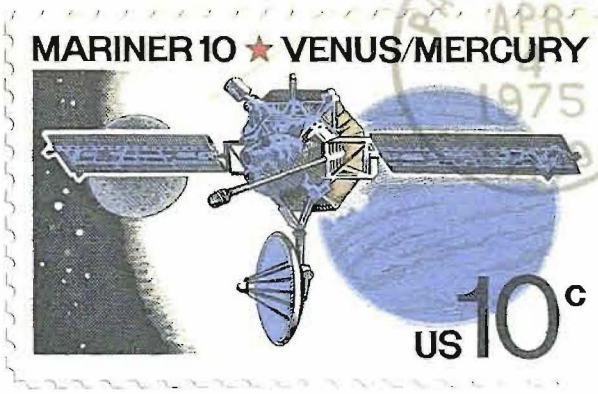

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1975

Jet Propulsion Laboratory 1974-1975 Annual Report

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 July 1, 1974, to June 30, 1975.

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Cover The Mariner 10 commemorative postage stamp was officially issued by the U.S. Post Office in a first-day-of-issue ceremony held at the Jet Propulsion Laboratory on April 4, 1975.

The planet Mercury figured spectacularly in the year's flight activities. The second and third encounters of the sun's closest neighbor by the Mariner Venus/Mercury 1973 spacecraft were historic accomplishments in space exploration.

Testing of the two Viking Orbiters was completed at the Laboratory, and the spacecraft were shipped to the Cape for launch preparations. The Mariner Jupiter/Saturn 1977 Project evolved into the definition and planning of science and mission operations, and fabrication of subsystems was begun.

During the fiscal year, JPL was assigned management of the SEASAT-A Project, designed for 1978 launch to demonstrate the capability for making ocean state measurements from polar orbit. The mission will be a precursor for later operational systems.

The Laboratory continued to support the Pioneer 10 and 11 missions to Jupiter and Saturn and participated in preliminary work on the Pioneer Venus 1978 Project. JPL provided mission and tracking support for the Helios 1 spacecraft, working in conjunction with a West German team.

Planning proceeded for a proposed Mariner Jupiter/Uranus 1979 mission. An authorized FY 1977 project start would enable this effort to interface with the Mariner Jupiter/Saturn 1977 Project at minimum cost.

The year was productive in other areas of Laboratory commitment. Project ARIES gathered data in a system of distance measurements across fault lines that may develop into an earthquake early-warning system. Research and advanced development continued as a significant JPL effort, including such tasks as x-ray photoelectron spectroscopy, drop dynamics, laser technology, and photovoltaic research.

Major trends were beginning to emerge in non-space fields. Energy research promises to achieve prominent stature during the 1970s and 1980s in the Laboratory's evolvement as a national resource facility. Projects included definition of a national geothermal energy program and development of low-cost silicon arrays in an effort to improve industry's capacity to utilize solar radiation in reducing the nation's dependence on fossil fuels.

The hydrogen injection engine project entered the vehicle system design phase. A study on alternative automotive power plants for the future was completed in collaboration with the Environmental Quality Laboratory.

The Deep Space Network supported the Mariner 10 mission, several of the Pioneer series, and Helios 1. The DSN was geared to provide full coverage of the dual Viking mission that will culminate in landings on the surface of Mars in mid-1976.

JPL personnel participated in a task instituted by the NASA Administrator that would attempt to define and forecast the trends and capabilities of the national space program during the next quarter century. This study examined all aspects of the program, ranging from the contribution of space science and technology to the quality of life through the social, political, and economic impact of space on the total society.

W. H. Pickering
Director

Flight Projects

Major project activities at the Laboratory during the 12-month period ending in June 1975 included

(1) Completion of the extended mission phase of the Mariner 10 dual-planet flyby mission to Venus and Mercury.

(2) Conclusion of the development and fabrication of the Viking Orbiter spacecraft, and continuation of the planning and checkout of mission support activities for launchings in August 1975 and for gathering data from orbit and Lander operations at Mars in 1976.

(3) Continuation of spacecraft development and mission operations planning for the 1977 launches of two Mariner dual-planet missions, each to fly by Jupiter and Saturn.

(4) Initiation of development of an ocean observation satellite, SEASAT-A, including mission operations planning for placing the satellite in earth orbit in 1978.

JPL also continued to be heavily involved in providing significant flight operations support to the Pioneer 10 and 11 flyby missions launched toward Jupiter and Saturn. Additionally, technical consultation and mission operations support continued to be furnished on the West German–US Helios missions to investigate solar phenomena to within approximately 0.30 astronomical unit (45 million kilometers) of the solar surface.

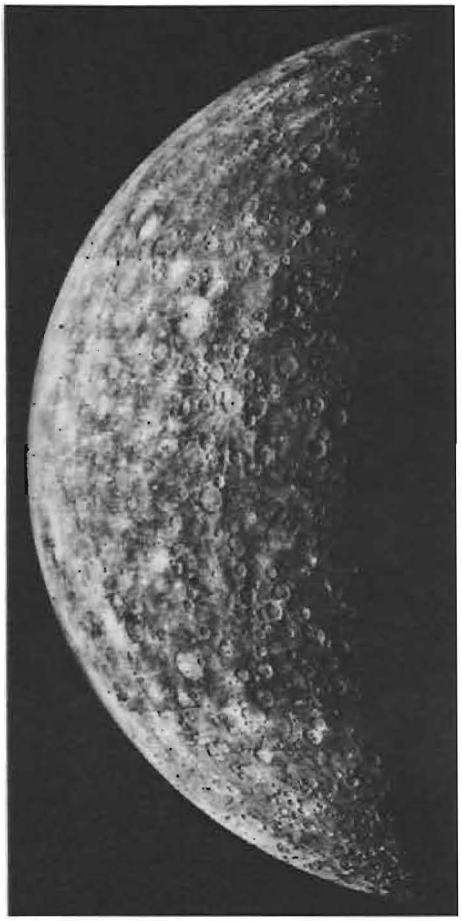
Mariner Venus/Mercury 1973

Mariner 10 exhausted its attitude control gas supply on March 24, 1975, and the spacecraft transmitter was turned off. The end of the historic flight of Mariner 10, after 506 days and nearly 1.6 billion kilometers of travel since liftoff on November 3, 1973, marked the completion of the world's first dual-planet gravity-assist mission.

Artist's concept of Viking spacecraft.

Following successive flybys of Venus at 5000 kilometers on February 5, 1974, and Mercury at 703 kilometers on March 29, 1974, trajectory correction maneuvers were executed that resulted in a second flyby of Mercury at 50,000 kilometers on September 21, 1974, and a third at 327 kilometers on March 16, 1975.

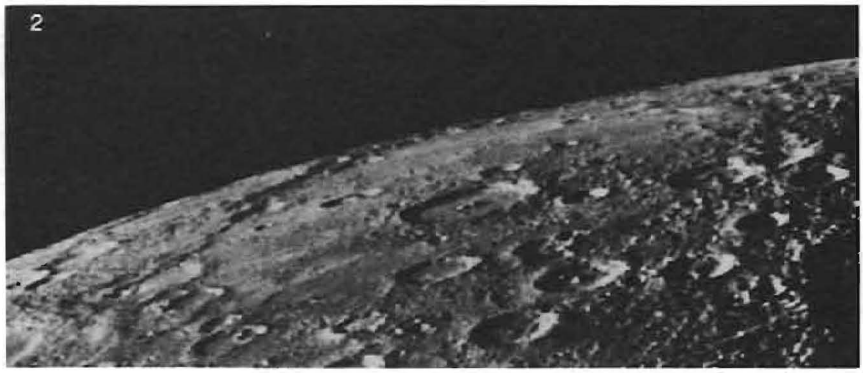
Man's knowledge of the two innermost planets of the solar system has been dramatically enlarged by the Mariner 10 mission. The large amount of data returned, including 3500 photographs of Venus and 3700 of Mercury, has resulted in information of great scientific value concerning these two planets—and has raised additional questions yet to be answered by future missions.



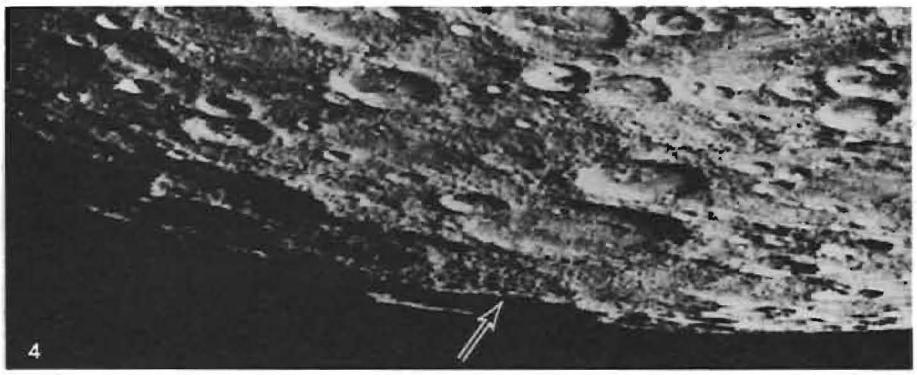
The Venus encounter yielded new information regarding the planet's atmosphere, atmospheric flow, and solar wind interaction, extending and complementing results obtained by previous Mariner and Venera spacecraft. A comet-like plasma tail, extending hundreds of Venus radii downstream, was observed. Ultraviolet spectroscopic measurements revealed the presence of atomic helium in the atmosphere and ten times the amount of atomic oxygen existing at Mars, placing an important limit on vertical atmospheric mixing. Radio propagation and television observations of the upper atmosphere indicate the presence of stratification, specifically two distinct aerosol-bearing haze layers above the tropopause. Near-ultraviolet imaging showed, in remarkable detail, a symmetrical but complex system of cloud-like patterns, indicating circulation in the upper atmosphere in the same retrograde direction as the planet's rotation. However, the atmospheric circulation has a period of about 4 earth days, compared with 243 for the solid surface, and develops into vertical vortices at the poles.

Mercury, the smallest planet of the solar system, has always been difficult to observe because of its size and proximity to the sun. The best earth-based photographs have revealed only an enigmatic, virtually featureless disc. Mariner 10's three successive flybys of Mercury have dispelled much of the mystery surrounding the sun's closest neighbor. The photographs reveal a highly cratered moon-like surface with vast areas strikingly similar to the lunar highlands and maria, suggesting a well developed crust some tens of kilometers thick of a silicate composition resembling that of the moon. The existence of a light crust on a high-density planet indicates it to be chemically differentiated, i.e., moon-like near the surface and earth-like in the interior.

Photomosaic of Mercury made from Mariner 10 pictures taken at a distance of 234,000 kilometers from the planet.



1. Largest structural feature discovered on Mercury is a basin 1300 kilometers in diameter, bounded by mountains as high as 2 kilometers. 2. Mercury's northern limb showing scarp hundreds of kilometers long is believed to be the result of compression due to crustal shortening. 3. Fresh impact crater, photographed from a distance of 34,000 kilometers, has a diameter of 120 kilometers. 4. Mercury's south pole, located inside a large crater, was photographed during Mariner's second flyby.



Analysis of data from the ultraviolet experiment indicates that Mercury is surrounded by an extremely thin atmosphere having helium as a prime constituent at a partial pressure at the terminator of about 5×10^{-12} millibar. The total pressure of the atmosphere at the surface is less than 2×10^{-9} millibar, which contrasts with a pressure of approximately 980 millibars at the sea level of earth.

A particularly surprising discovery was a planet-related magnetic field acting as a barrier to solar wind flow toward the surface. Mariner's third encounter with Mercury showed that this field is of internal origin. Thus Mercury joins the earth and Jupiter in the list of planets possessing internally generated magnetic fields. While this finding is consistent with the concept of a large iron core in Mercury, it is somewhat puzzling in light of Mercury's slow rotation.

The results of the celestial mechanics experiments have confirmed that the mean density of Mercury is 5.44 grams per cubic centimeter, only slightly less than that of earth, and that its equatorial diameter of 4878 kilometers, as contrasted to earth's diameter of 12,750 kilometers, is in close agreement with measurements made by earth-based radar.

The success of the Mariner 10 mission is an achievement not only in interplanetary scientific exploration and engineering but also in project management. In the words of the Administrator at NASA, "The Project Team developed and agreed to a restrictive financial plan at the onset, and proceeded to deliver full performance on time and under the cost estimate."

Viking Mars 1975

The Viking Project comprises two missions designed to orbit and soft-land spacecraft on the surface of Mars. Each spacecraft consists of an orbiter carrying a sterilized capsule to be landed by parachute, and braking rockets. The spacecraft will be launched by Titan/Centaur vehicles in August 1975, with the first landing scheduled to occur on July 4, 1976.*

The basic objective of the Viking missions is to make direct measurements in the atmosphere and on the surface of Mars, and to make observations of the planet during approach and from orbit. Particular emphasis is being placed on obtaining data concerning biological, chemical, and environmental factors that may indicate the past, present, or potential existence of some form of life on the planet.

The Langley Research Center of NASA has overall management responsibility for the Viking Project. The Lander System has been developed under contract to Langley by the Martin-Marietta Corporation, and the Lewis Research Center has responsibility for the Launch Vehicle System. JPL's assignment is the development of the Orbiter System, the Tracking and Data Acquisition System activities, and the Mission Control and Computing Center System.

The Orbiter System serves as the Lander capsule transport through the launch, cruise, orbit injection, and surface surveillance phases prior to capsule detachment and descent to the surface. During descent and after landing, the Orbiter acts as a radio relay to earth for data coming from the Lander.

The objectives of the Orbiter System, in addition to placing the Lander into a Mars orbit suitable for a landing sequence and serving as a communications relay between the Lander and earth, are to obtain visual, thermal, and water vapor data while in orbit. Information derived from these data will be used to select sites for the Landers and permit further investigation of the dynamic characteristics of the planet and its atmosphere. Radio experiments will obtain data that will improve planetary navigation capabilities and, through measurements of radio propagation characteristics in and through the Martian atmosphere, provide additional information concerning the properties of the atmosphere.

Viking Orbiter (lower portion of spacecraft) will transport the Lander to Mars.

Each Orbiter carries two television cameras with color filters and high-resolution telescopes to provide visual imaging of the planet's surface. Water vapor mapping will be accomplished with an infrared spectrometer, and thermal mapping will be carried out by an infrared radiometer.

Each Lander contains eight science investigation packages. These packages provide instrumentation for imaging, biological, molecular analysis (organic), and chemical analysis (inorganic) experiments and for meteorological, seismological, and magnetic and physical properties measurements.

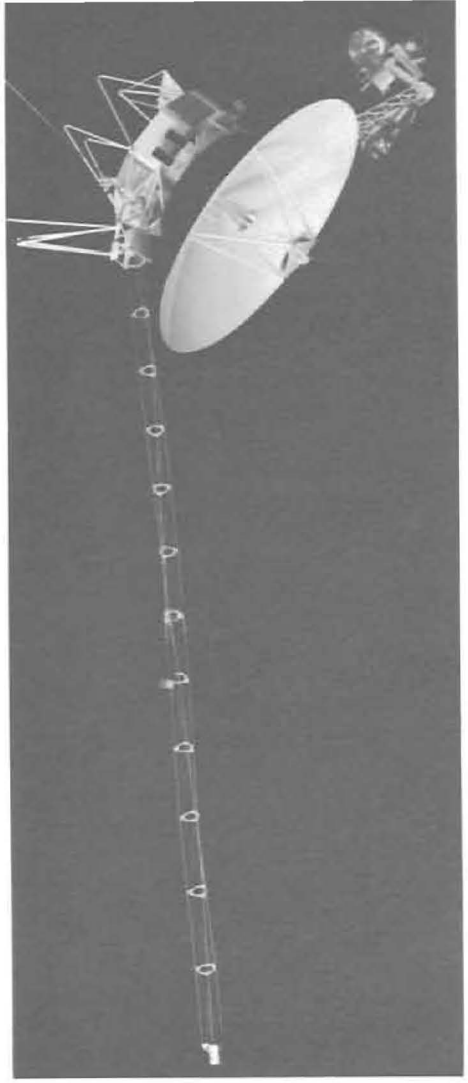
Upon completion of the pre-shipment review in January 1975, both flight Orbiters were delivered by the Laboratory to the Eastern Test Range at the Kennedy Space Center to undergo final checkouts and assembly with the Landers. Following intensive interface and system testing, the Orbiter and Lander were mated for the first time in March as part of the overall flight compatibility testing program. The Orbiter/Lander assembly was then encapsulated inside the shroud of the Centaur stage and mated with the Titan III-D launch vehicle for additional compatibility testing. All tests were successfully completed.

Both flight Orbiters are now in final flight preparation, with the mating operations for the first launch scheduled to start in early July. Target for the first launch is August 11; the second launch is scheduled for August 21.

Viking mission operations test and training activities have involved the participation of a considerable number of JPL personnel, including people from the Deep Space Network and the Office of Computing and Information Systems. Extensive ground data system and computer software testing was performed to ensure that a full capability exists to acquire and process the data returned from both the Orbiters and the Landers. Special tests were conducted between the flight spacecraft at the Eastern Test Range and the Viking Mission Control and Computing Center at JPL to verify the overall compatibility between the systems.

Orbiter science planning continued, and the Orbiter and Lander mission design documents were published. Primary and alternate landing sites have been selected that will allow the Orbiter investigations to fully complement the Lander investigations while the Orbiter instruments conduct surface surveys.

* Viking 1 was launched on August 20, 1975, and will arrive at Mars on June 19, 1976. Preparations for the launch of Viking 2 were under way at the time of this printing.



Model of Mariner Jupiter/Saturn 1977 spacecraft.

Mariner Jupiter/Saturn 1977

The Mariner Jupiter/Saturn 1977 Project, being managed by the Laboratory, involves the launching of two spacecraft in August and September 1977 on flyby missions to Jupiter and Saturn. Each spacecraft will successively encounter Jupiter in 1979 and Saturn in 1981 using energy acquired by gravity turns at Jupiter to accelerate it on its trajectory toward Saturn. The basic objectives of the Project are to further knowledge concerning the origin and the properties of the two largest planets of the solar system and to gain additional information on the characteristics of interplanetary space in the vicinity of the outer planets. Particular emphasis is being placed on obtaining data on the environments, atmospheres, and surface and body features of the two planets, including investigations of one or more of their satellites and the rings of Saturn.

Power for operation of the fully attitude stabilized spacecraft will be provided by radioisotope generators under development by the Energy Research and Development Administration (ERDA). The spacecraft, each carrying a mission module weighing approximately 775 kilograms, will be launched by Titan IIIE/Centaur D-IT vehicles, with the final velocity increment being provided by a spacecraft propulsion module. The mission module is an extension of the Mariner spacecraft family, augmented in capability to meet the requirements for 4 or more years of operational life, longer-range communications, precision navigation, solar-independent power, and resistance to the radiation at Jupiter, and to provide in-flight adaptive capability to support the science investigations.

Instruments are under development to support eleven distinct but complementary investigations of the planets, their satellites, and the interplanetary and interstellar media. Five optical instruments, which can view the entire celestial sphere, are mounted on a scan platform. On-board computer systems will adapt spacecraft and instrument operations to the differing data acquisition requirements at Jupiter and Saturn, and during other mission phases. The use of X-band as well as S-band communications frequencies and a large directional antenna permits data to be returned at very high rates at both Jupiter and Saturn. Data return should be achieved to a distance of at least 20 astronomical units (3 billion kilometers) reached 8 years after launch.

During the past year, activities have focused on detailed definition, review, and fabrication of spacecraft subsystems and instrumentation, leading to the assembly and test of the initial spacecraft system in mid-1976. As a result of Pioneer 10 and 11 measurements of the severe radiation environment at Jupiter, a major activity has been to assess the spacecraft design relative to the ability to survive and make meaningful scientific measurements in this environment. Component parts, materials, and circuit design have been analyzed and tested for radiation effects. Redesign, parts substitution, and processing changes have been undertaken where appropriate, and moderate amounts of shielding have been incorporated into the spacecraft structure.

Detailed planning of the science observation sequences and mission operations was also begun, based on preliminary trajectories. A mission operations system capability required to control and support spacecraft operations has been defined and reviewed.

SEASAT-A

The SEASAT-A Project was initiated in the fall of 1974, with the Laboratory being assigned the Project management role. The Project is being conducted for NASA's Office of Applications and is a proof-of-concept mission for a program that is expected to culminate in an operational system. The launch of SEASAT-A, an earth-orbiting ocean observation satellite, is planned for the spring/summer of 1978, and the satellite will be operated in orbit for at least 1 year.

The SEASAT-A objectives include

(1) Demonstrating a capability to make important applications-oriented ocean measurements from orbit.

(2) Providing these data to a broad group of users interested in applying them for economic and social benefit.

(3) Investigating and demonstrating key techniques needed for future operational systems.

The satellite instrumentation will measure such physical characteristics as surface winds, surface water waves, currents, ice fields, bergs and leads, conditions in coastal regions, and the geoid.

Users associated with the Project are a number of interested government agencies (National Oceanic and Atmospheric Administration, Department of Defense), research institutions (Scripps Institute of Oceanography), universities (City University of New York, University of Michigan), and private industry (Sea Use Council). Foreign participation is also expected. The SEASAT concept is in large part the creation of these user representatives, who have been involved in the planning of the Project from the outset, operating as a group termed the SEASAT Users Working Group.

The satellite will consist of a spacecraft bus carrying a sensor (payload) module. The module will contain the five flight sensors, their antennas, and supporting control and data handling equipment. Four of the sensors will use microwave radar techniques to obtain surface information. They include a short-pulse radar altimeter, a wind measuring sensor or scatterometer evolving from Apollo and Skylab flights, a synthetic aperture radar which will provide images of wave patterns, ice fields, etc., and a scanning multichannel (five-frequency) microwave radiometer (SMMR), which will provide global sea surface temperature data. The fifth instrument is a visible and infrared radiometer derived directly from an Improved Tiros Operational Satellite (ITOS) Project experiment.

The satellite will orbit at an 800-kilometer altitude and will be able to detect conditions at the ocean surface through cloud cover as well as in areas where the atmosphere is clear. Fourteen orbits will be flown each day, providing a network of data over the oceans between 72° north and south latitudes.

Data will be returned to earth on an orbit-by-orbit basis and will be studied by the users as they are collected during the mission. The daily worldwide network of information will be combined with data from local sources to provide detailed knowledge of what can be learned from orbit with these kinds of sensors, and to yield for the first time integrated coverage of the whole ocean surface over a full seasonal cycle.

The Project is planned so as to use existing equipment and facilities to the maximum extent appropriate. Development is being limited mainly to the radar instruments and to methods for the handling of the data produced. The satellite bus will employ an already designed spacecraft obtained by a competitive bidding process from industry. The synthetic aperture radar and the SMMR are being provided by JPL, the altimeter by the Wallops Flight Center, the scatterometer by the Langley Research Center, and the visible and infrared radiometer by the Goddard Space Flight Center. The data collecting and recording activity will use the satellite tracking and operations facilities operated by Goddard Space Flight Center. Some users plan significant data processing activities employing their own facilities and resources.

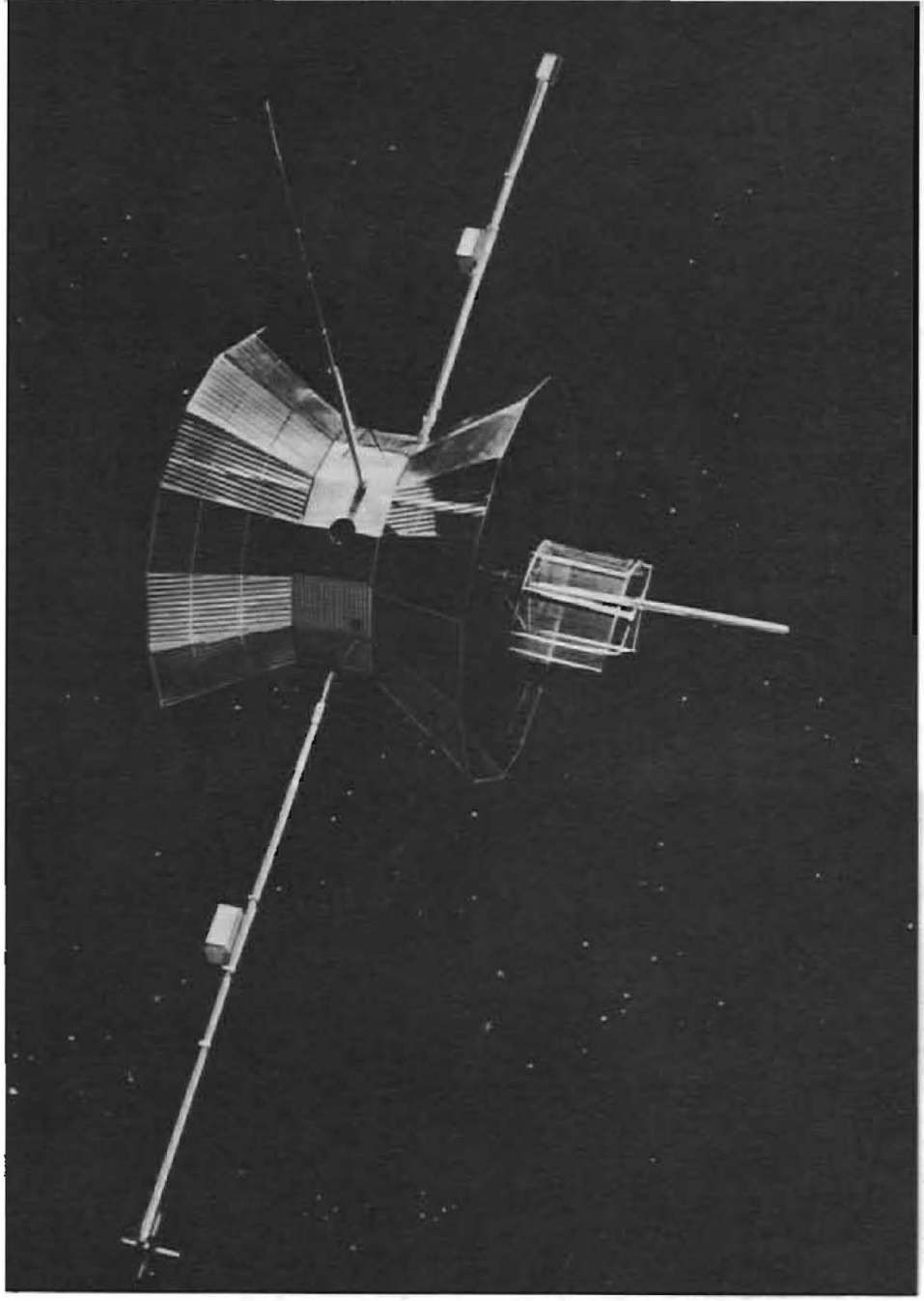
SEASAT A, to be launched in 1978, will make ocean measurements from orbit.

Other Project Activities

The Laboratory is participating in the Pioneer Venus 1978 Project, managed by the Ames Research Center. This Project includes a multiprobe mission and an orbiter mission to Venus to investigate the Venusian atmosphere and surface. JPL will assist the Project by providing navigation, tracking, and data acquisition and computing support to both missions.

Support to the Pioneer and Helios Projects is continuing. The Pioneer 10 and 11 missions to Jupiter and Saturn are managed by the Ames Research Center of NASA, with JPL being responsible for the spacecraft navigation, operations and analysis, tracking and data acquisition, and computerized mission control support. The US–West German joint Helios Project is co-managed on behalf of the United States by the Goddard Space Flight Center. JPL is providing technical advice and support on mission operations, spacecraft design and testing, tracking and data acquisition, mission control computing, and navigation.

One year after the first flyby of Jupiter by Pioneer 10 on December 3, 1973, Pioneer 11 encountered Jupiter at a distance of 43,000 kilometers from its equatorial cloud cover. During the 60-day encounter phase with Jupiter, the ground-based data acquisition and reduction system obtained significant data concerning the largest planet in the solar system. These data, transmitted over a distance of 5-1/2 astronomical units (800 million kilometers), provided new and revealing information on features of Jupiter, including the infrared, ultraviolet, polarized light, magnetic field, atomic particle, plasma, and micrometeorite characteristics and the atmospheric properties. Pioneer 11 has also given man his first view of the Jovian north and south polar regions. Following its passage of Jupiter and the doubling of its velocity by the planet's gravitational attraction, the spacecraft has been placed on a trajectory designed for a Saturn flyby in September 1979. Pioneer 10 is currently 7.5 astronomical units (1.26 billion kilometers) from earth and is on an escape trajectory from the solar system headed in the direction of the star Aldebaran.



Helios spacecraft.

After a series of comprehensive ground data system tests and compatibility checkouts, Helios A was launched by a Titan IIIE-Centaur-TE 364/4 vehicle from the Eastern Test Range on December 10, 1974, into a highly elliptical solar orbit having a period of 190 days and an inclination to the ecliptic of 0.016 degree. Operations were conducted by a German team at the JPL Space Flight Operations Facility until operations control was transferred to the German Space Operations Center near Munich in January 1975. The first perihelion passage, at 0.31 astronomical unit (46.3 million kilometers), on March 15, 1975, provided excellent data from the ten experiments, including plasma magnetometer, plasma and radio wave, cosmic ray, electron detector, zodiacal light photometer, and micrometeoroid analyzer measurements. The first solar occultation, between April 28 and May 15, yielded valuable data for the celestial mechanics and the faraday rotation experimenters. The second solar occultation will occur at the end of August and the second perihelion in September 1975. The second spacecraft, Helios B, is currently undergoing modification and testing in West Germany preparatory to shipment to Cape Kennedy in September and launch in December 1975.

The Laboratory has continued to fulfill the planetary quarantine role assigned by NASA in 1973. Quarantine research essential to future planetary missions has been carried out, and direct support has been given to ongoing flight projects by providing measures to control spacecraft contamination and conducting primary bioassays.

The primary prelaunch microbiological assay operations for the Viking spacecraft were conducted in the Planetary Quarantine Laboratory at the Eastern Test Range. The laboratory was arranged so as to permit activities in support of Langley Research Center, Martin-Marietta Corporation, and JPL to proceed separately but in a coordinated manner.

A long-range planetary quarantine planning document has been prepared for the NASA Headquarters staff. Contributions to this plan were collected from nationwide sources, including leading workers in the field of planetary quarantine, and plans were provided for updating it annually. In addition, a document entitled "Planetary Quarantine Provisions for Unmanned Extra-Terrestrial Missions" was prepared for NASA. This document, when approved and issued, will serve to elucidate national quarantine requirements for all planetary missions.

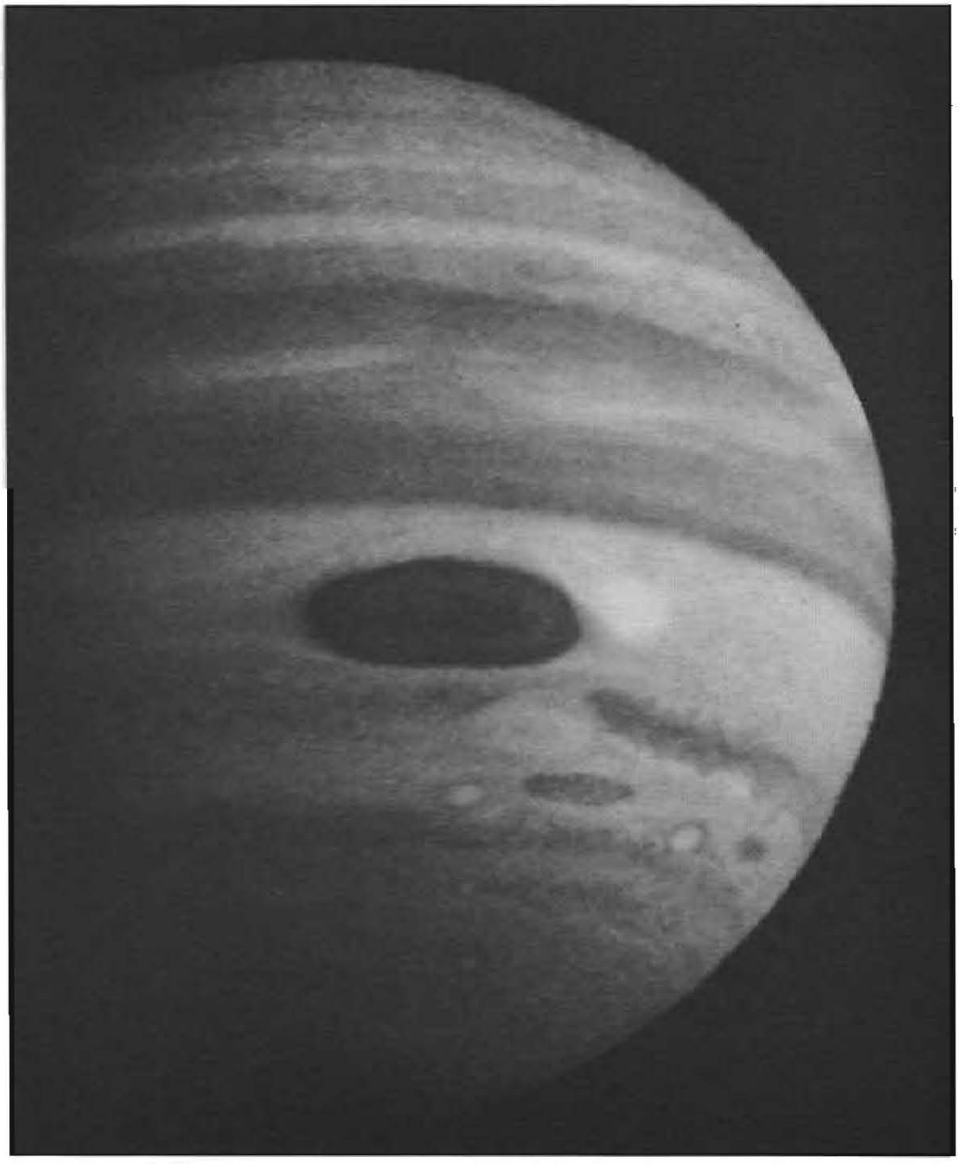
Planetary quarantine research this year was focused on two new areas. The first is concerned with the quarantine implications of using the Space Transportation System (Space Shuttle) for planetary vehicle launches. The second area involves preliminary investigation of planetary sample return missions and the methods by which returned samples can be examined, processed, and evaluated such that any possible threat to earth biological systems is minimized.

The Flight Projects Planning Office continued to investigate more cost-effective methods for carrying out future flight projects, both planetary and applications-oriented. Many approaches have been studied, ranging from standardization of designs at various levels to increasing the benefits to be derived from greater utilization of the experience from past projects. All of the approaches represent ways of reducing the engineering manyears required for future projects by taking advantage of the technology and design base generated during the past decade of space exploration and related activities.

Plans for a Mariner Jupiter/Uranus 1979 flyby mission were structured during the year, with particular emphasis on minimizing the cost of such a mission. It is hoped that a FY'77 Project start can be achieved for this mission and that an efficient joint implementation plan, coupled closely with the Mariner Jupiter/Saturn 1977 Project, will provide the means of accomplishing this objective.

Studies are in progress on candidate projects to start in 1978 and 1979. These include a ballistic flyby mission to the comet Encke in 1980 and various possible missions to orbit Jupiter in the time frame 1980–1983. Preliminary studies on a new family of spacecraft for orbiter-type missions during the 1980s to emphasize comparative planetology have also been initiated, and an increasing interest is expected in this program area.

Pioneer 11 photo of Jupiter taken from a distance of 1 million kilometers.



Earth

Project ARIES

Project ARIES (Astronomical Radio Interferometric Earth Surveying) began accurate measurements of a set of locations in the southwestern United States, starting at JPL in Pasadena, as a part of a program to study crustal motion for the purpose of earthquake hazard assessment.

Sixty hours of observational data were obtained over 10 months between the Goldstone 64-meter (Mars) station and the ARIES 9-meter transportable station located at JPL. Based upon analysis of two experiments, separated by 5 months and totaling 15 hours of data, the JPL/Goldstone baseline vector (approximately 180 kilometers in length) was measured with a precision of 15 centimeters or better in three dimensions. ARIES uses remote quasars and radio galaxies as a frame of reference for its measurements.

The Caltech Seismological Laboratory, in its geophysical advisory role, made gravity measurements to coincide with ARIES experiments. The ability to correlate vertical crustal deformations using completely different techniques could prove to be very important in the search for earthquake precursory phenomena.

The geodetic capabilities of the ARIES technique attracted the attention of the National Geodetic Survey (NGS). The NGS has incorporated Southern California ARIES sites into the National Gravity Base Network.

Surface Thermal Properties

A thermal model of the response of the earth's surface layer to diurnal heating has been developed. When the model is applied to aircraft or satellite measurements of surface albedo and midday and predawn temperatures, the thermal inertia of the surface can be inferred. Thermal inertia complements the use of spectral reflectivity data for lithologic mapping. The JPL Image Processing Laboratory created a thermal inertia image from aircraft day–night thermal and reflectance data of Pisgah Crater, California.

Antenna station being used by Project ARIES in studies of the earth's crustal motion.

Equipment in transportable ARIES station.

Moon

Magnetic Field

A theoretical study of the plasma environment around the moon has advanced the understanding of the lunar interior. Magnetometer data on the moon's induced magnetic field (obtained from surface instruments and from lunar orbiters) are most revealing when the moon is in the earth's geomagnetic tail. Previously published surface and orbital data attributed differences to a lunar ionosphere. The new study shows that no lunar ionosphere can exist while the moon is in the geomagnetic tail. An alternative explanation is that eddy currents in the lunar interior are generated by time-dependent external magnetic fields. This reinterpretation permits correct estimation of the magnetic permeability of the moon's interior.

Lunar Farside Gravity

Orbit analyses of the Apollo 15 and 16 subsatellites by two JPL/Caltech teams led to the determination of two independent farside lunar gravity fields. Although different modeling techniques were used, the teams' results agreed that the farside highlands show broad positive gravity anomalies, while the farside empty ringed basins manifest negative anomalies. This is strong evidence that the mascons are indeed due to the filling of large basins and not to buried remnants of the initial impactor that produced the basins.

Planets

Mars

Wind speeds were computed for three seasons on Mars. The maximum value of the mean zonal wind was 75 meters per second (270 kilometers per hour) for the northern winter season (during the waning phase of the 1971 dust storm), 56 meters per second (200 kilometers per hour) for the northern spring season, and 29 meters per second (105 kilometers per hour) for the northern summer season.

The first detailed map of Phobos, larger of Mars' two moons, was produced based on Mariner 9 high-resolution imaging data. Oblong in shape, Phobos wobbles about 5 degrees as it circles Mars in an apparently decaying orbit.

Thermal inertia image of Pisgah Crater shows response of earth's surface layer to heating by the sun.

Venus

Seven high-resolution (10 × 10 kilometer) radar images of portions of Venus were obtained. Each covers an area of about 1/270 of the planet's surface. Several images overlap slightly, and, within the overlap, correlate strongly. Each image shows topographic structure of great geological interest, such as craters, chaotic terrain, long rills, and great canyons.

Jupiter

As part of the JPL/University of Texas infrared astronomy program, new high-resolution (0.2 cm^{-1}) spectra of Jupiter were obtained in the 5-micron wavelength region using a Connes-type Fourier spectrometer at the McDonald Observatory 2.7-meter telescope. These spectra revealed for the first time the presence of a trace quantity of carbon monoxide in the lower atmosphere of the planet.

Analysis of two-way Doppler data from Pioneer 10 and 11 provided the first definitive measurement of the third-, fourth-, and sixth-degree zonal harmonics (J_3, J_4, J_6) of the Jovian gravity field. The second-degree harmonic, J_2, has also been measured with improved accuracy. The new results, which have an important application as boundary conditions for theoretical models of Jupiter's interior, are consistent with a planet in hydrostatic equilibrium.

The vector helium magnetometer carried by Pioneer 11 to its December 1974 encounter with Jupiter was identical to the one flown there a year before on Pioneer 10. Twofold changes were again observed in the size of Jupiter's magnetosphere. This dynamic magnetosphere with its many hydromagnetic wave phenomena extends outward about 100 Jupiter radii.

Pioneer 11 measurements, closer to the planet and providing better latitude and longitude coverage than the Pioneer 10 measurements, lead to larger estimates of Jupiter's dipole, quadrupole, and octupole fields, up to twenty times larger than the maximum on earth.

Bursts of energetic electrons upstream of Jupiter's magnetosphere were detected by Pioneer 10 and 11 experiments. A joint JPL/University of Chicago study found that the particles escape from the magnetosphere by traveling along interplanetary field lines, forming a beam of runaway electrons.

The Radio Astronomy Group measured variations in intensity and polarization of the microwave synchrotron emission from Jupiter's radiation belts and found that at the time of the Pioneer 11 encounter, the synchrotron emission was about 15% greater than during the Pioneer 10 encounter.

A sodium- and sulphur-rich surface, which evaporates in a steady stream, appears to be a unique feature of Io, Jupiter's innermost moon. This theory was advanced by a JPL team based on telescopic spectra made at Table Mountain and continuing theoretical studies. Their theory apparently explains the strong sodium D-line emission in Io's vicinity. The moon appears to be surrounded by a huge cloud of sodium vapor excited by sunlight scattering.

Radar echoes from Ganymede, Jupiter's largest satellite, were recently detected for the first time. The radar cross section is similar to that of the other terrestrial planets. The roughness measure, however, is considerably greater for Ganymede. Roughness is made evident in this experiment by the presence of echoes away from the center of the disk. A smooth target would reflect only a glint from the center, whereas a very rough one would reflect power from over the entire disk.

Saturn

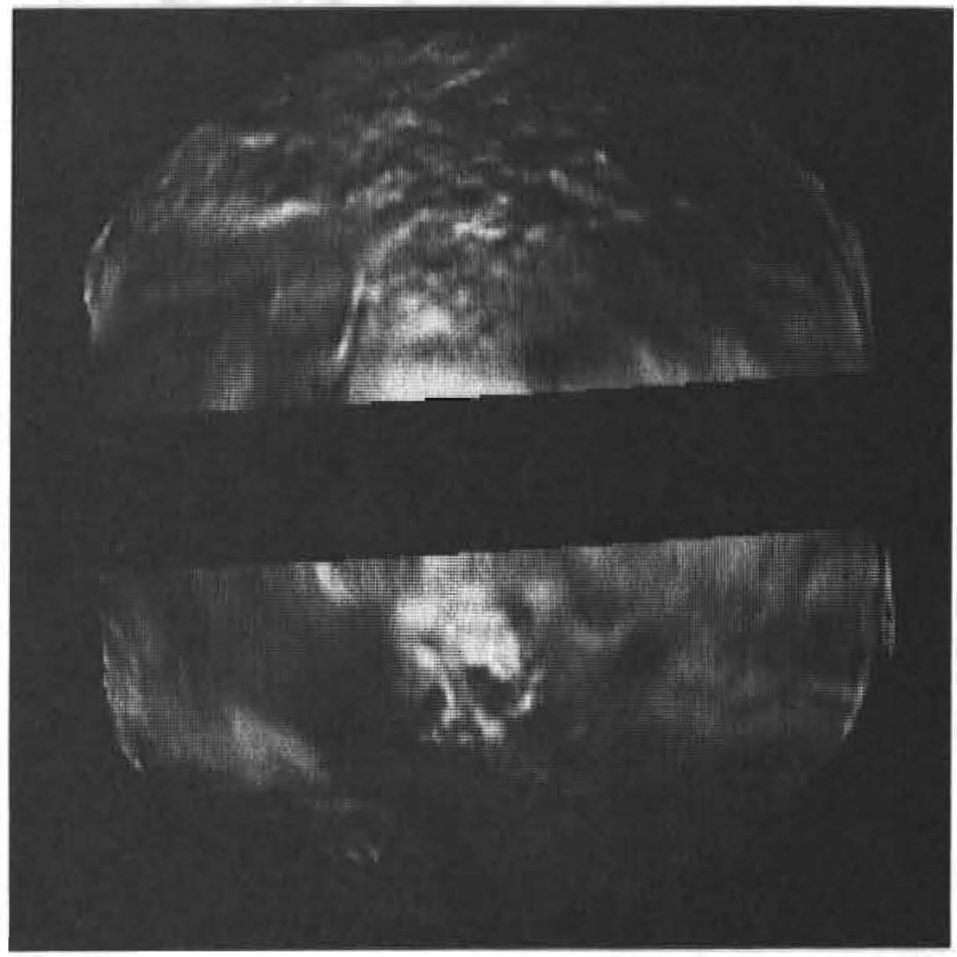
Observations of the rings of Saturn made with the recently upgraded X-band (3.5-centimeter) facility show that the solid particles in the rings reflect the shorter-wavelength as well as the 12.6-centimeter band. Results indicate that the particles are rough, rocky or metallic chunks 1 meter or larger in diameter.

Director's Discretionary Fund

This fund supports promising research and development in several fields, tending to strengthen relationships with the university community. More than 200 professors and students have participated in JPL activities through this fund, which grants an average of about $25,000 per task.

Three examples of continuing projects successfully started by the fund are power plant emissions research, automotive pollution studies, and superfluid helium experiments.

Based on original JPL research results, the Southern California Edison Company and the Environmental Protection Agency (EPA) have continued extensive work on reducing furnace emissions. The EPA and Department of Transportation are sponsoring additional research into the JPL-proposed hydrogen generator developed to reduce automobile pollution. The superfluid helium study has opened up a vast investigation of helium droplets and films that NASA is backing in several high-budget projects, including the Spacelab module.



High-resolution radar image of portion of Venus showing chaotic topography.

Multiple-pulsed copper chloride laser in operation.

Research and Advanced Development

Physical Sciences

X-Ray Photoelectron Spectroscopy

A new laboratory was established to study the chemical and electronic structure of interfaces and surfaces by means of x-ray photoelectron spectroscopy (XPS). The facility includes a high-resolution electron spectrometer with an x-ray monochromator; ultra-high vacuum, clean sample environment, and variable temperature capability; computer control; and equipment for ion milling and secondary ion mass spectroscopy (SIMS).

The XPS capability is enhanced by an electron probe fitted to the spectrometer to provide superior resolution. Studies of mobile ions in SiO_2 indicate high sensitivity to sodium ions in the spectrum and the existence of general chemical states of Na^+. In metalloprotein studies, the active site of copper enzymes has been examined and sulfur binding confirmed.

Thermionic Energy Conversion

To help solve electrical energy problems, thermionic energy conversion research was directed toward increasing conversion efficiency to 30%. An important improvement was the development of an efficient electron collecting electrode. A silicon collector electrode with a work function of less than 1.2 electron volts was demonstrated and performed 30% better than metal collector electrodes.

Drop Dynamics

When the Space Shuttle becomes operational, it will be possible to carry out scientific and technological experiments in very low gravity. The behavior of liquid drops undisturbed by the necessity of supporting the drops is being studied. Answers to questions concerning the equilibrium shape of rotating drops, the fissioning of drops into two or more parts, potential purity of a drop uncontaminated by contact with walls, and uniformity of mixtures cooled in zero gravity could contribute to fields as diverse as nuclear fission, the formation of binary stars, and space processing of ultrapure and ultrahomogeneous materials.

The studies require a device to position and manipulate a liquid drop, free of any contact with confining and contaminating walls. JPL scientists developed an acoustic positioning device capable of manipulating a liquid drop up to 2.5 centimeters in diameter and demonstrated it in aircraft flying a zero-g trajectory. A facility has been proposed for a wide variety of liquid drop experiments on the first 1980 Spacelab flight.

Metallic Vapor Lasers

Metallic vapor laser research has produced high-efficiency, high-power visible lasers. Previous work had shown that double-discharge pulsing could be used as a technique for electrically pumping metallic vapor compounds to achieve lasing in the visible spectrum at temperatures much lower than would be required using pure metal vapors. The technique now has been stepped up to rates approaching 30,000 pulses per second.

Both lead and copper chloride lasants were tested successfully using the multiple-pulsing technique. The best results were obtained with copper chloride at a wavelength of 4106 angstroms and a pulsing rate of 20,000 pulses per second. An average laser power of 30 watts was obtained at a 1% efficiency. (The pulse length was 20 nanoseconds; the energy and peak power density per pulse were 35 μJ cm^{-3} and 1.7 kW cm^{-3}, respectively.)

The laser efficiency, which is defined as the ratio of average laser power output to electrical power input, may eventually lie in the range of 1–10%, making the copper chloride laser up to three times as efficient as other visible lasers.

Compact Laser

A laser project, sponsored by the US Army, developed a pulsed laser as a research tool for the generation of shock waves in solid films. By directing the high-power pulsed beam to the target, shock strengths up to 2×10^9 N/m^2 can be readily achieved.

The project provided a portable, lightweight instrument to convert electrical energy to laser pulse energy. Several recent advances achieved under NASA-sponsored laser technology work for spacecraft were employed in the project. The laser system delivered to Picatinny Arsenal weighed less than 7 kilograms and had a maximum output of 6 joules. Furthermore, the 50% efficiency of the Q-switched mode with respect to the normal mode is about five times greater than efficiencies available previously. This performance was obtained by a new design using a miniature Pockels cell, energy bank, high-voltage converter, time-delayed high-voltage pulser, high-efficiency laser head, and precise low-loss optical train.

Portable, lightweight instrument developed for the Army converts electrical energy to laser pulse energy.

Space Power and Electric Propulsion

Electric Propulsion Systems

Future comet-rendezvous and out-of-ecliptic missions with solar electric propulsion may be followed by detailed exploration of the outer planets using nuclear electric propulsion. JPL established a cooperative effort with Los Alamos Scientific Laboratory, New Mexico, for nuclear space power technology. This group defined a heat-pipe-cooled reactor with out-of-core thermionic power conversion at high efficiency, and developed a high-temperature cermet insulator. The goal is a 400-kilowatt (electric) nuclear power system.

Batteries

The remotely activated silver–zinc battery was selected as being capable of meeting the rigorous environmental requirements of planetary probes.

A nickel–hydrogen battery cell, being considered for future space use, was tested aboard a sounding rocket vehicle. This was the first flight of a metal–gas battery system.

Solar Power

Parametric test data for present and advanced solar cells were acquired for the design of space solar arrays. To ensure reliable design of end-of-life performance, the data included the effects of temperature, illumination level, and charged particle radiation.

The construction of a prototype automated solar array module fabrication facility was completed. This facility will enable automatic assembly and electrical evaluation of solar array modules.

Photovoltaic Research

A new type of solar cell promising high efficiency was developed. Made from gallium arsenide, with an extremely thin interfacial layer and gold film on its surface, the cell demonstrated an efficiency of 15% in terrestrial sunlight. The cell, called AMOS (anti-reflection-coated metal-oxide semiconductor), has superior radiation resistance as well. AMOS may also have potential use on earth as a low-cost device for obtaining electricity from the sun.

The cell is also being considered for converting high-energy laser beams to electrical power for possible use in a power transmission system in space.

Navigation, Guidance, and Control

Multiple Maneuver Strategy

The Advanced Analysis of Maneuvers (ADAM) software program was completed, enabling maneuver strategy optimization and reduction of propellant cost. ADAM also cuts computer costs and analyst time required to perform mission maneuvers. Use of the program resulted in a 60% savings in per run cost for MJS'77 maneuver studies.

Advanced Estimation

Advanced planetary missions employing on-board autonomous guidance and navigation will require estimation technology different from that used in more elaborate ground-based navigation software systems. On-board estimation constrains spacecraft computer storage and word length; furthermore, the on-board algorithms must be capable of updating estimates in real time as new data are received. These considerations have led to the development of a new estimation algorithm especially suited for on-board use.

The algorithm has several key properties which qualify it for on-board estimation: (1) Its numeric accuracy is up to twice that of conventional filter algorithms, a feature critical in applications involving short word length. (2) Efficient single point processing reduces storage requirements and produces estimates in real time. (3) Its compact and simple implementation makes it well suited for use on a computer with limited capabilities. (4) The dynamic model upon which the algorithm is based allows for the presence of random perturbations, thus improving filter stability.

Satellite Modeling

Utilizing an improved mathematical model of the Galilean satellites of Jupiter and newly developed ephemeris system software, an improved Ganymede ephemeris was computed enabling the first successful radar bounce off Ganymede, largest of Jupiter's moons. Because of the extremely weak return signal, ephemeris accuracy was critical in programming the frequency of the transmitted signal at the Goldstone 64-meter antenna.

Interferometry

The extended mission of Mariner 10 employed radio tracking and data differencing techniques using radiometric data from two DSN stations simultaneously. The technique is similar to the very long baseline interferometry (VLBI) and hence has been named quasi-VLBI (QVLBI). Doppler QVLBI enabled (1) reduction by a factor of 5 of the errors normally resulting when the tracking signal passes through the solar corona and (2) the removal of a significant data signature caused by the spacecraft being in a rolling mode.

Advanced Systems

Advanced systems work accomplished this year includes development of a standard inertial reference system using dry gyros for the Mariner Jupiter/Saturn spacecraft and subsequent JPL–NASA planetary missions, design of a long-life star tracker for spacecraft attitude use, and development of a concept for a magnetic bearing reaction wheel to help stabilize spacecraft in flight and reduce use of attitude control gas.

Unified Data System

A new spacecraft subsystem breadboard was built using multiple interconnected, distributed computers to perform functions previously accomplished by either hard-wired subsystems or single computers operating independently. The proposed feasibility model allows a single design to satisfy the requirements of many different missions. Interconnection of computers provides redundancy and failure protection with no increase in cost.

Robotics

A hand-eye robot system was developed for exploring the surfaces of planets or their satellites by remote control. It includes an electromechanical arm, a television camera, a laser rangefinder, a minicomputer at JPL, and a larger computer at Caltech. By analyzing TV and range data, the system is able to determine the location and orientation of an irregular object, such as a rock, placed on an experimental platform. A series of trajectories is then planned and executed that enables the arm to reach out, grasp the object, display it to the camera, and place it in a prearranged spot.

Spacecraft Development

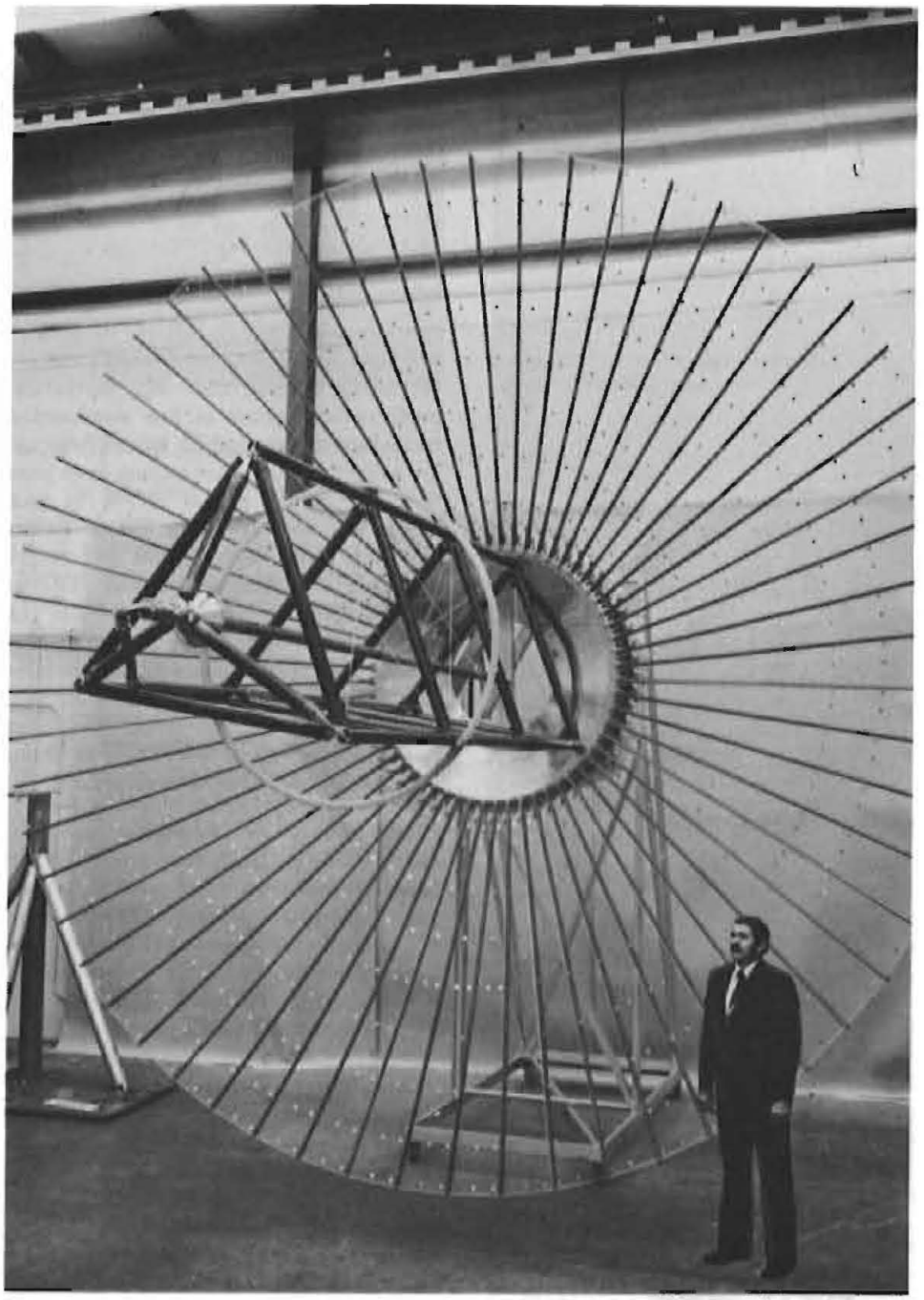
Outer Planet Entry Study

Study continued of the heating that probes will encounter during entry into the atmospheres of Jupiter, Saturn, and Uranus. Measurements of the spatial distribution of electrons—important in estimating radiative plasma heating to an outer planet atmosphere entry probe—were obtained for the first time in plasmas moving at planetary entry speeds. A double-exposure holographic modification of the Mach–Zehnder interferometer developed at JPL gave fields of view up to 9 × 11.5 centimeters. Electron density measurements were made in hydrogen–helium plasmas moving at 33 kilometers per second. Understanding of the ionization process may lead to improved spacecraft safeguards against emissions from shock-heated planetary gases. This could enable the reduction of heat shield weight and an increase in the scientific instrument payload.

Furlable Spacecraft Antenna

Development continued during the year on the 5-meter conical furlable reflector antenna, which uses a line source feed for single-frequency operation at 8.5 gigahertz (X-band). The reflector surface is a knitted mesh made from silver-plated beryllium copper wire and has a surface deviation of 0.5 millimeter RMS. The folding graphite epoxy ribs provide tension to the radial spokes over which the mesh is stretched. Additional spokes originating at the rib tips and terminating at the top of the line feed support structure determine the deployed position of the ribs. The Kevlar tube truss structure that supports and aligns the feed structure carries the boost loads of the ribs when they are furled against it. Deployment of the ribs is accomplished by means of four-bar linkages at the base of each rib, driven by a single motor-operated cable.

Five-meter conical furlable spacecraft antenna in deployed position.



Test of low-thrust rocket motor for outer planet missions.

Chemical Propulsion

Combustion in Venus' Atmosphere

Future scientific explorations of Venus could provide opportunities to test the use of the planet's atmosphere as one reactant in power and propulsion combustion systems. Theoretical analysis shows that the atmosphere of Venus (97% CO_2) would yield high-energy release when reacted with several liquid and solid fuels. The fuel would be carried to Venus from earth.

Steady combustion of aluminum powder (5-micrometer mean diameter) in a Venus-like pure carbon dioxide atmosphere has been demonstrated at JPL. The gas was preheated to 400°C. Successful ignitions also were demonstrated with boron powder. These experiments are being extrapolated using reactor theory to predict the behavior of a more energetic beryllium powder system.

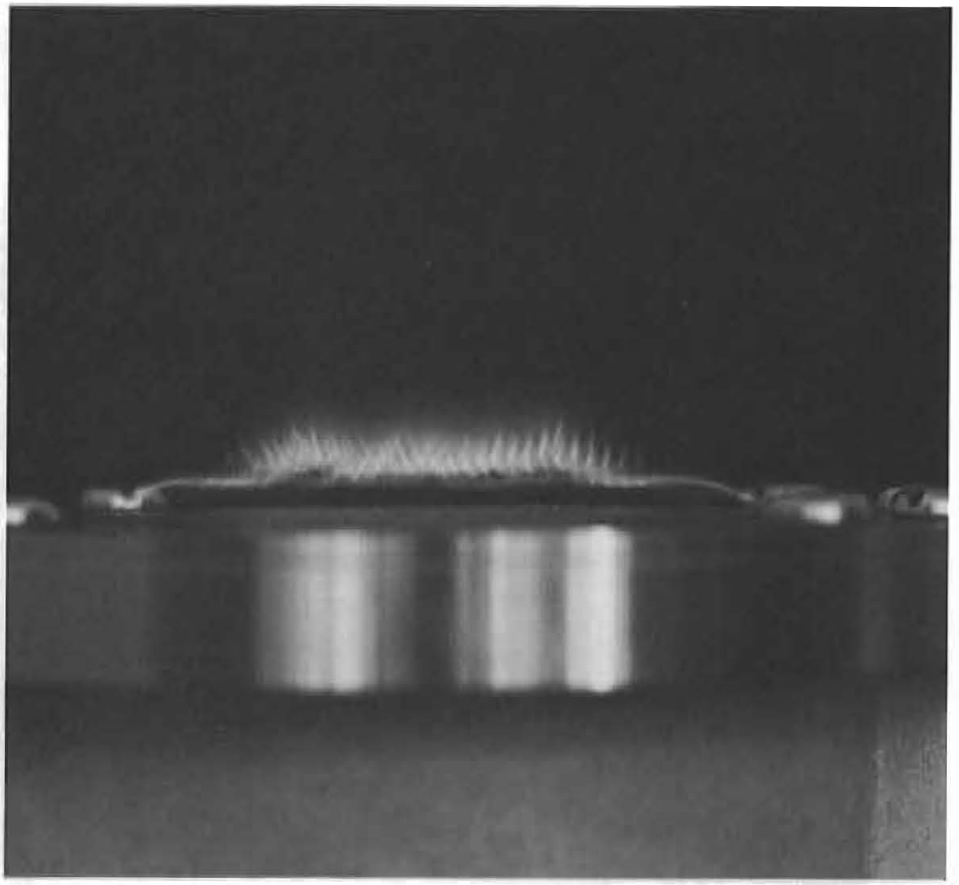
Hydrazine/Boron Hydride Combustion

Hydrazine/boron hydride propellant combinations for spacecraft propulsion are of interest because their high theoretical performance occurs at low combustion temperatures; but thus far, attempts to use the propellants in rocket engines have been disappointing. A critical review of past experience, together with recent results from JPL experiments, yielded new insight into the combustion problem. Energy release efficiency can be raised from the typically observed 80–85% to the level of 95% by thoroughly premixing the reactants in the liquid phase. Near-theoretical performance for this interesting propellant system appears to be achievable at chamber pressures of about 50 atmospheres.

Advanced Propulsion Motor

The technology of the solid rocket in the Mariner Jupiter/Saturn spacecraft propulsion module must be upgraded to provide adequate payload capability for future outer planet missions, since the alternatives of a reduction in launch window or an extension of flight time are undesirable. Advances are needed in terms of higher-performance propellants and lighter-weight motor components. Preliminary design studies showed that a motor weighing about 1800 kilograms would be required for a Jupiter–Uranus mission, involving a motor mass fraction of 0.95 and a specific impulse of 2910 newton seconds per kilogram. The motor will operate at an average thrust of 66,700 newtons for 75 seconds. The propulsion module using this motor could be launched from either a Titan III E/Centaur or the Shuttle Orbiter.

A propellant is presently being developed to meet the specific impulse performance requirement using an 87% solids-loaded (17% aluminum) hydroxy-terminated polybutadiene binder; preliminary motor tests have indicated that a specific impulse of 2910 newton seconds per kilogram will be achieved.



Porous plate burner designed to simulate composite propellant combustion.

A Porous Plate Burner to Simulate Solid Propellant Combustion

Complete understanding of the physics and chemistry of combustion for composite solid propellants cannot be obtained without a solution for the gas phase heat transfer rate. A porous plate burner, simulating idealized composite propellant combustion, was designed and fabricated to expand the gas phase zone of importance and facilitate measurements. Gaseous fuel and oxidizers were used to simulate the propellant vapors. The oxidizer gas was passed through discrete perforations in the porous plate and the fuel gas through the rest of the plate surface. Measurements of surface temperature were made with thermocouples. Though idealized, the concept of flame standoff distance has proved extremely useful in analytical studies. The burner has been successfully operated over a range of "regression rates" and has been found to create realistically a standoff flame, much like in solid propellants but scaling with the oxidizer tube diameter.

Low-Thrust Rocket Motor

An advanced low-thrust rocket motor enabling less spacecraft acceleration than most high-performance solid propellant motors was test fired successfully at sea level. This test culminated several years of research and development devoted to producing a high-performance solid rocket motor for orbit insertion maneuvers in future planetary missions.

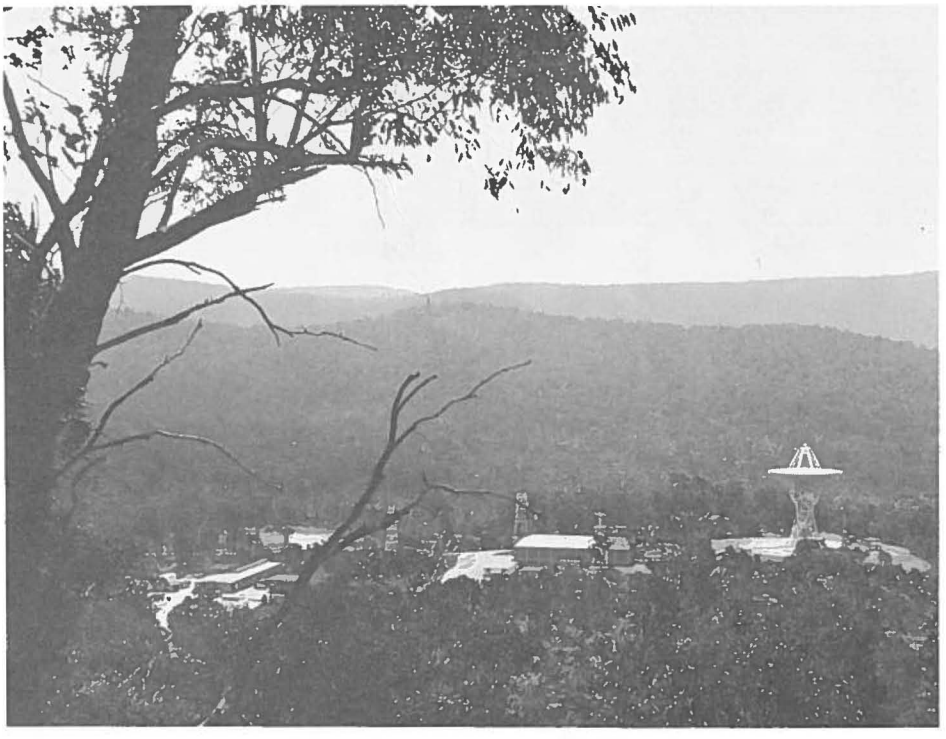
Components of the 268.6-kilogram motor designed and developed by JPL were an advanced graphite/epoxy composite chamber, a low-density silicone/phenolic microballoon insulation, an 86% solids-loaded hydroxy-terminated polybutadiene/ammonium perchlorate/aluminum propellant, and a carbon–carbon nozzle. The motor burned for 120 seconds, with a peak pressure of 124.1 and an average pressure of 101.1 newtons per square meter.

The Deep Space Network

Operations

During the year, the Deep Space Network (DSN) continued to operate its worldwide facilities to provide tracking and data acquisition for Mariner 10, Pioneers 6 through 11, and Helios 1. Tracking coverage was accomplished by the deep space stations at Goldstone, California, near Canberra, Australia, and near Madrid, Spain. The 26-meter antenna subnets were augmented by the former Manned Space Flight Network antenna in Australia. The conversion of this station, designated Honeysuckle Creek, to deep space tracking was completed, and it was committed to support Pioneer spacecraft. Thus, with the closing of the deep space station in South Africa last year, the DSN retained two 26-meter antenna stations at each of the three principal longitudes.

The three-station 64-meter antenna subnet completed its first full year of operational support since completion of the antennas in Australia and Spain. The Jupiter encounter of Pioneer 11, the second and third Mercury encounters of Mariner 10, the solar conjunction of Pioneers 10 and 11, perihelion of Helios 1, and the requirements of these spacecraft projects for high data rates at extended distances combined to place a heavy tracking load on the 64-meter subnet. When a 64-meter antenna was not available, the 26-meter subnets provided coverage at reduced data rates. They also provided coverage at normal rates for the Helios 1 launch and flight and the Mariner 10 cruise. The Network Operations Control Center (NOCC), with the recently augmented capability for analysis of network performance, supported all of the missions.



Recently converted Honeysuckle Creek Station in Australia.

Mariner 10

Tracking support for Mariner 10 concluded in March 1975 after the unprecedented third encounter with Mercury. In both the second and third encounters, the DSN recovered good quality TV pictures in real time. In order to attain a data rate of 117,000 bits per second during the second encounter, it was necessary to combine the signals of two 26-meter antennas and the 64-meter antenna at Goldstone, using an antenna arraying technique. The signals from the 26-meter antennas were sent to the 64-meter antenna station by microwave relay. There the signals of all three stations were combined in an experimental signal correlator provided by the DSN Advanced Systems program. The 17% (0.7-decibel) improvement over the 64-meter antenna signal alone was adequate to meet the required performance during the 2-1/2 hour near encounter.

Helios 1

Launch of Helios 1 and early cruise were supported by the DSN and data supplied to mission control at JPL. When control shifted to the German control center near Munich about a month after launch, data acquired by the DSN were sent there by high-speed data circuits. Both the 26-meter and 64-meter subnets were used to track and acquire data, the latter when the spacecraft passed perihelion and operated on the far side of the sun.

Pioneer Mission Support

The Pioneer 11 encounter with Jupiter in December 1974 was supported by the 64-meter subnet, and support continued as the spacecraft trajectory was modified to encounter Saturn in 1979. Because Pioneer 10 is farthest from earth of any spacecraft launched to date, the data received each time it is tracked set a new communication distance record (currently more than 1 billion kilometers). Pioneers 6 through 9 were tracked for special events such as solar conjunction.

One of the three DSN 64-meter antennas during night operations.

Radio Science

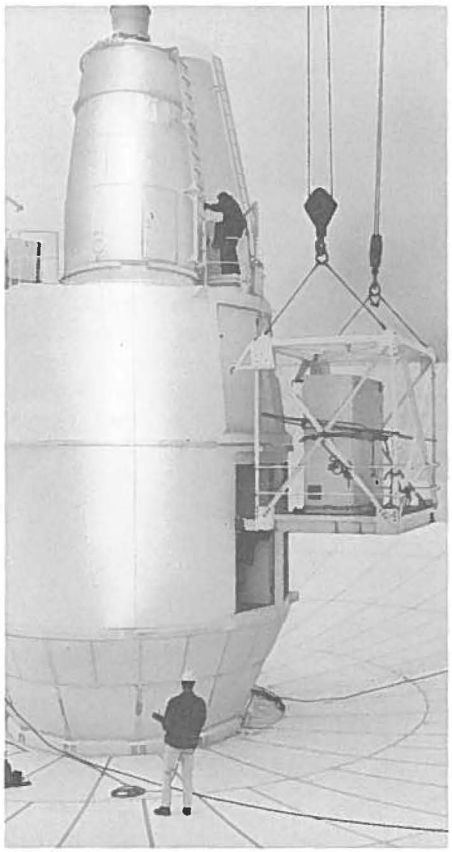
NASA and non-NASA radio astronomers continued to use DSN antennas for ground-based radio science experiments. Most of the support was provided by the 64-meter antenna and one of the 26-meter antennas at Goldstone. Observations for the experiments using very long baseline interferometry (VLBI) were made in cooperation with other radio astronomy observatories such as the Haystack antenna of the Northeastern Radio Observatory Corporation in Massachusetts, the National Radio Astronomy Observatory in West Virginia, and the Owens Valley Observatory of Caltech near Big Pine, California. Baselines between Goldstone and the DSN antennas in Spain or Australia were also used.

The most active of these experiments was the Quasar Patrol. Established in 1972, the Patrol consists of regular observations by several teams of scientists from Caltech, JPL, MIT, the University of Maryland, and the Goddard Space Flight Center. The experiments conducted on the DSN facilities used both 3.5- and 2.1-centimeter frequencies for observations. The Quasar Patrol has continued to gather data at these frequencies, observing the structure of the radio sources and the variability of their radiation.

Considerable support was provided to JPL radio astronomers for the observation of pulsars, the search for interstellar molecules at microwave frequencies, and the study of Jupiter radiation.

Facility Modernization

Considerable reconfiguration and augmentation of DSN capability were undertaken during fiscal year 1975 to meet requirements of the Viking and Mariner Jupiter/Saturn Projects. The DSN telemetry equipment in the 26- and 64-meter stations was expanded to provide support by two stations at each longitude during planetary operations. Two stations will be required to process six telemetry streams from the two Viking Orbiters and one Lander simultaneously. The telemetry processing equipment was reconfigured at all stations to accommodate this requirement. The DSN tracking and command systems were also augmented for Viking. X-band antenna feed cones and maser amplifiers were installed on the 64-meter antennas to provide metric data simultaneously with the S-band data, the dual-frequency capability being required to calibrate ionospheric and interplanetary charged particle effects and achieve navigation accuracy requirements. New receiving equipment, an inherent part of this capability, was installed at all 64-meter stations. Work was started to increase the power of the transmitters used to send commands at the 64-meter stations. The power increase to 100 kilowatts will provide an adequate power margin in case unusual problems arise during the mission.



Power amplifier being placed into 64-meter Goldstone antenna tricone for testing prior to transfer to Viking Project operations.

Mariner Jupiter/Saturn spacecraft require additional capability in the DSN. Although the Project telemetry rates are similar to those of Mariner 10, the data are coded and transmitted at X-band from distances up to 9 astronomical units. These requirements, as well as others for increased navigation accuracy and command rates, were reviewed and evaluated in terms of the functional demands they place on DSN systems. An implementation plan to achieve the necessary capability was developed. Similar planning for support of the Pioneer Venus mission in 1978 was started in order to formulate preliminary requirements for tracking and acquiring data from a spacecraft entering the Venusian atmosphere while also releasing four probes, each with its own telemetry.

The second phase of development of the Network Operations Control Center was completed. The NOCC provides tracking instructions to the stations, monitors performance of the network, and keeps track of the quality of the data being acquired and sent to the project mission control. Recent development provided more detailed computer-generated displays of the qualitative analysis of the tracking, telemetry, command, and monitor systems. In addition, the NOCC gained the capability of configuring the command system at the stations. The computer in the network operations processing area at JPL provides instructions to the computers at the stations on selection of command subcarrier frequencies, modulation type and indices, and data rates.

Advanced Systems Development

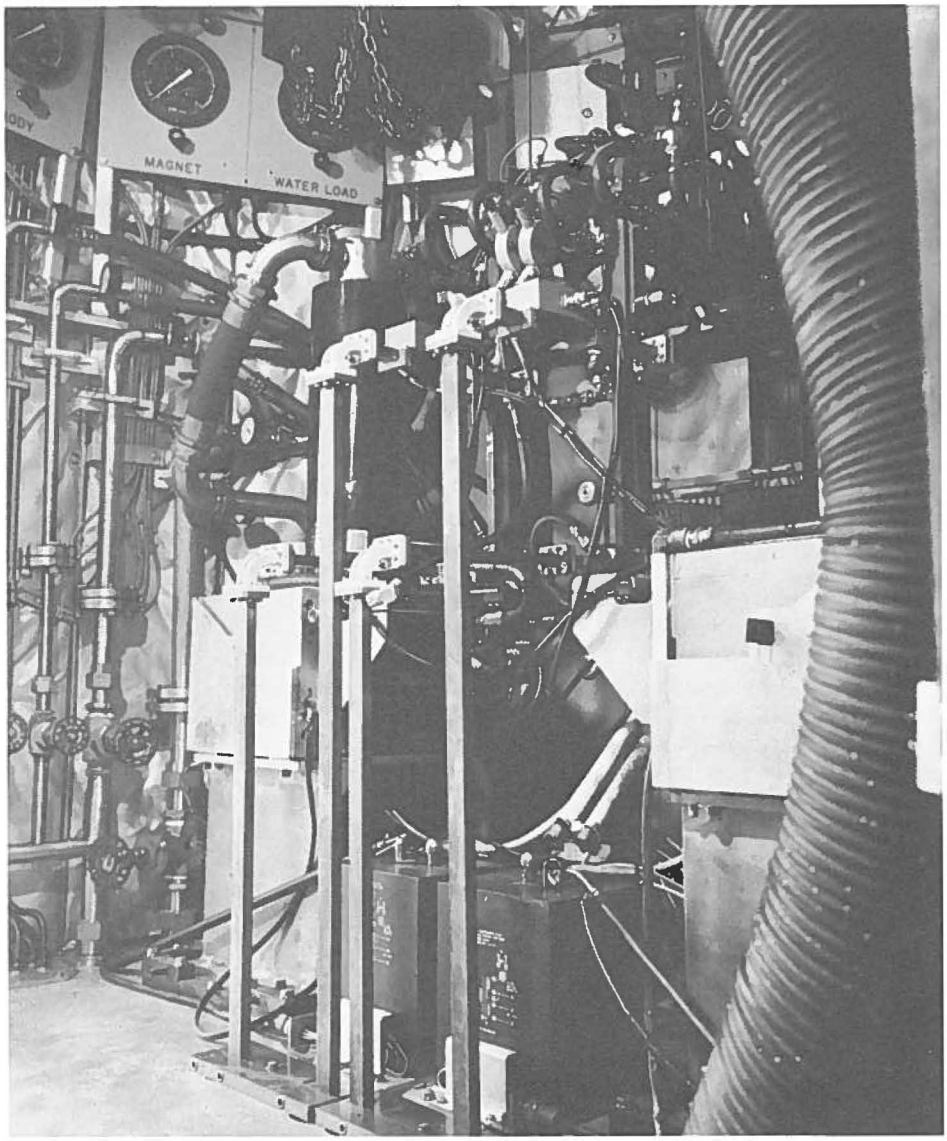
Development to provide capabilities for future projects was conducted in several areas. One such effort was the antenna arraying at Goldstone to assist in the Mariner 10 second encounter. Construction of a 400-kilowatt X-band (8495-megahertz) transmitter was completed. Key developments required for the new transmitter include phasing the outputs of two 200-kilowatt klystrons into a single waveguide and feed, design of new low-loss waveguide and microwave components, and solving of difficult component cooling problems. The transmitter was installed in the 64-meter

antenna at Goldstone with a radar receiver for field testing. These tests at X-band successfully demonstrated the operation of the system as a radar at powers up to 400 kilowatts. Radar returns were received from the rings of Saturn and the asteroid Eros. The echoes from the former indicate that the rings are composed of rough, rocky, metallic chunks about a meter in diameter or larger. The possibility that the rings are clouds of ice spheres has been ruled out.

The S-band (12.6-centimeter) radar capability continued operation in research on the detection of weak signals. Radar echoes from Ganymede, Jupiter's largest satellite, were detected for the first time. The radar cross section of 12% (compared to a perfectly conducting sphere of the same size and at the same distance) is similar to that of the other terrestrial planets; the roughness, however, is considerably greater.

Very long baseline interferometry techniques were used to study ways to improve the accuracy of metric data used for the navigation of spacecraft. Doppler data from the stations in Spain, Australia, and at Goldstone were differenced by VLBI techniques to reduce the effects of the solar corona and of unmodeled spacecraft accelerations. The solar corona effects on metric data during solar conjunction of Pioneers 10 and 11 were reduced by a factor of three. Unmodeled spacecraft accelerations during the third Mariner 10 Mercury encounter were reduced by one order of magnitude.

Efforts were continued to develop greatly improved navigational accuracy by using VLBI techniques to monitor the motion of interplanetary spacecraft against a background of extragalactic radio sources. Initial observations of Pioneer 11 were made when the spacecraft was near Jupiter so as to reference the orbit of that planet to the celestial background. A survey of extragalactic radio sources in the ecliptic region was made in order to develop a catalog of about 100 sources suitable for the purpose. VLBI uses only the very compact sources, and the known number in the ecliptic region was increased from about a dozen to 43.



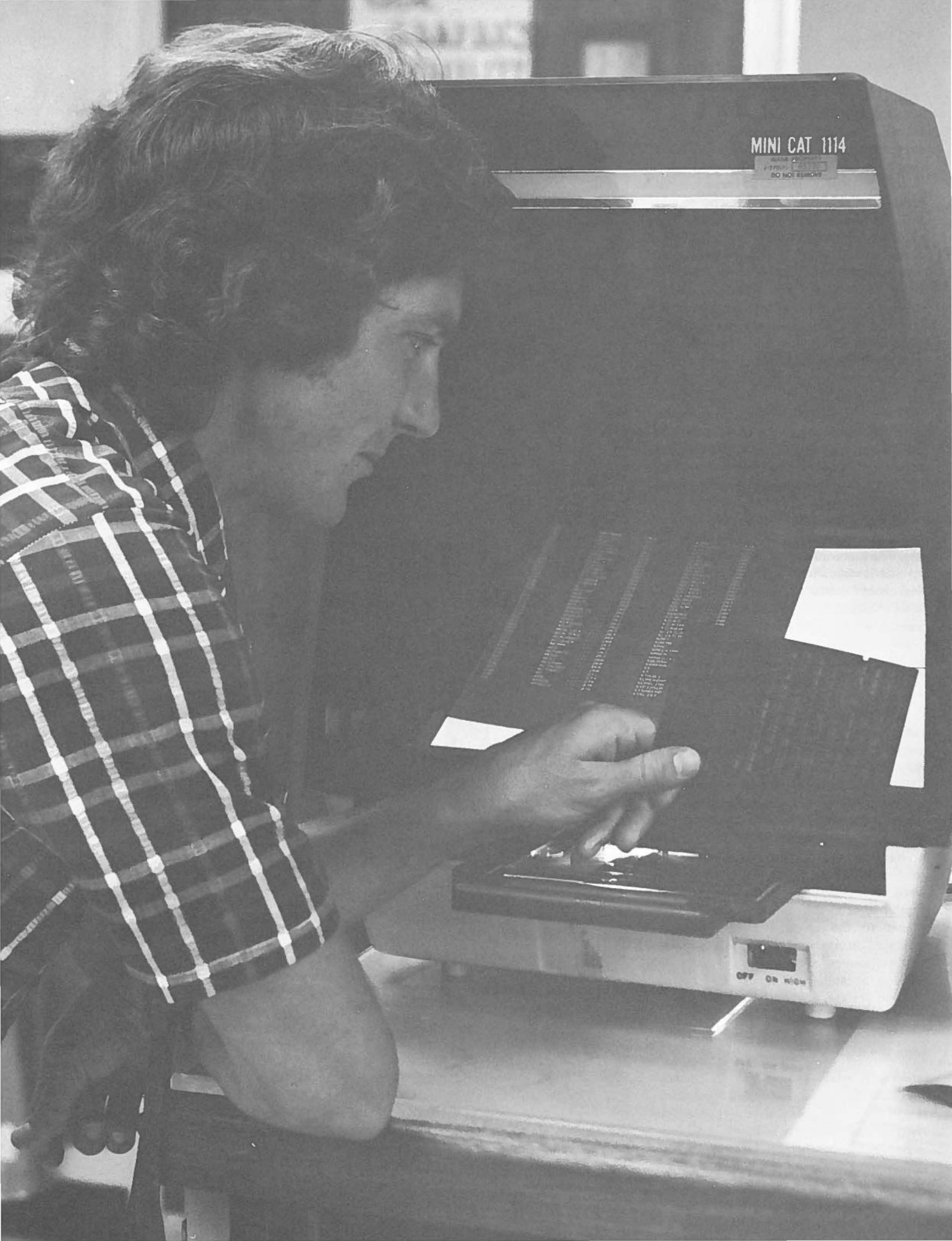
High-power X-band transmitter provides capabilities for future space projects.

The VLBI activities were critically dependent on the frequency stability provided by the hydrogen maser frequency standard at the Goldstone 64-meter antenna. Field testing of this unit continued in support of these measurements as well as the VLBI measurements performed by radio astronomers. The maser has been operating normally, without failure or maintenance, for 2 years.

Flight–ground tradeoff studies were continued to improve end-to-end performance for future missions in a cost-effective way. The development of a standardized command system using variable rates, and a coding and data compression experiment to be performed during the Viking mission were identified as the most profitable tasks to be undertaken.

The DSN contributed to the development of planetary program standards for telemetry adopted by NASA. Study of the telemetry design for the Mariner Jupiter/Saturn Project showed that inclusion of a simple design feature in future spacecraft ensured the ability of the DSN ground equipment to acquire data using the current designs. A radio frequency equipment standard was also adopted that follows current DSN practice.

The DSN also participated in a study to evaluate the antennas and receiving systems proposed for a project to search for and detect intelligent life at interstellar distances.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Computing and Information Systems

The Office of Computing and Information Systems (OCIS), through the Data Systems Division, operates the Mission Control and Computing Center (MCCC), which consists of computing and display systems equipment, personnel, facilities, and associated resources. The MCCC includes three major facilities: the Mission Control and Computing Facility (MCCF), the General Purpose Computing Facility (GPCF), and the Mission and Test Computing Facility (MTCF). The past year has provided the greatest challenge as well as the heaviest load yet experienced by the MCCC. Simultaneous critical flight support was provided for the Pioneer 11 Jupiter encounter, the Helios A solar research mission, and the second and third encounters by Mariner 10. Intensive preparations were made for flight operations of the Viking Mars 1975 and Mariner Jupiter/Saturn 1977 Projects.

A Long-Range Computing Plan was published in August 1974, outlining plans for a new data system employing distributed, dedicated minicomputers to support future real-time flight operations in the mission control center. The minicomputer has reached a stage of development where the features and reliability offered are superior to those of larger computers in handling data for flight control functions such as telemetry, tracking, commanding, and operations control. The reliability and flexibility provided by small, functionally dedicated computers will reduce costs for software development and operations. The nonreal-time processing of mission sequence plans, navigation calculations, data records, and engineering and science analysis functions will still be done on the larger (e.g., IBM 360/75 and Univac 1108) computers.

Along with the expansion and improvement of the direct flight project support capability, considerable extension has been made to the computing support services provided to the general scientific and engineering computer users of the Laboratory. In addition to increasing the job throughput, the large computers have been augmented with increased software flexibility, which has served to minimize costs for program development and operations. On-line terminals provide ease of access and flexibility in the environment of the user's laboratory or office. Considerable emphasis has been placed on providing a simple, easy to use timesharing capability through a cooperative arrangement using the Booth Computing Center PDP-10 computer at Caltech. New capabilities have also been provided to JPL financial and administrative users by the Administrative Computing System, which uses the IBM 370/158 computer at Caltech. Of note is the installation of a new System 2000 data base system linked to the 370/158, which provides on-line terminal access by JPL personnel to key management and financial information for Laboratory work.

Mission Control and Computing Facility

The past year has placed the greatest demand yet experienced on both personnel and resources of the Mission Control and Computing Facility. The support of two simultaneous critical mission events—the Helios A launch and Pioneer 11 Jupiter encounter; the development, testing, prelaunch and real-time support of the two Mercury encounters 6 months apart by Mariner 10; and the development and testing of Viking Mars 1975 Mission Ground Control Systems required not only new operational techniques for simultaneous mission support but the development of new and improved computing and support capabilities to meet these increased demands.

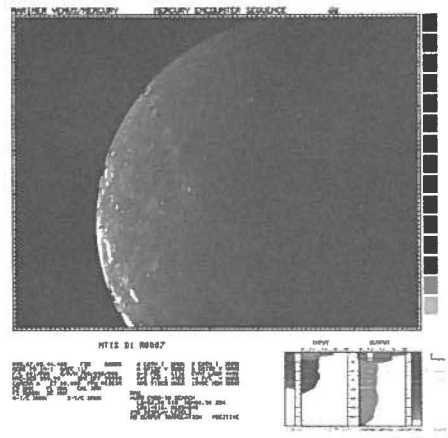
The Helios mission involved cooperation with a foreign country, training of foreign personnel, and support of a major international space program. Visiting German scientists, engineers, and operations personnel were in residence at JPL and shared, with the Pioneer Project and Mariner 10, the use of the JPL/NASA control center, including cohabitation of software within the real-time IBM 360/75 computers. Navigation of the Helios mission was accomplished by JPL engineers using the Univac 1108 nonreal-time computers.

General Purpose Computing Facility

During 1974, the General Purpose Computing Facility provided support for the Pioneer, Helios, and Mariner Venus/Mercury missions and the Viking Project software development, in addition to servicing the general scientific and engineering computer users. A major modification was made to the Univac 1108 executive system to improve its efficiency. In addition, one 1108 was physically augmented by an additional central processing unit to enable it to handle future Viking peak loads. This machine is now operating in the dual processor mode, with improvement throughout approaching 45%.

Technician using optical reader to view one of 208 images on microfiche generated by new computer output device.

Enhanced image of Mercury (below) being removed from computer-controlled Digifax reproducer.



Mission and Test Computing Facility

The Mission and Test Computing Facility continued its support of the second and third Mercury encounters for the Mariner Venus/Mercury extended mission, completing this operation in March 1975. Six hundred pictures were received and processed for the second Mercury encounter in September 1974, and an additional 600 resulted from the third encounter of that planet. The MTCF also supported multiple Viking Orbiter prelaunch testing at JPL and at the Eastern Test Range after a complete test system was transported to Cape Canaveral and placed on-line in February of this year. Viking mission operation testing was conducted concurrently with these and other development activities for both the Viking and Mariner Jupiter/Saturn missions.

Advanced Development in Software

Significant activity took place in software design and development through the use of modern programming techniques. These include top-down software design and coding, structured programming, and the use of software development team concepts. The use of these tools or techniques offers programmers improved methods of producing software of higher quality and understandability at less cost. Intensive investigations of the applicability of modern programming methods to NASA-sponsored software development have been made at the Laboratory. The JPL structured coding language/processor, structured FORTRAN (SFTRAN), was used to implement four navigation programs which control the logic flow of the Viking orbit determination program system. These programs were implemented in one-third the time normally allocated to such tasks and with an unusually high reliability.

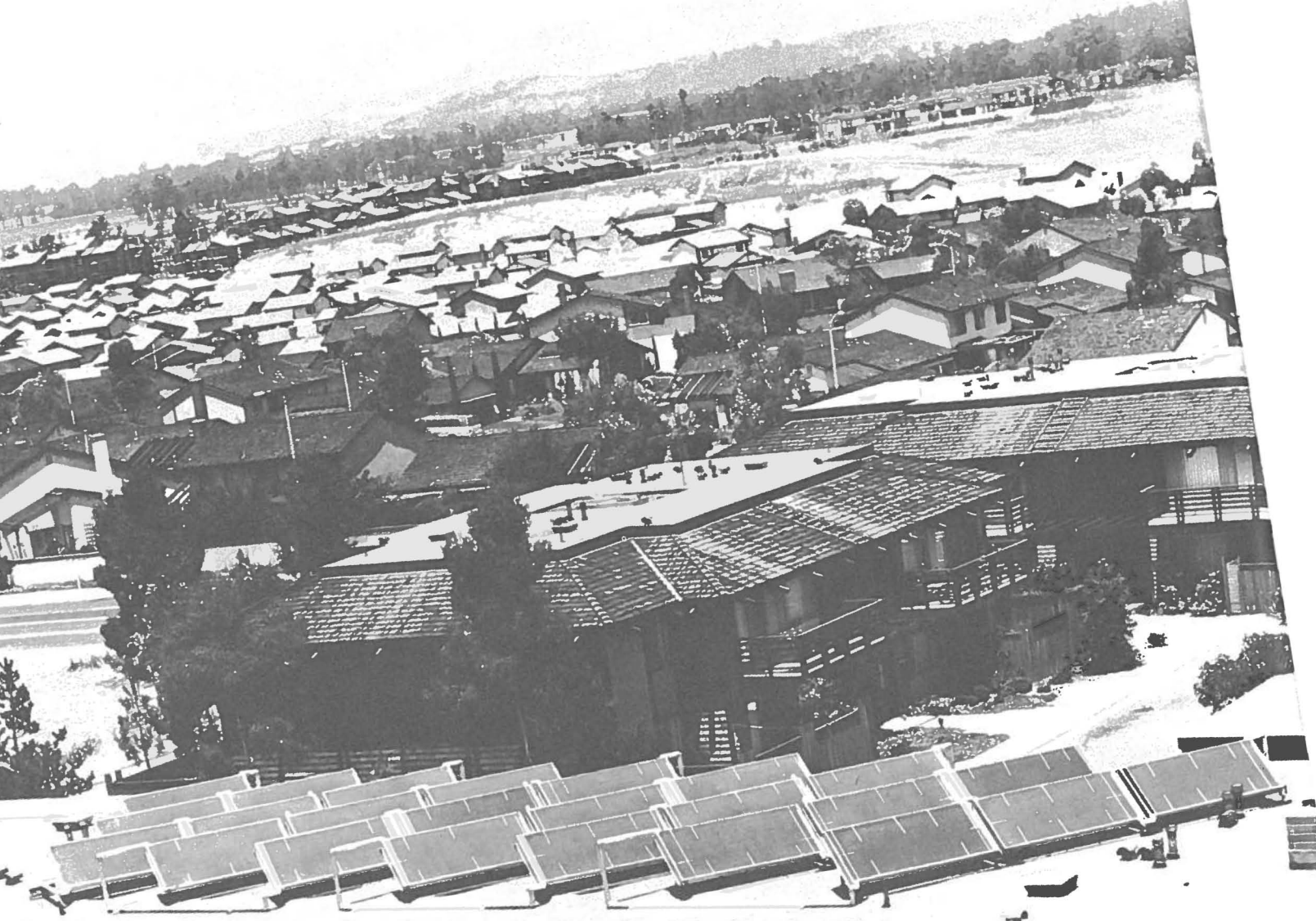
Mission and test imaging system produces near-realtime first-order image enhancement of TV data transmitted by spacecraft.

Various JPL members of the software development and user organizations have formed a Committee on Modern Programming (COMP) to study the interrelationship and compatibility of these and other structured techniques. This work appears to be leading to a consistent, coordinated structured approach to software development.

Administrative Computing Services

The Administrative Computing Services continued its support of the business management and accounting functions of the Laboratory through cooperative arrangement with the Caltech Booth Computing Center for sharing of an IBM 360/158 computer. During the year, the processing time for the JPL month-end financial report was reduced from 8 to 4 days elapsed time, which considerably improves the ability of the Laboratory to manage its financial resources. Data-based management information support has been extended to cover personnel data, travel authorizations, cost accounting, and communications equipment information, offering new and better management visibility in these key administrative areas. Input processing of data by the outdated method of keypunch systems has been replaced by direct keyboard-to-disk file, reducing time required for getting data into the computer by an order of magnitude. A remote job entry capability to the Caltech computer via terminals located at JPL was implemented during the year as a further enhancement of the administrative computer support.

Control center of MCCC 360/75 computer complex.



Energy and Environmental Systems

Geothermal Program

A comprehensive program plan to develop the nation's geothermal energy resources was prepared for NASA and will be transmitted to the Energy Research and Development Administration (ERDA) for submission to the President and Congress.

The proposed program includes adoption of national goals, the potential steps in geothermal exploitation, industry and community participation, and an integrated federal program to coordinate national geothermal efforts.

Solar Cells

A project to develop low-cost solar cell arrays for large-scale terrestrial electric power applications was begun for the Energy Research and Development Administration Solar Photovoltaic Program. A major objective of this JPL-managed project is, by 1985, to develop industry's capacity to fabricate 500 megawatts of terrestrial photovoltaic solar arrays per year. The project seeks to produce silicon cells at a fraction of today's cost and, by 1979, to have quantities ready for evaluation. Their lifetime, performance, and economics will be studied under terrestrial system test conditions by ERDA.

Solar Assisted Gas Energy

Test work at JPL was completed on the Solar Assisted Gas Energy water heating systems, sponsored by the Southern California Gas Company. A major pilot test system was installed by the Gas Company at a 32-unit apartment complex. JPL will assist in the testing and evaluation of this pilot system.

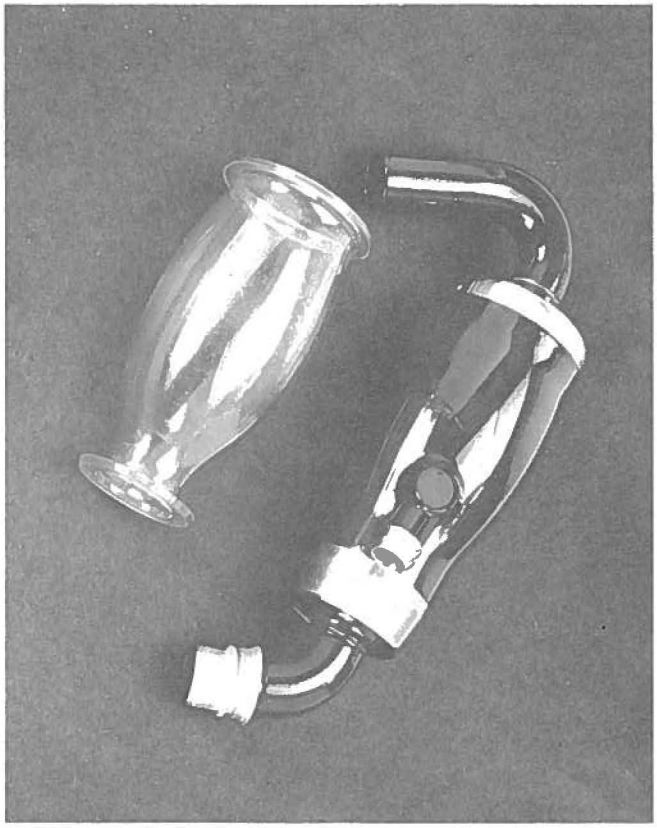
Solar assisted gas energy water heating pilot system installed in apartment complex.

Wastewater Purification

The JPL-developed Activated Carbon Treatment System (ACTS) for municipal sewage will be demonstrated on a 1-million-gallon-per-day pilot plant scale at the Orange County Sanitation District early in 1976. The pilot plant will be constructed by the Sanitation District with JPL as technical consultant. The pilot plant demonstration will be used to evaluate the ACTS process for design and construction of a sewage treatment plant to serve 1-1/2 to 2 million Orange County residents and will meet stricter standards for ocean discharge of wastewater.

The process, which is based on the conversion of sewage solids to activated carbon for purification of the wastewater, was proven feasible by an intensive laboratory and pilot equipment test program. Facilities of equipment manufacturers were utilized. Tests were conducted on indirect-fired rotary calciners, direct-fired rotary kilns, and multiple-hearth furnaces. Carbon-sewage feed for the tests was generated in a 10,000-gallon-per-day mobile unit operated at a Sanitation District facility.

Left-ventricular heart-assist pump, shown with polymeric bladder removed from metal housing, must operate 72 times a minute for many days without failure.



Biomedical Systems

Thermal Burn Diagnosis

Techniques developed for the multispectral analysis of Earth Resources Technology Satellite photographs are being used to assist in the treatment of burn victims. Physicians at the Los Angeles County–University of Southern California Medical Center burn ward are working with volunteer patients to evaluate the technique developed by researchers at JPL for determining whether an area of burn tissue has suffered irreversible damage. A series of photographs in the visible and the infrared portions of the spectrum are taken of the burn wounds of selected patients. The photographs then undergo computerized image processing at JPL. Diagnosis of the deepest burns appears to be accelerated by using infrared photographs with enhanced images.

Polymeric Biomaterials

Materials used in implantable medical devices require careful testing to avoid deterioration in the human body. Using a computer program developed earlier under NASA sponsorship, an analysis of flow through an artificial heart valve showed that transient shear rates two orders of magnitude higher than the average flow rate through major blood vessels may be achieved. This result poses potential problems for a number of cardiac-assist devices, as the validity of materials evaluation based on average flow rate appears questionable.

Consequently, a rotating disc device was constructed to evaluate abrasion characteristics of bio-compatible coatings under a broad range of physiologically significant shear rates.

This study, performed for the National Heart and Lung Institute, will provide supporting evidence for the qualification of materials for implantable devices such as heart-assist pumps.

Blood Sterility

The high risk of microbial contamination prevents hospitals from storing costly fluids, such as blood cells for transfusion, for long periods. Under sponsorship of the National Heart and Lung Institute, JPL has built an Aseptic Fluid Transfer System (AFTS) which essentially eliminates the risks of contamination in the blood bank, and provides a safe and reliable system for other fluid transfers.

The prototype AFTS employs small plastic tubes made of Teflon and Kapton and a heat sealer which sterilizes and causes two of these devices to become fused. During the heating process, the common inner walls of Teflon fuse and begin to flow under pressure, eventually producing an opening in the fused regions. The outer Kapton portions remain undisturbed during fusion and support the critical areas where the Teflon has melted. The resulting configuration enables fluids to pass freely from tube to tube. Thus, the system allows two or more separate containers to be mated for a sterile fluid transfer.

The entire system, with tubes attached to conventional blood containers, is being tested at Harbor General Hospital in Torrance.

Transportation Systems

Automotive Alternatives

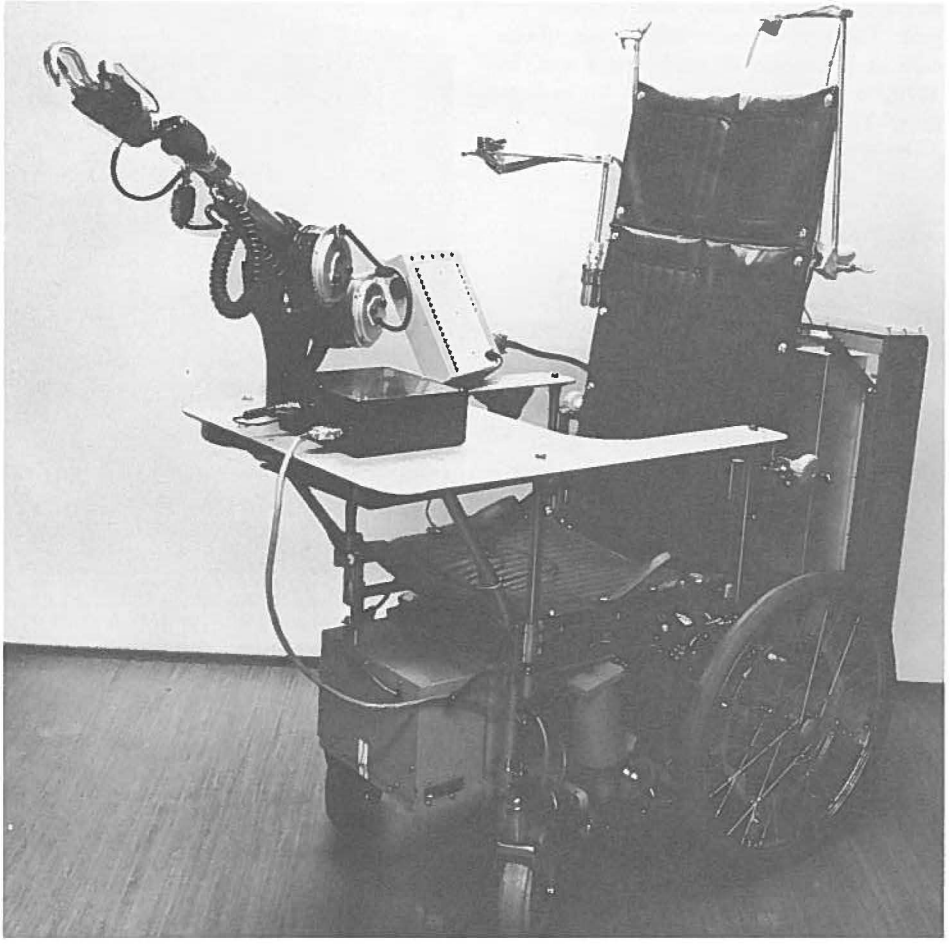
JPL completed a major study on alternative automotive powerplants for the 1980s under a Ford Motor Company grant. The Caltech Environmental Quality Laboratory participated in the study, and a Caltech/JPL review board worked with the team in the 18-month study effort.

The study team proposed the following development strategy:

(1) Begin immediate implementation of design changes to the automobile itself to reduce fuel consumption, regardless of the kind of engine used.

(2) Accelerate the development of two particularly promising alternative engines—the Brayton and Stirling—until one or both can be mass-produced, with introduction in the improved cars targeted for 1985 or sooner.

(3) Meanwhile, press development of the conventional internal combustion engine to increase efficiency and reduce emissions.



Experimental version of a voice-controlled wheelchair. Both the wheelchair motion and the VA-developed arm manipulator can be controlled with simple one-word commands.

Hydrogen generator produces hydrogen as needed for clean, more efficient operation of conventional internal combustion engine.

Hydrogen Injection Engine

This project is working to improve the efficiency of the spark-ignition internal combustion engine while reducing its emission of carbon monoxide and oxides of nitrogen. This is accomplished by operating at an ultra-lean mixture ratio through the injection of hydrogen generated from gasoline in the vehicle system.

The project has progressed into the vehicle system design phase. Development of an on-board hydrogen generator has significantly reduced the generator size.

Automobile Drag Reduction

An experimental program was conducted for the Department of Transportation to evaluate the potential for reducing the aerodynamic drag of automobiles. Several tests were run to measure the drag of three popular American cars, and to demonstrate that a significant decrease in drag could be achieved with relatively minor changes to the body shapes.

The aerodynamic characteristics derived from three tests compared favorably. A 20–25% decrease in the aerodynamic drag, translating into approximately 5% fuel saving, was observed as a result of minor changes (suggested in part by the car manufacturers) to the car bodies. These changes included restricting air flow under the cars with a plate which extended a few centimeters below the front bumper, increasing corner radii at the front fenders and grill area, and adding a small spoiler to the back edge of the trunk.

Public Safety Systems

National Communications

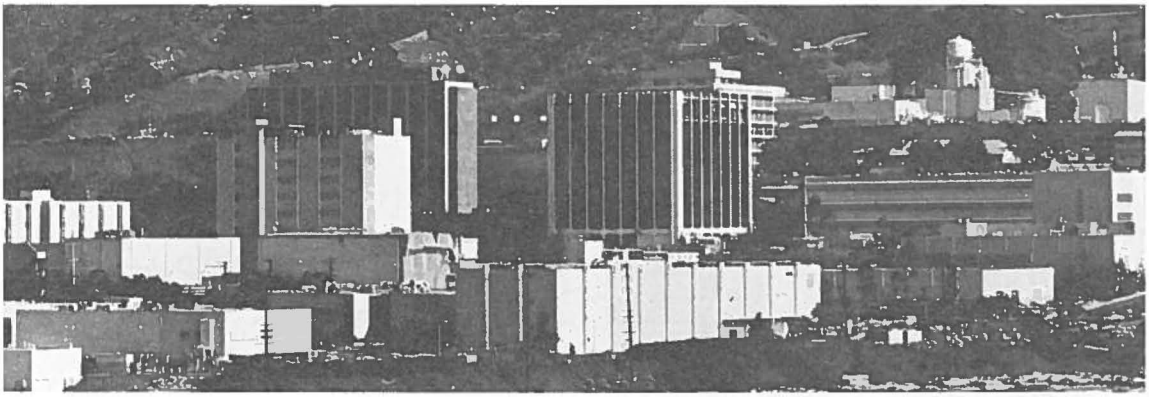
This project, funded by the Law Enforcement Assistance Administration (LEAA) of the Department of Justice, achieved two primary objectives: (1) to develop and quantify requirements for state-to-state and state-to-national digital computer communications traffic through 1983, and (2) to develop a group of networks and evaluate each on performance and cost factors.

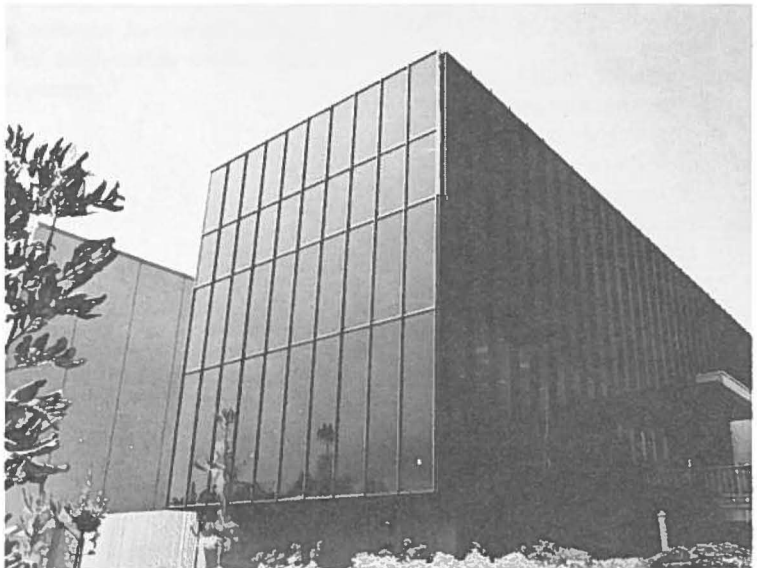
The prime variable in the networks considered was the number of message-switching computers. The simplest configuration used one switcher, with the most complex network having switchers in each state in the continental United States. Study results favored a limited number of switchers, with several networks providing similar cost and performance capabilities.

The project was suspended in March 1975, until LEAA receives clarification from the Department of Justice regarding agency ownership and management responsibilities, and from Congress regarding individual privacy rights. These items affect the final choice of systems and detail designs.

Emergency Communications

A 1-year project to develop a set of requirements, a design, and specifications for an Emergency Command Control Communications System (ECCCS) for the Los Angeles Police Department was started with funds granted by LEAA to the city. This system includes use of computers to assist in the handling of citizens' calls for police service and in maintaining a current status file of officers and vehicles. Project plans call for an improved radio communications network, including the use of computer terminals with keyboard and display capability in police patrol cars.





Other Activities

Plans and Programs

Operational Planning and Special Studies

The launch of planetary spacecraft using the Space Shuttle will become possible in the early 1980s, assuming that compatible upper stages are made available and integrated with the basic Shuttle vehicle. These developments hold considerable interest for JPL and have broad implications. The Office of Plans and Programs continues to provide overall coordination of the Laboratory's participation in NASA's preparations for use of this new primary launch vehicle. JPL's special interests and contributions have dealt principally with operational concepts, Shuttle–payload interfaces, and upper stage planning. Direct support to several NASA-wide study, steering, and working groups has continued.

As in previous years, NASA's budget submittals were examined in detail. These examinations constitute market assessments and highlight projections of the NASA program. Among other purposes, they assist in the annual updating of JPL's internal 5-year planning goals and objectives. In recognition of continuing budgetary restraints, supporting studies were carried out to investigate the potential of flight missions in which a significant reduction in development costs might be achieved through the utilization of existing technologies and minimum modification of existing hardware designs.

Inflation is a cause for concern in the space program, no less so than elsewhere in the economy. In order to better understand the effects that inflation has had at JPL, an effort was initiated to develop an inflation model applicable to JPL flight projects. The aim is to develop a relatively simple index, derivable from authoritative, readily available statistical data, which will account in retrospect for cost increases from this source.

In addition to the normal processes for planning and justifying the application of resources, the Laboratory conducted (as did each of the NASA field centers) a Zero Base Institutional Study designed to certify "to the Director's personal satisfaction" that the resources applied are in fact the minimum required to carry out the assigned workload. This study, together with others that were requested by NASA dealing with such topics as productivity measures and functional manning standards, reflects the continuing heavy pressure on NASA's budget and institutional resources.

Advanced Technical Studies

JPL carries on a continuing series of advanced technical studies whose objectives are to define the prospects and problems of future deep space missions. During the past year, these studies included analyses of Jupiter and Saturn orbiters, Mars orbiter and sample return missions, Venus radar mapping orbiters, and comet flyby missions. Several advisory groups were sponsored to aid in the development and evaluation of scientific rationale for such prospective ventures. In keeping with budgetary pressures, advanced studies at JPL are increasingly oriented toward finding low-cost schemes and technical advances that will enable missions of high scientific value to be flown at minimum cost.

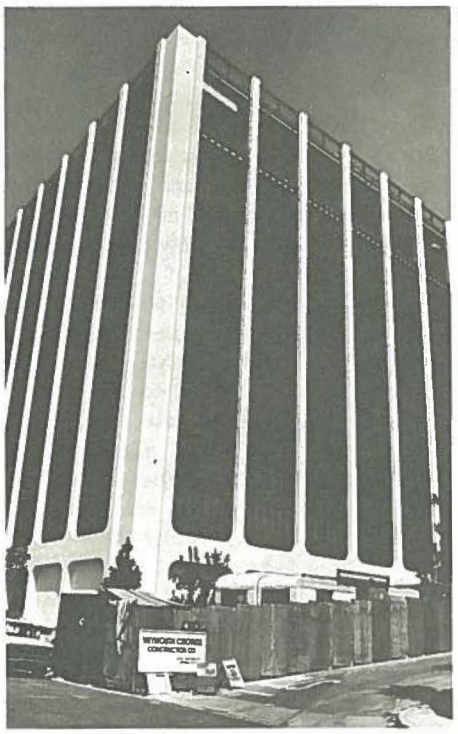
The Jupiter orbiter studies further explored gravity-assist techniques and showed how multiple encounters with Jupiter's natural satellites can be used to direct the spacecraft in time to nearly all parts of the Jovian system. Similar considerations apply to trajectories among the planets. An investigation of a class of trajectories involving swingbys of Venus and earth demonstrated that, given enough time, a spacecraft launched with moderate energy from earth can be placed into an inclined heliocentric orbit or into high-energy trajectories reaching the outer planets.

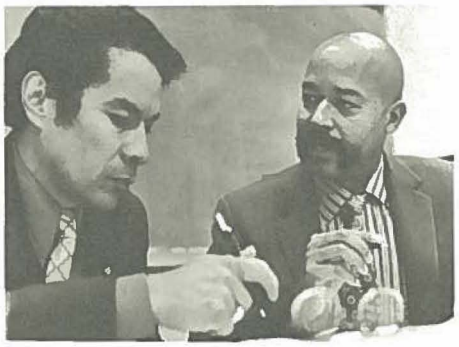
A Viking-derived Mars polar orbiter was also studied during the year. This would be a very attractive scientific mission, building upon Mariner 9 and Viking results to give complete global and seasonal coverage of the planet.

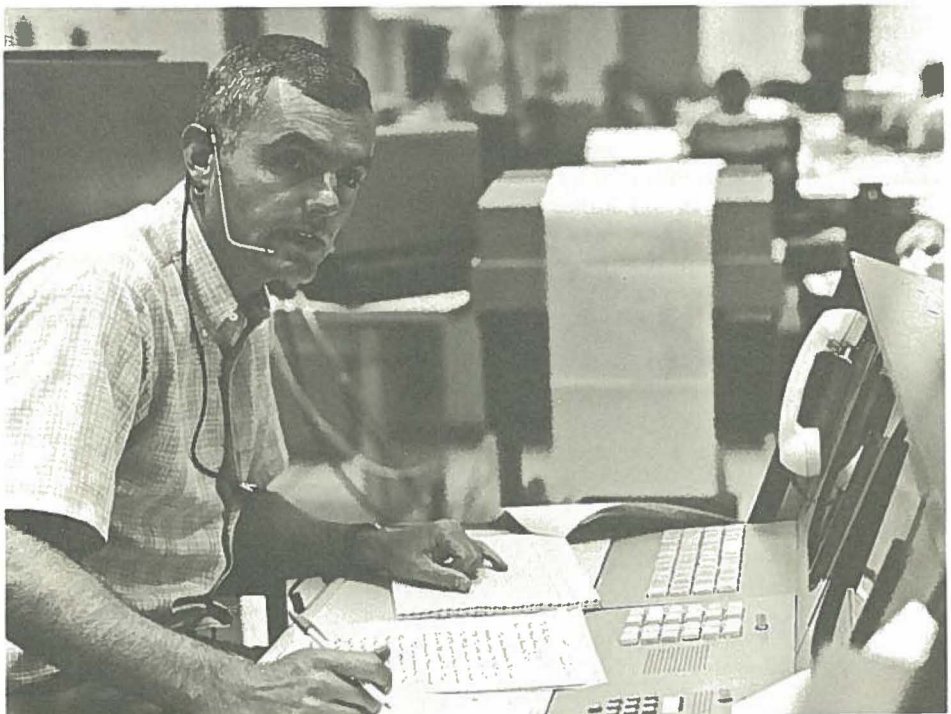
The return of a sample from Mars remains a high-priority, long-term scientific objective and the subject of continued study. It will be a very complex and expensive mission. For this reason, it is regarded by many as a logical candidate for execution jointly by the US and USSR. Isolation of the sample from the terrestrial environment is the major problem to be solved before detailed engineering of the mission can begin.

Studies of low-cost comet missions have continued. Ballistic flights to the comet Encke would offer a low-cost way to begin comet exploration, but they involve difficulty because the encounter is brief and phenomena must be measured quickly.

Remotely manned systems and robotics techniques are important, not only in certain phases of Shuttle operations but increasingly so at the target planet. Work continued on systems for safely increasing the autonomy of the remote vehicle, so that human control can become merely supervisory in character. As an offshoot of this technology development, JPL—in cooperation with the staff of the Rancho Los Amigos Hospital, the NASA Office of Technology Utilization, and the Veterans Administration—developed a prototype voice-controlled, manipulator-equipped wheelchair for use by the severely handicapped.







Personnel

Efforts to recruit and employ qualified minority candidates were continued. The 35 colleges and universities on whose campuses the Laboratory recruited included six predominantly black schools offering degrees in engineering and five colleges in the Southwest with significant enrollments of American Indian and Spanish-surnamed students.

Four Pasadena City College credit courses were brought onto the Laboratory starting with the fall 1974 semester. These classes augment the University of Southern California Interactive Television courses that have been viewed at the Laboratory since the previous spring semester. The college program enables both JPL and Caltech employees to participate in undergraduate and graduate-level credit courses without traveling to the college campus.

Administrative Divisions

The NASA/Caltech contract for the operation of the Jet Propulsion Laboratory has been extended for an additional 3 years and 3 months through September 30, 1978.

Funding for JPL's ongoing tasks and new efforts in research and development amounted to $226,000,000 during the FY'75 reporting period, including funding for 75 new tasks. Funds provided for ongoing and new construction of facilities totaled $11,100,000.

Funding for fiscal year 1976 is planned for $230,000,000 for research and development and $6,400,000 for construction of facilities.

Proposal activity in FY'75 relating to non-NASA-sponsored tasks remained at a high level. Approximately 40% of the submitted proposals were accepted by sponsors, with a total of $4.5 million being authorized.

The Technology Utilization Office has established a small library facility which contains reported items of new technology from JPL and NASA Centers. This library is available to the JPL technical community as well as the general business community and is arranged in such a manner that visitors can quickly find and review items related to their interests.

During 1975, JPL conducted 25,000 procurement transactions, representing obligations of approximately $134,230,000. Principal activities centered about the Viking Orbiter 1975 and Mariner Jupiter/Saturn 1977 Projects, tracking and data acquisition, and various space science and research and development projects.

Special Recognition

During the reporting period, many JPL personnel were recipients of awards and citations. These include

W. E. Giberson, Outstanding Engineer Merit Award of the Institute for the Advancement of Engineering.

R. L. Phen and J. E. Green, selected for and presently serving 1-year detailee assignments to NASA offices in Washington as part of NASA's Career Management Development Program.

W. H. Pickering, Guglielmo Marconi Award for contribution to communications technology, received jointly with Dr. Joseph V. Charyk, president of Communication Satellite Corporation, and Dr. John R. Pierce, Caltech professor of electrical engineering.

For the recent accomplishments of the Mariner Venus/Mercury 1973 Project and the Pioneer 10 flyby of Jupiter, numerous NASA awards were given to JPL personnel, including the following:

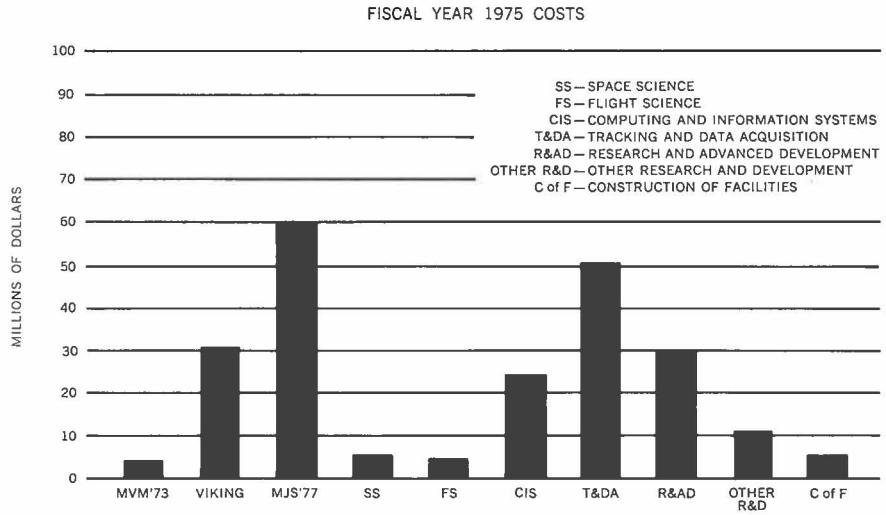
W. E. Giberson, NASA Distinguished Service Medal.

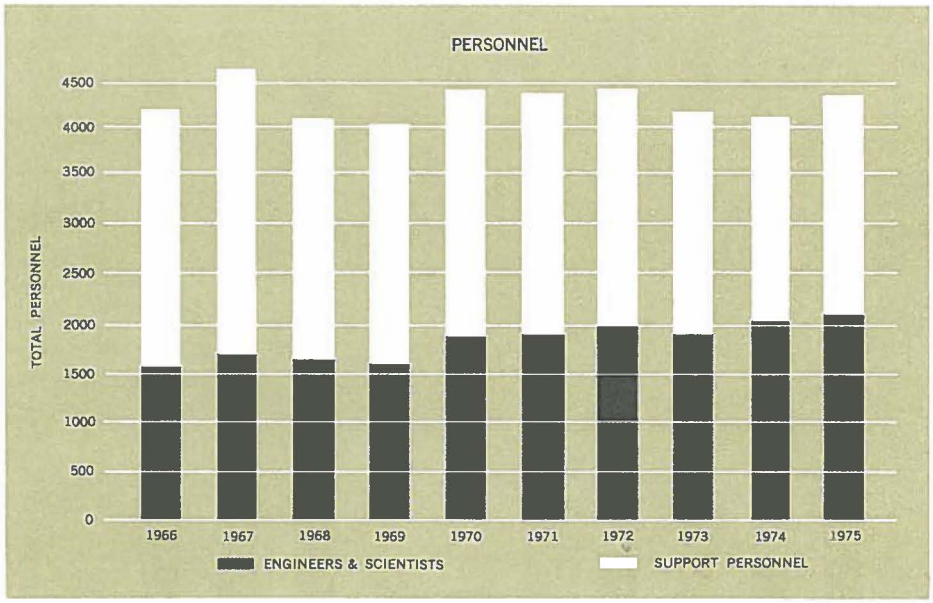
J. R. Casani, NASA Outstanding Leadership Medal.

J. D. Anderson, V. C. Clarke, Jr., and J. A. Dunne, NASA Exceptional Scientific Achievement Medal.

L. M. Bates, L. V. Burden, E. Cutting, G. E. Danielson, E. K. Davis, R. L. Foster, D. T. Gant, H. J. Gordon, A. J. Hooke, W. R. Howard (deceased), W. E. Kirhofer, E. H. Kopf, Jr., W. I. Purdy, A. J. Siegmeth, N. Sirri, F. L. Sola, A. J. Spear, G. F. Squibb, F. M. Sturms, Jr., F. Vescelus, P. B. Whitehead, and J. N. Wilson, NASA Exceptional Service Medal.

In addition, the 1974 Award for Management Improvement was given to the Mariner Venus/Mercury 1973 Management Team by the President of the United States, and Mariner 10 was named one of the top ten engineering achievements in 1974 by the National Society of Professional Engineers.





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