an object.

The modified numbers picture then is converted to a "normal" picture by substituting different colors for the numbers. The picture now can reveal subtleties and small differences that may have been indistinguishable in the original photo.

Monitoring the Sun's Radiation

A new JPL instrument has made the most precise measurement yet achieved of the amount of energy being continuously radiated by the Sun. This important measurement paves the way for monitoring the radiation—the solar constant—with sufficient precision (within 0.1-percent uncertainty) to predict changes in the Earth's climate resulting from any variation in the constant.

The observations were made at altitudes of 120 to 250 kilometers with a cavity pyrheliometer mounted on a sounding rocket launched from the White Sands Missile Range. The experiment yielded a total solar radiation of 1,368 watts per square meter.

Similar instruments will be flown on the NASA Solar Maximum Mission beginning late this year and on Spacelab 1 in 1980. These missions should establish the long-term baseline on total solar flux.

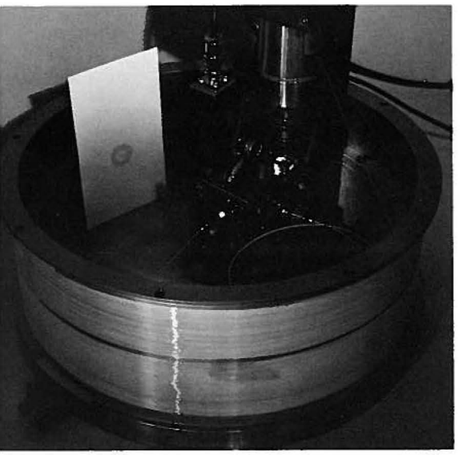
Solar Poles Wind Flux

The Mariner 10 spacecraft has provided the first evidence of a solar wind flux depletion over the Sun's poles. It had been thought that the flux increased near the poles. Mariner 10's flight to Venus and Mercury in 1973 and 1974 provided close-up evidence from the spacecraft's ultraviolet

spectrometer of greater hydrogen density and decreasing solar wind intensity near the Sun's poles. The 1978 analyses of the Mariner 10 measurements will provide a data base for the projected Solar Polar mission.

Cloud Layers on Venus

As Mariner 10 flew by Venus, its radio occultation data suggested a series of three cloud layers at altitudes of 48, 60, and 68 kilometers. The data were analyzed to obtain the effects of dispersive microwave (at 13.06 and 3.56 centimeters) absorption by the clouds. After making necessary corrections, the ratios of absorptivities are consistent with the cloud layering, the upper and lower layers of which are composed of sulfuric acid and water. The absorption ratios of the middle layer are inconsistent with this composition.



Because of Venus' high surface temperature of 430 degrees centigrade, sulfuric acid rain from the clouds would evaporate before reaching the planet's surface, and the clouds would be expected to form at higher elevations than on the Earth.

Quasar Reference Frame

Work is nearing completion at JPL on a celestial map of 665 fixed cosmic radio sources. The map already is being used in the navigating and positioning of interplanetary spacecraft and in precisely tracking the motions of the planets and the Moon.

The quasar reference frame, as it is called, has been compiled from results of a three-year search with DSN radio telescopes using very long baseline interferometry (VLBI) to detect and precisely locate these very distant radio sources, whose positions are virtually fixed in the sky. The spacecraft and planets can then be accurately positioned against this backdrop of radio sources.

Chlorine Monoxide Measurement

JPL scientists have made the first remote measurement in the stratosphere of an aerosol by-product that attacks the upper atmosphere's ozone layer; this layer shields the Earth from much of the Sun's damaging ultraviolet rays. The unwanted by-product is chlorine monoxide, given off by certain Freon aerosol spray propellants that are being replaced by others because of this hazard.

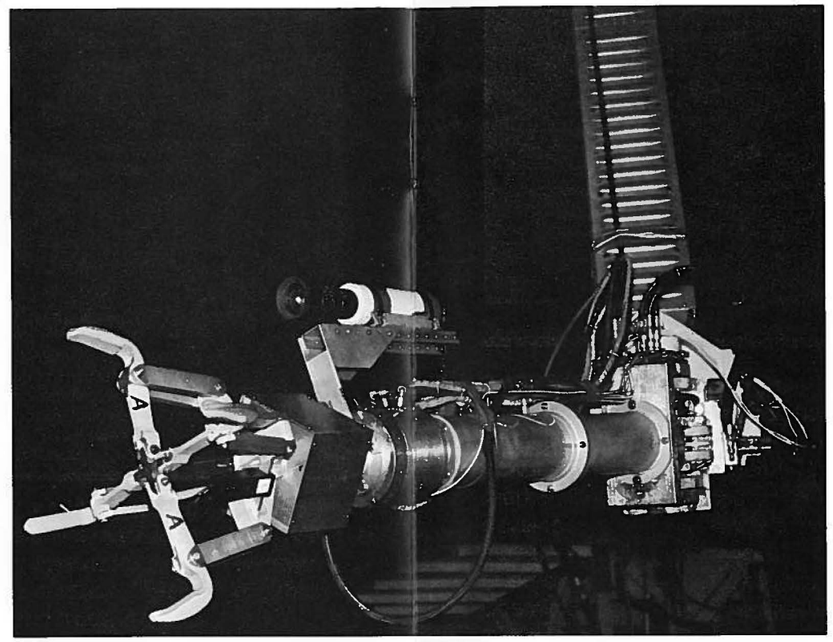
The measurement was made with a laser heterodyne radiometer carried to an altitude of 40 kilometers by a balloon launched from Palestine, Texas. The radiometer was aimed at the setting Sun, from whose infrared light the chlorine monoxide spectral absorption signature was detected. The data were telemetered to the launching facility, operated by the National Center for Atmospheric Research for the National Science Foundation and NASA.

A peak concentration of two to three parts per billion was measured. That is two to three times the density predicted from theories that considered the Freons the major source of the offending molecule.

Rapid Analyses of Atmosphere

A new technique for rapidly measuring concentrations of ozone and some other gaseous pollutants in the atmosphere has been developed at JPL. It consists of flying a laser and a spectrometer aboard an airplane. Instantly and continuously measuring concentrations of the gases as the plane flies over an area, the system is much faster than the air-sampling-and-analysis techniques now in use.

A weak infrared laser beam is projected from the plane to the ground and bounces back to the absorption spectrometer in the aircraft. The returning beam bears the "spectral fingerprints" of any of three gases it has contacted in the atmosphere. In addition to ozone, the system detects ammonia and ethylene. NASA is also working on a detector for oxides of nitrogen.



(Above) An electronic proximity sensor system developed by JPL helps this four-clawed extensor arm pick up loads much as will be done on the Space Shuttle.

(Left) This breadboard model of a sensitive fiber optic rotation sensor for spacecraft stabilization uses laser beams that travel in an optic fiber coil. Rotational movement of the spacecraft results in a phase change in the interference pattern through a relativistic effect.

The system has been successfully tested on both coasts of the United States and measurements correlate well with other measurement techniques. Use of the system on a Shuttle mission is planned, with global surveillance of the Earth's atmosphere the long-term goal.

Color Enhancement Technique

Analysis of Landsat photographs and other multicolored remote sensing data is facilitated with a new JPL procedure involving color enhancement. Essentially, the system forces more color into a scene, intensifying the color range and increasing color differences. This has the effect of increasing the information in the picture.

The technique applies equally well to pictures in the infrared or other frequencies, depending on the information desired concerning the terrain being photographed. The new color intensifying method includes using a computer technique to enhance color components to their full range.

Sensitive Analyzing Technique

The composition of materials used in semiconductors must be precisely known and controlled.

Heretofore, spectroscopic techniques used in studying the crucial structures and interfaces of the materials—generally silicon and gallium arsenide—destroyed the materials about which chemical information was required.

An advanced JPL technique makes possible for the first time the analysis of semiconductor materials at the atomic level without destroying the material itself.

The new probing system uses modifications of an X-ray photoelectron spectrometer to obtain information on fundamental structures not previously obtainable. The new methods are expected to lead to improved electronic device structures.

Fiber Optic Rotation Sensor

A more effective spacecraft rotation sensor has been developed at JPL that offers improved performance and stability with potentially higher reliability, and less weight and cost than gyros now used in guidance and navigation systems.

With no moving parts, the sensor uses the interference pattern of two laser beams drawn through long optic fibers. Any rotational movement of the spacecraft results in a disturbance of the interference pattern through a relativistic effect. The disturbance (a phase change) is converted into an electrical signal that can be displayed or used directly in a guidance system.

Antenna Analysis Technique

The state of the art in the analysis and syntheses of reflector antenna systems has been greatly advanced by recent work at JPL. A new series expansion technique has been developed that improves by one to two orders of magnitude the classical computational speed for the far-field pattern analysis of antennas. This makes possible less costly, more efficient new designs.

The Laboratory also has achieved significant breakthroughs in new synthesis methods for the design of shaped dual reflector antenna systems.

Integrated Antenna-Transmitter

A new integrated antenna-transmitter for spacecraft has been built and tested by JPL. Initial evaluation indicates that it could have a significantly longer lifetime than traveling wave tubes at substantially lower cost. The high-gain, X-band antenna is 3.7 meters in diameter with a 32-element, solid-state modular array transmitter feed system mounted in front of the vertex of the main reflector.

New Light Phenomenon

Work is under way at JPL to make use of a new insight into the physics of light absorption to modulate lasers. The phenomenon was discovered in the JPL Submillimeter and Microwave Spectroscopy Laboratory during experiments designed to test theoretical models of molecular absorption modulators. A microwave signal sent through a sample of methyl fluoride gas was subjected to spectral analysis. When the sample was electric-field modulated, the results were inconsistent with the expected classical results.

The object now is to use this modulation effect to convert fixed-frequency, far-infrared lasers into more flexible tunable sources. These tunable sources will be used as local oscillators for submillimeter radiometers as part of a program to measure trace species of gases in the Earth's atmosphere.

Also, this revised picture of how light is absorbed led to a new theoretical model.

Space Shuttle Teleoperation

JPL teleoperator engineers developed a proximity sensor system for an advanced version of the mechanical arm designed to be used aboard NASA's Space Shuttle. Produced for the Johnson Space Center Manipulator Development Facility, the electronics system uses four sensors integrated with four claws on a 16-meter (50-foot) extender arm simulating the Space Shuttle's Remote Manipulator System.

Correcting for depth, pitch, and yaw errors, the sensors enable a remote-control operator to guide the claws accurately to grasp and move a large payload. The sensors verify the grasp of the payload position to a computer, which signals success by a buzzer or green light, or both.

Ground tests have been successfully conducted with the sensor and display system at Johnson Space Center under realistic payload handling conditions—both in grasping stationary loads and capturing moving targets.

Tracking and Data Acquisition

The Tracking and Data Acquisition (TDA) Office manages the development, implementation, and operation of the Deep Space Network (DSN) for NASA's Office of Space Tracking and Data Systems. The primary objective of the DSN is to support the tracking and communications needs of deep space probes. During 1978, the major DSN activity in support of spacecraft projects was for Voyager and Pioneer Venus.

In addition to direct flight project support, the DSN achieved significant advances in less glamorous but equally important areas. The DSN is developing ways to reduce maintenance and operation costs, while maintaining the high-quality support required by flight projects. This includes development of an unmanned deep space communications station at Goldstone, and a 24-percent reduction in energy consumption at Goldstone between 1973 and 1978. New technology for the future is an important TDA concern, along with continued progress in the development and demonstration of advanced concepts for meeting DSN requirements.

Operations

Three records were broken by DSN operations during 1978: the total number of spacecraft tracked, the longest communications distance to a spacecraft, and the most consecutive years a single spacecraft has been tracked. A total of 15 separate spacecraft (19, including the four Venus probes) were tracked for periods ranging from a few hours per year for Pioneers 6, 7, 8, and 9 to nearly 24 hours per day for Voyager. Pioneer 10 was tracked beyond 2.5 billion kilometers, and returned fields and particles data from a region of the solar system never before explored by a man-made object. Pioneer 6 was launched in 1965, and 1978 marked the thirteenth year the DSN has maintained communications with it.

Helios 1 and 2, in orbit around the Sun, continued to send back data, and were tracked primarily in the time available after the needs of prime missions had been satisfied. Pioneer 11, in transit to a September 1979 encounter with Saturn, was supported for its final trajectory correction maneuver. Viking extended mission operations at Mars were supported at a level greatly reduced from 1976 and 1977.

Pioneer Venus orbit insertion and probe tracking provided the DSN's major technical challenge in 1978. The Orbiter was inserted into orbit around Venus December 5, and the four probes entered the Venusian atmosphere December 9 for a planned 60-minute descent to the surface. DSN support was critical, since the probe data were sent directly to Earth and the transmitters were turned on only 20 minutes before entry into the atmosphere. In a near-perfect performance, the DSN acquired the probe signals within seconds after they were turned on and received 100 percent of the expected data.

The new DSN Radio Science System became operational and provided extensive support to both the Pioneer Venus multiprobe entry and the orbital operations. A unique experiment was conducted in conjunction with the Massachusetts Institute of Technology (MIT) during the probe entry. This was an interferometry experiment, which evaluated the velocity of the Venusian winds as the probes descended through the atmosphere. Signals from the four probes were received on high-phase stability receivers at NASA stations in Goldstone, California; Canberra, Australia; and Goddard stations in Guam and Santiago, Chile. These data were digitally recorded at 12 megabits per second on new high-rate digital instrumentation recorders, and the bandwidth reduced in the new radio science facility prior to turning the data over to the experimenter.

To measure neutral atmosphere refractivity and ionospheric free-electron content on Venus, Pioneer Venus Orbiter S- and X-band signals were received and digitally recorded at Goldstone and Canberra as the spacecraft passed behind the planet and emerged on the other side. The data recording system was under control of a new computer program that substantially reduced the amount of data required to be recorded without reducing the information content.

TDA support for Voyager involved two important parallel activities: (1) providing continuous communications for Voyager cruise operations and (2) completing implementation of new capabilities required for Jupiter encounter in time to begin far-encounter support in January 1979. Voyager communications were provided through a network of three stations shared by the two spacecraft; 26-meter stations were used for S-band cruise science and commanding, and 64-meter stations were employed periodically for dual-frequency navigation cycles and special science events. The coverage pattern was altered in April 1978 to accommodate Voyager 2 receiver

problems, which required the 64-meter station uplink frequency tuning capabilities until emergency implementation of similar capabilities in the 26-meter stations.

The task of preparing for Jupiter encounter was accomplished on schedule with minimum impact on mission operations of the Voyager and other flight projects. Major adjustments included: (1) installation of wideband communication circuits for handling Voyager's 115,200 bit-per-second imaging data in real time; (2) installation of radio science system equipment at the Spanish station location for Voyager 1 Earth occultation support, including rapid relocation of equipment from Australia and Guam after the Pioneer Venus probe entry; (3) conversion of a Goldstone 26-meter S-band station to a 34-meter, S-X-band station; and (4) installation of a second X-band maser at each 64-meter station.

Improvement was made in very-long-baseline interferometry (VLBI) techniques for precision determination of spacecraft position at planetary distances. Software and hardware for a demonstration with the Voyager spacecraft were developed and installed in the stations and a demonstration was set for the Voyager 1979 Jupiter encounters. The goal is to develop the VLBI technique to meet the extremely precise navigation requirements of Project Galileo in 1982.

To coordinate Goldstone operations with Mojave Desert military activities that create radio interference problems, the TDA office worked with NASA and the Department of Defense on a memorandum of understanding that became effective September 1978. A Mojave Coordinating Group was set up to develop joint procedures for compatible operations, implement improved monitoring equipment for detecting interference sources, provide rapid communications for control, and perform detailed analysis of problems and possible solutions.

Facility Implementation

A major network modernization activity was the conversion of an existing set of three S-band 26-meter antennas to 34-meter antennas capable of handling S- and X-band. Since current deep space missions require X-band for high-rate telemetry data, this update will significantly increase the capability of the DSN to handle several missions simultaneously. For Voyager, the output of the 34-meter stations will be combined with the output of the 64-meter station at the same longitude. This increases receiver sensitivity to allow real-time television reception from Saturn.

Upgrading of the 26-meter station at Goldstone was completed and it is now on line and supporting the Voyager project. Hardware for conversion of the 26-meter stations in Spain and Australia was procured.

Another major implementation task was completed on time to prepare the Deep Space Network for support of Pioneer Venus and Voyager encounters. This involved the installation of new telemetry, command, and dual frequency radiometric data handling capability at each of the stations. Existing obsolete and special purpose equipment was replaced by more modern, minicomputer-based equipment. As with other station modifications, these were planned and accomplished while maintaining committed support to ongoing spacecraft projects.

Implementation of a Meteorological Monitor Assembly at all 64-meter stations was completed prior to Voyager encounter to provide weather and ionosphere calibration data. Weather data have taken on a new significance for Voyager, and future missions using X-band telemetry, due to the

(Upper left) This Goldstone antenna has been enlarged from 26 meters in diameter to 34 meters to increase its sensitivity. (DSN 26-meter dishes in Australia and one in Spain will be similarly improved.) The instrument was jacked up on 10-foot concrete pedestals to keep the enlarged dish from touching the ground when aimed at the horizon.

(Left) The parametric up-converter, shown with test horn, is a new receiving system that converts a received signal to a higher frequency prior to amplification by the maser. This provides a wider bandwidth, permits a higher data rate, and requires only one maser to receive both S and X bands.

(Above) The ARIES monitoring site at JPL showing the new 4-meter high-mobility antenna (left) and the 9-meter antenna (right). The new 4-meter antenna will allow two site measurements per week compared with one per month for the 9-meter system. ARIES is used to detect very small Earth deformations.

sensitivity of X-band to moisture in the atmosphere. Weather data are also now more important for calibrating navigation data to achieve the precision required by Voyager and future missions. Other major changes were the addition of a second X-band maser amplifier to the receiving systems of all 64-meter stations to increase reliability, and the addition of precision hydrogen maser frequency standards to improve navigation accuracy. The radio science capability at the 64-meter antenna in Spain was increased with the addition of two-channel multimission receivers, an open-loop receiver, a spectral signal indicator, a digital recorder, and a special assembly for taking occultation data.

Wideband digital data acquisition systems were installed at the 64-meter stations to use radio interferometry to measure the offsets between the precision clocks at the stations. These systems were designed to determine clock offsets to a 10-nanosecond accuracy, and monitor the drift of frequency standards to 1 part in 10^{14}. Accuracies of this high level are necessary to meet Voyager navigation requirements and support radio science experiments. A hydrogen maser frequency standard, implemented at the 64-meter stations, uses the energy states of the hydrogen atom to generate a frequency reference that is stable to 1 part in 10^{14} over an 8-hour period. This is 100 times better than existing cesium standards. The 64-meter subnet now contains the first worldwide network of hydrogen masers operating on a 24-hour basis.

In the cost and energy reduction effort, a new energy analysis program was developed and used to analyze the energy consumption at six major buildings at Goldstone. The goal is to effect further energy cuts beyond the 24 percent achieved in the past five years. Similar reductions are being sought at overseas stations. As part of this effort, an engine generator waste heat utilization system was installed at Madrid.

Advanced Systems

DSN Advanced Systems continued development of new capabilities to support future projects. Many advanced development activities in 1978 employed new technologies to reduce costs.

For example, operations of existing stations require large staffs, plus considerable time for calibrations, maintenance, operator training, and other necessary nontracking activities. A demonstration task has been underway for several years to increase available station time for flight projects by reducing the time spent on nontracking activities and the size of the staff required to operate the station. An existing 26-meter station at Goldstone is the demonstration station for this concept. In 1978, the station was set up to track and acquire telemetry data from a spacecraft while being controlled remotely from JPL in Pasadena. During demonstrations, the station was turned on and checked out, the spacecraft was tracked and telemetry acquired, and the station was shut down—all with no operations personnel in attendance. During recent months, telemetry data have routinely been provided to the Voyager, Pioneer, and Helios Projects using the unattended operations mode.

Another concept that shows potential for reducing costs is spacecraft navigation by down-link one-way ranging (DOR). This concept significantly reduces tracking time necessary to navigate a spacecraft, and can be carried out by a network of three simple, low-performance, inexpensive stations located entirely in the United States. This reduces demands on the DSN stations and frees them for telemetry and command activities. Angles to spacecraft can be determined very accurately with this technique, which uses VLBI to determine spacecraft location. A narrow bandwidth demonstration of the technique was conducted with Voyager.

A study was conducted to consider an Orbiting Deep Space Relay Station (ODSRS) as a supplement to the DSN. This concept calls for a sensitive receiver and large antenna in Earth orbit receiving spacecraft telemetry unperturbed by the Earth's atmosphere. Although implementation costs do not make the concept attractive with present technology, it has some significant advantages over ground-based stations, and is a likely candidate for DSN long-term planning.

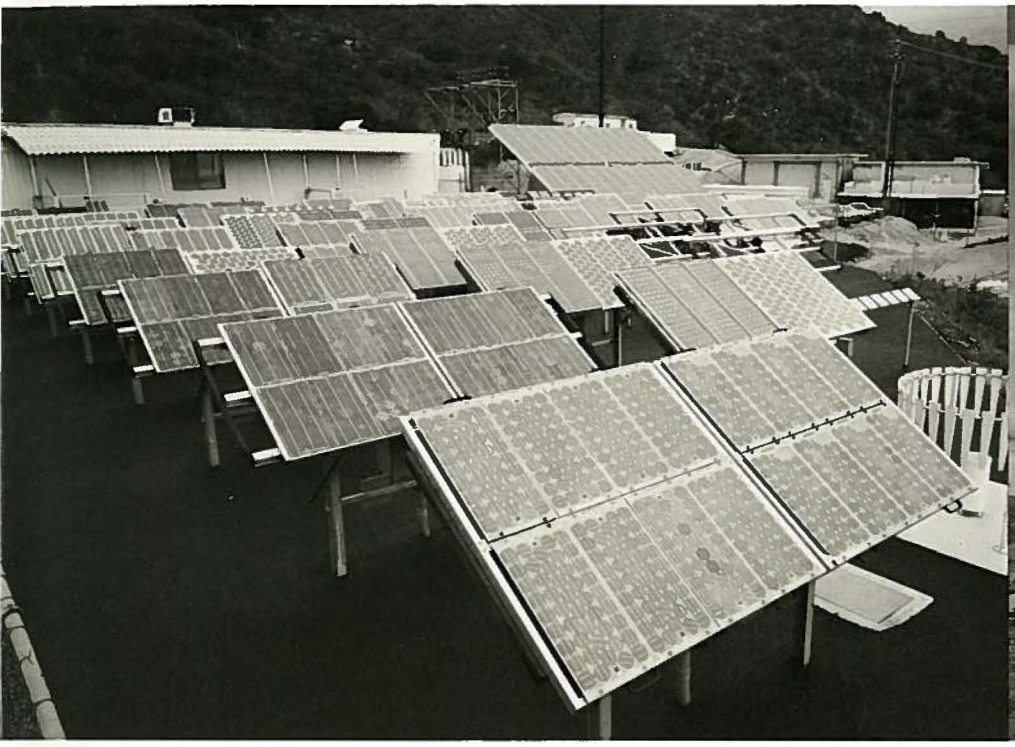
A more cost-effective next step in increasing DSN capability to meet future telemetry requirements is the Large Advanced Antenna System (LAAS). This is an Earth-based deep space communications station that would increase by a factor of five the X-band telemetry reception capability of the present 64-meter stations. The feasibility of the LAAS has been established and it was determined that electronically combining the outputs of several smaller antennas was more economical than building one large antenna. It is proposed to start construction in 1981 so that it can become operational in 1984, in time to support Galileo, VOIR, and a Voyager-Uranus encounter.

At present, DSN's 64-meter and 34-meter stations operate at S- and X-bands through a complex set of RF optics that allow simultaneous reception at dual frequencies. Significant progress was made last year on a feed system that would operate at S- and X-bands through one concentric feed; this system would simplify the antenna design and improve performance at X-band. A demonstration has been conducted showing good performance for simultaneous reception at both S- and X-band. The goal is simultaneous reception and transmission at both S- and X-band.

Recent technological advances have made possible the development of ultralow-noise receiving systems that perform as well as current microwave maser amplifiers, but have many times greater bandwidths. This system uses a cryogenic parametric up-converter followed by a maser amplifier operating at a much higher frequency. The system, incorporating several cryogenic up-converters driving a single maser amplifier, could provide the basis for an economical multifrequency standard low-noise amplifier for the DSN.

The Astronomical Radio Interferometric Earth Surveying (ARIES) Project has demonstrated the feasibility of determining Earth positions with an accuracy of a few centimeters over baselines of 100 to 1,000 kilometers. Using VLBI and a quasar reference frame, ARIES has determined that JPL is moving westward relative to Goldstone at a rate of about five centimeters per year. ARIES has proved useful for studying crustal deformations and has promise for detecting tectonic plate movement and possibly as a tool for predicting earthquakes. This work was done for NASA's Office of Space and Terrestrial Applications.

Energy & Technology Applications



(Upper left) Test stand arrays of manufacturers' candidate solar cells undergo continuing evaluation at the JPL Photovoltaic Laboratory as part of the Low-cost Solar Array Project. JPL is the lead center for the Department of Energy's Photovoltaic Program.

(Top) Installation of the Solar Thermal Unit Omnium-G 6-meter-diameter Solar Concentrator at JPL's Point Focusing Solar Test Site at the Edwards Test Station. Panels, receiver, and power conversion unit are yet to be installed.

The Laboratory's steadily-growing involvement in Energy & Technology Applications (formerly called Civil Systems) produced significant results in several areas. Among these were solar energy, both photovoltaic and thermal-electric; coal technology; energy-conserving transportation vehicles and systems; environmental studies; and biomedical technology.

Photovoltaics

The four-year accomplishments of the JPL-managed Low-cost Solar Array (LSA) Project prompted the Department of Energy (DOE) to designate the Laboratory as the lead center for photovoltaic technology development and applications beginning October 1, 1978. In this role, JPL will be responsible for directing activities in the federal government's 10-year photovoltaic power systems development program. JPL-managed research and development, until now concentrating on silicon-based cells, has been expanded to include cadmium sulphide, gallium arsenide, and thin-film hydrogenated silicon solar cells.

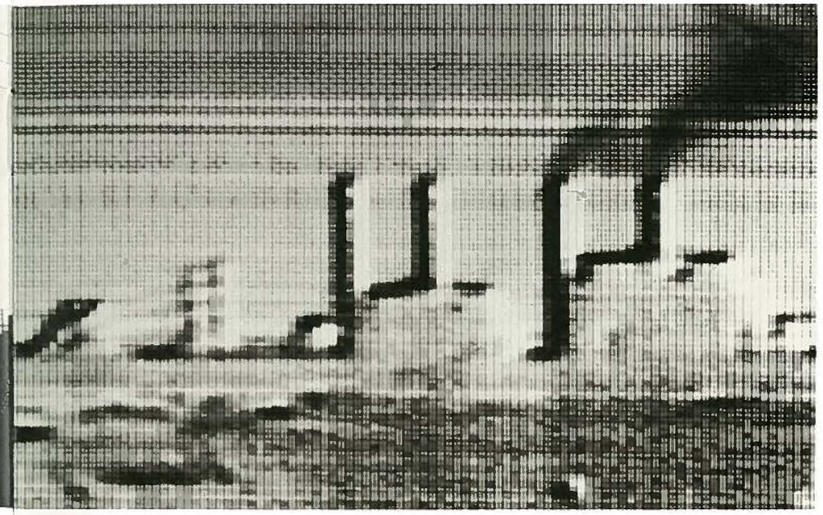
Growing industry participation (LSA lists nearly 100 contractors) produced advances in silicon sheet manufacturing and ribbon-growing technology. Fifteen candidate designs for flat-plate arrays were put under test for electrical output and life expectancy at JPL's Photovoltaic Laboratory. The field testing coverage of diverse environments was extended with the establishment of a coastal site in addition to the existing desert and mountain test sites.

A production cost-modeling computer program was developed by JPL as an aid for comparing various production processes. The software (called SAMICS, for Solar Array Manufacturing Industry Cost Standards) has been validated by manufacturers in their own analytical studies. Evaluations continue to support the expectation that the 1986 DOE price goal of 50 cents per peak watt (in 1975 dollars) can be achieved by photovoltaic arrays—provided commitments to plant construction are made in 1981 or 1982.

Solar Thermal

Another DOE program under JPL management is the Solar Thermal Power Systems Project. The first contracts were let for small systems application for supplementing electrical power in small communities and rural areas; the first engineering test, at one-megawatt capacity, is scheduled for operation in 1982.

The project's hardware technology is concentrating on point-focused modules. Procurement of present designs was begun, design contracts were awarded, and a test facility was established for such modules at the Edwards Test Station on the Mojave Desert. In the advanced technology area, a structural glass concentrator was designed with low-cost performance potential. Some 25 research contracts with universities and industrial laboratories extended the technology. NASA's Lewis Research Center, Cleveland Ohio, supports this activity and also is active in developing heat engines for the Solar Thermal Power System.



(Above) This large coal extruder pump developed at JPL uses an overhead crusher feed, a 2-1/2 inch screw extruder with heaters (and protective covering), and, right, a cylindrical receiver. The program, sponsored by the Department of Energy, seeks to determine feasibility of high-pressure conversion of coal into liquid and gaseous fuels.

(Right) Dual-band spectral scanner (MOPS) detects sulfur dioxide pollutant. Left, plumes are invisible to normal eye or lens; at right, processed scanner output reveals pollution.

Coal

In the fossil energy sector, a comprehensive coal technology study defined new systems for underground coal mining. The study, originally sponsored by the Bureau of Mines, is now proceeding for DOE's Division of Fossil Fuel Extraction. It analyzed mining factors—cost, miner health and safety, environment, and coal conservation—and established requirements for the Central Appalachia coal fields of Eastern Kentucky. The effort is now focusing on the design of innovative coal-mining equipment.

The Laboratory's role as a catalyst was evinced by a three-day Pasadena conference on coal use in California, which JPL conducted under the cosponsorship of the California Energy Commission and the DOE. More than 350 representatives of industry, government, universities, utilities, and environmental groups attended the sessions. A week-long workshop at Watsonville later pursued the financial, environmental, regulatory, and public acceptance issues pertinent to broadened coal use.

Development of a JPL coal-feeding device, which works on the principle of a helical screw extruder, continued promisingly. Steady-state operation was demonstrated when a small extruder was operated successfully for 34 continuous hours with two different Eastern coals, and a larger coal pump achieved several runs of at least five hours. The JPL-conceived chlorinolysis process for chemical removal of sulfur from coal was further developed and tested in the laboratory. Significant reductions in both organic and pyrolytic sulfur were achieved in many coals.

Transportation

The Laboratory conducts both a major project for DOE's Office of Transportation Energy Conservation and a large number of tasks in highway and transit systems and subsystems for NASA, DOE, and the Department of Transportation. In the Electric and Hybrid Vehicles Project for DOE, contractor development of electric passenger vehicles continued during 1978, while four competitive development contracts were issued for development of hybrid vehicles. JPL completed its world state-of-the-art assessment of electric vehicles, and evaluated and tested a Cutler-Hammer electric retrofit Corvette and a hybrid electric van.

A wide-area detection system, designed by JPL to be the key element of a freeway traffic monitor and control system, or to supplant induction loops in a surface intersection control system, completed its breadboard qualification test. The design involves a video pickup with image-processing and pattern-recognition programs to measure in real time all dynamic parameters on a multilane traffic system, switching to a conventional picture for incident reporting.

A 1-to-30 scale, full-speed model of a two-way freeway tunnel system, with removable cover sections, was designed and built at JPL for the Federal Highway Administration. Injected tracer gas is used to chart the flow of air and pollutants. Tests have produced useful design information for the proper ventilation of tunnels.

Oceanography

In addition to the Seasat system and mission, the Laboratory has been applying remote-sensing instrumentation and data enhancement to the needs of undersea exploration. Image processing has improved both photographic and sonar data for various oceanographic institutions. The JPL-developed chirp sonar device was tested off the California coast and in the Gulf of Alaska. The Laboratory organized and hosted the first annual International Sea Floor Imaging Workshop for the National Oceanic and Atmospheric Administration and NASA. The workshop attracted 50 representatives of universities, oceanographic laboratories, and government, including specialists from the United Kingdom and Canada.

LNG Vapor Detection

Environmental instrumentation developments pursued under DOE and Coast Guard sponsorship included two approaches to optical detection of vapors from liquefied natural gas. The first instrument, a two-band differential infrared radiometer, uses ratioing to separate water-vapor signals from those of methane; the second employs a helium-neon laser with semiconductor detectors to measure absorption by methane in a single band. Both prototype devices successfully measured methane concentration in a spill test at China Lake, California.

MOPS Smog Detector

The Multispectral Observation of Pollutants System (MOPS) is a dual-band spectral scanner successfully designed to image trace gases in the atmosphere. The system employs two electronic cameras—one operating in the spectral absorption region of the gas to be mapped, and the other at a wavelength region of lower absorption.

The light from each camera is focused onto a detector line array and the signal from the detectors electronically translated into an image of the scene. Images are electronically ratioed and enhanced to bring out pollutant concentrations not seen in the film.

The MOPS can be used at ground level or in the bottom of an aircraft for regional mapping of sources, sinks, and the dispersion of pollutants. In aerial use, on-board equipment can provide image display in real time, enhancements as desired, and tape-recording of all data for further analysis. While presently designed for use in the ultraviolet region where ozone, sulfur dioxide, and nitrogen dioxide absorb, the system may be modified for use to detect other gases in the visible and infrared regions of the spectrum.

Biomedical

Electro-Optical Ion Detector

An Electro-Optical Ion Detection system for mass spectrometry was developed under the joint sponsorship of the National Institutes of Health and NASA's Office of Life Sciences. The ion detector is central to a focal plane mass spectrometer, which has been tested as nearly a thousand-fold more sensitive than any other chemical analyzer now available.

Of potential benefit in hospital clinics and space, the system provides a continuous electronic photoplate capable of chemically analyzing microscopic ionized samples of materials. Biomedical research uses of the machine may include studies of metabolism, blood, tissue, hormones, amino acids, and the effects of drugs on all of these. In space, a smaller version of the system is designed to help NASA monitor air conditions aboard future Spacelabs and could aid in smog component identification on Earth. It is particularly applicable to aerosol analysis, which was a joint Caltech-JPL project sponsored this year by the President's Discretionary Fund.

A minicomputer digests and displays the results of this high-speed system, which is capable of producing up to 72,000 spectra per hour.

Hip-Joint Prosthesis

Another instrumentation development, carried out in collaboration with the UCLA School of Medicine's Department of Orthopedic Surgery, will result in an implanted hip-joint prosthesis carrying six strain gauges at the neck of the ball joint. Powered externally by induction, the implanted radio telemetry system can deliver research data on stresses at the joint in action. During 1978, the feasibility model was successfully tested; first clinical operations with a patient, to be conducted by UCLA, may occur in 1980.

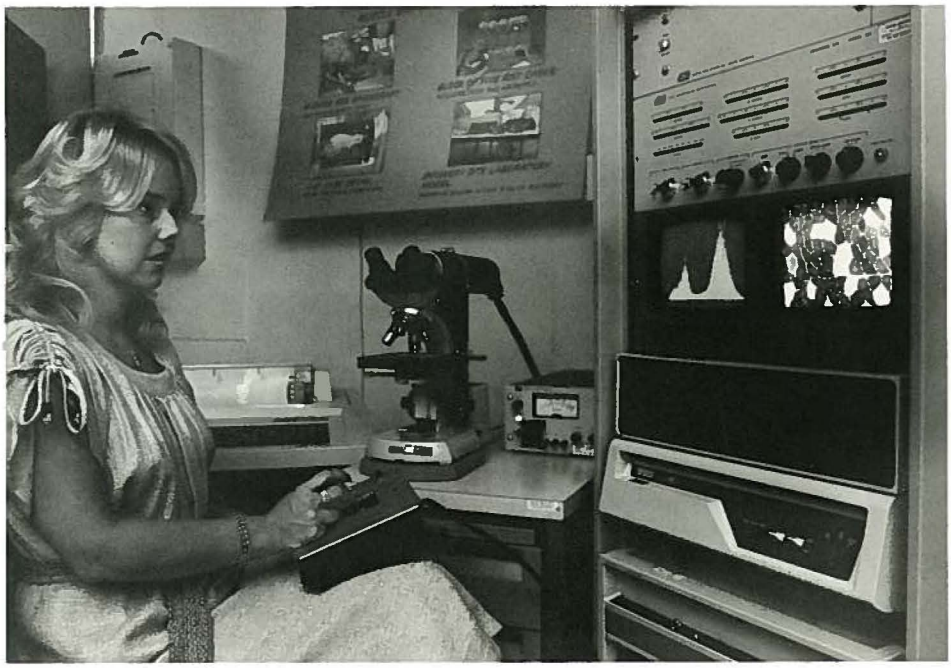
Materials research and design work, also in collaboration with UCLA, focused on the development of a ceramic and plastic hip-joint replacement. Polyethylene plastic was used to replace the socket on the pelvis, and sialon ceramic was chosen for the ball joint on the thigh bone. A fabrication process was developed to control porosity in the thighbone end of the prosthetic so that the bone would grow into the material, establishing a firm, natural bond. When animal biocompatibility tests raised questions about sialon, an alumina ceramic was selected for new material testing.

Muscle Biopsy Analysis

A medical imaging processing system was devised for muscle biopsy analysis, in collaboration with the USC Department of Neurology and sponsored by NASA and the Muscular Dystrophy Association. It was used in 1978 to analyze muscular tissue samples from rats flown aboard the Soviet biosatellite Cosmos 936. Arrangements have been made for participation in a planned 1979 Cosmos mission as well.

Cell Labeling by Polymeric Reagents

Using the expertise of polymer synthesis developed for NASA solid propellants and semiconductors, JPL chemists produced

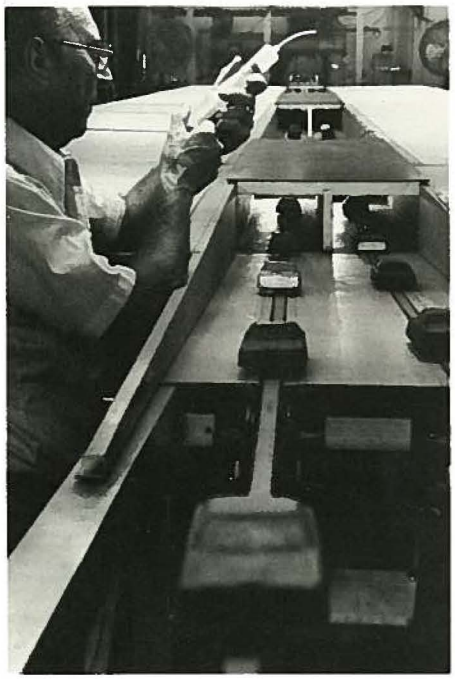


(Left) This JPL computerized muscle biopsy analysis system can show deterioration of muscle fiber 10 to 20 times faster than human analysis. The system proved its efficiency in a Soviet biosatellite test on rats, which is scheduled to be repeated in 1979.

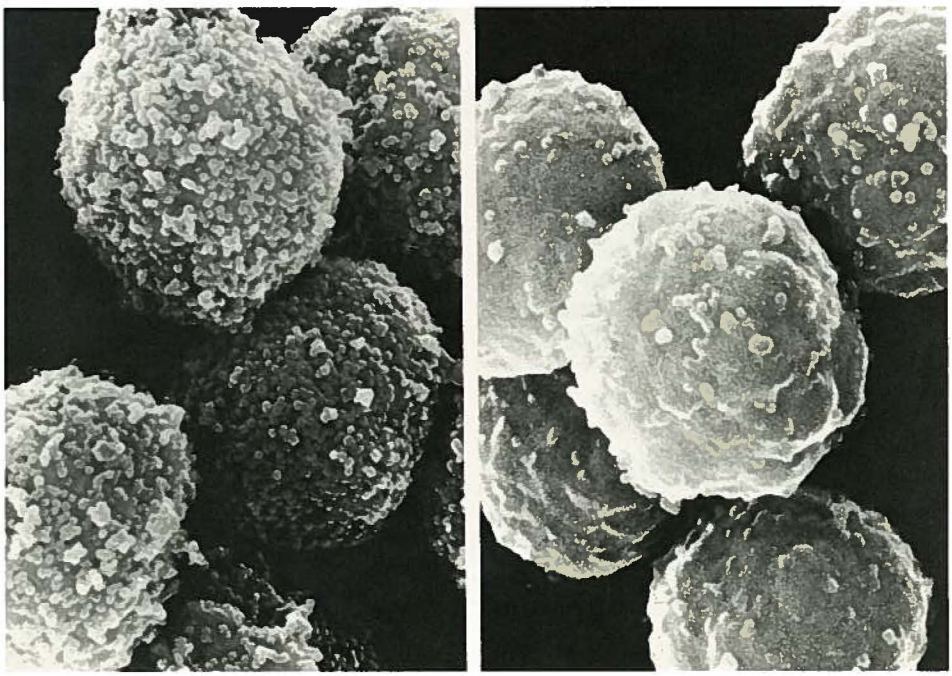
new polymeric reagents that can be used to label cells in the human body. This ability to tag red blood and lymphocyte cells has allowed medical researchers to see molecules called antigens on cell surfaces in light and electron microscopes.

The labeling of cell surfaces was achieved by binding specific antibodies to polymeric microspheres visible only in the more powerful microscopes. These immunomicrospheres, as they are called, can identify antigens on cell membranes and map cell surfaces.

The new reagents and methods may prove useful in tumor research, since nearly all cancer cells have altered surfaces. In biomedical terms, the separation and identification of cell molecules could lead to improved diagnostic and therapeutic techniques.



(Above) Model freeway tunnel system, built at JPL for the Federal Highway Administration, charts the air flow of a tracer gas. Tests have produced design ideas for the better ventilation of tunnels.



(Lower left) Labeled cells fixed with polymeric immunospheres are shown at left, and unlabeled control lymphocytes at right, each enlarged 10,000 times in this scanning electron microscope photograph. This JPL-developed technique is aiding medical researchers in molecular disease studies.

Planning and Review

The Office of Planning and Review (OPR) functions primarily in a staff and support role to the Director's Office, and is responsible for a variety of administrative, planning, assessment, and review activities. Its responsibilities also include administration of the reliability and quality assurance functions in support of the Laboratory's programs.

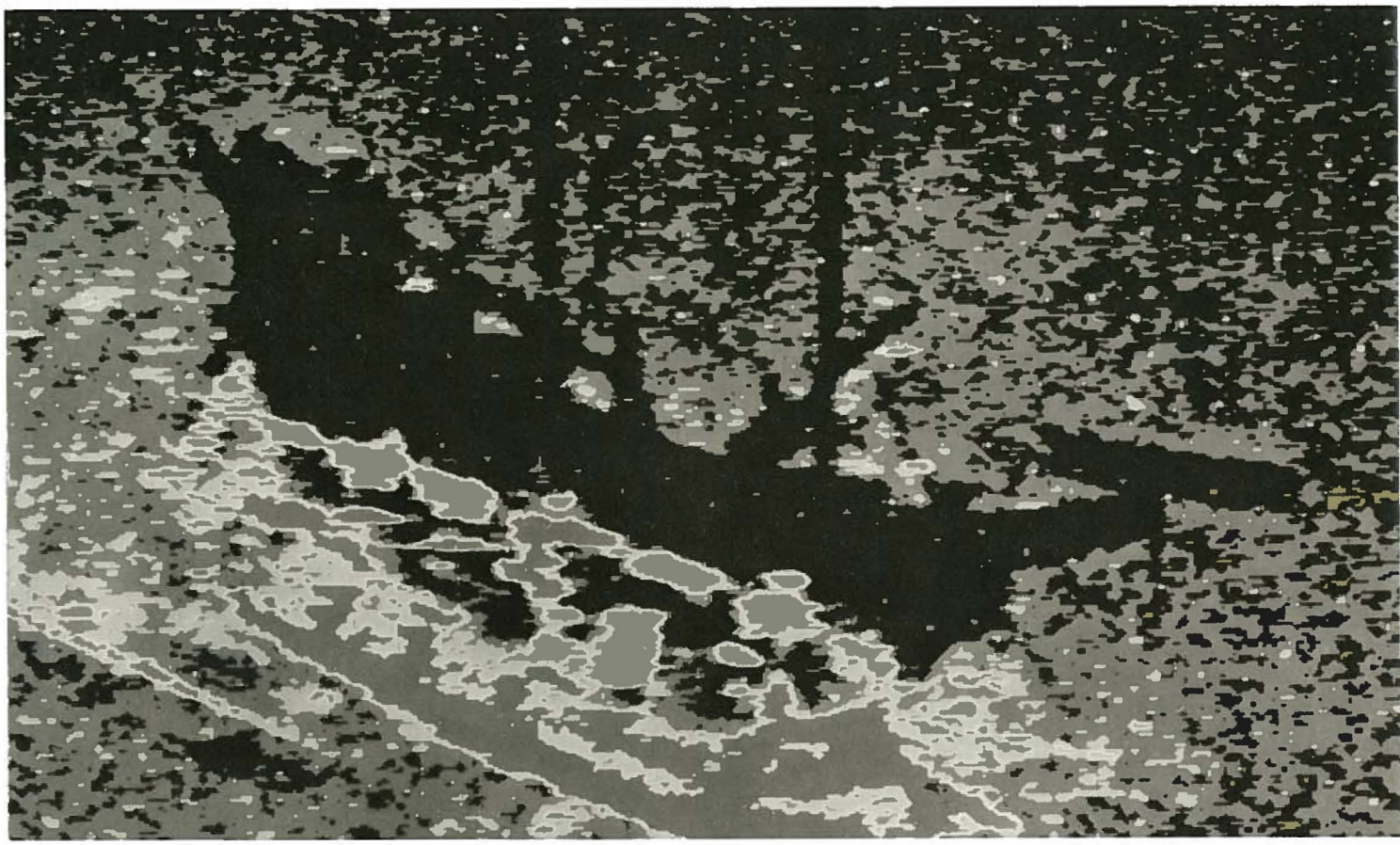
Specific tasks undertaken during the reporting period included the coordination and editing involved in preparation of the JPL Five-Year Plan. This plan, which is updated annually, is an internal working document designed to record and communicate important principles, intentions, objectives, guidelines, and decisions that collectively express what the Laboratory is doing, its future directions, and the actions believed necessary to accomplish its objectives. As in previous years, programmatic plans and budget projections of both NASA and the Department of Energy were examined by OPR and considered in establishing the Laboratory's planning goals.

In selecting technical work to be performed in-house, the Laboratory emphasizes tasks involving research, innovative technology, and the development and demonstration of advanced concepts. Certain key functions in the management of major projects are also performed in-house. These practices were strengthened by a formal make-or-buy policy that expresses JPL's intention to use industry in the performance of technical work to the maximum extent feasible.

A new policy statement on reviews was completed. The Laboratory's work output and all proposals for new work will be reviewed for quality and consistency with JPL objectives and commitments, to aid cognizant managers in making decisions. Formal reviews will be conducted when the activity or proposal involves large dollar amounts or major tasks, or affects important future assignments or institutional policies.

At the Director's request, OPR initiated a comparative study of JPL program offices, examining their functions and approaches, and identifying their similarities and differences.

As the focal point for Laboratory-wide manpower plans, the OPR made recommendations for manpower allocation to the operating elements of the Laboratory. The Office also coordinated the semiannual preparation of the Program Operating Plans (POPs) for NASA, which provide budgetary estimates of dollar and manpower requirements for each NASA program supported by the Laboratory. Each POP deals with the



current and six future budget years, in accordance with NASA guidelines.

The Office participated in a management intern program, which enables qualified JPL employees with relatively little experience to join the OPR staff on a temporary basis. Two management interns assisted in various studies and supporting activities, gaining valuable experience and an exposure to the Laboratory at large.

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. From a total of $550,000 in Fiscal Year 1978, the fund will increase to $750,000 in FY 1979 and $1,000,000 in FY 1980 under terms of the new JPL/NASA memorandum of understanding. Grants vary from $15,000 to $60,000 per task.

Work completed in 1978, with research cooperation from other institutions indicated where applicable, included these diverse tasks:

1 Demonstration of the feasibility of a multiple-wavelength laser using mixed metal halides as the lasant.
2 Photometric studies of Saturn's rings (Lowell Observatory and University of Massachusetts).
3 Digital image processing techniques to detect Uranus' ring system and gross features of the planet's surface.
4 A speech-operated telephone for use by the severely handicapped.
5 Zeolite catalysts for hydrogen production from waste heat (Caltech).
6 A potential system for guiding automated vehicles using discrete markers.

Continuing studies or innovations initiated during the reporting period:

1 Development of instrumentation to study the clinical significance of bone-marrow temperature in children with leukemia (with Children's Hospital of Los Angeles).
2 Infecting corn roots with a nitrogen-fixing bacillus to increase crop yields (with University of California, Davis).
3 Developing photo-activated catalysts on polymeric supports for the fixation of small molecules (with Caltech).
4 Detailed theoretical studies of the electronic structure of semiconductor interfaces using electron spectroscopy for chemical analysis.
5 Photochemical production of hydrogen from water using the long wavelength radiation of sunlight (with Caltech).
6 Guayule cell culture research for a potential alternate source for rubber (with University of California, Irvine).

A total of 47 projects received grants from the fund during the calendar year.

Quality Assurance and Reliability

Following the launch of the Voyager spacecraft in 1977, the JPL Quality Assurance and Reliability Office realigned its work force to support both current planning activities and the Galileo Project in 1980. During 1978, the Office was assigned a new responsibility to assess and report the Laboratory's performance relative to formal

(Left) This JPL-enhanced acoustic image by sidescan sonar is of the U.S.S. Hamilton, an American armed schooner sunk in Lake Ontario as a result of a storm during the War of 1812, and now resting on the bottom 300 feet deep. Images obtained by the Canada Centre for Inland Waters were improved by the Image Processing Laboratory at JPL.

(Above) An imaging library was opened at JPL to provide a reference library of planetary and satellite images returned by space missions during the past 20 years, in addition to Earth-based photography, and topographic and geologic maps produced from space images. These can be retrieved on computerized video monitors.

reviews and to recommend areas for improvement. At year end, the circumstances of the Seasat in-flight failure were being reviewed to determine any need to reorient JPL reliability program efforts.

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 1978, the Office of Patent Counsel reported 331 inventions to NASA, 237 of them by Caltech/JPL employees. Patent applications were filed by outside counsel in 97 cases, 62 on behalf of NASA and 35 on behalf of Caltech. Of the more than 300 U.S. patents acquired by Caltech in the last 30 years, over 100 have been licensed. At the end of 1978, 33 of these patents were still under active license, resulting in 12 commercial products being sold by industry and several more under development.

Technology transfer is promoted by the Technology Utilization Office, which mailed over 15,000 information packets in 1978 to persons or firms seeking information about innovations created at JPL.

Administrative Divisions

Funding for JPL's ongoing tasks and new efforts in research and development during the Fiscal Year 1978 amounted to $277,100,000—the highest in the history of the Laboratory. Energy & Technology Applications tasks are included in this amount, and accounted for $53,400,000 or 19% of the total Laboratory activity. Funding for construction of facilities totaled $11,000,000 during Fiscal Year 1978.

More than 22,000 procurement actions totalling $157,600,000 were conducted, with $3,100,000 going to minority businesses, an increase of 78% over 1977 in this category. Procurement activities involved all major projects at the Laboratory and included a number of new areas such as Electric Hybrid Vehicles and Solar Thermal Power in the Energy & Technology Applications sector.

Since the 1971 San Fernando earthquake, the Laboratory has had a program aimed at better understanding the seismic risk in the JPL area. As a result, construction funds in Fiscal Years 1978 and 1979 have been provided to strengthen nineteen buildings. Work is well underway or completed on ten of the buildings.

The hiring and upgrading of minorities and women continue on an upward trend despite a tightening in the labor market. Career advancement opportunities have been broadened through career counseling, a management intern program, an off-Lab study program leading to a bachelor's degree in business administration, and various professional and management development courses. An employee assistance program was instituted for short-term counseling and referral services for employees who have been identified as having emotional and personal problems, or problems involving alcoholism.

To enhance the communication link, a microwave system was installed to provide voice, data, and video services between the Caltech campus and the Laboratory.

Special Recognition

The NASA honor awards program has afforded special recognition of a number of outstanding individual contributions. The following combines the awards lists for 1977 and 1978 because the 1977 awards were announced too late to be mentioned in the corresponding annual report.

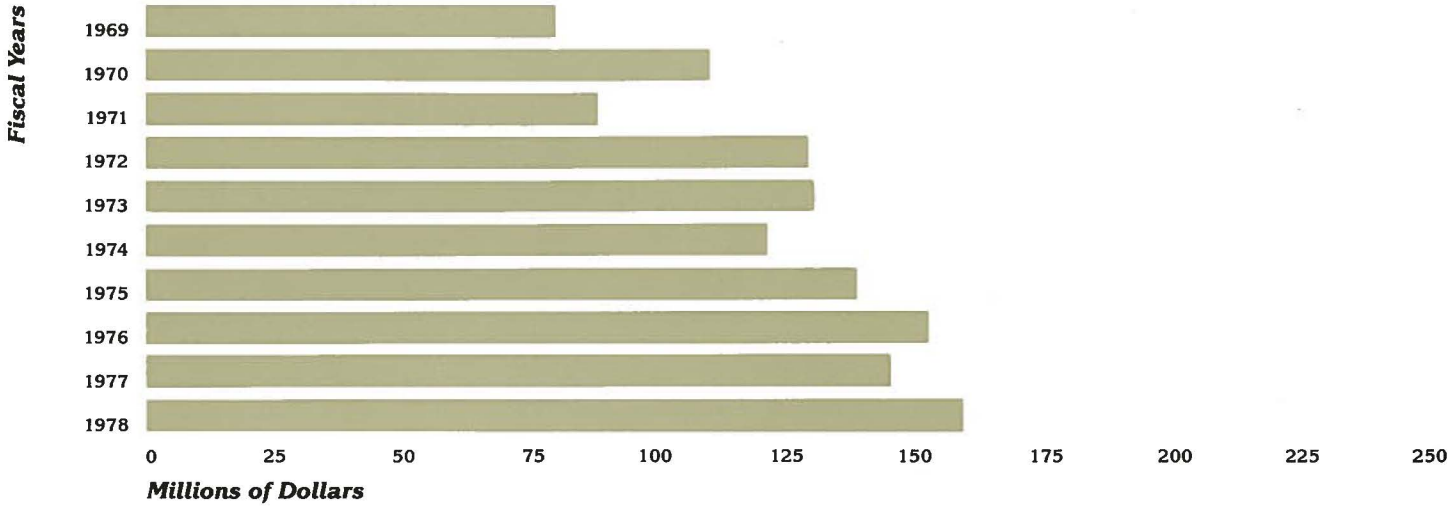
Geoffrey Robillard, NASA Outstanding Leadership Medal.

Jay H. Lieske and Gunnar Fjeldbo Lindal, NASA Exceptional Scientific Achievement Medal.

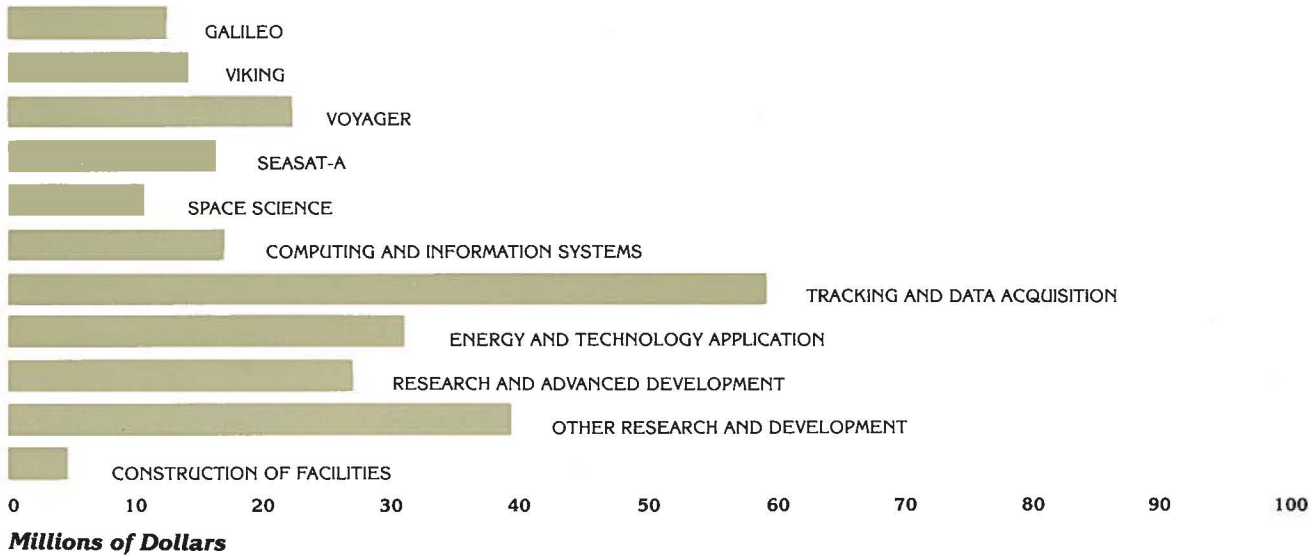
Walter H. Anderson, Stanley A. Butman, Mahlon F. Easterling, Claude E. Hildebrand, Carl W. Johnson, George E. Nichols, Floyd W. Stoller, and Walter K. Victor, NASA Exceptional Service Medal.

In addition, six NASA Group Achievement Awards were presented in recognition of especially noteworthy accomplishments involving many other persons in team efforts.

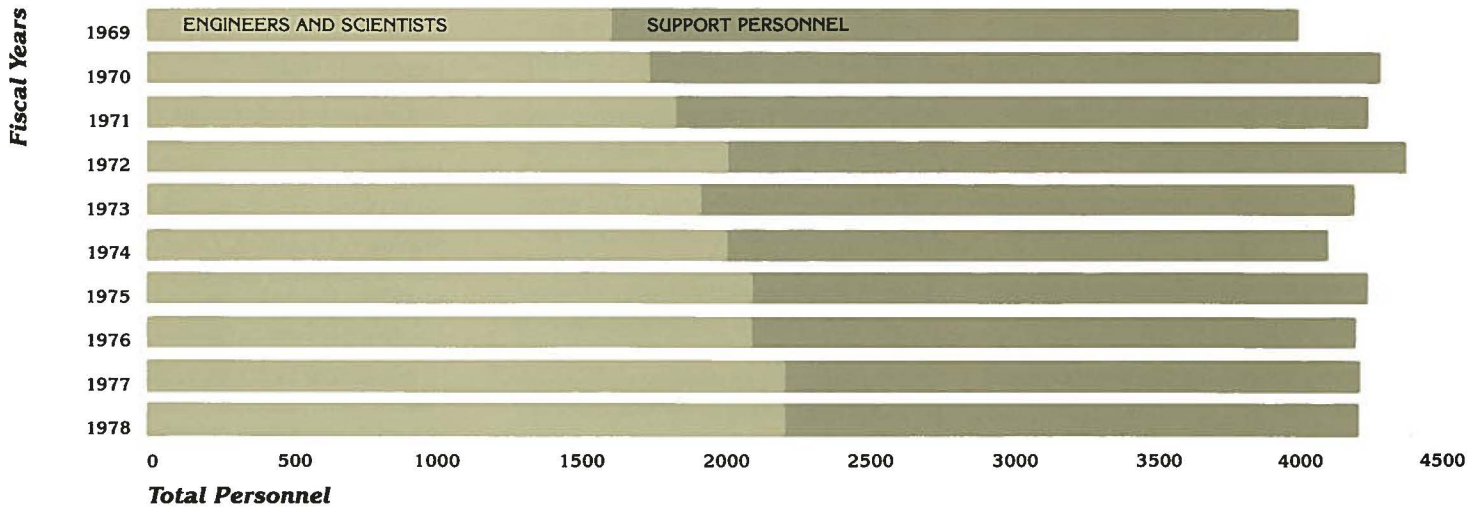
Procurement Costs

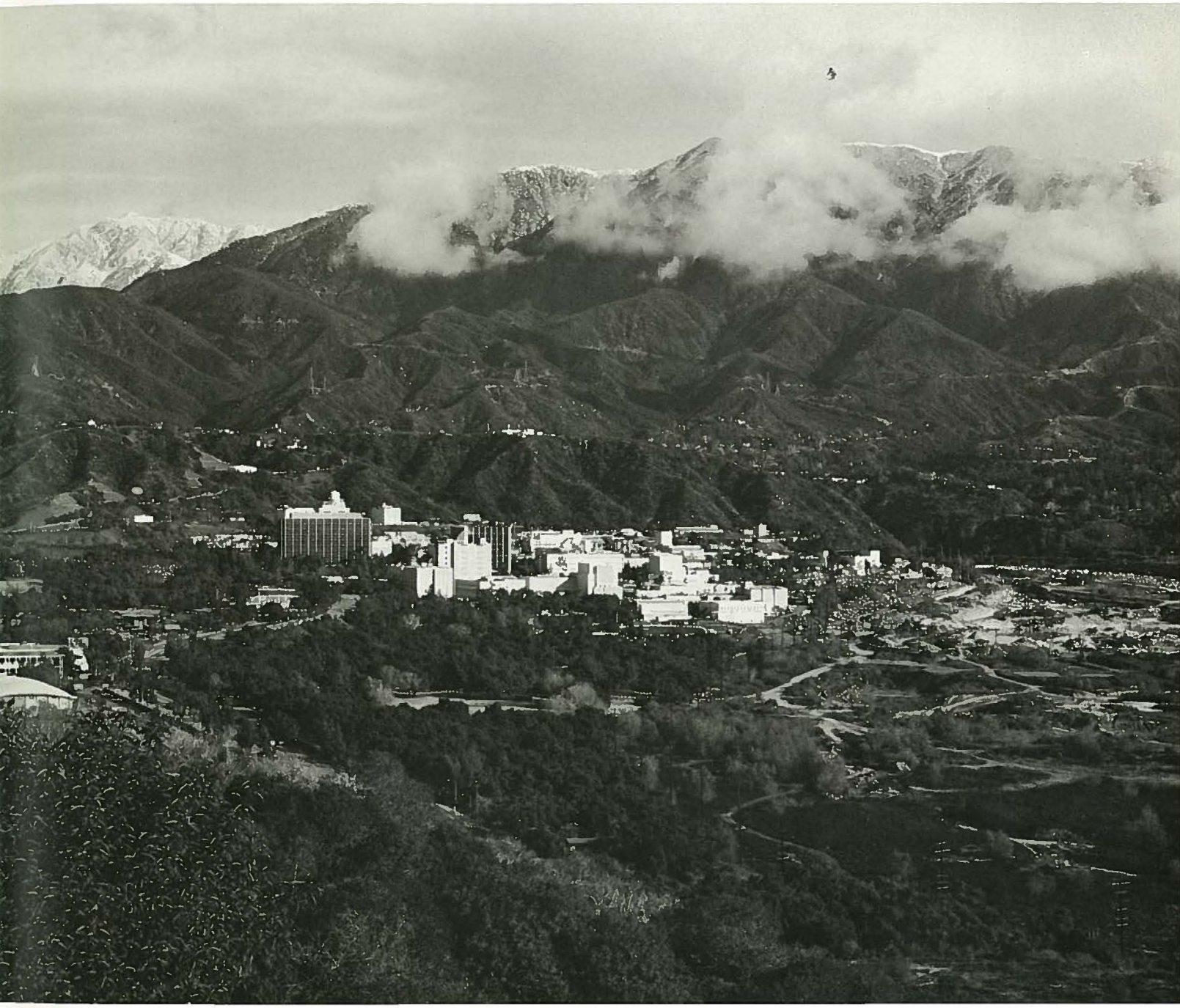


Fiscal Year 1978 Costs



Personnel





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