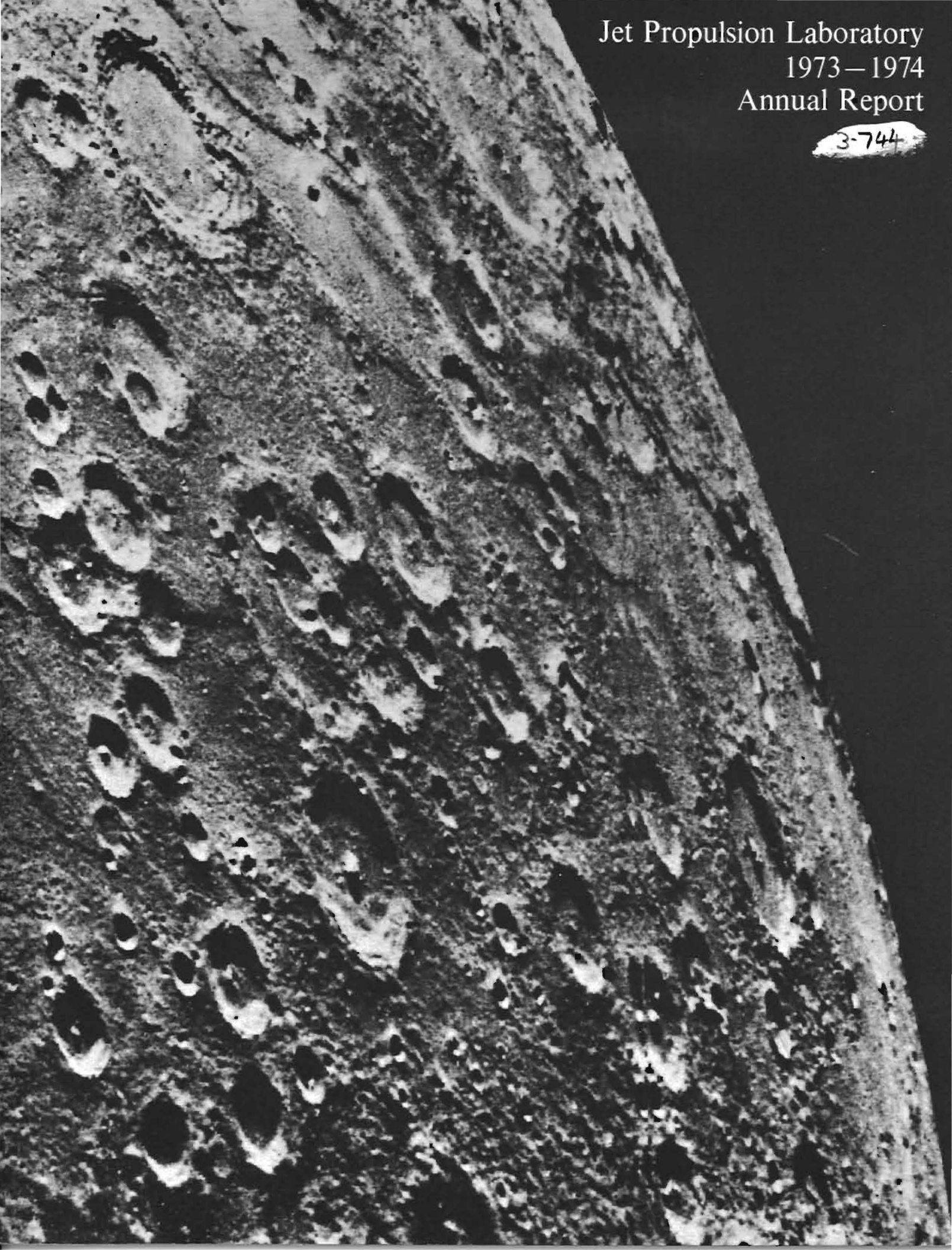
Jet Propulsion Laboratory
1973 – 1974
Annual Report

3-744



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, 1973, to June 30, 1974.

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Cover: View of Mercury's northern limb from a distance of 77,800 kilometers. Mariner 10 photograph shows prominent scarp extending from planet's limb southward for hundreds of kilometers.

The year 1974 marks the 30th anniversary of the founding of the Jet Propulsion Laboratory by Theodore von Karman. Since 1944, JPL has had an outstanding record of achievement in space exploration, which was further extended during Fiscal Year 1974. Mariner 10 accomplished a dual encounter of Venus and Mercury, using the gravity-assist technique for the first time. Imaging data taken at Venus led to new concepts of the planet's atmospheric flow patterns. The spacecraft returned the first close-up photographs of Mercury and secured other spectral and particulate information.

Other projects conducted by JPL in the NASA program of unmanned planetary exploration included the 1975–1976 Viking Mars Orbiter, the Mariner Jupiter/Saturn 1977 Project, and support to Pioneers 10 and 11 and the West German Helios Project to investigate space in the vicinity of the sun.

The Deep Space Network also provided support for both radio and radar astronomy. Significant reduction of noise temperatures in the S-band receiving systems enabled the successful reception of high-data-rate television pictures during the Mercury encounter of Mariner 10.

Project ARIES (Astronomical Radio Interferometric Earth Surveying) completed its first phase during the fiscal year. Coordinated observations of quasars and radio galaxies will provide data on the Earth's crustal deformation across fault lines in relation to potential earthquakes.

An active program of research and advanced development was pursued during the year. These activities included important experimental work with metallic vapor lasers, investigation of failure mechanisms in metal-oxide-semiconductor components used in integrated circuits, development of solar power devices, and research in aircraft noise abatement.

Typical in a growing program of nonspace activities was a project to investigate the commercial potential for solar-assisted gas water heating, and a new process for treating municipal wastewater that virtually eliminates sludge disposal problems. Work continued on a study of alternative automobile power plants, and on a system to supplement standard fuel with hydrogen for improved operating economy and reduced exhaust emissions.

Generally, the period was one of satisfactory growth for JPL. The continuing high level of capability of the Laboratory's scientific, engineering, management, and support staffs has provided an important national resource for the space agency, nonspace sponsors, and the California Institute of Technology.

W. H. Pickering
Director

Major flight project activities at the Laboratory during 1974 included

(1) Completion of the Mariner 10 dual-planet mission to Venus and Mercury and initiation of extended mission activities for subsequent flybys of Mercury.

(2) Continuation of the development and fabrication of the Viking Orbiter spacecraft and mission support activities for gathering data from orbit and carrying lander missions to Mars in 1975.

(3) Continuation of mission planning and early development work on the Mariner 1977 Project to send fully automated spacecraft on dual-planet missions to Jupiter and Saturn.

In addition, JPL continued to be heavily involved in providing tracking and navigational support to the Pioneer 10 and 11 flyby missions to Jupiter. Mission support planning and assistance on spacecraft environmental testing for the international Helios Project to investigate solar phenomena at close range also continued throughout the year.

Mariner Venus/Mercury 1973

The flight of Mariner 10, the world's first dual-planet gravity-assist mission, entered into its extended mission phase in April 1974, with all primary mission objectives having been accomplished. Successful encounters with Venus on February 5 and Mercury on March 29 yielded a rich return of scientific information about these planets. Some of the major findings include

(1) Evidence of symmetrical global circulation in the upper atmosphere of Venus with a period of approximately 4 days retrograde.

(2) Discovery of a plasma tail at Venus extending hundreds of Venus radii downstream.

(3) Discovery of atomic helium in the Venusian atmosphere.

(4) Determination that the oblateness of Venus is less than 1/100 of that of the earth.

(5) Evidence of the early chemical differentiation of Mercury.

(6) Discovery of a magnetic field associated with Mercury, and a distinctly non-lunar solar wind interaction region.

(7) Detection of highly structured streams of accelerated electrons and protons in the Mercury plasma cavity.

(8) Determination of an upper limit of 2×10^{-9} millibars for Mercury's atmosphere and the existence of small amounts of helium (approximately 5×10^{-12} millibars).

(9) Accurate determination of Mercury's mass and radius, confirming its high density.

Following solar thermal vacuum testing in the JPL space simulator in July 1973, the flight spacecraft was shipped to the Kennedy Space Center for final launch preparations and tests. The spare spacecraft, upgraded to full flight worthiness in order to provide a backup launch capability, acted as a pathfinder for these operations. Launch occurred within the first few seconds of the opening of the launch window on November 2, 1973.

Shortly after launch, an anomaly appeared, when television optic heaters failed to function. A short circuit in the spacecraft supplemental heater system proved to be the cause, as the optics heaters started to function shortly before Venus encounter when another subsystem's supplemental heater was turned off. The optics heater failure required the TV camera power to be left on for approximately 2 months longer than the design lifetime. Picture quality at Venus and Mercury encounters was unaffected, however.

The preplanned mission sequence included television and ultraviolet airglow spectrometer calibrations using the earth and the moon as targets. These calibrations were conducted successfully, yielding information of value in the conduct of both Venus and Mercury experiments. Because the spacecraft trajectory carried it almost directly over the moon's north pole, data useful for lunar cartography were obtained. Measurements of lunar albedo in several extreme ultraviolet wavelength regions provided new scientific data, as did observations of the earth's helium corona. The collection of cruise science data (plasma, magnetic fields and charged particles) was initiated before the completion of the earth–moon calibration sequences. From the time of its first turn-on, the plasma instrument functioned only partially. This was the only serious instrument malfunction during the mission, but fortunately the principal plasma science objectives were attained at both encounters. Cruise data were obtained continuously at a data rate of 2450 bits per second from a few hours following launch until a few weeks following Mercury encounter, and for several hours a day thereafter.

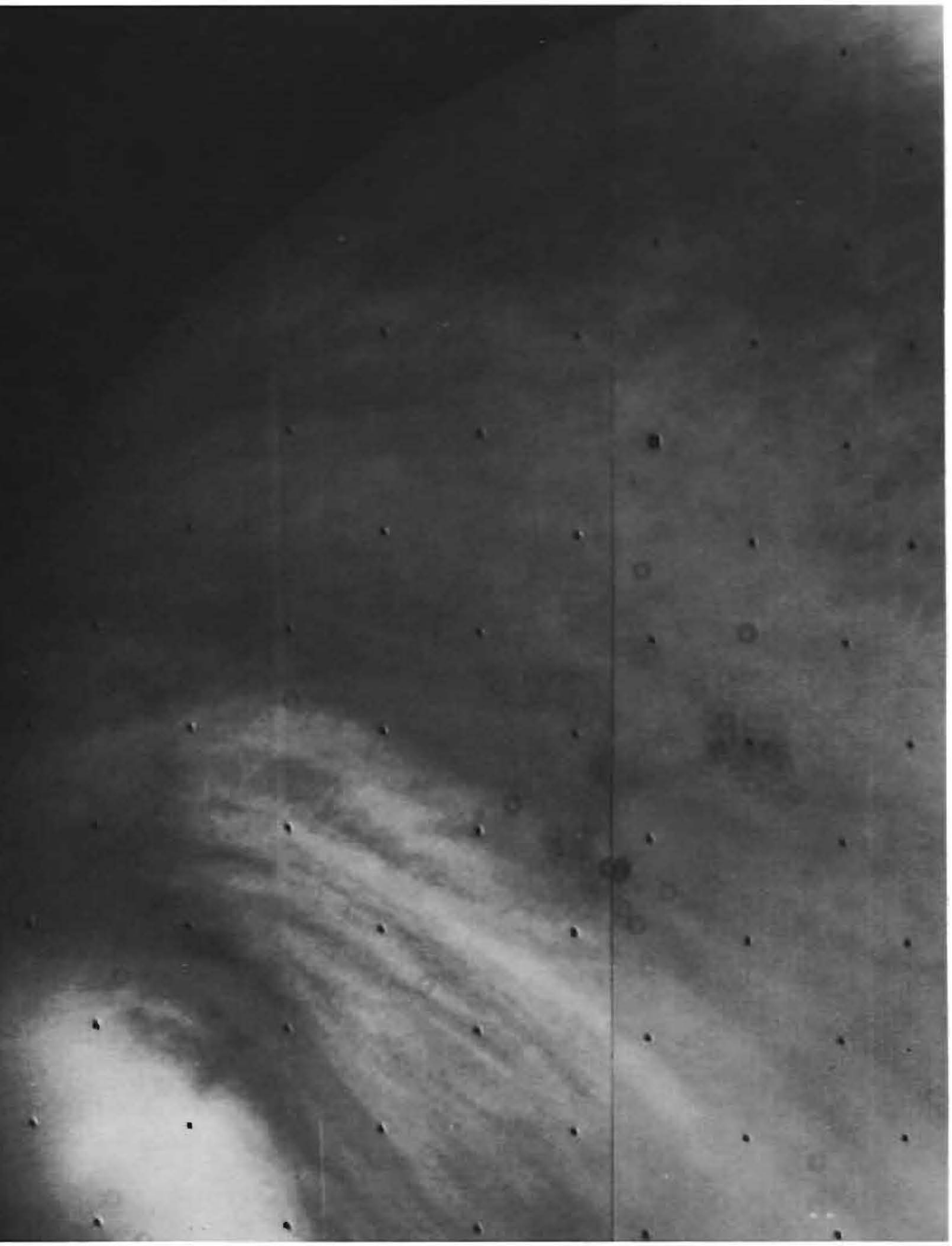
Periodic roll calibration maneuvers had been planned to allow evaluation of the magnetic field experiment's performance and the determination of long-term changes in the spacecraft's magnetic field. After several such maneuvers, this experiment was terminated. During the first of

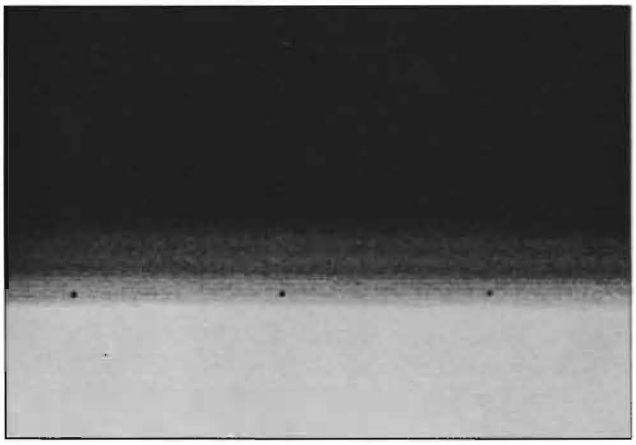
Opposite: Intricate patterns of the upper atmosphere of Venus photographed by Mariner 10 in ultraviolet light.

Below: Mariner 10 being launched on its dual-planet flight, November 3, 1973.

Top: Venus' southern hemisphere as seen by Mariner 10 from a distance of about 725,000 kilometers.

Bottom: Haze layers on the limb of Venus above the visible clouds.





these maneuvers, however, totally unexpected intensities were obtained in the 300–900 angstrom wavelength range from the Gum Nebula and the hot star, Gamma Velorum. The angular extent of the Gum was found to be more than twice that deduced from maps made in visible wavelengths.

The first of the four planned trajectory correction maneuvers was conducted in mid-November 1973, cutting the flyby point from 50,000 to 17,000 kilometers at Venus.

A number of power-related problems plagued the spacecraft and mission controllers during December and January. The most significant of these occurred in early January, when the spacecraft automatically switched from its main to the standby power chain. This switchover is necessarily irreversible, and was of concern primarily because of the possibility of a fault common to both power chains. If the standby chain failed, it would terminate the mission. Following this occurrence, extreme caution was exercised for some time in changing spacecraft power states and maneuvering relative to the sun.

In late January, observations were made of the comet Kohoutek, with the ultraviolet airglow spectrometer mapping neutral hydrogen emission intensities over a range of 17 degrees from the comet's nucleus. These observations were unique, despite the extensive effort mounted by NASA to study this comet, as other ultraviolet spectrometers capable of measuring hydrogen emission (sounding rockets, Skylab) were buried in the earth's geocorona, with the result that sky background precluded measurements beyond a few degrees from the nucleus.

A second trajectory correction maneuver was conducted later in January, correcting the spacecraft flyby point by some 2400 kilometers and its arrival time by 3 minutes.

Near the end of January, following a pre-Venus roll calibration maneuver, an oscillation was observed in the roll gyro channel which caused the expulsion of attitude control gas at an alarming rate. In the hour's time it took to recognize, analyze, and respond to the problem, some 16 percent of the spacecraft's attitude control gas was expended. Analysis showed that the oscillation resulted from a spacecraft mechanical resonance, combined with the attitude control system dynamics. Subsequently, ways were found

to position the movable components (solar panels, scan platform) in such a way as to avoid the oscillation, thereby allowing spacecraft attitude maneuvers to be conducted under certain conditions. The oscillation problem and its attendant risk of losing all attitude control gas in the event of loss of celestial reference resulted in a number of changes and workarounds in mission operations, including a period of "solar sailing," during which spacecraft roll attitude was maintained by differential tilting of the solar panels which produced controllable solar pressure torques.

Venus encounter operations began in late January with the turn-on of the scientific instruments and continued for more than a week following closest approach, which occurred at 10:01 a.m. PDT on February 5, 1974. The encounter sequence, planned long before launch, was performed flawlessly, controlled for the most part by the spacecraft's programmable central computer and sequencer. The Venus flyby geometry, dictated by that planet's role as a "third stage" to provide a gravity assist for the spacecraft's flight to Mercury, was such that the planet was approached from the dark side. This trajectory allowed far downstream (antisolar side) measurements of the solar wind interaction region, and provided entirely new scientific information. The television search for structure in the visible clouds, which was conducted during the receding phase, yielded negative results, although several distinct detached haze layers were observed at the limb. The richness of detail provided by ultraviolet images was highly gratifying, however, as was the successful conduct of the high-gain antenna steering experiment, which allowed deep penetration of the S-band radio signal into the Venus atmosphere.

The spacecraft photography through near-ultraviolet filters revealed in remarkable detail global circulation in the upper atmosphere, with a 4-day general rotation rate of 100 meters per second relative to the planet's surface. The symmetry and relative simplicity of the circulation may allow meteorologists to use Venus as a simplified laboratory experiment in the study of earth's more complicated atmospheric circulation. The ultraviolet markings and their general rotation rate were suspected from earlier observations, but their role as "dye markers" tracing a well developed, systematic atmospheric circulation was not. The imaging experiment also discovered the visible clouds to be unstructured and sharply bounded at the top by multiple detached layers.

Fields and particles instruments made extensive downstream observations of the solar wind interaction with the planet, adding valuable new light on this unique, ionospheric type of interaction, i e., one which results from the impingement of the solar plasma and magnetic fields upon a planet with an atmosphere but no magnetic field. Mariner's plasma and magnetic fields instruments detected the presence of the disturbed region at hundreds of Venus scale radii downstream, revealing the existence of a "plasma tail," analogous to the tail of a comet. Such a phenomenon has not been observed at any of the other planets studied to date. A sensitive (several orders of magnitude more than Mariner 5) search for accelerated electrons or protons by the charged particle instrument proved negative, suggesting that the required acceleration may depend upon the existence of a planetary magnetic field. Ultraviolet observations of hydrogen, helium, and argon in the Venusian atmosphere gave important insights into its origin and evolution, while the dual-frequency radio experiment probed deepest of any of the experiments, well below the cloud tops, discovering temperature inversion zones suggestive of deeper stratiform cloud layers. Analysis of the detailed effect of Venus' gravity field on the spacecraft trajectory revealed that the planet is quite spherical, with an oblateness less than one-hundredth that of the earth.

As a result of the spacecraft's oscillation problem, it was decided to avoid any attitude maneuvers until after Mercury encounter and the attainment of all major mission objectives. Fortunately, the Venus flyby point was such that a modest maneuver requiring no spacecraft roll or pitch could provide the correction required to achieve the desired aimpoint. This maneuver was conducted in mid-March and moved the flyby point from a position approximately 10,000 kilometers on the bright side to the desired dual-occultation aimpoint.

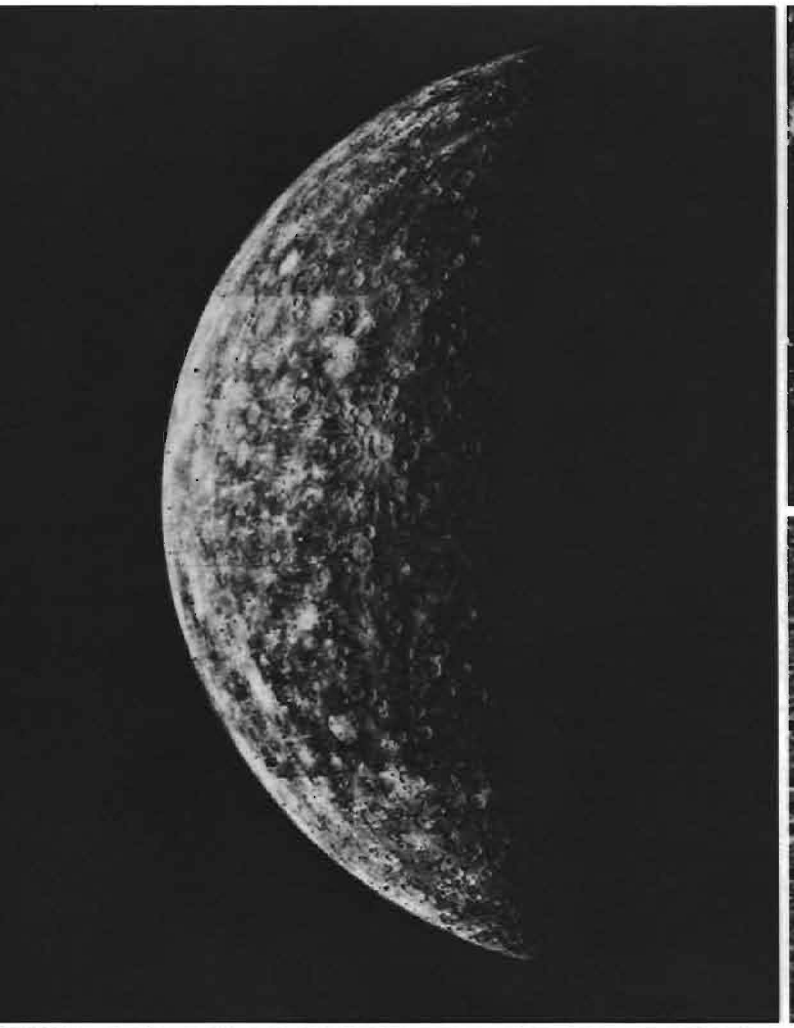
Closest approach to Mercury occurred at 1.46 p.m PDT on March 29, at an altitude of 703 kilometers. The spacecraft cameras saw a half-lit Mercury on both approach and departure legs, and useful imaging was obtained for several days before and after closest approach. The spacecraft functioned well during the encounter period, and important exploratory data were obtained on the features of this little known planet. The television experiment was significantly enhanced by the capability to send full-resolution pictures in real time, a capability which required a telemetry transmission rate of 117,600 bits per second. The standard plan had been to transmit ¼ strips of the pictures because of expected telemetry performance at the encounter distance of 148 million kilometers from earth. However, rapid development and installation of supercooled maser assemblies by the Deep Space Network, combined with spacecraft telecommunications performance at the design value, allowed the 117,600-bit-per-second transmission.

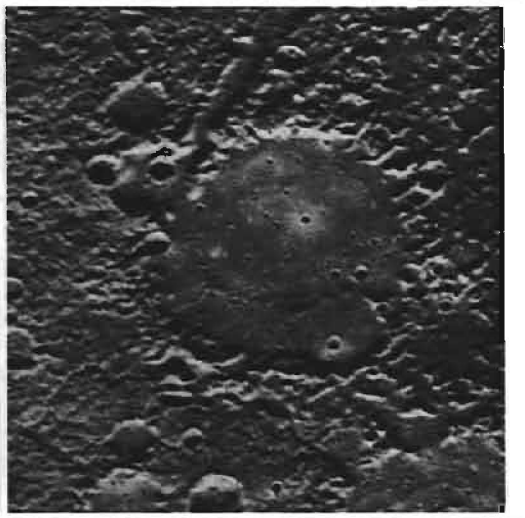
The photographs revealed a highly cratered, moon-like surface, with vast areas of striking similarity to lunar highlands and maria, suggesting a well developed crust, some tens of kilometers thick, of silicate composition similar to that of the moon. The existence of a light crust on the generally dense planet indicates it to be chemically differentiated, i.e., moon-like near the surface and earth-like in its interior. Since the surface is clearly ancient, this chemical differentiation must have occurred very early in the planet's history, even before it had been completely formed by the accretion process.

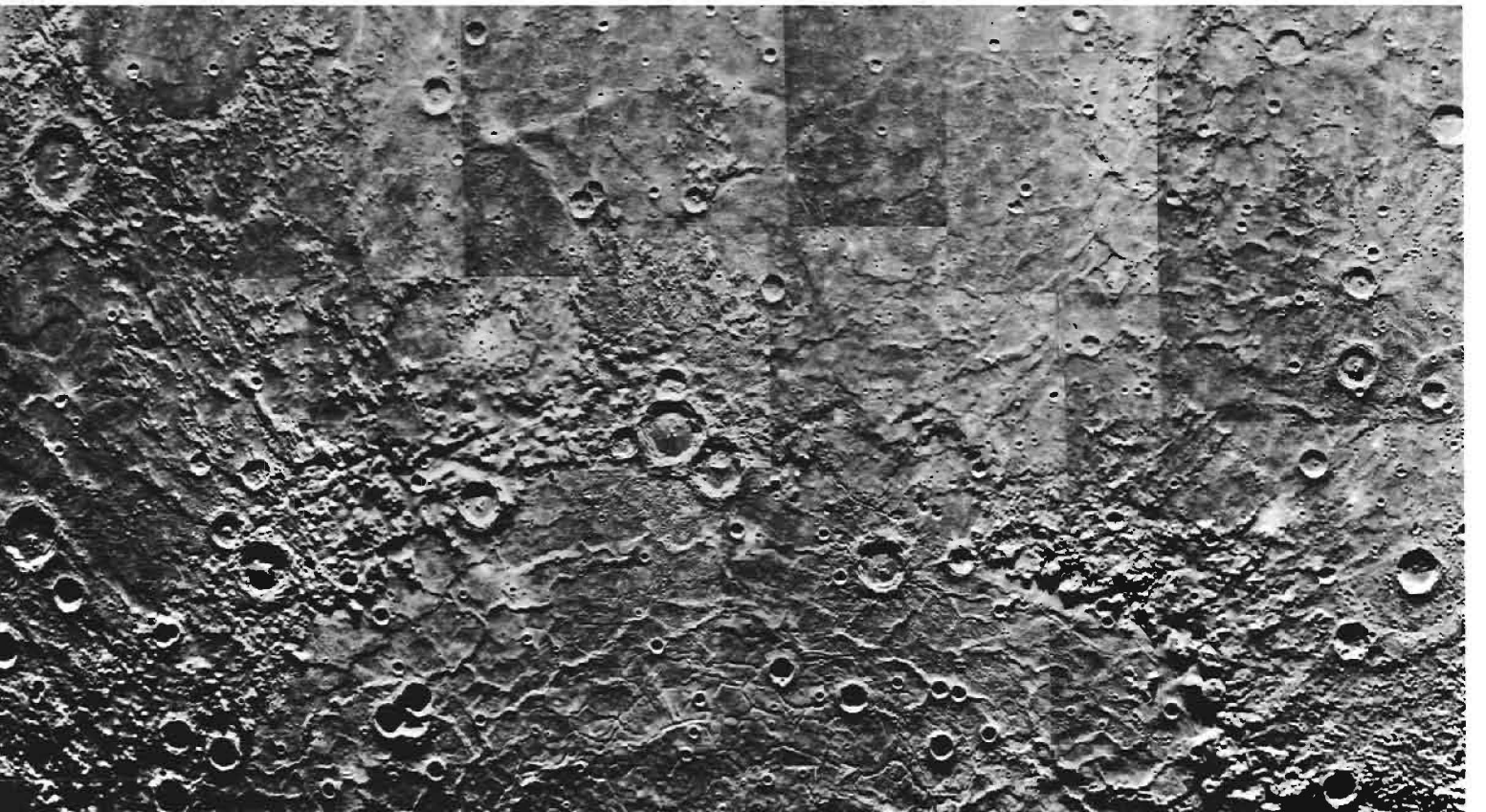
Highly significant results were obtained by Mariner's plasma, magnetic fields, and charged particles instruments. Contrary to preflight expectations, the fields and particles experimenters were surprised to find a well developed bow shock wave and magnetosheath, highly structured streams of accelerated ions and electrons, and a planetary magnetic field. The rapid onset of and variations in the electron fluxes and their correlation with proton intensity bursts indicate that they are transient events, not stable trapped particle populations, perhaps like phenomena which have been observed at earth and Jupiter.

The occultation ultraviolet spectrometer data allow the placing of an upper limit on the total Mercury atmospheric pressure of 2×10^{-9} millibars—several orders of magnitude lower than previous data permitted. A small (5×10^{-12} millibars) but measurable helium atmosphere was discovered, and Mercury's optical (including extreme UV) and thermal properties were found to be similar to

Top left: Crescent of Mercury photographed during Mariner 10's approach to the planet. Top right: Dark, smooth, relatively uncratered area on Mercury shows surface similar to that of lunar maria. Below right: Heavily cratered Mercury surface area contains a valley about 7 kilometers wide and 100 kilometers long. Bottom: Cratered mountains up to 2 kilometers high shown in photomosaic form boundary for largest basin photographed on Mercury.







those of the moon. Mercury's mass and radius were determined with increased accuracy, and its high (5.5 grams per cubic centimeter) density was confirmed. Altogether, Mariner's observations will tell much about the planet and, by inference, the nature and evolution of the terrestrial planets and the physics of plasma–magnetic fields–neutral gas interactions. The exciting suggestion of accretionary differentiation and the equally exciting possibility that tiny, slowly rotating Mercury may possess an intrinsic magnetic field will keep theoreticians busy for years.

The day after Mercury encounter, another spacecraft anomaly occurred, resulting in a sudden 20 percent loss in power and raising concern over spacecraft survival. Temperatures in the affected electronic compartment, although high, soon stabilized, and no further degradation occurred. Some 2 weeks later, an analog-to-digital converter failed in the flight data subsystem, causing the loss of about half of the spacecraft's engineering telemetry, mostly temperatures. This failure, while disturbing, did not jeopardize the mission.

In early May, a fourth trajectory correction maneuver was executed, followed by a fifth in July, setting up a second Mercury encounter. The second Mercury encounter is anticipated on September 21, followed by two maneuvers in November and December which should allow a third encounter if all goes well by March 15, 1975.

Viking Mars Orbiter 1975

In 1975–1976, the Viking Project will fly two spacecraft to Mars that will orbit and soft-land on the planet's surface. The spacecraft, each consisting of an orbiter carrying a sterilized lander capsule, will be launched by Titan/Centaur vehicles in August 1975, with the first landing scheduled on July 4, 1976.

The basic objective of the Viking missions is to advance the knowledge of Mars by direct measurements in the atmosphere and on the surface, and observations of the planet during approach and from orbit during the 1975 opportunity. Particular emphasis will be placed on obtaining information concerning biological, chemical, and environmental factors that would indicate the existence of life on the planet now, in the past, or the potential for its future development.

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

Orbiter System objectives, in addition to placing the Lander into Mars orbit and serving as a communications relay, are to obtain visual, thermal, and water vapor information while in orbit. This information will be used to select sites for the Landers and to study the dynamic characteristics of the planet and its atmosphere. Radio experiments will obtain data that will improve planetary navigation capability and measure radio propagation characteristics in and through the Martian atmosphere.

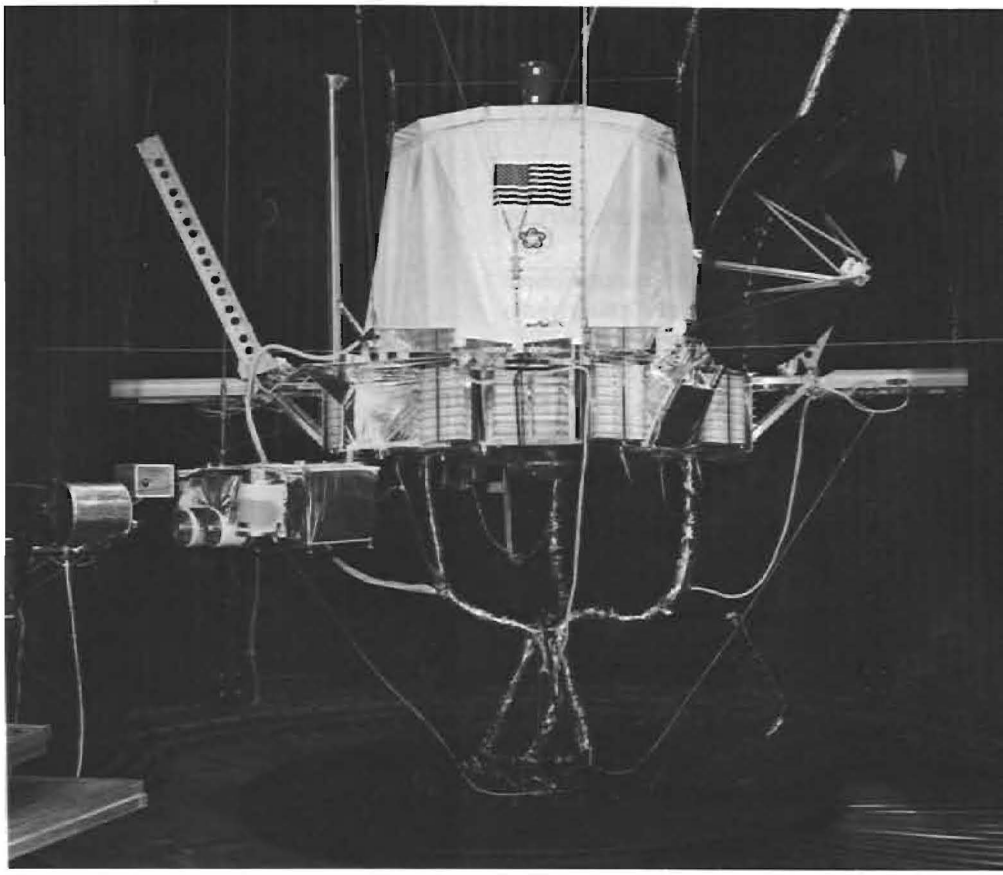
The Orbiter will carry two TV cameras for visual imaging with color filters and high-resolution telescopes on each camera. Water vapor mapping will be accomplished with an infrared spectrometer; thermal mapping will use an infrared radiometer. The Orbiter will also serve as the Lander capsule transport through launch, cruise orbit injection, and surface surveillance prior to capsule detachment and descent. During descent, and after landing, the Orbiter will act as a radio relay to earth for data coming from the Lander.

The Lander will carry eight science investigation packages, comprising imaging, biology, molecular analysis (organic), mineral analysis (inorganic), meteorology, seismology, and magnetic and physical properties of the soil experiments. The complete Viking science investigation package is outlined below:

Orbiter investigations

- Visual imaging by two high-resolution TV cameras
- Atmospheric water vapor mapping by infrared spectrometer
- Surface and atmosphere thermal mapping by infrared radiometer

Viking Orbiter undergoing environmental testing.



Entry investigations

- Atmospheric composition and structure by mass spectrometer and retarding potential analyzer (upper atmosphere)
- Pressure/temperature sensors
- Accelerometers
- Radar

Lander investigations

- Visual imaging (color/infrared, stereo) by two facsimile scan cameras
- Biology (life detection) by three experiments measuring photosynthesis and metabolism
- Molecular analysis (organic chemistry of soil, mass spectrum of atmosphere) by gas chromatograph mass spectrometer
- Meteorology by pressure, temperature, wind velocity/direction sensors
- Seismology by three-axis seismometer
- Magnetic properties of surface material by magnets on soil sampler and camera target, visual detection
- Physical properties of surface by cameras and soil sampler, engineering data from appropriate instruments and experiments

Radio investigations

- Physical properties of Mars by Orbiter radio
- Properties of Mars atmosphere by occultation of Orbiter radio signal
- Solar system and interplanetary medium properties by Orbiter radio
- Surface properties of Mars by Lander radio
- Location of Landers by Lander radio

With the completion of the Orbiter System critical design review in June 1973, development and fabrication of hardware has progressed steadily, meeting all major milestones at a projected cost lower than that set in mid-1970. Significant accomplishments include the successful completion of Orbiter temperature control model testing in the JPL space simulator, and completion of the Orbiter developmental test model interfacing with the Lander dynamic test model to confirm the overall spacecraft structural design.

Following delivery of the required subsystems, the Proof Test Orbiter (PTO) was assembled and subjected to two 80-hour detailed functional system tests, as well as vibration, acoustic, pyro shock, and electromagnetic interference/compatibility tests. Solar thermal vacuum tests have been initiated on the PTO, and the thermal design of the PTO compares well with temperature control model development test results. Assembly was initiated on the test flight model Orbiter, with subsystem deliveries being made in a timely manner for both this and the second flight model.

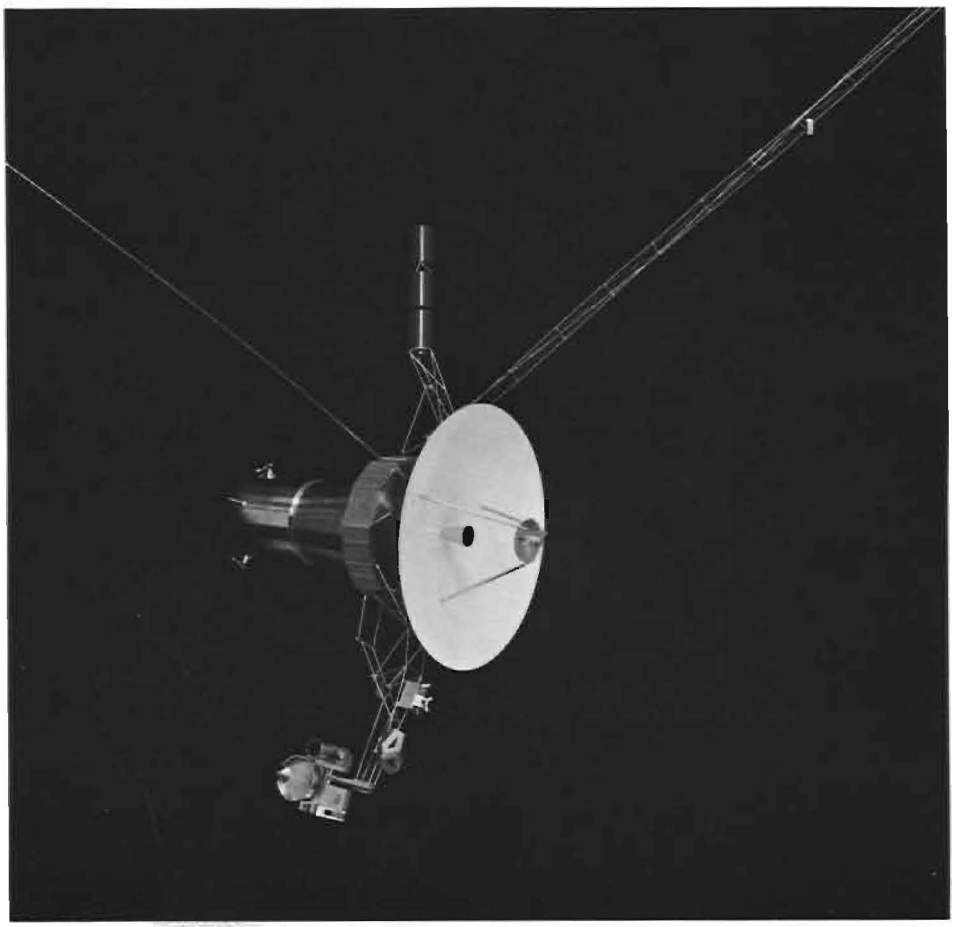
Support effort was intensified for the design and planning for Viking Flight Operations, which are scheduled to be conducted at JPL. The Office of Computing and Information Systems and Deep Space Network personnel have been involved in initiating ground system and software tests for Viking-unique configurations. Preparations are now being made for design and data compatibility tests that are scheduled between selected Lander subsystems and the Proof Test Orbiter.

The elaborate planning for Orbiter science operations was accomplished through close coordination with the Viking Science Steering Group. This effort established methods by which the Orbiter investigations will complement Lander investigations, while still allowing ways to conduct meaningful investigations with the Orbiter instruments.

Mariner Jupiter/Saturn 1977

The Mariner Jupiter/Saturn 1977 (MJS'77) Project, initiated in 1972, will launch two spacecraft in late summer of 1977 on dual-planet flights to fly by Jupiter in 1979 and Saturn in 1981. The basic objective of the MJS'77 Project is to extend the exploration of the solar system

Mariner Jupiter/Saturn spacecraft model.



to the vicinity of Jupiter and Saturn with spacecraft that can conduct significant scientific investigations of both planetary systems and the interplanetary space Particular emphasis is placed on obtaining data on the environments, atmospheres, and surface and body characteristics of Jupiter and Saturn, and investigating one or more of the satellites of these planets and studying the rings of Saturn. The scientific experiments listed below will be carried out on these missions.

The MJS'77 spacecraft will have a propulsion module and a mission module. The propulsion module provides the final launch injection velocity after separation from the Titan IIIE/Centaur D-1T launch vehicle. The mission module is an extension of the Mariner spacecraft family, augmented in capability to meet the requirements for long life, long-range communications, precision navigation, solar-independent power, and for support of the science investigations

Investigating area and instrument	*Primary measurements*
Imaging—Television camera	Imaging of planets and satellites at resolutions and phase angles not possible from earth Atmospheric dynamics and surface structure
Radio science—S/X-band radio	Physical properties of atmospheres and ionospheres Planet and satellite masses, densities, and gravity fields Structure of Saturn rings.
Infrared—Interferometer/radiometer	Energy balance of planets. Atmospheric composition and temperature fields. Composition and physical characteristics of satellite surfaces and Saturn rings
Ultraviolet—Spectrometer	Atmospheric composition, including the hydrogen-to-helium ratio. Thermal structure of upper atmospheres Hydrogen and helium in interplanetary and interstellar space
Magnetic fields—4 fluxgate magnetometers	Planetary and interplanetary magnetic fields
Plasma—2 faraday cup detectors	Energy spectra of solar wind electrons and ions, low-energy charged particles in planetary environments, and ionized interstellar hydrogen
Low-energy charged particles—Particle analyzer/particle telescope	Energy spectra and isotopic composition of low-energy charged particles in planetary magnetospheres and interplanetary space
Cosmic rays—High- and moderate low-energy telescopes	Energy spectra and isotopic composition of cosmic ray particles and trapped planetary energetic particles.
Visual photometry and polarimetry—Photopolarimeter	Methane, ammonia, molecular hydrogen, and aerosols in atmospheres. Composition and physical characteristics of satellite surfaces and Saturn rings.
Planetary radio astronomy—Radio receiver	Planetary radio emissions and plasma resonances in planetary magnetospheres.
Plasma waves—Electric field analyzer	Electron densities and local plasma wave–charged particle interactions in planetary magnetospheres.

The mission module, to be separated from the propulsion module after final injection, carries the science payload. Several of the science instruments are mounted on a two-degree-of-freedom scan platform. Power is supplied by three multi-hundred-watt radioisotope thermoelectric generators. The mission module has three software-oriented computers, which can be reprogrammed on command from earth These computers perform the onboard commanding and sequencing, provide the logic for attitude control and articulation of the scan platform, and control the science instruments and process science and engineering data. The mission module will transmit data at S-band and X-band at rates from 40 to 117,000 bits per second, and has an integrated system of trajectory correction and attitude control thrusters utilizing monopropellant hydrazine.

MJS'77 activities have concentrated on developing the mission and systems design, integration of the science investigations, and the initial development of the subsystems and science instruments. Two standard trajectories have been developed which will encounter the Galilean satellites Io and Ganymede of Jupiter in early 1979 and Titan and several minor satellites of Saturn in late 1980 and early 1981.

During the 1973 flyby of Jupiter, the Pioneer 10 science instruments detected a charged particle radiation belt at Jupiter three times more intense at the planned MJS'77 flyby distances than previously calculated. As a result, the MJS'77 Project is strengthening the design of the mission module to enhance its ability to withstand a high radiation environment without detrimental effects to the spacecraft and its scientific instruments. This phase of the Project activities will conclude with a final mission and systems design review in the fall of 1974, prior to the start of detailed subsystem design and fabrication of the spacecraft.

Other Project Activities

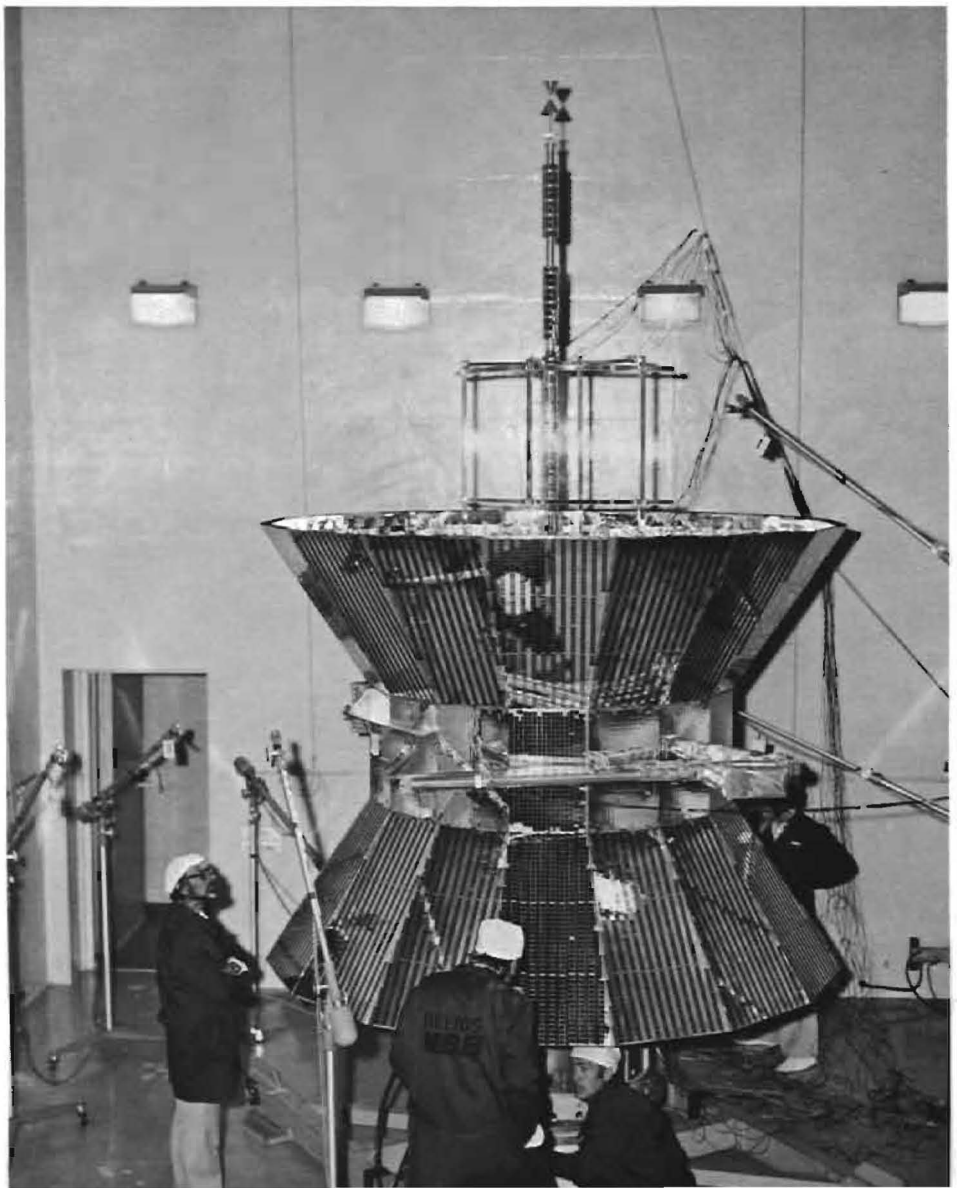
The Laboratory is continuing to provide significant support to two other projects, Pioneer and Helios. The Pioneer 10 and 11 missions are managed by the Ames Research Center, with JPL responsible for space and navigation operations, spacecraft tracking and data acquisition, and mission control computer support. Pioneer 10 passed by Jupiter at a distance of 132,250 kilometers on December 3, 1973, and during the 60-day encounter phase provided continuous imaging, infrared, ultraviolet, polarized light, magnetic field, atomic particle, atmospheric, and celestial mechanics data on the solar system's largest planet. The spacecraft at Jupiter was at 5½ astronomical units from earth, a distance requiring a one-way communication time of 46 minutes, which set a record for the longest telecommunications link established to date in the solar system. Pioneer 11 was launched on April 6, 1973, and will encounter Jupiter on a different trajectory on December 3, 1974.

The Helios Project, a joint US–West German undertaking, is being co-managed by the Goddard Space Flight Center and includes two flights near the sun to investigate the properties and processes in interplanetary space. The first Helios is scheduled for launch in late 1974 and will be targeted to a perihelion of 0.31 astronomical unit. The second Helios, scheduled for launch in late 1975, will probably be retargeted based on the experience with the first mission and is currently planned for a perihelion of 0.25 astronomical unit. Each flight is expected to continue in heliocentric orbit, returning usable data for approximately 18 months. JPL is assisting this project by providing technical and operational support for mission operations, spacecraft technical consulting and testing, tracking and data acquisition, and mission control computing support. During the April–July 1974 period, the prototype spacecraft was tested to the equivalent of eleven solar constants in the environmental simulator. In addition, the spacecraft–Deep Space Network telecommunication compatibility was demonstrated with station CTA-21, the Titan–Centaur launch vehicle environment was simulated in the acoustic chamber, a separation-shock test was performed, and an open air test to confirm the satisfactory performance of the plasma and radio wave experiments was conducted with the spacecraft spinning at 60 revolutions per minute while operating directly from the solar panels.

Project definition studies were completed on Seasat, an earth-orbiting satellite designed to provide information on global ocean dynamics and physical properties of the seas. Characteristics to be

Top: Photograph of Jupiter taken by Pioneer 10 from a distance of 2,500,000 kilometers shows Jupiter's Red Spot and shadow of the moon Io.

Bottom: Helios spacecraft will fly closer to the sun than any previous spacecraft.



measured are sea surface topography and temperature; wave height, length, and direction; wind amplitude and direction; and feature identification, such as ice fields and leads. Experiments would also be conducted in geodesy, ocean dynamics, storm dynamics, air–sea interaction, coastal/ice processes, and ocean thermal process. These studies could lead to a JPL project management role for the development of such a satellite to be launched in 1978.

At NASA's request, a Project Office role was assumed by JPL to staff and operate the Planetary Quarantine Laboratory at the Eastern Test Range. This is a research microbiological laboratory that provides support to the NASA Planetary Quarantine Program to fulfill the requirement that prelaunch assays, independent of those conducted by an involved flight project, be performed for the purposes of verifying microbial load reduction and estimating microbial loads on interplanetary spacecraft. The Laboratory will conduct assays of the microbial contaminants present on the Viking Orbiter and Lander spacecraft prior to their launch to Mars.

The Flight Projects Advanced Planning Office is investigating various cost-effective methods for performing near-term future planetary missions. One method will utilize, where practicable, the designs, components, subsystems, and procedures which are being developed for the Mariner Jupiter/Saturn 1977 spacecraft. A detailed cost model was developed to achieve savings through standardization. A plan to buy standardized spacecraft hardware elements during FY'75 is under consideration.

One of the near-term future projects which could make use of the standardized approach is the Mariner Jupiter/Uranus 1979 flyby. An examination of this mission was initiated with the formation of a study team and a Science Advisory Group, which are working together in planning the spacecraft, scientific complement, and ground support elements of this mission.

Studies on possible future missions such as a Jupiter orbiter 1981 mission, Comet Encke and Comet d'Arrest missions are in progress, together with preliminary studies on a Mars sample return mission and a Saturn orbiter mission based on utilization of the Shuttle during the next decade.

Operations

Mariner 10

Tracking and data acquisition support for Mariner 10 was provided by the Deep Space Network (DSN) 26- and 64-meter stations in Australia, Spain, and the United States from launch in 1973 through the encounters with Venus in February 1974 and Mercury in March 1974. The tracking coverage continued into the extended mission through solar conjunction and is planned to extend through the second Mercury encounter late in 1974.

Significant achievements included the first return in deep space communications of telemetry data at rates as high as 117,000 bits per second. Data received at this rate at Goldstone during both the Venus and the Mercury encounters were transmitted by wideband microwave circuits to Pasadena for real-time display of television pictures at JPL. The data received at the 64-meter antenna stations in Australia and Spain were recorded on magnetic tape and replayed in near-real time at a lower data rate through wideband satellite circuits to Pasadena. The significant increase in the high-resolution photographic coverage of the two planets during the flyby mission is directly attributable to this high data rate. By contrast, the data rate from Mariner 9 at Mars in 1971–1972 was 16,200 bits per second.

Also significant was the first use in deep space communications of X-band (3.5 centimeters) for obtaining metric data. Doppler and ranging data were obtained at both X- and S-band (13 centimeters) simultaneously. In addition to demonstrating the feasibility of using the higher frequencies, the dual tracking provided calibration of the effects of charged particles along the path traveled by the signal and resulted in more accurate navigation. Such metric data were routinely returned to the Mission Control and Computing Center at JPL by high-speed data lines at rates varying from 1 sample per minute to 10 samples per second. More than 18,000 commands were sent routinely to the spacecraft. During the critical encounter period, the new high-power transmitter, available only at the Goldstone 64-meter station, provided 100 kilowatts of power.

Pioneer Mission Support

Pioneer 10 was supported by the 64-meter antennas during its encounter with Jupiter in December of 1973. This activity was the first major flight support by the newly completed 64-meter antennas in Australia and Spain. Use of these antennas permitted a threefold increase in the number of pictures obtained at Jupiter. An unusual feature of this mission was the large doppler effect as the spacecraft flew by the planet. In order to permit ground receivers to remain locked on the spacecraft transmitters, it was necessary to manually operate precision frequency control to compensate continuously for the large doppler effect.

The Jupiter encounter of Pioneer 10 set a record for the greatest communications distance at which such activities have been supported. By mid-summer of 1974, the spacecraft was more than 6 astronomical units (900 million kilometers) from earth, and Pioneer 11 was tracked on a near-continuous basis as it successfully traversed the asteroid belt. The DSN will support its encounter with Jupiter in December 1974.

Continuing support was provided to Pioneer 6, 7, 8, and 9 spacecraft, which are still active after more than 5 to 8 years in solar orbit. In January 1974, two of them returned data on the comet Kohoutek during its close approach to the sun.

Helios

The DSN continued support of the preflight phase of the sun-orbiting Helios spacecraft, planned for launch in late 1974. The United States, through NASA, will provide the launch vehicle and launch operations at the Kennedy Space Center, several scientific instruments and principal investigators, and support by the DSN. West Germany has constructed the spacecraft and, after the first few weeks of

Opposite: Interior view of special feed cone used on Australian antenna during Mariner 10 Mercury encounter.

Above right: Mission analysis room in Space Flight Operations Facility.

Right: Data from Mariner 10 being examined during the mission.

flight, will conduct mission operations from a control center near Munich, Germany. The DSN has provided the necessary telemetry and command computer software required for Helios support In addition, compatibility tests between the prototype spacecraft and the DSN have been successfully completed at JPL.

Viking

The Viking spacecraft, to be launched in August–September 1975, impose the most comprehensive requirements on the DSN to date After the two spacecraft are in orbit around Mars and the landers from each have reached the surface, the supporting DSN stations must simultaneously command two of the spacecraft and receive metric and telemetry data from three (the two orbiters and one lander).

Six simultaneous telemetry streams will be transmitted from the three spacecraft. The compatibility test area at JPL has been equipped with additional receivers and telemetry processing equipment in order to handle the six data streams simultaneously Tests were also conducted with models of the orbiter and lander for telemetry and command ground data system tests with the Mission Control and Computing Center.

Radio Science

The DSN antennas continue to be used for support of ground-based radio science by both NASA and non-NASA experimenters and radio astronomers. The 64-meter antenna and one 26-meter antenna at Goldstone furnished most of the support during the year Additional support was provided for very long baseline interferometer measurements by the 26- and 64-meter antennas overseas A significant activity was a continuation of the Quasar Patrol established in 1972. Regular observations started then were continued by the several teams of scientists from Caltech, JPL, MIT, the University of Maryland, and the Goddard Space Flight Center Interest centered on measurements at higher frequencies and primary use of experimental equipment at 3 5 and 2.1 centimeters. The value of the data was greatly enhanced when more than one of the cooperating observatories could observe simultaneously, the availability of three, rather than one, baselines providing a much more powerful technique for examining the structure of quasars. The cooperating observatories were usually the 37-meter Haystack Antenna of the Northeast Radio Observatory Corporation in Massachusetts and the 43-meter antenna at the National Radio Astronomy Observatory in West Virginia. Numerous reports of the results of these observations appeared in the scientific literature. Analysis of the data indicates that more complex models of some quasars, such as the three-component structure, appear to provide an alternative explanation to the reported apparent relativistic expansion of the two-component model for quasars such as 3C273.

Conventional radio astronomy methods were also used Astronomers at the Hale Observatories continued mapping regions around spiral galaxies. Using the 2-centimeter capability at Goldstone, other radio astronomers from the Universities of California and Maryland, and Yale University searched for molecules in the dark interstellar clouds. This search required a sensitivity provided only by the 64-meter antenna at Goldstone. Other University of California radio astronomers made measurements to check the 2.7-Kelvin cosmic black-body radiation in the vicinity of the Coma cluster of galaxies to check the effects of hot-gas radiation on the surrounding region.

All of these investigations were carried on by teams made up primarily of non-NASA scientists. In addition, support was provided to NASA-sponsored radio science activities that included observations of pulsar rotation constancy, radiation from Jupiter, Uranus, and Neptune, and the mapping of interstellar molecules. Radar astronomy activities were supported by the Goldstone 64-meter antenna, both to obtain surface structure data of Venus, Mercury, and Mars in support of flight project needs, and in support of DSN development activities in evolving advanced capabilities by use of radio science techniques and observations.

Facility Modernization

The second of the two overseas 64-meter antennas was completed, bringing a three-station 64-meter subnet into support of flight project activities. The station near Madrid, Spain, was dedicated in May 1974.

The 26-meter station in Johannesburg, South Africa, has been closed, and the tracking activities for that longitude have been transferred to other stations in the network.

Reconfiguration of the NASA facility at Honeysuckle Creek, Australia, will begin in July 1974. Formerly used for earth satellite manned spaceflight support under the direction of the Goddard Space Flight Center, the station will be equipped to support deep space flight project missions.

The DSN launch support station at Cape Canaveral, Florida (DSS 71) has been merged with the Satellite Tracking and Data Network (STDN) operated by the Goddard Space Flight Center. DSN equipment was moved from its location on the Cape to the existing STDN station on Merritt Island. The combined station, designated MIL 71, will continue to support prelaunch testing and launch operations for deep space missions supported by the DSN.

The Network Control System project completed implementation of the Block I phase in January 1974 and supported the Mariner 10 mission and testing of Pioneer, Helios, and Viking. The Network Control System provides the capability for control of the network, network monitoring, data validation, and real-time operations coordination.

DSN Development

S/X-Band Experiment

An S- and X-band experiment was conducted with Mariner 10. It had three major objectives. (1) to obtain scientific data describing the electron content of the medium through which the microwave energy is propagated, (2) to demonstrate navigation and orbit determination enhancement by using dispersive S- and X-band tracking data, and (3) to demonstrate and evaluate X-band as an interplanetary communication frequency band.

In addition to the usual S-band radio system, the spacecraft contained an X-band transmitter and a combined S- and X-band high-gain antenna which radiated coherent S- and X-band carriers with identical range modulation The DSN 64-meter antenna at Goldstone was equipped to receive both frequencies simultaneously. The measured quantities were differential doppler, range, and signal amplitude

Dual-frequency charged particle calibrations were used to significantly improve position determinations at Mercury.

The error in the Mariner 10 position estimate obtained from a single station was reduced by 80 percent. The charged particle calibration capability provided by dual-frequency measurements has the potential for replacing Faraday rotation data for orbit determination corrections. Although the use of dispersive doppler data has been demonstrated, the dispersive range data need additional study and interpretation.

In addition to these experiments with metric data, an X-band telemetry experiment was conducted. The uplink ranging channel was used to simulate a telemetry channel. The turnaround ranging channel and X-band transmitter on the spacecraft returned the signal, and the error statistics of the received signal were measured. The purpose of the experiment was to gain experience for the design of the X-band telemetry system for high-rate video transmission on the Mariner Jupiter/Saturn 1977 mission.

Ultra Cone Use for Mariner 10

A significant reduction in the noise temperature of DSN developmental S-band receiving systems used at the Goldstone and Australian stations was accomplished for the Mariner 10 mission. The resulting received signal-to-noise ratio enabled successful reception of real-time television pictures at a 117.6-kilobit-per-second data rate as Mariner 10 passed Mercury. The alternative rate, if the higher performance had not been available, was 22.05 kilobits-per-second, which would have resulted in one-fifth the number of pictures obtained at Mercury.

The improvement was accomplished by the use of specially built low-noise antenna feed cones. The cones were assembled as listen-only subsystems using low-loss feed components and a traveling-wave maser with an equivalent input noise temperature of 2.1 Kelvins at 2295 megahertz. Use of this cone reduced the total zenith system noise temperature from approximately 18.5 to 12.4 Kelvins. The noise reduction represents an approximate 1.5-decibel improvement in the figure of merit (antenna gain/system noise temperature ratio) at the elevation angle used during Mercury encounter.

64-Meter Antenna Enhancement

Studies were completed on the potential antenna gain and system temperature figure-of-merit improvements possible on the DSN 64-meter antennas. Antenna diameter extensions to approximately 70 meters, beam shaping, and improved low-noise amplifiers can provide nearly a 3-decibel increase in performance to a point within a factor of two of the theoretical limit. In addition, arraying techniques for combining outputs of two 64-meter antennas have been studied which have the potential of increasing the performance an additional 2.7 decibels. The study effort was initiated in response to flight project requirements for outer planet and planetary atmosphere entry missions which presently cannot return all of the data acquirable by the spacecraft.

Altitude Profiles

Altitude profiles of the south equatorial zone of Mars (-14.5 to $-21°$) have been measured to an accuracy of up to ± 50 meters by high-resolution radar. Large-scale variations in altitude give the equatorial figure of Mars; small-scale features correspond closely to the Mariner 9 photographs.

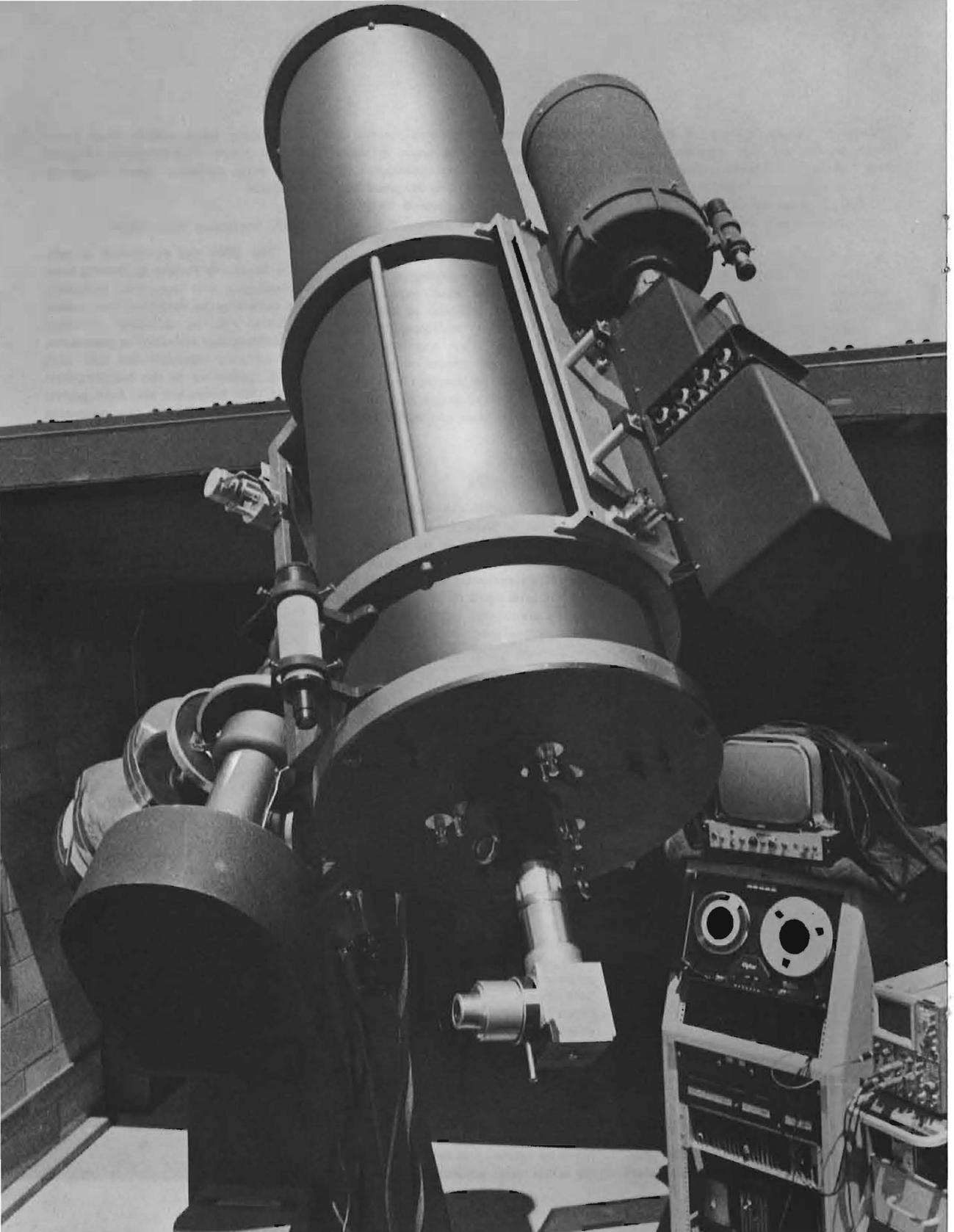
Very-Long Baseline Interferometry

Radio tracking and data differencing techniques for using standard DSN radio metric data from two stations simultaneously are being developed and demonstrated. The technique is similar to very long baseline interferometry (VLBI); hence the name quasi-VLBI (QVLBI). Use of such data reduces navigation errors produced by unmodeled small spacecraft accelerations and low declination geometries. Accuracy analysis studies predict that the QVLBI data should improve navigational capabilities by an order of magnitude. Preliminary demonstrations performed during the Mariner 10 mission have shown that (1) doppler data obtained by QVLBI reduce the navigation errors produced by large and moderate unmodeled accelerations by an order of magnitude and (2) range data obtained by QVLBI can significantly reduce navigation errors resulting from low spacecraft declination geometries. To fully assess the value of these new data types, it will be necessary to determine whether the actual range accuracy is in the 1- or the 10-meter range, and to obtain a substantial amount of dual-frequency doppler data using hydrogen maser frequency standards.

DSN Software Standards

The DSN has established a Software Standards Project to develop both technological and managerial disciplines for increasing the likelihood that needed software will be delivered error-free within budgetary and schedule constraints. The software standards not only have direct application to the minicomputer-based DSN needs but also have general application to the NASA data processing community.

Sixty-four-meter antenna at Goldstone Deep Space Station.



Research and Advanced Development

Physical Sciences

Thermionic Energy Conversion

It was shown that a direct conversion of heat to electricity could be efficiently achieved (15 percent) by using thermionic energy converters operating at high emitter temperatures (1700°C). Higher efficiency (≃30 percent) could be achieved by lowering emitter temperatures to approximately 1100°C, by developing a low-work-function (1 electron volt) collector electrode, and by reducing plasma losses. JPL research seeks to develop a lower-work-function collector utilizing a negative electron affinity electrode. Terrestrial solar thermionic power systems and nuclear electric power systems are key applications of high-efficiency thermionic converters.

Continuum Mechanics

A major breakthrough in applying the principles of continuum mechanics to large deformations in compressible rubbery materials has been achieved. For a simple synthetic rubber (styrene–butadiene), the behavior is given by a simple two-constant equation almost identical to that for linear elasticity—the two constants being the shear modulus and bulk compressibility. A way has been opened for a simpler, more complete theory of mechanical response and the role of cavitation in the rupture of polymeric solids.

Metallic Vapor Lasers

JPL researchers, working to develop continuously pulsed metallic vapor lasers, have constructed a supersonic copper vapor laser, operating at a wavelength of 5106 angstroms and temperatures of about 1800°C. Such high temperatures are deemed impractical. However, an important discovery has been made which allows vapor lasers to utilize metallic compounds as lasants at lower temperatures. These compounds are made to lase with a series of electrical discharges—the first producing dissociation of the compound, and subsequent discharges pumping the laser. Lasing has been attained with copper iodide, copper chloride, lead chloride, manganese chloride, and copper formate from 100 to 700°C. Copper chloride at a temperature of 400°C yields the best performance. Supersonic copper chloride lasers under development indicate a potential laser with an average power output of 1 kilowatt and and efficiency exceeding 1 percent.

Superconducting Microcircuits

A cooperative program between researchers at the Caltech campus and at JPL has developed techniques for fabricating superconducting devices in a microminiature form suitable for commercial production. Superconducting microcircuits can now be made in much the same way as the presently widely used semiconducting integrated circuits, but with unique capabilities unmatched by their semiconducting counterparts. This method promises widespread use in astronomy, communications, geology, medicine, and meteorology.

Acoustic Chamber for Space

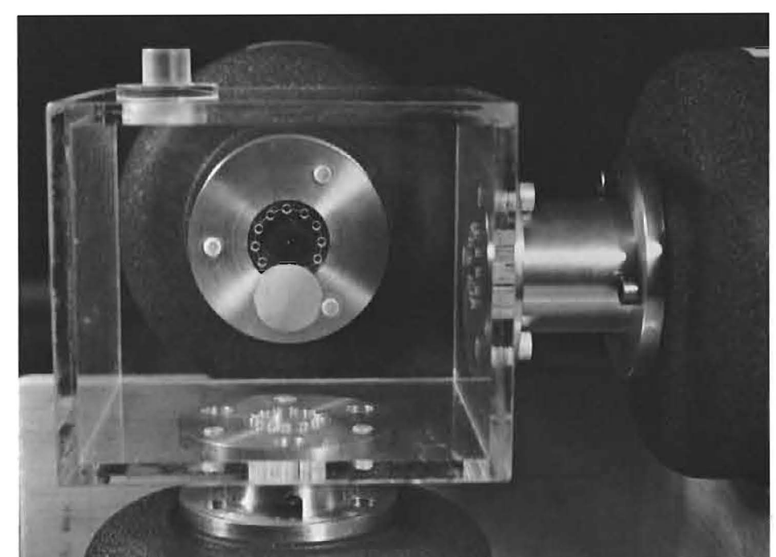
An acoustic chamber for future space research and application has been developed. This apparatus utilizes acoustic pressure to actively control a freely suspended liquid mass and has been demonstrated under a 1-*g* environment. A more sophisticated version of the chamber will be used in the Space Shuttle to perform fundamental studies on the dynamics of liquid drops and to control molten material for space processing applications.

Space Power

Solar Electric Spacecraft

Solar electric propulsion (SEP) has unique capabilities for accomplishing a wide range of missions, including a slow flyby of the Comet Encke in 1980, and an out-of-ecliptic mission to solar latitudes in excess of 50 degrees. Development of specific technology to support a first mission was given impetus in late 1973 by NASA with the establishment of an Advanced Systems Technology (AST) Project. Demonstration of SEP technology readiness to support the start of a flight project in 1976 includes coordinated activities at Lewis Research Center, Marshall Space Flight Center, and JPL.

Activities at JPL include mission and system design, electric thrust subsystem technology development, and navigation system development. The Comet Encke mission established the baseline spacecraft design. The electric thrust subsystem technology effort will prove the adequacy of present thrust subsystem designs in meeting new requirements, particularly in the areas of thermal design, electrical performance, and thrust level control. The



Opposite: Optical guidance television test setup mounted on tracking telescope for use in spacecraft guidance.

Right: Acoustic chamber for studies on the control of liquids and molten materials for space applications.

navigation system effort is developing techniques necessary to navigate a continuously thrusting spacecraft. Software has been completed for analyzing the functions of trajectory targeting, orbit determination, and approach guidance.

Thermoelectric Power Sources

Radioisotope thermoelectric generators (RTGs) constitute one class of solar-independent power sources Long-term evaluation of ten RTGs continued under a contract with the Atomic Energy Commission. This evaluation includes a materials investigation program to establish the degradation model for the silicon–germanium thermopile of the RTGs to be used in the Mariner Jupiter/Saturn space mission Preliminary models were formulated to assess bulk property changes, deterioration of thermal insulation, and changes in electrical resistance.

Work was initiated under funding provided by NASA-OAST to evaluate thermoelectric material of a selenide-base alloy which may double conversion efficiency The OAST work includes a radiation study defining neutron and gamma fields emanating from the RTG Interference effects of radiation on science instruments were established

Solar Power

Development of solar cells produced from silicon ribbon, development of performance characteristics of new, improved-performance silicon solar cells, and study of ways to reduce the cost of solar arrays were major activities.

Fabrication of the first solar cells produced from a shaped ribbon of silicon grown directly from silicon melt was accomplished. If successfully developed, ribbon silicon solar cells could significantly reduce the cost of future space and terrestrial solar arrays

Several improved solar cell designs were developed which could influence the design of solar arrays, subject to space testing. Hence, JPL resumed high-altitude (37-kilometer) balloon solar cell calibration flights Three of these flights were successfully completed, and data were obtained on a wide variety of cells JPL not only calibrated cells for its own evaluation but also measured cells for other organizations, including several foreign governments

Power Processing

Significant improvements were produced in the areas of control circuitry for high-performance power conversion circuits, analytical techniques for nonlinear switching processes, and magnetic component design and fabrication techniques

Two new analog-to-digital feedback controllers were developed, each resulting in increased transient performance. Each can be standardized for use with any typical power-switching circuit and cut costs

A method for analysis and design of high-efficiency switching circuits used for conversion, inversion, or regulation of voltage or current promises to improve the response time, overshoot, and damping factor of breadboard voltage regulators with either one or two feedback loops.

Navigation, Guidance, and Control

Satellite System Dynamics Model Development

A mathematical dynamics model of the outer planet natural satellites has been partially developed for use in spacecraft navigation during future missions to the outer solar system. The model includes solar, planetary, and mutual satellite interactions. A computer program is used to fix satellite positions and velocities

Related software developed within this activity was utilized by the Pioneer project to improve the ephemeris of Io, Jupiter's innermost Galilean satellite This contributed to the successful occultation of Io by the Pioneer 10 spacecraft.

Advanced Estimation

Until recently, interplanetary navigation relied on so-called "batch filtering" in the estimation of spacecraft position and velocity during the orbit determination process. These filters worked well, but not infallibly, during gas leaks, fluctuations in thrust level, or solar plasma encounters Sequential estimation filters which can cope with such situations were successfully demonstrated during the Mariner Venus/Mercury mission. Navigation on the approach to Venus enabled attainment of the 90 percent science aim zone at Mercury and assured the opportunity for a return to Mercury

Extended Life Attitude Control System

A breadboard demonstration of the hybrid programmable attitude control electronics (HYPACE) on the single-axis gas-bearing spacecraft simulator was successfully completed. HYPACE provides an adaptable analog/digital design approach that permits preflight and in-flight accommodation of mission changes, component performance variations, and spacecraft changes through programming. HYPACE was selected for use on the Mariner Jupiter/Saturn 1977 project.

Optical Guidance

Experiments were conducted to characterize a comet as a navigation target for terminal optical guidance purposes. Proposed missions such as the solar electric propulsion (SEP) spacecraft to Encke in 1981 will require guidance pictures with the comet shown against a star background Data were taken on various planetary and celestial targets, including the comet Bradfield. A small commercial telescope with parameters close to the Mariner Venus/Mercury lens was used with a digital slow-scan vidicon camera The results verified the capability to perform the required navigation functions

Telecommunications and Data Handling

Imaging Communication Systems

An advanced imaging communication system (AICS) was devised which potentially offers four- to fivefold increases in image information rates from planetary spacecraft This system will include a coding element on board the spacecraft and a decoding element at a JPL data processing center When used in conjunction with the already planned coded communication capability of the Deep Space Network, the Reed–Solomon coding system will eliminate the error vulnerability problem normally associated with the transmission of compressed data. The compression factor of the planned data compressor can be arbitrarily selected on a frame-by-frame basis to achieve compression ratios up to 32 to 1.

S/X-Band Experiment

A communication experiment was performed utilizing simultaneous transmission of phase-coherent S- and X-band radio signals from the Mariner 10 spacecraft. This S/X-band experiment had three major objectives: (1) to obtain data on the electron content of space, (2) to demonstrate navigation and orbit determination enhancement, and (3) to evaluate X-band as an interplanetary communication frequency band.

The occultation of Venus provided information on the night and day planetary ionospheres. The Mercury occultation showed that any ionosphere was below detection threshold, which meant that it had to have an electron density of less than 4000 electrons per centimeter on the nighttime side and less than 1500 on the daytime side. Data taken near superior conjunction are being evaluated for solar wind and corona effects.

Dual-frequency doppler was used to improve the Mercury plane position determinations based on the tracking data acquired from the one dual-frequency tracking station. The Mariner 10 position estimate error was reduced by approximately 80 percent.

The turn-around ranging channel of the X-band transmitter was also used to conduct an X-band telemetry experiment. This established history's first interplanetary X-band telemetry link between the Mariner 10 spacecraft and Goldstone, California. The experiment demonstrated the feasibility of X-band for future planetary telemetry operations.

Structures, Materials, and Aerothermodynamics

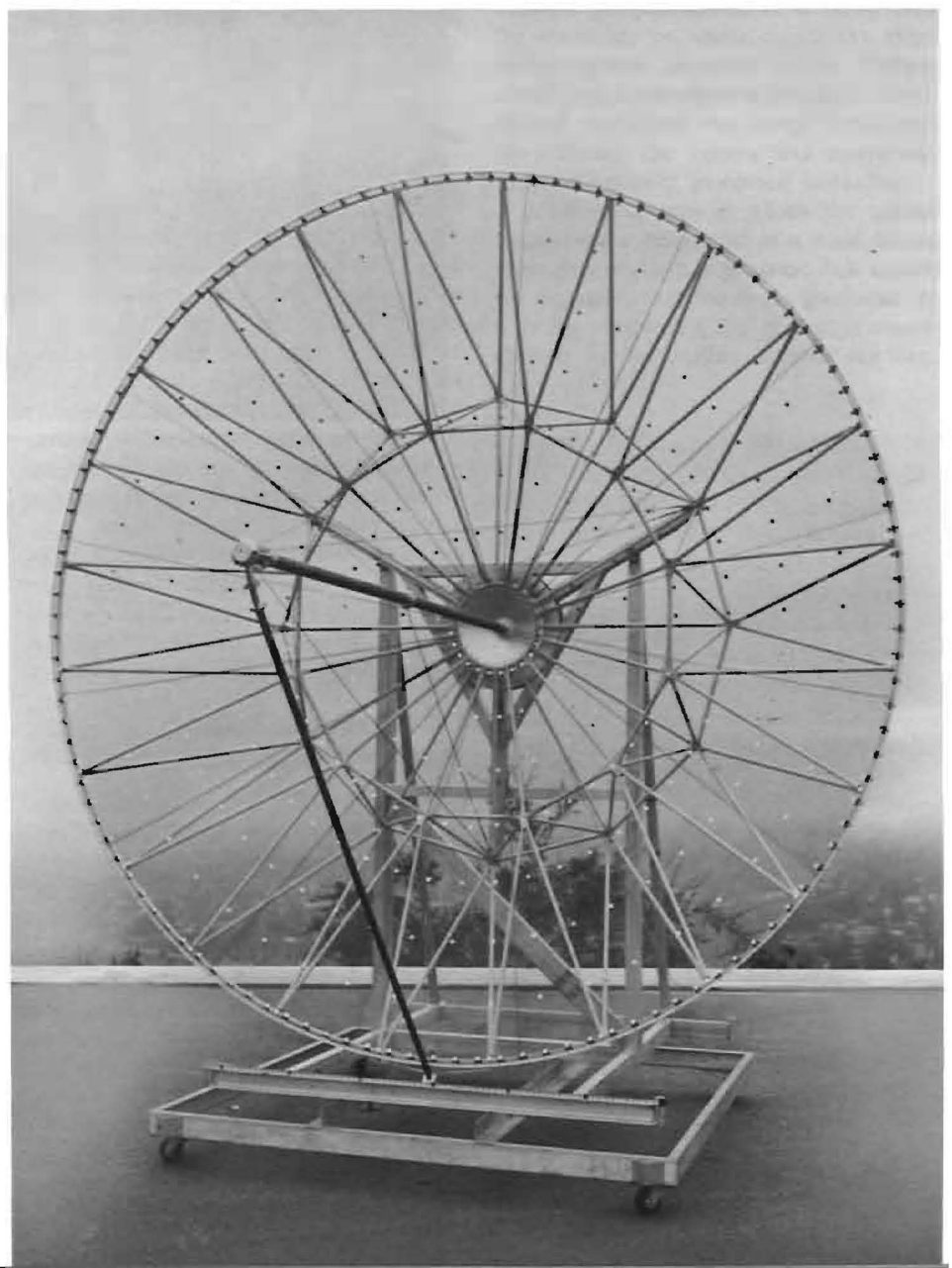
Outer Planet Entry Study

Understanding of radiative heat transfer to an outer planet atmospheric entry probe was enhanced by high-temperature gas dynamics studies. A 1-megajoule capacitor energy storage system in the hypervelocity laboratory, coupled with an advanced driver shock tube, permitted gases to be driven at speeds and pressures comparable to entry into Jupiter's atmosphere. Based upon the slow reaction rates observed, less radiative heating is now expected for a probe entering the atmosphere of an outer planet than had been previously predicted.

Advanced Spacecraft Antenna

A 3.66-meter-diameter nonfurlable conical mesh antenna utilizing a line source feed has been designed, built, and RF tested for possible space flight application. The 16.5-kilogram mesh reflector structure had an RMS surface deviation of 2.7 millimeters, with an overall RF performance of 65 percent at 8.448 gigahertz for a gain of 48.3 decibels. The gold-plated Chromel-R mesh, supported by tensioned spokes and an aluminum space frame truss structure, offers weight advantages as compared to the more conventional honeycomb antenna reflectors.

Light-weight conical antenna has aluminum space frame truss structure covered with gold-plated Chromel-R mesh.



Chemical Propulsion

Heat-Sterilizable Solid Propellant Rockets

"Biologically clean" solid propellant rocket motors are being studied for planetary missions requiring sterile equipment such as the Mars surface-sample return. Under JPL direction, the first heat-sterilized solid propellant rocket motor of significant size was successfully prepared, sterilized, and test-fired. The flight-type motor, containing 61 kilograms of propellant, required a unique, new, stress-free chamber insulation system. The only other firings of flight-type heat-sterilized motors involved 1.0-kilogram motors at JPL in 1967. A much larger motor, with 360 kilograms of propellant and an alternate stress-free insulation system which potentially offers a higher performance, is also being heat-sterilized and evaluated. This motor has survived two sterilization cycles of 54 hours at 125°C with no sign of failure.

Shuttle Exhaust Research

To comply with federal environmental regulations, JPL is studying rocket exhaust problems with particular reference to Shuttle launches starting in 1979 Using instrumented aircraft—a helicopter for the troposphere and a U-2 for the stratosphere—exhaust samples are collected for laboratory analysis Aluminum oxide particles are sized by means of electron microscopy and the images analyzed automatically by digital computers. Several chemico-physical devices, such as x-ray fluorescence, electron spectroscopy, and electron diffraction, are used to determine the exact structure, composition, and reactivity of particles.

Shuttle Booster Separation Motor Propellants

The NASA Shuttle launch vehicle consists of two very large solid rocket booster motors attached to the external tank which supports the Shuttle orbiter. Analyses indicate that exhaust gases from sixteen small separation motors used to separate the large booster rockets from the orbiter would impinge on the orbiter and possibly damage the insulation of the Shuttle to the extent that the orbiter would not survive an earth reentry environment.

A program was initiated by NASA Marshall Space Flight Center to develop a solid propellant for the separation motors that would not damage the orbiter insulation material by having minimal or no condensibles in the exhaust. Eight propellant batches were mixed at the JPL Edwards Test Station, and a total of 55 2.25-kilogram subscale motors were cast for testing at both JPL and NASA-MSFC.

Four propellant formulations are to be cast into 28 larger motors for tests at JPL and the Arnold Engineering Development Center Altitude Facility in Tennessee.

Bimodal Rocket Engine

Experimental development has begun of a high-energy liquid propellant bimodal rocket engine capable of operating in a monopropellant mode, at a reduced thrust of 890 Newtons (200 lb_f), by decomposing hydrazine in a catalytic reactor, or in a bipropellant mode at a thrust level of 2670 Newtons (600 lb_f), by introducing fluorine into the monopropellant reactor gases This arrangement takes full advantage of the high performance capability of fluorine–hydrazine bipropellant for large-impulse maneuvers, and the low-thrust monopropellant operation for small trajectory corrections. The bimodal approach appears to provide maximum flexibility in a single engine, indicating simplified spacecraft design and improved propellant utilization

Aeronautics

Airline System Study

A computer-based system for the simulation of commuter airline operations has been developed, affording interactive conversation between the user and the computer during program operation. A network of prompting "helpers" makes it possible for persons not familiar with computers (or the program) to build, save, display, and update all the data necessary for the simulation. The program can vary all cost/revenue and operational parameters such as fleet composition, schedule, passenger demand, and fare tables. The simulator then executes the flight schedule, simulating passenger pick-up and delivery. It is anticipated that this simulator will be used in the evaluation of cost/revenue and operational feasibility of planned future short/medium-range aircraft under study by NASA.

Below: Solid propellant being cast into NASA Shuttle motor.

Bottom: Air Force U2 carrying JPL particulate sampling experiment.

Jet Noise Research

Noise sources in subsonic and supersonic jets at temperatures comparable to those encountered in aircraft jet engines were shown to involve large-scale eddies ranging in size up to the jet diameter. These eddies appear to decrease in size as the temperature of a jet is increased. The extent to which the eddies contribute to the noise radiated from a jet will be studied further.

Aircraft Noise Research

Another research task assessed noise produced by the airframe interacting with turbulent shear flows in order to establish design principles for quieting aircraft during the low-altitude landing approach when jet engine noise is minimal. An acoustic imaging technique is being used for sound-source identification. An ellipsoidal-segment acoustic mirror focuses sound onto a microphone with diffraction-limited resolution. An image is obtained by scanning the system and converting acoustic intensity to optical intensity.

Measurements in which the mirror focuses on a test model in a wind tunnel through a port are in progress. It is found, for example, that the noise produced by a lifting wing with a flap originates almost entirely at the trailing edge of the flap.

Earth

Project ARIES

Extremely remote quasars and radio galaxies are about to play an important role in increasing man's understanding of earthquakes. Beginning in August 1974, Project ARIES (Astronomical Radio Interferometric Earth Surveying) will begin the measurement of a grid of sites in the southwestern United States with annual visits to these sites to determine their relative motions.

The feasibility of using such distant objects for measurements on earth was demonstrated earlier by the ARIES transportable 9-meter antenna, operated independently of the Goldstone 64-meter antenna. Accuracy of 3 centimeters was obtained over a 307-meter baseline. ARIES is now entering its second phase of development by using a 200-kilometer baseline, where 10-centimeter accuracy will be the initial goal, with a later goal of 2 centimeters.

Modern geophysical theories hold that deformations of the crust must precede earthquakes. ARIES will aid in determining regions where strain energy is accumulating and perhaps indicate the location, time, and magnitude of impending earthquakes.

Geology

In a continuing investigation of the arid Coconino Plateau, Arizona, using the Earth Resources Technology Satellite (ERTS) photographs, a joint JPL–Caltech research team has found indications of widespread near-surface water deposits. Acting on clues from ground-based geologic mapping that water might be found in near-surface sandstone deposits, an extrapolation was made to a wider area by the use of computer-enhanced multispectral ERTS images. Exploratory drilling in one small area successfully located water.

Microwave Remote Sensing

Since December 1972, the JPL microwave spectrometer on the Nimbus-5 satellite has measured global atmospheric temperature profiles, atmospheric water content over oceanic areas, and certain surface geophysical parameters. The primary purpose of the experiment is to evaluate passive microwave techniques for use on operational meteorological and geophysical satellites. Results from the microwave spectrometer have been compatible with coincident radiosonde measurements and with standard northern hemisphere atmospheric analysis data from ground stations.

Concorde Stratospheric Measurements

JPL continued its studies of stratospheric background composition with a Michelson interferometer aboard the British prototype of the SST Concorde. Absorption of solar radiation was observed over long atmospheric paths at altitudes above 15 kilometers, from which concentration levels of gases of particular interest to the study of the effects of engine emissions into the stratosphere were derived. The observations verified the existence of nitric oxides in the stratosphere and led to a preliminary determination of the altitude profile of this trace constituent in the 30°N latitude region covered by the flights. Other significant accomplishments included the refinement of latitudinal and vertical variations in the concentrations of methane and carbon dioxide.

Cloudy Atmosphere Sounding

A decade of experimentation with satellite remote sounding has shown that the development of cloud-filtering techniques is indispensable to progress in the field of remote sounding of atmospheric temperature profiles for weather forecasting. A dual-frequency method was numerically applied to filter out effects of up to three cloud layers using computer-simulated radiance data. Resulting temperature profiles were as accurate as those taken under cloudless conditions. Dual-frequency results are being verified by JPL and the Scripps Institute of Oceanography as part of the North Pacific Experiment (NORPAX).

Moon

Apollo Science

Later altimeter data acquired by orbiting Apollo spacecraft reveal that the ringed mare surfaces of Mare Imbrium, Mare Serenitatis, Mare Crisium, Mare Smythii, Grimaldi, and Tsiolkovsky fit extraordinarily well to an ellipsoidal surface. The ellipsoid bulge of 2.5 kilometers faces toward the earth and revives the contention that the moon once was

Opposite: Transportable 9-meter antenna used by Project Aries in determining deformations in the earth's crust that precede earthquakes.

Right: High-speed interferometer installed in SST Concorde for stratospheric observations.

much closer to the earth and that tidal forces caused the distortion. The 2-kilometer offset of the center of gravity from the optical center remains the same as previously reported and implies that there must be an asymmetry in the internal distribution of mass.

Lunar Heat Flow

A series of model numerical thermal calculations simulating the expected geologic settings of the Apollo sites was made. The model takes the lunar regolith to be a highly effective thermal insulator that varies significantly in thickness between mare and highlighted regions. A pronounced heat refraction effect was shown to occur at the geologic interface where measurements were made. Magnifications in heat flow ten times the global average could be expected. The bulk uranium implied by equilibrium flow-production calculations may be considerably lower than previously supposed. If such a near-surface model is correct, the special insulating properties of lunar regolith are also important in global lunar thermal history calculations.

Old Lunar Basalt

JPL scientists found that KREEP (potassium–rare-earth–phosphorous rich material) basalt fragments collected along the lunar Apennine Front predate the Imbrium impact by about 300 million years. The evidence for this antiquity is the presence of large densities of fission tracks in whitlockite crystals. These were ascribed to plutonium-244, a nuclide believed formed in interstellar processes before the formation of the solar system. Such fission tracks are not found in rocks younger than 4000 million years. From the track excesses observed, the age of the fragments was estimated at 4250 million years. The fragments were probably eroded from a primary KREEP basalt body which lay beneath the lunar surface at the time of the Imbrium impact. Later isostatic readjustment of the huge crater raised the Apennine Front by normal faulting, and thus exposed the primary body along the fault wall.

Lunar Sample Studies

The ferromagnetic resonance technique used to investigate the magnetic properties of Apollo 16 and 17 samples showed the predominant ferromagnetic constituents to be metallic iron. This technique proved to be particularly effective for studying the magnetic properties and thermal history of fine grains and small fragments of lunar material that cannot be examined by other methods.

Planets

Mars Gravity Field

A definitive gravity field for Mars was obtained in the form of a distribution of 92 point masses over the surface. The resolution of the corresponding geoid ranges from 50 meters in the equatorial belt to about 500 meters at the north pole. The principal visual features such as the volcanic ridge at Tharsis, the large canyon Valles Marineris, and the mare-like regions Argyre Planitia and Hellas Planitia exhibit gravity anomalies, suggesting a strong correlation between gravity and topography.

Mars Geophysics

A study of Martian gravity data showed that the geological structures reflected in the topography of Mars fall into two distinct age groups. The older group is isostatically compensated at relatively shallow depth. The younger topography is either partly compensated at shallow depth or completely compensated at greater depth. Mars topography appears to be the product of viscous relaxation in an environment of approximate thermal steady state over the past 4 billion years.

Mars Atmosphere

Mariner 9 S-band radio occultation measurements taken over half a Martian year were examined for seasonal variations in atmospheric pressures, temperatures, and zonal geostrophic winds. Seasonally related global atmospheric pressure oscillations of approximately 14 percent were discovered and appear correlated to seasonal growth and decay of the polar caps.

Venus and Mercury Atmospheres

Data from Mariner 10 occultations of Venus and Mercury showed four distinct temperature inversions in the atmosphere of Venus at altitudes of 56, 58, 61, and 63 kilometers. As expected, the X-band radio signal was more rapidly attenuated than the S-band and disappeared completely at an altitude of 52 kilometers. The nightside ionosphere was found to consist of two layers having a peak density of 10^4 electrons per cubic centimeter at altitudes of 140 and 120 kilometers. The dayside ionosphere had a peak density of 3×10^5 electrons per cubic centimeter at an altitude of 145 kilometers.

The analysis of the Mercury occultations yielded values for its radius of 2440 ±2 and 2438 ±2 km at latitudes of 2°N and 68°N, respectively. No evidence of either an ionosphere or an atmosphere was found. The noise in the data due to fluctuations in the interplanetary space plasma and the earth's ionosphere yielded upper bounds on the Mercury ionosphere electron density of about 1500 and 4000 electrons per cubic centimeter on the dayside and nightside, respectively, and implied an upper bound on the surface atmospheric pressure of 10^{-8} millibars.

Jupiter

Two-way doppler data received from Pioneer 10 during its encounter with Jupiter in December 1973 have been analyzed and results obtained on the mass and gravity field of Jupiter and on the masses of the four Galilean satellites. The mean densities of the satellites decrease with increasing distance from Jupiter. The two inner satellites, Io and Europa, have mean densities a little greater than that of the moon, while the two outer satellites are less dense—about 1.9 and 1.6 times the density of water for Ganymede and Callisto, respectively.

The first definitive measurement of the fourth-degree zonal harmonic of the Jovian gravity field has been obtained, and the second-degree harmonic has been measured with improved accuracy. Application of the Hubbard gravitational inversion technique to the Pioneer 10 gravity data yields a structure for the Jovian envelope which is consistent with an adiabatic, solar-composition model with a boundary temperature of 190 ± 40 Kelvins at the surface of the planet.

A thermal component of Jupiter's radio spectrum between 0.1- and 21-centimeter wavelengths yielded information on the vertical structure and composition of the Jovian atmosphere. A computer program was developed to utilize new values of the microwave absorption properties of ammonia and generate theoretical microwave spectra which are then compared with the observations. The precision of the observed microwave spectrum was improved, with new temperature values at 3.7 and 11.1 centimeters and at several wavelengths near the 1.3-centimeter NH_3 inversion band.

A theoretical study is in progress to interpret both the results of the Pioneer 10 particles and fields experiments and the earth-based radio-astronomical data with a consistent model of the Jovian radiation belt. Pioneer 10 electron fluxes are consistent with the ground-based data to within a factor of three. The study lends strong support to University of California, San Diego, electron flux data, which show fewer low-energy electrons than either the University of Chicago or University of Iowa data.

Pioneer 10 carried a JPL magnetometer, an improved version of the vector helium magnetometer previously flown to Mars and Venus. The Jovian field was found to be about ten times stronger at the surface than the geomagnetic field and to have a source that is displaced from the center of Jupiter. The planetary field extends outward from the surface approximately 100 Jupiter radii, although it is strongly deformed, presumably by trapped particles, over most of this distance.

Saturn

In collaboration with the University of Hawaii, it was shown that infrared absorptions in the spectrum of Saturn, which occur in the vicinity of strong ammonia bands, coincide with weak lines of the methane spectrum. This puts a very low upper limit on the amount of ammonia in the IR line of sight on Saturn. There have been observations of ammonia on Jupiter by means of a much weaker band.

Some absorption features in the spectrum of Titan, a satellite of Saturn, remain unexplained. In collaboration with workers at the University of Texas, it was established that these are not due to ethane, ethylene, propane, methane, ammonia, or hydrogen sulfide.

Jupiter-Io Atmosphere

Pioneer 10 occultation tests showed Jupiter and Io atmospheres to be hotter and to have higher electron densities than anticipated. The ionosphere is produced by solar radiation on the dayside and decays on the nightside of Io. High temperatures at all levels between Jupiter and Io were explained by JPL scientists as possibly caused by sun-heated dust or ions in the upper Jovian atmosphere.

Asteroid Evolution

Studies of 2800 asteroid orbits revealed that 44 percent of the bodies in the asteroid belt between Mars and Jupiter may have formed as fragments from over 100 collisions. These collisions apparently account for the small size of most asteroids. Only three have diameters of more than 400 kilometers.

Gamma-Ray Astronomy

The JPL high-spectral-resolution gamma-ray telescope fulfilled all technical objectives during its maiden flight on June 10, 1974. Lofted to 40 kilometers above the earth's surface by a 4.4 million cubic meter balloon, the 500-kilogram observatory transmitted gamma-ray data from the Crab Nebula and its associated pulsar. Data were also collected from the diffuse cosmic gamma-ray background and the earth's atmospheric background. The data, presently being analyzed, will provide information to further characterize and improve the effectiveness of the observatory for use on future balloon flights, and will be vital to the construction of a similar but larger instrument to be orbited on the High Energy Astronomy Observatory (HEAO) in 1979.

Gamma-ray telescope flown on a balloon transmits gamma-ray data from the Crab Nebula and associated pulsar.

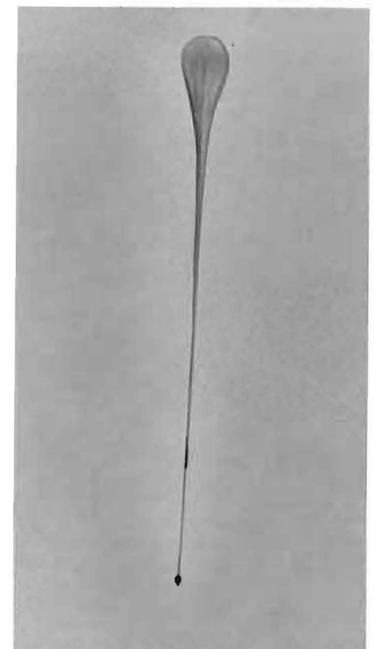


Table Mountain

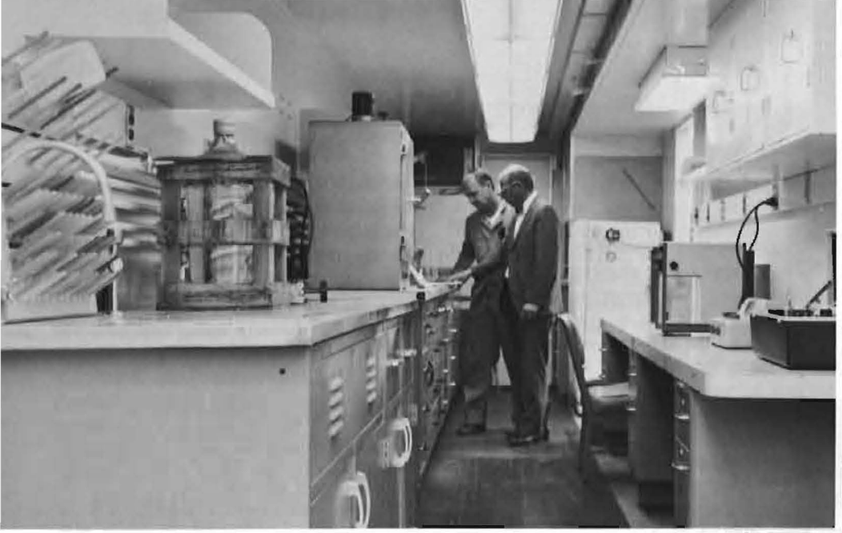
The new radio interferometer at JPL's Table Mountain Observatory was successfully operated for the first time on May 15, 1974, when interference fringes were observed from small-scale features of the sun. Interference fringes from the Quasar 3C273 and from the partially resolved disk of Venus were observed the following day. This interferometer has the highest known operating frequency, using two parabolic dishes, 5.5 and 3 meters in diameter, operating at 36 gigahertz on a 60-meter east–west baseline.

Director's Discretionary Fund

This fund provides seed money (typically from $15,000 to $50,000 a year per project) for promising research and development projects that have possible applications in fields other than space. The following were among those showing significant progress in 1973–1974.

A study of pulsating flow in castings of disease-roughened human coronary arteries which may help to explain certain vascular diseases. It was shown that all roughness significantly slows blood flow. In the case of 20 percent obstruction in flow, resistance was four times greater for rough than smooth tubes. For a given pressure drop, the flow rate for rough tubes was only half that for smooth ones.

A vector helium magnetometer system was designed and used for possible magnetic measurements in earthquake prediction. Collection and analysis of data relating changes in the earth's magnetic field to earthquake activity is well under way.



Energy and Environmental Systems

Wastewater Purification

A process to treat municipal wastewater was invented and demonstrated by JPL under sponsorship of the National Aeronautics and Space Administration (NASA). The process, called ACTS (Activated Carbon Treatment System), utilizes the sewage solids and pyrolyzes them to form an activated, powdered carbon which is fed counter-current to treat and purify the incoming wastewater stream. The process virtually eliminates the sludge disposal problem typical of a biological process because it uses the waste solids to clean the water. The process equipment requires less area, since aeration processes employed in conventional treatment methods are not necessary.

A 10,000 gallon-per-day mobile pilot plant has been operated in a cooperative program between JPL and the Orange County Sanitation District, Fountain Valley, California. Test operations showed that the process is stable, and the carbon dosage rates can be varied to adapt to fluctuations in organic and/or hydraulic loading. Potential odors are reduced through the adsorption by the activated carbon. The process produced a higher quality water than conventional biological methods and appeared to extract heavy metals as well. ACTS is potentially applicable to any industrial waste stream which contains carbon-forming organic materials.

The ACTS process has been demonstrated to Environmental Protection Agency (EPA) officials, California State agencies concerned with water quality, and interested community and industrial groups. Further tests are planned to obtain operational characteristics applicable to a system in the million-gallon-per-day operating range.

Solar-Assisted Energy Systems

A project to investigate the commercial possibilities of solar-assisted gas energy water heating (Project SAGE) has continued under sponsorship of the Southern California Gas Company. A pilot plant has been constructed to perform comparative tests and evaluation of various apartment water heating system designs. The pilot plant comprises a rooftop collector array, storage tank, heat exchanger, gas boiler, electric heater and associated pumps, valves, and instrumentation. The plant is sized to be representative of a ten-unit apartment. Principal objectives of the project are to select the best apartment water heating system and to determine specifications for components.

Plans are being prepared to install a solar water heating system on an existing apartment complex in the Southern California area in order to demonstrate to industry the feasibility of retrofit installations and to gather further information on the commercial potential to a gas utility of solar-assisted water heating systems.

Under National Science Foundation sponsorship, JPL performed two further tasks in solar energy application. A national workshop on photovoltaic solar energy conversion was organized, as was a conference on the use of solar energy to heat and cool buildings. The information presented at these meetings will be used to assist in the evaluation of solar energy conversion possibilities for augmenting the national energy supply.

Opposite: Development and demonstration of Activated Carbon Treatment System wastewater purification process and equipment.

Below: Project Sage roof-mounted solar collector array for heating water.

Biomedical Systems

Prosthetics Motor

A small, high-powered, brushless dc motor for use with artificial limbs or prosthetic devices was developed for Rancho Los Amigos Hospital. This motor, including the drive electronics, is able to supply the required torque and speed needed for upper limb prosthetics. Because it has no brushes and operates at low speed, the motor is relatively quiet and does not disturb patients.

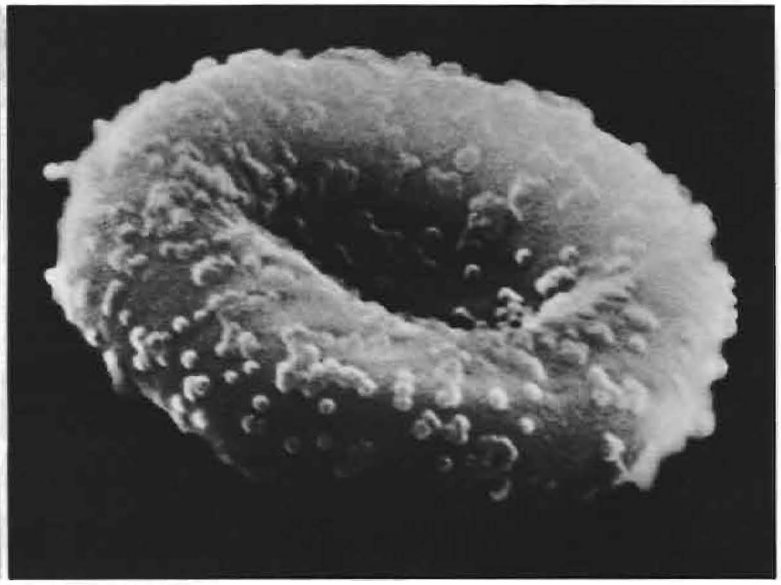
The dc motor, along with documentation to allow for its commercial fabrication, has been transferred to Rancho Los Amigos Hospital for clinical testing.

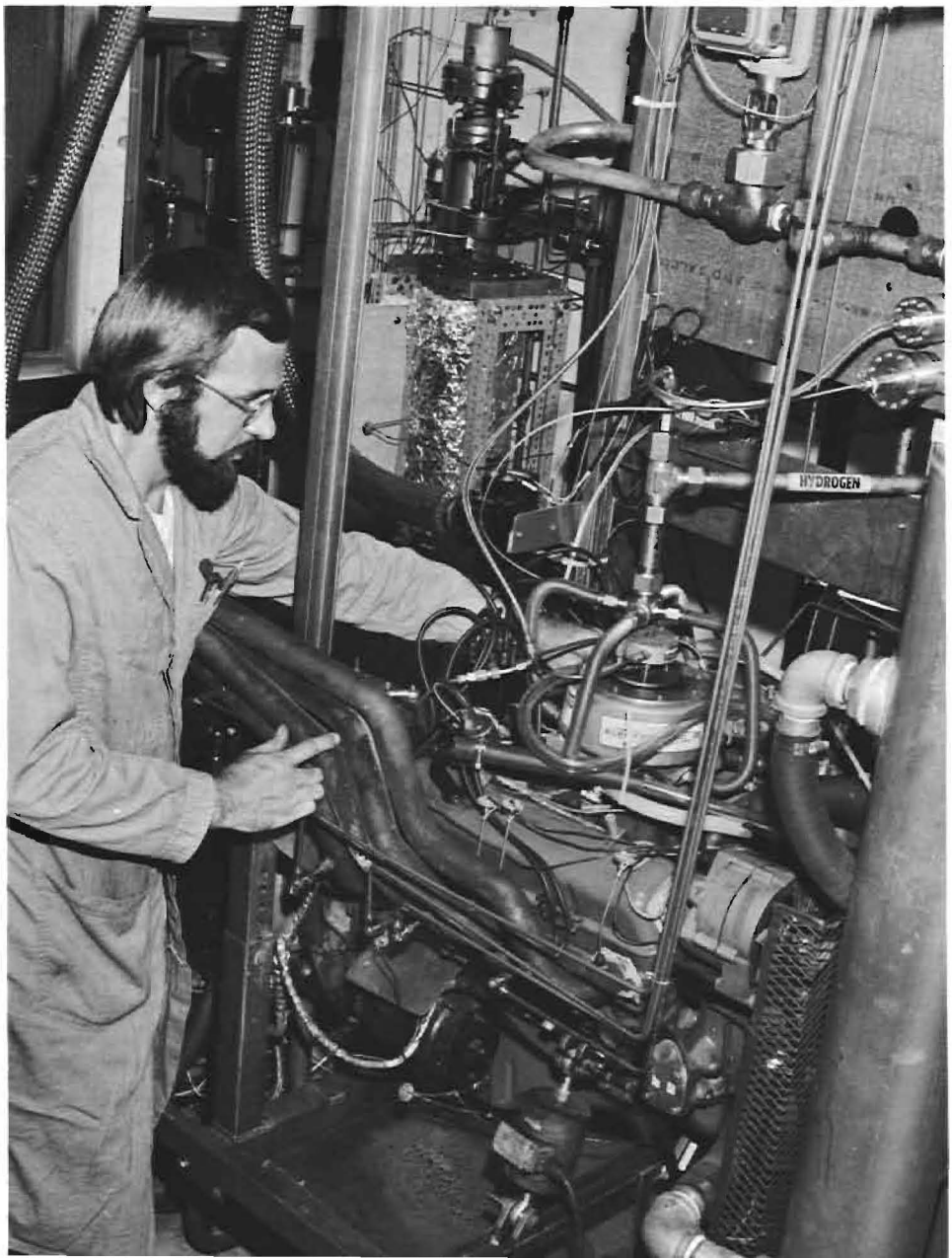
Latex Spheres

JPL, in collaboration with Caltech, has developed a family of microscopic latex spheres whose surfaces are coated with antibodies which direct them to specific cells in the body. These spheres are 300 to 20,000 angstroms in diameter and can also carry dyes and radioactive materials to mark the specific sites they attach to on the cell surface. This technique offers a powerful new tool for mapping cell surfaces and, potentially, for directing lethal drugs to attack unwanted cells.

Below: Normal red blood corpuscle (left) and cell with antibody-coated latex spheres attached (right).

Bottom: Internal combustion engine uses hydrogen to supplement gasoline fuel, resulting in reduced exhaust emissions and improved operating economy.





Electrocardiography

In an electrocardiography study, it was shown that a lumped localized current source distribution in the heart may be calculated from body surface electrocardiogram (ECG) potential measurements by the application of finite element mathematical modeling techniques developed originally for spacecraft structural analysis. The technique is an improvement over the presently utilized Vector and/or Scaler ECG techniques and is expected to aid in early detection of localized heart disease.

Health Care Technology

A regional Health Care Technology Resource Project (HCTR) was established to provide technical and scientific support to local medical institutions. Cooperative needs analyses with administrative and medical staff contributed to several contracts with hospitals for technical task support. Two tasks were completed.

A collaborative investigation of a blood preservative concept was made by City of Hope staff and JPL engineers involving the use of chemical additives, special plastic bags to contain whole blood, and a special agitator. Test results indicate that the storage life of whole blood can be doubled by these combined techniques.

A new type of x-ray exposure control dosimeter was developed in collaboration

with the Huntington Memorial Hospital Radiation Department. Clinical evaluation was initiated in mammography, where the ability to achieve desired radiograph densities was greatly enhanced. A 15% reduction in the number of x-ray exposures required is anticipated.

Health Resources Planning

The Comprehensive Health Planning Council of Los Angeles County has used two computerized static models of a health care delivery system developed by JPL. These incorporated data provided by the National Center for Health Statistics of the U S. Department of Health, Education and Welfare. The JPL software enables planners to estimate the demand for health services by medical specialty, and the number of physicians and hospital beds required

JPL was appointed to the California Committee on Models and Data Base Management, a subcommittee of the California Department of Health's Committee on Comprehensive Health Planning. JPL now provides systems analysis, economic analysis, health systems modeling, and data processing for the State of California Department of Health and local planning agencies.

Transportation Systems

Hydrogen Injection Engine

The use of hydrogen to supplement gasoline fuel for an internal combustion engine has been demonstrated and has significantly extended the engine lean operating limit. Such lean operation resulted in improved operating economy and in reduced exhaust emissions during both engine and research vehicle tests. Test results using bottled hydrogen gas indicate that the 1977 Environmental Protection Agency nitrogen oxide and carbon monoxide emissions requirements can be met using hydrogen-supplemented fuels in engines essentially like those in use today

Development and testing of a hydrogen generator, which provides a hydrogen-rich gas from gasoline, indicated the practicality of generating hydrogen aboard the vehicle. The next planned phase of this project is to modify a research automobile to incorporate a fully self-contained hydrogen generator/engine system which would demonstrate satisfactory operational characteristics, low emissions, and improved efficiency.

The current effort is sponsored by the EPA and NASA, with associated work on lean combustion of gasoline without hydrogen sponsored by the Department of Transportation

Alternate Automotive Power Plants

Under a grant from the Ford Motor Company, a 14-month study was begun to assess power system options feasible for cars and light trucks in the 1980s. JPL investigators are estimating the effects of selected alternative engines on the environment, probable use of natural and synthetic fuel supplies, and the economic implications resulting from large-scale conversion to alternative systems.

The spark ignition internal combustion engine—plus modifications such as stratified charge—was compared with alternative engines such as the diesel, gas turbine, Rankine cycle, and Stirling cycle. Tentative findings indicate that a practical automotive gas turbine requires a materials processing breakthrough in high-temperature ceramic components. The Rankine cycle engines have inherently poor thermal efficiency and may not be acceptable in a period of severe fuel shortage. The Stirling engine has low emissions and fuel economy but is in an early state of development. The diesel is a possible medium-term alternative if its nitrogen oxide and particulate measurements prove acceptable from an environmental point of view.

The Caltech Environmental Quality Laboratory is supporting the study in the areas of fuel availability, vehicle use patterns, and societal impact analysis.

Public Safety Systems

National Law Enforcement Telecommunications

The objective of this project is to analyze the requirements of criminal justice agencies for nationwide, or interstate, telecommunications in the next decade. The purpose of the study phase was to develop communication traffic projections and communication system configuration options for use by the Law Enforcement Assistance Administration (LEAA) in conjunction with the development of law enforcement telecommunications policy.

The results of the study indicate that the interstate communication traffic among the more than 40,000 criminal justice agencies in the United States will increase from the present load of about 1.5 to 36 kilobits per second in 1983, a 22-fold increase. Most of the projected increase will be due to expanded use of digital techniques and automation of record and information systems. From a technical point of view, several communication system configuration options could satisfy the need projected through 1983. However, the possible introduction of video and other broadband uses beyond 1983 suggest that these potential uses deserve further study before a specific system is chosen

A set of functional requirements for a national law enforcement telecommunications system was submitted to LEAA for use in its planning processes. In addition, a user interface guideline document was submitted to LEAA for distribution to local law enforcement agencies in all fifty states.

Automatic Vehicle Monitoring

Many cities feel a need for a capability to monitor the locations of the vehicles in their emergency vehicle fleets, such as police and fire, by some automatic means. A few cities have, or plan to experiment with, automatic vehicle monitoring, and several private companies are promoting automatic vehicle monitoring systems of various types. These factors pose a complicated set of problems for interested cities. Do they need automatic vehicle monitoring (AVM), will it be cost effective, and which system is best suited to a particular city?

A JPL study sponsored by the National Science Foundation is intended to provide some of the answers to these questions so that cities contemplating the use of AVM will have better information upon which to base their decisions. The first phase of the study concentrated on the compilation of data concerning existing and a few conceptual AVM systems, and city characteristics relevant to AVM were analyzed. The performance and costs of the various AVM system options were studied, and preliminary options were synthesized for seven Southern California cities in preparation for a more detailed series of case studies.

Plans and Programs

The Office of Plans and Programs continued in its staff role, providing support to the Director's Office as the focal point at the Laboratory for the functions of planning and program development. These functions encompass the formulation of operational plans and the coordination of resource allocations, the conduct of special studies relevant to Laboratory objectives and potential areas for the application of future effort, and the performance of technical investigations and evaluations of candidate flight missions and spacecraft systems.

Operational Planning

The steady decline in NASA budget and manpower resources which has characterized recent years appears to have stabilized somewhat, at least temporarily. Throughout this period, the Laboratory has been subjected to corresponding restrictions through provisions of its contract with NASA. As a consequence, an unusual degree of attention has been required to the processes of resource planning and allocation and to the maintenance of balance among the various program areas The Laboratory has had to adjust to a reduction in its work force of about 500 positions (12 percent) during the past four years.

Recently, the Laboratory proposed, and NASA accepted, a modification in the application of the contractual manpower ceiling providing for a ceiling on man-years of effort rather than on positions Concurrently, broadened recognition was given to the exclusion from the ceiling of manpower applied to or supporting non-NASA tasks. These changes are of importance and significance in permitting JPL considerably more flexibility in the management and application of its manpower resources.

Special Planning Activities

Planning activities included a review and assessment of NASA's prospective future programs and budget. Such assessments are performed periodically for their own value and to develop essential background materials for use in the annual review and updating of the Laboratory's goals, objectives, and institutional plans. In two related assessment studies, special attention was devoted to questions of expanded involvement by NASA and JPL in programs suitable for international cooperation.

NASA's commitment to the Space Shuttle as the primary launch vehicle of the future has major implications throughout the agency and the aerospace industry. At the present stage of Shuttle development, the Laboratory's special involvement is in upper stage planning and in the establishment of Shuttle–spacecraft interfaces to assure mutual compatibility for the classes of deep space missions which NASA and JPL may want to undertake. The Laboratory also participates in selected technical tasks affecting Shuttle development Thus far, the Office of Plans and Programs has provided the overall coordination of the Laboratory's Shuttle-related activities, and has additionally lent direct support to several NASA-wide study and working groups.

Advanced Technical Studies

Technical studies of possible future deep space ventures are made to examine the prospects and problems of each mission In 1973 and 1974, JPL's advanced studies included analyses of Venus radar mapping from orbit, Mars orbital and surface missions, outer planet flyby and orbital missions, and several types of missions to comets.

Radar mapping of Venus from earth has already shown a variegated, cratered surface beneath the planet's dense clouds. Mapping from orbit would offer great increases in coverage and resolution, yielding knowledge of Venus comparable to that gained about Mars through the cameras of Mariner 9. The study of the Venus radar mission highlighted problems of synthetic aperture radar imaging from orbit, data storage, and data transmission to earth. Based on the study's findings, advanced work in the needed techniques is continuing.

The exploration of Mars by Mariner 9 in 1971–1972 revealed fascinating aspects of the planet's surface and atmosphere, including details of the polar caps, ancient water channels, tectonic and volcanic activity, and a wide variety of aeolian landforms. A long-lived spacecraft in a polar orbit about Mars could provide a great extension of our knowledge of these features and their evolution. Studies of such missions have been started.

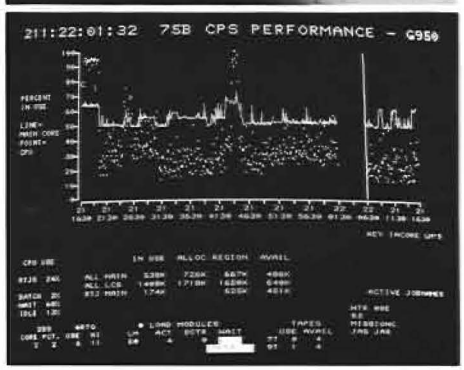
Also under active study is the complex and difficult but potentially very rewarding mission of returning samples of Mars to earth. Among the many critical questions bearing on this mission is the problem of contamination of the biospheres of Mars and earth with each other's organisms. Study of the sample return mission began with an analysis of various ways of performing it, and is now continuing into a further study of the more promising concepts, with due consideration of the biological quarantine problem.

One of the most interesting of the recent studies dealt with a Jupiter orbiter. Once in orbit about the giant planet, a spacecraft can be made to fly closely and repeatedly past each of Jupiter's Galilean satellites (Io, Europa, Ganymede, and Callisto), with each gravitational encounter changing the spacecraft's orbit so that, in time, it completes a tour of the entire Jovian system. The potential scientific yield of such a mission is so striking that the study is actively continuing, with the intent of making the mission a reality some time in the early 1980s, when the launching of interplanetary missions by the Space Shuttle is a possibility.

As the Space Transportation System (STS), which includes the Shuttle, its upper stages, ground facilities, and support, comes into being, JPL is active in studies of how this new and different launch system may be used to increase the reliability, economy, and flexibility of its missions. In addition to payload interface studies and exchanges with the STS agencies and their contractors, the Laboratory is doing R&D work in some of the required techniques, including remotely manned systems, in which the human operators are integrated with computer-driven robot devices. The potential of such systems, and some of the pitfalls that may be encountered in using them, are just beginning to be explored.

Among the international initiatives now being considered are several future flight missions whose tracking data can be used for experiments in general relativity. Also, the concept of an international planetary exploration decade is being studied. By examining these problems early, we can bring them into focus and provide technical data for future program decisions; this is, in essence, the purpose of the advanced technical studies at JPL.

Mission and data system control center in Space Flight Operations Facility (top) and video display showing computer performance in real time (bottom).



Office of Computing and Information Systems

The Office of Computing and Information Systems (OCIS), through the Data Systems Division, operates a General Purpose Computing Facility, a Mission Control and Computing Facility, and a Mission Test and Computing Facility in a complex referred to as the Mission Control and Computing Center (MCCC). It administers the Administrative Computing Services separately. In the past year, major system changes and improvements were made to support the coinciding requirements of the Mariner 10 launch, the Pioneer 10 encounter, and the Mariner 10 encounters with Venus and Mercury. Significant progress has been made in developing and testing computer programs for the future projects, Helios and Viking. Preliminary software compatibility tests have been successfully completed, thus giving a higher level of confidence in the ability of the MCCC system to support these two planetary missions.

The MCCC simulation system capability was improved to provide a multimission support environment to meet requirements of the Helios and Viking Projects. Other accomplishments include the redesign of the ground command system, which has been automated, made easier to operate, and made more reliable. Also, a celestial mechanics/radio science data processing capability was developed to support Mariner 10 scientific activities; it will also be used for the Viking Project.

General Purpose Computing Facility

The General Purpose Computing Facility (GPCF) UNIVAC 1108 computers processed 45,000 jobs per month during the year, providing mission support, project program development, and general user services. The system operates in both conversational and batch processing modes, providing Laboratory personnel with access to the system through any of the 175 demand terminals or seven remote batch input terminals. In the latter part of the year, emphasis was placed on flight mission support and preparation for the Viking missions. A recent activity has been the implementation of Viking Project models in the mission navigation programs. Structured programming has been applied to the Orbit Determination Monitor Program, resulting in several cases, in significant increases in manpower efficiency and time savings in the development.

Emphasis has been placed on user services, including additional computer consultation and education, and initiation of a JPL/Caltech time-sharing PDP-10 facility.

Mission Control and Computing Facility

During the past year, the Mission Control and Computing Facility (MCCF) supported the Mariner 10 launch and the initial encounters of Venus and Mercury, the Pioneer 10 Jupiter encounter, and preflight testing for the Helios launch. In order to achieve this level of support, the third MCCF IBM 360/75 system was upgraded to a configuration equivalent to the other two IBM 360/75s for mission operations. In addition, significant operational and technical upgrading has been implemented to provide computer performance visibility. This included improvement of the IBM 360/75 operating system, expanded display capabilities, and an increase in the MCCF digital television system from 80 to 112 channels. An MCCC operations and analysis function was implemented for computer load forecasting and to aid in ensuring adequate mission operations support. The facility is undergoing significant mission area modifications to support the Viking and Mariner Jupiter/Saturn 1977 projects.

Mission Test and Computing Facility

The Mission Test and Computing Facility (MTCF) supported the Mariner Venus/Mercury Project for system test at Kent, Washington; launch operations at Air Force Eastern Test Range, Florida; and mission operations at JPL. In addition to processing and displaying engineering and nonimaging science data, the facility provided real-time television images and near-real-time hardcopy photo products for approximately 8000 pictures taken at the Venus and Mercury encounters. MTCF personnel designed, fabricated, and provided a word formatter to increase the transmission from 22.05 to 117.6 kilobits per second for real-time imaging data from the Goldstone Deep Space Tracking Station to the Space Flight Operations Facility (SFOF). These real-time imaging data were processed and displayed during encounters at both Venus and Mercury. Without the increased capability to transmit data, the real-time control of the spacecraft for the encounter sequence would not have been possible.

The Mission and Test Imaging Subsystem (MTIS), a new MTCF Viking capability based on Univac 1616 computers, was brought on the line early to support the Mariner 10 encounters of Venus and Mercury. The MTIS generated 7000 Digifax 203 × 254 millimeter (8 × 10 inch) photo prints in near-real-time and provided near-real-time TV images through the Video Image Display System during the Mercury flyby. Viking Orbiter support to Proof Test Orbiter system tests was provided on schedule in early February 1974 and the mission support software was delivered for design compatibility tests.

Administrative Computing Facility

The Administrative Computing Facility (ACF) continued its cooperative arrangement with the Caltech Booth

Computing Center for the shared operation of an IBM 370/158 computer. In February 1974, the remaining elements of the ACF Operations Group moved from JPL to the Booth Computing Facility at Caltech.

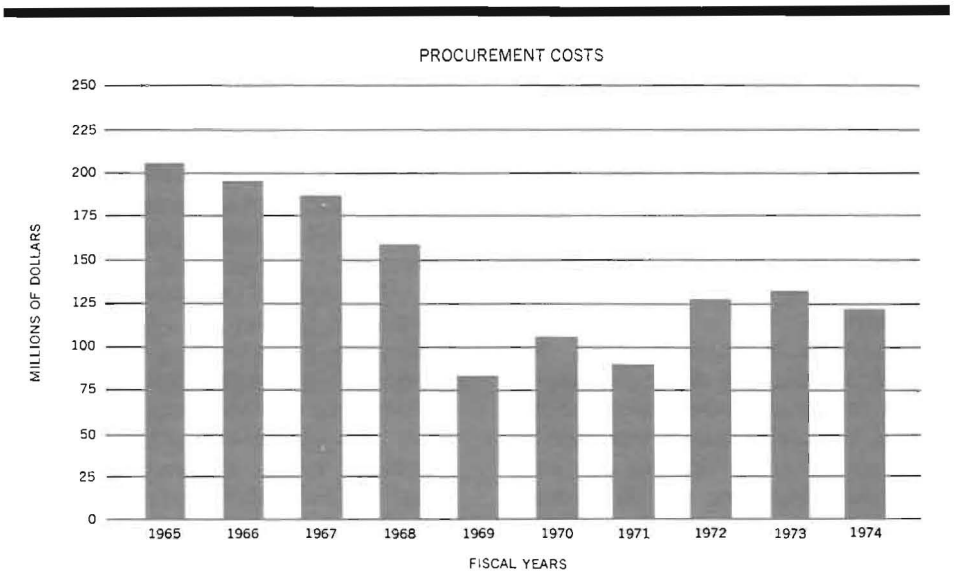
Implementation of a direct link from the IBM 370/158 computer to a remote batch terminal at NASA Headquarters for transmission of regular monthly reports, inclusion of burden planning on the System for Resources Management, automation of the preparation of the Laboratory Program Obligation Plan, and establishment of an on-line terminal-based inquiry system for data on the personnel master file were highlights of ACF development activities during the past year. Adaptation of the IBM 370/158 computer to a virtual memory operating system increased throughput efficiency, allowing the ACF to eliminate the third-shift computer operations. Installation of a Xerox 1200 output printer doubled print speed capacity while reducing the amount of paper used; also, the need for stocking many preprinted forms was eliminated. Month-end financial closing schedules were improved; as a result, the year-end closing of the financial reporting cycle will be easier and take a shorter time. In the Civil Systems task area, ACF personnel provided data processing assistance to the Los Angeles Children's Hospital, the Los Angeles County Regional Health Planning Board, and the Los Angeles Commuter Computer Service.

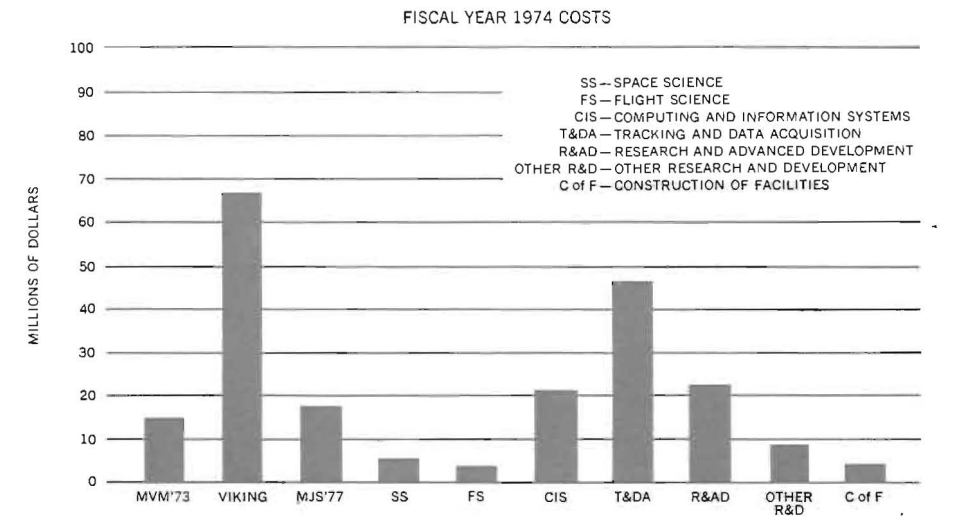
Administrative Divisions

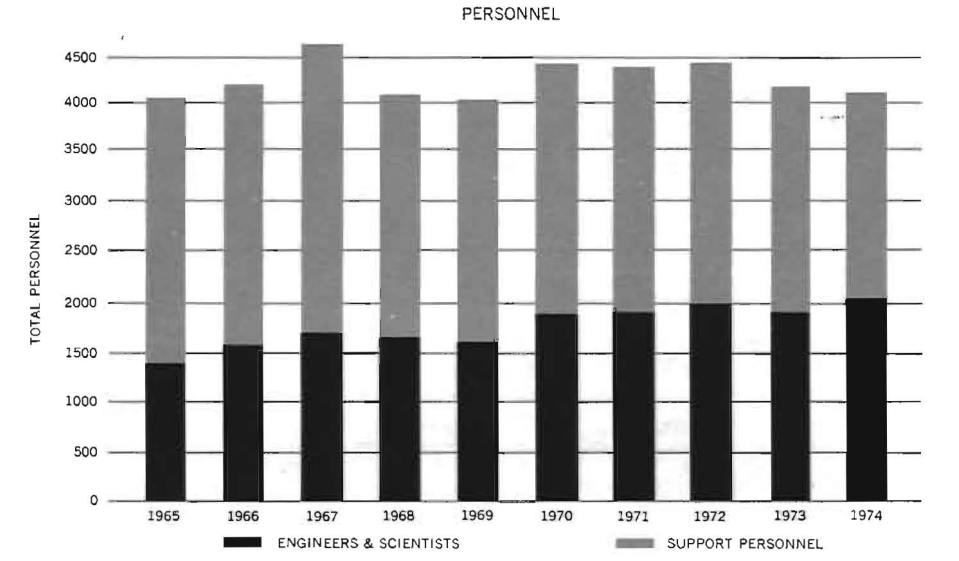
Funding for JPL's ongoing tasks and new efforts in research and development amounted to $209,710,000 during the reporting period, including funding for 72 new tasks. Funding for ongoing and new construction of facilities totaled $5,508,000.

Funding for Fiscal Year 1975 for research and development is planned for $217,000,000, and $17,700,000 is allotted for construction of facilities.

The Technology Utilization Office has developed a simplified system for manually searching the NASA New Technology data bank, which comprises only those items that have been reported as new technology by the various NASA Centers and their contractors. The system is designed for the use of the JPL technical community in regular project work,







as well as the surrounding business community in their search for promising new products and answers to technical problems.

During 1974, JPL conducted 26,938 procurement transactions, representing obligations of approximately $123,300,000. Principal activities centered about the Mariner Venus/Mercury 1973, Viking Orbiter 1975, and Mariner Jupiter/Saturn 1977 missions.

Shortages in paper products, fuel supplies, metals, and electronic supplies caused temporary disruption of normal services. Salvage operations increased because of the price increases for scrap paper, metal remnants, and oil products, and included the silver recovery from the extensive JPL photographic operation. In keeping with the national energy conservation plan, smaller-engine vehicles have been ordered to replace aging larger vehicles in the JPL fleet.

The JPL library moved into expanded quarters, adding approximately 3500 square feet to the present building. The library serves the Laboratory with collections of 90,000 books, 25,000 bound periodicals, 200,000 technical documents, and 575,000 microfiches. The library subscribes to 2100 periodicals and has a strong collection of abstracts and indexes to the world literature in science and technology.

The Technical Information and Documentation Division has intensified its applications of computer-assisted photocomposition to management documents, the telephone directory, and technical reports. A basic reports program and a systemized coding structure were completed for use with a text entry and updating terminal.

Quality Assurance and Reliability Office

The Laboratory's Quality Assurance and Reliability Office invests 2 percent of JPL's budget primarily to ensure the success of missions in the face of challenges from the unique demands of planet exploration and of rapidly advancing technology.

The two approaches of quality assurance for operational equipment and reliability assurance of related engineering and operations have been borrowed from the best industrial practice and applied through 100 JPL employees and larger numbers of subcontractors to support the Laboratory's more conspicuous mission efforts. Technical practices in these disciplines have been adapted to increases of an order of magnitude in equipment complexity and four orders of magnitude in science data recovery capability during 10 successful years.

Personnel

Although employment levels dropped slightly during the reporting period, con-

tinued efforts were made to recruit and employ qualified minority candidates. Laboratory representatives recruited on the campuses of twenty-two predominantly black colleges and universities and four universities in the Southwest with high American Indian and Chicano enrollments in support of the Laboratory's affirmative action program.

In April, a JPL cooperative education plan was announced. This program will provide practical experience to students in engineering and scientific disciplines of interest to the Laboratory.

At the start of the spring semester in February 1974, JPL joined the University of Southern California Interactive Television Network. This enabled employees at the Laboratory and Caltech to attend live, technical credit classes at the graduate level while still at the Laboratory. Forty-three classes were televised. Fifty-two employees participated in 30 classes.

The USC-TV Network links the University with surrounding organizations by means of four simultaneous channels of television. The Laboratory classrooms are linked back to the USC campus by radio transmitters, enabling interrupt, talk-back communications during live lectures. Classes are offered in all engineering disciplines, with the heaviest concentration on electrical engineering and computer science In addition, the University is offering to participating organizations lectures by noted authorities and papers being given at seminars and symposia that originate on the USC campus.

Facilities

Work will be completed this fall on a major air-lock and clean room addition to the 7.6-meter (25-foot) space simulator. This will permit pre- and post-test activities to be conducted in a clean environment and will provide a significant improvement in working space.

Construction of a six-story addition to the Systems Development Laboratory will add nearly 6700 square meters to the building. Three floors will be for computer-type utilization, and three floors for office space.

In late 1974, construction will start on a major addition to the Spacecraft Assembly Facility (SAF). A heavy concrete radiologically shielded test cube over 20 meters on each side will be used for clean assembly and systems tests of complete spacecraft with radioisotope thermoelectric generators installed for testing of in-flight power sources. In addition, an air lock will be installed between the SAF, the test cube, and the outside of the facility, together with space for bonded inspection and stores, personnel change areas, radiological control, and a visitors' lobby.

First use of this facility will be made by the Mariner Jupiter/Saturn spacecraft immediately upon completion of the facility.

Special Recognition

Many JPL employees received awards and other recognition in this period. Among them are the following:

H Caird served as President of the Society for Technical Communication.

J. P. Click, NASA Exceptional Service Medal for JPL administrative operations.

T. C. Duxbury and C. H. Acton, Jr., Samuel M. Burka award for the best paper appearing in the Journal of the Institute of Navigation for the 1973 award year.

F. E Goddard, Jr., NASA Exceptional Service Medal for leadership of research and advanced development.

A. F. H. Goetz, Charles E. Ives award of the Society of Photographic Scientists and Engineers for the most outstanding contribution in engineering published in "Photographic Science and Engineering."

S. L Manatt, Alexander von Humboldt Foundation's Senior U. S. Scientist Award for research and teaching as a visiting professor for two years at the University of Cologne, Federal Republic of Germany.

A. E. Metzger, NASA Exceptional Scientific Achievement Medal for gamma-ray spectroscopy.

S. Trajmar, NASA Exceptional Scientific Achievement Medal for electron impact spectroscopy.

W K. Victor was elected a Fellow of the Institute of Electrical and Electronics Engineers.

Mariner Venus/Mercury 1973 Program Team, NASA Group Achievement Award for Management and Cost Effectiveness.

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