A description of work accomplished under Contract NAS 7-100 between the California Institute of Technology and the National Aeronautics and Space Administration for the period January 1, 1972, to June 30, 1973.

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Director's Message

1972 was the Year of Mariner 9, a landmark in the history of deep space science.

In addition to Mariner 9, the Laboratory continued to furnish research and development and operational support to the NASA program of unmanned exploration of the solar system. Flight projects again constituted the major thrust of JPL effort, including the dual flyby of Venus and Mercury, orbiter spacecraft to support the 1975-1976 Viking Mars Landers, and two Mariner-class vehicles for 1977 launch to Jupiter and Saturn.

Although the Laboratory has experienced some difficulty in funding NASA projects, preliminary studies are being conducted on such interesting proposed missions as a 1979 Mariner Jupiter/Uranus flight, a 1981 Jupiter orbiter, and a slow flyby, solar-electric powered spacecraft to Comet Encke in the 1980s.

In an effort to effect significant cost savings, flight projects have sought to standardize hardware subsystems and interfaces, and to establish commonality in mission operations.

The Laboratory has again pursued strong programs of supporting research and development and science investigation.

The past year also has seen a large increase in nonspace activities. Although NASA participation has declined, support from other governmental and private-sector agencies has expanded. Development of a low-pollution engine concept holds considerable promise for the improvement of internal combustion engine performance.

There has been growing collaboration with the Caltech campus, including joint projects with the Environmental Quality Laboratory. The development of a proposed Caltech/JPL Medical Sciences Laboratory has been among the most important of these tasks.

Starting with this issue, the period of coverage of the JPL Annual Report is being converted from a calendar-year to a fiscal-year basis. To make the adjustment, this publication reports on the 18-month period from January 1, 1972, through June 30, 1973.

W. H. Pickering
Director
Flight Projects

Flight project activities at the Laboratory during the reporting period were concentrated in four specific areas:

1. Completion of the Mariner 9 orbital mission to Mars.
2. Implementation of the 1973 Mariner Project to fly a dual-planet mission to Venus and Mercury.
3. Acceleration of the 1975 Viking Project for missions to Mars, which will gather data from orbit and, in a soft-landed mode, on the surface of the planet.
4. Continuation of early work on the Mariner 1977 Project to send fully stabilized automated spacecraft on dual-planet missions to Jupiter and Saturn.

JPL is also heavily involved in the tracking and navigational support of the missions of Pioneers 10 and 11 to Jupiter, and in planning the mission operations and data acquisition support for the international Helios Project to investigate solar phenomena at close range.

Mariner Mars 1971

The Mariner 9 spacecraft—the first man-made object to orbit another planet—circled Mars 698 times in 349 days, from November 13, 1971, to October 27, 1972, gathering a wealth of science data that has revised all previous concepts of the planet. For more than half a year in Martian orbit, the spacecraft maintained an instrumented surveillance of the planet.

Some of the major findings of the mission were:

- Evidence of geologically active regions with volcanic mountains and calderas larger than any on Earth.
- An equatorial crevasse several thousand kilometers long and three to four times the depth of the Grand Canyon.
- Indications that free-flowing water may have existed in Mars' geologic history.
- Observation of the evolution of a monumental dust storm that raged to an altitude of 25 kilometers above the surface.
- The realization that dust storms and cloudiness account for much of the puzzling variability of Mars' appearance over the years.
The Mariner Mars 1971 Project was planned around a two-spacecraft mission, with the launches to be made during the 1971 opportunity. The second stage of the Atlas/Centaur launch vehicle failed during the early minutes of the Mariner 8 flight on May 8, 1971. Plans were revised to allow the remaining spacecraft to conduct the major portions of the missions of both Mariner 8 and 9.

Mariner 9 was successfully launched on May 30, 1971, and 6 days later, a scheduled trajectory-correction maneuver was conducted. Since Mariner 9 was not sterilized, the initial Earth–Mars trajectory was biased from a desired aiming point so that the spacecraft would not impact the planet. The trajectory correction was so accurate that no other maneuver was needed, and, 167 days and 395 million kilometers later, the flight was culminated by a 15-minute, 23-second rocket engine burn that placed Mariner 9 in orbit around Mars, with an accuracy of within 50 kilometers of the desired course.

Left: Mariner 9 picture showing fault lines on the Martian surface above the "North Spot" volcano.

Below: Panoramic view of Mars equatorial region composed of several hundred TV photo frames.
The mission was threatened, however, by a dust storm on the surface that began in September 1971 and expanded to global coverage within a week. Although such storms were not unfamiliar to Earth observers, their duration in the past had seldom been more than 3 or 4 weeks. Observations in late October indicated a growing intensity of the storm. By the time Mariner 9 started the pre-orbital picture-taking sequences, the surface of Mars was completely obscured by dust. Although the top of the dust cloud had been calculated to rise as high as 25 kilometers, the last series of pictures before insertion into orbit showed a faint south polar cap and four dark spots near the equatorial region, later revealed as very high, cratered peaks. As the storm began to abate in December, additional surface features gradually became visible, particularly in the southern latitudes.

Two days after orbit insertion, a spacecraft trim maneuver was executed to synchronize the spacecraft periapsis at the zenith of the Goldstone 64-meter-diameter antenna view period. As several orbits were completed and tracking data could provide additional information about the spacecraft orbit characteristics, it became apparent that Mars has a gravity field that is much rougher than those of the Earth and Moon. In mid-December, the nature of the gravity variation became apparent enough to indicate that a second orbit trim of the spacecraft would be required to maintain synchronism with the Goldstone antenna viewing periods. The trim was successfully performed in late December, and beginning in January 1972, with the dust settling, Mariner 9 began a series of mapping cycles.

Actually, these events marked only the beginning of what was to become the most remarkable year in planetary study in the history of man. The three 20-day mapping cycles were executed perfectly, providing all the area coverage possible with the north polar hood limiting the northern extent of the photography to a latitude of 45°N, as expected.

All of the other science objectives were also being satisfied as the Mission Operations Team worked every possible capability of Mariner 9. Atmospheric targets revealed clouds and fronts, local dust storms, and haze layers at altitudes as high as 70 kilometers above the surface. Variable surface features were detected, and evidence of surface dust material being transported was recorded on many occasions and at many sites. Photographs of the polar areas recorded residual frost caps that are probably water ice rather than the carbon dioxide frost seen at the end of the Martian winter. The caps and surrounding area appear as smooth-terraced and grooved surface formations reminiscent of wind-blown glacier fields on Earth, with the terraces resembling layered or laminated terrain fields.

In the northern latitudes, the retreat of the polar hood revealed a surface resembling the lunar maria. Tectonic examples were found throughout the planet, and a great rift—now called Valles Marineris—was discovered stretching some 5000 kilometers along the equator with widths of 200 kilometers and depths of 6 kilometers.

The channels are probably the most unusual and unanticipated features observed; they have a striking fluvial erosion pattern seemingly a result of water flow. However, Mars now has such a low surface atmosphere pressure that water would boil there until enough heat had been extracted to freeze the remaining liquid. No fully acceptable explanation for flow patterns has yet been advanced.

In April 1972, the trajectories of Mariner 9 carried it into a series of solar occultations by the planet. Operations were limited to tracking the spacecraft until early June, when it was once again in full sunlight.

The Mariner 9 spacecraft continued to perform exceptionally well throughout the summer of 1972, periodically recording and playing back data to the 64-meter antenna at Goldstone. During this period, each data playback required a maneuver to point the spacecraft high-gain antenna toward Earth. On August 7, the last of the antenna-pointing maneuvers was performed prior to superior conjunction, when Mars and Earth were diametrically opposite each other in relation to the Sun. In approaching and retreating from the superior conjunction position, the spacecraft appeared to be in the solar corona. Because the noise introduced into the radio signal by the corona interfered with communications, no science instrument data return was attempted when the spacecraft was within about 10 degrees of the Sun.

A test of the general theory of relativity, as evidenced by the effect of solar gravity on a radio propagation path, was performed. Tracking data obtained while the spacecraft approached to within 1 degree of the limb of the Sun showed the predicted relative effects. Analysis of these data should be completed within the next year.

As the Earth–Mars–Sun relationship continued to change with time, it again became practical to acquire science data. Two final data recording and antenna maneuvering sequences were performed in mid-October which yielded some pictures and other science data. On October 27, the compressed gas supply for the attitude control subsystem was depleted, and the spacecraft began a slow tumbling that resulted in a loss of solar converter power. After a few additional hours of battery-powered operations, the mission ended with the loss of tracking by Deep Space Station 14 at Goldstone.

Results from the Mariner 9 mission continue to describe a new and unexpected Mars. Even the cratered terrain that was anticipated is shown to be of a different character from that evident on the Moon. Volcanic mountains and lava flood basins demonstrate that Mars has a complex history of vulcanism. Rift, fault, and other tectonic evidence is recorded in each part of the planet. The polar-layer modified terrain, eroded areas that suggest fluvial characteristics, aeolian-modified landscape, light and dark albedo markings (some of which change with time), and an atmosphere possibly more complex than that of Earth suggest an intriguing planet of vital importance in the study of the solar system.
Mariner Venus/Mercury 1973

The primary objective of the Mariner Venus/Mercury Project is to conduct for the first time exploratory investigations of the atmosphere, surface, and body characteristics of Mercury. Data also will be taken from Venus, and interplanetary experiments will be performed as the spacecraft proceeds toward Mercury.

The launch window for the flight extends from late October to late November 1973. A single spacecraft will be launched to perform the first dual-planet, gravity-assist type of mission. Arrival at Venus will occur in early February 1974, followed by encounter of Mercury in late March or early April.

Scientific instruments, provided by five principal investigators, will be used in experiments involving charged particle, magnetic field, and plasma science measurements, infrared radiometry, and ultraviolet spectroscopy. In addition, two science teams have been appointed to ensure effective use of the data returned by the television and S/X-band radio subsystems.

During the period of January 1972 through June 1973, the spacecraft system and subsystem detail design and functional and environmental testing (except for solar thermal vacuum testing of the flight spacecraft in the JPL 7.6-meter space simulator) were successfully completed. The spacecraft system was designed and built by the Boeing Company in Kent, Washington, using much of the technology developed on the Mariner 1969 and 1971 Projects. Some subsystems and the scientific instruments are being supplied through JPL. At the end of June, the flight and spare/test spacecraft were being prepared for shipment from the Kent facility, thus completing, on schedule, the planned spacecraft activities at the Boeing plant.

Unique features incorporated in the spacecraft system design to meet mission requirements include:

(1) A two-degree-of-freedom, 137-centimeter parabolic high-gain antenna.

(2) A two-channel telemetry system capable of handling data rates as high as 117,600 bits per second for the television while simultaneously returning 2450 bits per second of nonimaging science data.

(3) A data-handling subsystem which mixes engineering and science data in various modes.

(4) A propulsion subsystem capable of performing multiple burns to provide for several trajectory-correction maneuvers that will permit accurate targeting at Mercury.

(5) Solar power panels which can be articulated about their long axis for thermal control purposes.

(6) A deployable sunshade to aid in controlling the temperature of the octagonal structure housing most of the electronic assemblies.

(7) An S/X-band transmitter to provide dual-frequency occultation for measuring atmospheric characteristics of Venus and Mercury and electron density in interplanetary space.
The spacecraft separated weight, including all scientific instruments, is approximately 500 kilograms.

The Project was started in January 1970, with a target cost of $98 million at completion. As of June 1973, with operations on the planned schedule, the projected cost at completion was slightly under the target figure. Actions taken to achieve this objective included minimizing the number of units of hardware; using spare subsystems from the Mariner Mars 1969 and 1971 Projects; and continual periodic status reviews. Some added, but acceptable, risk was assumed, such as minimizing documentation requirements, relaxing quality and reliability standards for non-imaging scientific instruments, and planning only a single launch.

The detail design and development of the Mission Operations System was accomplished during 1972 and early 1973. An additional 1230 computer was integrated into the second Mission Test Computer (MTC) System. One MTC System with its associated software has been used to support spacecraft system tests, and the other has been prepared for use on the telemetry processor during mission operations.

Essentially all software development and acceptance testing have been completed, and integration of the computer facilities (360/75, 1108, and 1230 systems) with the Ground Communications Facility and the Deep Space Network has been initiated. A demonstration of the entire Ground Data System, as configured for the Project, is scheduled for July 2, 1973.

Viking Mars Orbiter 1975

In 1975–1976, the Viking Project will fly two missions that will both orbit and soft-land on Mars. The spacecraft, each consisting of an orbiter and a sterilized lander capsule, will be launched by Titan/Centaur vehicles in late summer 1975.

The basic objective of the Viking missions is to advance the knowledge of the planet Mars through observations from orbit and by measurements made during penetration of the atmosphere and after soft-landing on the surface of the planet. Particular emphasis is being placed on obtaining information on biological, chemical, and environmental factors relevant to the present or past existence of life on Mars.

The 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 activities, and the Mission Control and Computing Center System.

The objectives of the Orbiter System are to obtain visual, thermal, and water vapor information from orbit, including survey of potential landing sites and other areas of Mars. This information will be used to select sites for the landers and to study the dynamic characteristics of the planet and its atmosphere, and will serve as a basis for planning future missions.

Science experiments to be performed by the orbiter include visual imaging of the surface, water vapor mapping, thermal mapping, and radio experiments to obtain data that will improve planetary navigation capability and measure radio propagation characteristics in and through the Martian atmosphere.

In the 18-month period following January 1972, significant strides were made in the overall Orbiter System and detail design efforts, with all major milestones being met on schedule. The principal documents required for subcontracting were released, and the major subsystem contracts were let for development and fabrication. All subsystem Preliminary Design Reviews were completed by November 1972; the subsystem Critical Design Reviews, started in January 1973, were 90% completed at the end of Fiscal 1973. Subsystem hardware fabrication had progressed through the prototype and breadboard phases, and testing was in progress prior to the beginning of the flight hardware fabrication. The Orbiter Developmental Test Model buildup was completed, and the model was undergoing test. The Orbiter Temperature Control Model was assembled and underwent initial testing in the JPL 7.6-meter space simulator.
With the selection of the primary and secondary landing sites for both Viking landers, detailed mission design activities were started to assure that all Viking science requirements can be met without exceeding the presently planned engineering capabilities of the Orbiter System.

Mariner Jupiter/Saturn 1977

The Mariner Jupiter/Saturn 1977 (MJS'77) Project, initiated in early 1972, is the result of conceptual planning activities begun as the Outer Planets Project in 1971. Two Mariner-type spacecraft will be launched to Jupiter and Saturn in the late summer of 1977, with arrival in 1979 and 1981, respectively.

The basic objective of the MJS'77 Project is to extend the exploration of the solar system to the vicinity of Jupiter and Saturn with a spacecraft that can conduct significant scientific investigations of both planetary systems and the interplanetary space, and act as a precursor for later missions to the outer planets. Particular emphasis is placed on obtaining data on the environments, atmospheres, and surface and body characteristics of Jupiter and Saturn, as well as investigating one or more of the satellites of these planets and studying the rings of Saturn. The investigation of the interplanetary and interstellar media is also of prime importance.

Initial conceptual planning and design activities at JPL and NASA led to the issuance of an "Announcement of Flight Opportunity" in mid-1972, requesting scientists to submit proposals for their participation in these missions. In December 1972, NASA selected the following scientific investigations to be carried out on these missions.

<table>
<thead>
<tr>
<th>Investigation area and instrument</th>
<th>Principal Investigator and institution</th>
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</thead>
<tbody>
<tr>
<td>Imaging—Television camera</td>
<td>B. A. Smith</td>
</tr>
<tr>
<td></td>
<td>New Mexico State University, Las Cruces, New Mexico</td>
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<tr>
<td>Radio science—S/X-band radio</td>
<td>L. Tyler</td>
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<tr>
<td></td>
<td>Stanford University, Stanford, California</td>
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<tr>
<td>Infrared—Interferometer/radiometer</td>
<td>R. A. Hanel</td>
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<td></td>
<td>Goddard Space Flight Center, Greenbelt, Maryland</td>
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<tr>
<td>Ultraviolet—Spectrometer</td>
<td>A. L. Broadfoot</td>
</tr>
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<td></td>
<td>Kitt Peak National Observatory, Tucson, Arizona</td>
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<tr>
<td>Magnetic fields—4 fluxgate</td>
<td>N. F. Ness</td>
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<tr>
<td>magnetometers</td>
<td>Goddard Space Flight Center, Greenbelt, Maryland</td>
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<tr>
<td>Plasma—2 faraday cup detectors</td>
<td>H. S. Bridge</td>
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<tr>
<td>Low-energy charged particles</td>
<td>Massachusetts Institute of Technology, Cambridge, Massachusetts</td>
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<td>S. M. Krimigis</td>
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<td>Johns Hopkins University, Silver Spring, Maryland</td>
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<td>Cosmic rays—High- and moderate</td>
<td>R. E. Vogt</td>
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<td>low-energy telescopes</td>
<td>California Institute of Technology, Pasadena, California</td>
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<td>Lyman alpha radiation—Ultraviolet</td>
<td>J. E. Blumont</td>
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<tr>
<td>photometer</td>
<td>National Center for Scientific Research, France</td>
</tr>
<tr>
<td>Visual photometry and polarimetry</td>
<td>C. F. Lille</td>
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<tr>
<td>Photopolarimeter</td>
<td>University of Colorado, Boulder, Colorado</td>
</tr>
<tr>
<td>Planetary radio astronomy—Radio</td>
<td>J. W. Warwick</td>
</tr>
<tr>
<td>receiver</td>
<td>University of Colorado, Boulder, Colorado</td>
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Since December 1972, intensive activity has concentrated on planning the mission and establishing a spacecraft design which will meet the mission and science requirements. To assure the achievement of maximum science capabilities on the mission, a Science Steering Group was appointed. The group is chaired by Dr. E. C. Stone, the Project Scientist, who is also a professor of physics at Caltech, and has a membership comprising the selected Principal Investigators. Regular meetings of this group, as well as regular interaction between the various elements of the Project and the group chairman, have been a key factor in shaping the activities of the mission and spacecraft Design Teams.

Trajectories have been developed which integrate the present understanding of the science requirements, provide for a Jupiter flyby, and utilize the moving Jovian gravity field to propel the spacecraft toward the planet Saturn. Additional features of these trajectories are a planned near-approach to several of Jupiter's Galilean satellites as well as the Saturnian satellite, Titan. The trajectories are within the capability of the Titan/Centaur launch vehicle and provide for an August-September 1977 launch.

The spacecraft design is based on the proven Mariner technology. Solar panels used on previous Mariners are being replaced by a radioisotope thermoelectric generator (RTG) power source because of the mission lifetimes involved, and the distances from the Sun of the target planets.

The culmination of this phase of activity on Mariner Jupiter/Saturn 1977 will be the review of the overall Project design and implementation plans and the confirmation of the science investigations in the fall of 1973.

Other Project Activities

The Laboratory is providing significant assistance to two non-JPL-managed projects, Pioneer and Helios. The Pioneer 10 and 11 missions, scheduled to fly by Jupiter in December 1973 and December 1974, respectively, are managed by the NASA Ames Research Center. The Lab-
Laboratory is responsible for the space navigation operations as well as for providing spacecraft tracking and data acquisition support and computer services to both missions. The Helios Project, a joint U.S./West German undertaking, is being co-managed by the Goddard Space Flight Center and includes two flights to investigate the properties and processes in interplanetary space to within 0.3 astronomical unit of the Sun. Two launches are scheduled, in September 1974 and late summer 1976. Each flight is expected to continue in heliocentric orbit, returning usable data for at least 1 year. JPL is assisting on this Project by providing specific technical support for mission operations and spacecraft technical consulting, as well as tracking and data acquisition and computer support.

In keeping with NASA's emphasis on achieving effective cost-reduction approaches to carrying out its programs, the Laboratory's Advanced Planetary Missions Office has studied and is still developing a more cost-effective method for performing near-term future missions. This approach consists of standardizing wherever practicable on the designs, components, subsystems, and procedures being evolved for the Mariner Jupiter/Saturn 1977 spacecraft. The significant capabilities of the spacecraft can be combined with other existing special capabilities, such as the Mariner Mars 1971 orbit-insertion propulsion subsystem, to achieve cost-effective approaches to such missions as a flyby of Jupiter and Uranus, or an orbiter of Jupiter, Venus, or the Moon. This procedure would significantly reduce the nonrecurring design, development, and test costs of NASA's planetary exploration program, achieve savings through the purchase of multiple items of identical hardware subsystems, and reduce considerably the mission operations cost by sharing of operations personnel and software. An enabling technology program, directed toward later far-term missions, would be carried on concurrently.

Below: West German Helios spacecraft will study hitherto unexplored space near the Sun in the mid-1970s.

The Deep Space Network

During 1972 and the first half of 1973, the Deep Space Network (DSN) provided tracking and data acquisition for the Mariner 9 mapping of Mars and the deep space scientific missions of Pioneers 6 through 11. In addition, the 64-meter antenna at the Goldstone station supported the lunar landing and surface activities of Apollo 16 and 17.

A significant achievement was the start of operations, on March 30, 1973, of the 64-meter antenna in Australia, representing the second of the three-antenna subnet. The third 64-meter antenna in Spain is proceeding on schedule and will reach operational status in fall 1973.


The Goldstone 64-meter antenna was used during the year to obtain extensive radio science data on the structure and variability of quasars and radio galaxies. This work represents the combined efforts of scientists from Caltech/JPL, MIT, the University of Maryland, and Goddard Space Flight Center.

Operations

Mariner 9

Tracking and data acquisition support of the Mariner 9 mission was provided by the 26- and 64-meter stations at Goldstone, California, the 26-meter Woomera station in Australia, and the 26-meter Cebreiros station near Madrid, Spain. All normal data retrieval capabilities continued through February 1972. In early March, the increasing distance between the Earth and Mars and the gradual pointing of the spacecraft high-gain antenna away from Earth caused the telecommunications performance to degrade.

By mid-March, downlink carrier threshold was reached for the three 26-meter antenna stations, and for the remainder of the mission, they were used sporadically to provide only uplink/command support, while the 64-meter station continued its telemetry coverage for three to six passes per week.

To enhance the results from the Mariner 9 mission, the DSN was able to introduce several innovations in its equipment:

(1) The station assembly, which performs the block decoding of the spacecraft data stream, was modified to reduce its threshold, permitting reception of pictures at signal-to-noise ratios less than 2½ decibels.

(2) Use of a 26-meter station to provide uplink transmission made it possible to configure the 64-meter station into a more efficient listen-only mode, thereby improving picture data and three-way occultation data reception.

(3) At the 64-meter station, a special tracking loop filter was used in the phase-lock receiver to permit tracking the carrier through large doppler and acceleration rates.

(4) During Mariner 9 superior conjunction, a programmed local oscillator and a 3-hertz tracking loop were used at the same station to track the carrier when its spectrum was broadened by passing through the Sun’s corona.

Opposite: 64-meter antenna nearing completion at deep space station near Madrid.

Right: Installation of cone on Canberra 64-meter antenna; the Australian antenna was completed in March 1973.
Pioneer Mission Support

JPL continued to carry the responsibility for providing tracking and data acquisition support to the Pioneer spacecraft, with the Ames Research Center having Project responsibility. Pioneers 6, 7, 8, and 9, which were launched between December 1965 and November 1968, are still operating and continue to provide useful scientific data on interplanetary fields and particles.

Pioneers 10 and 11 were launched in March 1972 and April 1973, respectively, to explore the planet Jupiter. Pioneer 10 will arrive in December 1973 and Pioneer 11 in December 1974. The DSN has maintained continuous tracking coverage of these spacecraft since their launch.
Apollo Support

The DSN participated in the Apollo 16 and 17 lunar landing missions, providing tracking support from the 64-meter antenna station at Goldstone and three 26-meter stations in California, Spain, and Australia. These stations operate in conjunction with colocated stations of the Spaceflight Tracking and Data Networks, operated by the NASA Goddard Space Flight Center. Data received from the Apollo spacecraft were transmitted to the Goddard Station for relay to the Mission Control Center at Houston. Communication links were provided to the Command/Service Module, the Lunar Module, the Lunar Rover, and the instrumentation stage of the Saturn V launch vehicle. Communication with the Lunar Rover was maintained after the astronauts left the Moon, enabling unmanned television surveys to be made of the landing site.

The 64-meter antenna supported a special radar experiment performed by Apollo 16 in which a radio signal was reflected from the Moon and received on Earth, along with a direct signal from the Apollo transmitter, giving information on the properties of the lunar surface and subsurface materials.

Apollo 17 coverage from the Australian Parkes Radio Astronomy antenna was supplemented by the new 64-meter antenna station near Canberra, Australia, as the first mission for this newly activated facility.

Mariner Venus/Mercury 1973

During the period of this report, the planning, designing, implementing, and testing necessary to achieve the new capabilities required for support of the Mariner Venus/Mercury 1973 mission were performed. Two three-station networks consisting of 26- and 64-meter antenna subnets, respectively, are being readied for operations support. The 64-meter subnet includes the newly constructed stations in Spain and Australia. Data system testing for the Project began in May 1973 and was essentially on schedule by the end of June.

Viking

The Viking spacecraft, to be launched in August–September 1975, require support by both the 64- and 26-meter subnets, with additional coverage from a second 26-meter subnet for a period of several weeks prior to arrival of the second spacecraft at Mars. After the landing of both spacecraft in August 1976, the supporting stations must simultaneously command two spacecraft and extract telemetry from three.

Helios

The DSN continued the support of the preflight phase of the Helios Project. Initiated in 1968, Helios is scheduled for launch in September 1974. The spacecraft will orbit the Sun and reach a point of closest approach of 0.3 astronomical unit. The science experiments, primarily in particles and fields phenomena, also include celestial mechanics, magnetic fields, and Faraday rotation observations.

The United States, through NASA, will provide the launch vehicle and launch operations at Cape Kennedy, several scientific instruments and principal investigators, and support by the DSN. West Germany will construct the spacecraft and, after the first few weeks of flight, will conduct mission operations from a control center near Munich, Germany.

During the reporting period, three formal working group meetings were held involving all elements of the Project. The meetings, which took place in the United States and West Germany, were used to identify problems, work out interface agreements, and plan support of scientific data acquisition from the spacecraft. The network configuration has been established, and implementation is underway, with completion scheduled for early 1974.

Radio Science

The 64-meter antenna at Goldstone has been used extensively for radio science observations by both NASA and non-NASA experimenters and radio astronomers. Early in 1972, regular observations were begun for the purpose of examining the structure and variability of quasars and radio galaxies by several teams of scientists from Caltech, JPL, MIT, the University of Maryland, and the Goddard Space Flight Center. In addition to observations made at the normal operating frequency of 13 centimeters, experimental equipment was used to observe at 3.5 and 21 cm.

The unusually high sensitivity of the 64-meter antenna at Goldstone and the very high angular resolution (approximately 0.001 second of arc) of the very long baseline interferometry (VLBI) technique permitted resolving the quasars into structural components. A significant achievement this year was the extension of VLBI techniques to 2.1-centimeter wavelengths. An interferometer was formed by the 64-meter antenna at Goldstone, the 37-meter Haystack antenna of the Northeast Radio Observatory Corporation, and the 43-meter antenna of the National Radio Astronomy Observatory in West Virginia. The introduction of the K-band (2-centimeter) equipment at these observatories resulted in attaining a baseline length of the order of 10⁶ wavelengths.

Conventional radio astronomy methods were also used. Astronomers at the Hale Observatories began mapping regions around spiral galaxies, searching for weak sources, to provide further information on the nature of the quasars. Other radio astronomers made the most precise measurements to date of the cosmic radiation background "confusion distribution" factor.

The 64-meter antenna was also used by JPL radio scientists to search for and detect interstellar molecules. The presence of previously detected molecules was confirmed, and formaldehyde was found in regions where it had not been detected before. Time was also devoted to observing Jupiter and Uranus. A significant development in antenna design permitted simultaneous observation of pulsars at 13 and 3 cm.
Facility Modernization

A project has been established for implementation of a Network Control System in order to separate the DSN monitor and control functions and flight project data processing operations. This separation will result in simplified programs for both sets of functions, better control by both the DSN and flight projects, and easier management, and should achieve lower costs.

The Network Control System design incorporates small processors which perform the monitor and control functions previously accommodated by the JPL 360/75 computers, and includes the capability for DSN control, network monitor, data validation, and real-time operations coordination.

Implementation of the Network Control System will be accomplished in three phases: (1) Block I will provide network control capability by July 1973, which is adequate for support of the Mariner Venus/Mercury 1973 (MVM’73) and Pioneer 10 and 11 missions; (2) Block II will provide network control capability by July 1974 that will meet the requirements of missions through 1975; and (3) Block III will extend Block II capability by July 1976 to meet the requirements of missions through the early 1980s.

The Ground Communications Facility wideband data system was substantially modified in preparation for MVM’73 operations by extending it from JPL to Spain and Australia, serving both of the new 64-meter antenna stations. An additional circuit connects the Cape Kennedy station to JPL. The wideband system utilizes the 28,500 bit-per-second circuits recently implemented by the NASA Communications Network (NASCOM) and provides sufficiently low error rates for video (television) data transmission. It employs block formatting and error detection coding like that used on the high-speed data circuits.

During 1972 and the first half of CY 1973, data decoder assemblies were installed in the Deep Space Stations to provide decoding for the Pioneer 10 and 11 and Mariner Venus/Mercury coded telemetry data. New computer programs for the stations’ telemetry and command processor (TCP) were prepared to support these missions.

Implementation of the two overseas 64-meter antennas has proceeded well, with the completion of the Canberra antenna on March 30, 1973, 3 months ahead of schedule, permitting early support of the Pioneer 10 and 11 Jupiter missions and backup reception of Apollo 17 in December 1972. Completion of the Madrid station is scheduled for August 30, 1973.

DSN Development

S/X-Band Development

The dual S- and X-band-frequency ground system has been designed, built, and installed on the 64-meter antenna at the Goldstone Mars station. Preliminary tests of this combined system made in January 1973 showed that there is essentially no degradation of S-band reception performance and less than 0.5 decibel degradation of X-band reception performance over separate high-performance, single-frequency systems. The combined system also provides for a 400-kilowatt S-band uplink signal while simultaneously receiving low-noise data at S- and X-band. Work is continuing on reducing noise bursts in microwave components and on antenna surfaces resulting from the effects of the high-power transmission.

Other related X-band efforts underway include: (1) a combined S/X-band...
ranging system for use in MVM'73, which will provide higher stability and more accurate measurements of range data; (2) X-band weather data analysis, leading to a statistical prediction model of propagation losses for use in mission planning; and (3) an X-band planetary radar for gathering data on planetary ephemerides and surface mapping for use in both near- and outer-planet mission planning.

Radio Navigation

Efforts in very long baseline interferometry have been directed toward producing results of practical use for spacecraft navigation. Prototype VLBI experiments have provided Universal Time data which are competitive with current optical determinations. A monthly measurement schedule has been instituted, and efforts are underway to begin monthly measurements of Earth polar motion. In addition, the use of VLBI as a means of measuring the angular separation of a spacecraft relative to “fixed” extragalactic radio objects has been investigated. All indications are that this particular application of VLBI will be a powerful supplement to current navigation techniques. Demonstrations of this tracking mode will be made during the next year.
Research and Advanced Development

The Research and Advanced Development Program addressed new goals in 1972-1973, conducting an active set of basic research studies among many technological disciplines. With the implementation of the 1977 Mariner Jupiter/Saturn Project, about 50% of the technology developed under the Thermoelectric Outer Planet Spacecraft effort is being incorporated into the 1977 flight design. The R&AD Program began to focus on the technology required for a possible solar electric mission to the Comet Encke in the late 1980s. This continuous low-thrust propulsion technique also was investigated as a tool for accomplishing a number of other important high-energy scientific missions.

Physical Sciences

Materials

A new high-temperature, electrically insulating cermet (ceramic-metal) seal has been synthesized and tested. The insulating cermet was fabricated by coating a layer of alumina on spheres of niobium and hot-pressing the composite structure. The resulting metal-ceramic mixture has more than double the strength of commonly used brazed seals, and its electrical resistance is approximately one order of magnitude greater than the best available insulator, alumina ceramic. The cermet was tested for 2500 hours at 1000°C under an applied potential of 25 volts with no evidence of degradation. The material is machinable before the final hot-pressing step and is readily transitioned to several metals or alloys without loss of strength or inclusion of a braze alloy. The new cermet is expected to find application in electronic processes where mechanical properties are critical. The fabrication technique is being studied for such diverse uses as oxidation-resistant coatings and biomedical implant applications.

Supersonic Aerodynamics Noise

One aerodynamic flow parameter that cannot be reliably determined in a wind tunnel is the location over a test model at which the boundary layer of air changes from laminar to turbulent form because the transition process is sensitive to factors so subtle as to be nearly undetectable. At supersonic speeds, tunnel testing for transition to turbulence is especially unreliable because the noise generated by turbulence in the tunnel itself emerges as a dominant factor in promoting turbulence on the model.

A surprising result was recently obtained in the JPL hypersonic tunnel. Although the turbulence noise is even higher than at supersonic speeds, the mechanism by which turbulence is initiated on the model reverts to that occurring at subsonic speeds where turbulence noise is unimportant, apparently because the frequency band of the noise lies well below that range to which the boundary layer is sensitive. Therefore, turbulence location measurements in hypersonic tunnels could prove more reliable than at any lower speed.

Transonic Aerodynamics

The transonic speed regime is the most difficult regime of aircraft flight in which to accurately predict the performance of an aerodynamic vehicle. During the past 2 years, the JPL 20-inch supersonic wind tunnel has been operated at transonic speeds in a series of studies of the flow field surrounding simple two-dimensional airfoils. This program has included both theoretical and experimental studies in order to examine ideas of inviscid scaling of transonic flows and to determine the nature of the interaction between the flow field and the wind tunnel wall. The investigations have led to a better understanding of the differences between a conventional, solid-wall wind tunnel and a transonic, porous, or slotted-wall facility. In some instances, the solid-wall facility has been shown to model a uniform unbounded flow more closely.
From these studies has come a more complete understanding of the behavior of inviscid transonic flows and, consequently, of the modeling of transonic flows through inviscid theory. In addition, some preliminary investigations of viscous effects at low Reynolds numbers have produced a sketch of the laminar separated flow which, it is hoped, will serve as a model for the development of viscous–inviscid interaction theory at transonic speeds.

**Photochemistry of the Stratosphere**

Studying the effect of water vapor on ozone under conditions of photochemical irradiation is vital to determining the stability of the Earth's ozone layer, and possible adverse effects of high-flying aircraft which release water vapor and other materials at stratospheric altitudes. Laboratory photolysis of oxygen–water mixtures under conditions simulating the upper atmosphere shows that radical fragments derived from water cause chain decomposition of ozone. Individual reactions have been identified and rate constants measured. The results indicate that water vapor is important in limiting the ozone abundance in both natural and perturbed atmospheres.

**Forming and Control of Liquids in Weightlessness by Acoustic Pressure**

A program is being conducted to design, construct, and test an apparatus that can be used for the forming and control of liquids and melts in weightlessness by means of acoustic pressure. An apparatus such as this will be used in space processing, where metals and ceramics will be melted and purified in a containerless furnace aboard a spacecraft. The feasibility of the triaxial acoustical position chamber has been tested at JPL.

A device very similar to the one described has been proposed to fly on the joint American–Russian ASTP flight in 1975, where it will be used in a series of drop dynamic experiments.

**Laser Power Conversion**

An investigation of two laser energy-conversion schemes was continued as part of a NASA feasibility study of using lasers for power transmission. A gallium-arsenide, Schottky-barrier-type photocell has demonstrated a conversion efficiency of 20% at a laser wavelength of 6471 angstroms. In the other scheme, a laser plasmasdynamic converter (a diode containing a small amount of cesium) demonstrated its feasibility, producing a cesium ion current as large as 200 amperes per square centimeter peak when irradiated by a ruby laser at 0.69 joule per pulse. A conversion efficiency of better than 40% is the future goal for both schemes.

**Thermodynamic Properties of Liquids**

The free volume model for liquids was used along with the additivity of interaction energies to derive a set of molecular additive constants enabling estimates to be made of thermodynamic parameters for liquids from the chemical structure alone. The parameters include critical temperature, critical volume, density, thermal expansivity, heats of vaporization, and viscosity and its temperature dependence. The broadened table of constants is also applicable to liquid polymers. The work may aid in predicting polymer rheological response from molecular structures—a long-standing research objective at JPL.

**New Hydrocarbon Prepolymers**

Commercially feasible methods for preparing many types of hydrocarbon prepolymers by ozonolysis and reduction have been developed. These prepolymers can be used to make castable elastomers for numerous applications, including new solid propellant binders, encapsulants, caulking materials, and miscellaneous rubber goods. They are easy to make and show increased stability on exposure to extreme environments and long-term aging.

**Drive Belts and Magnetic Tape**

The failure of a magnetic tape drive belt during Mariner 1971 system testing led to an in-depth analysis of seamless polyester belt technology. From this research, a new technology evolved for the fabrication of mechanically balanced seamless belts. This technology is now being used by industry in the fabrication of belts for the Viking Project.

The knowledge of the chemical–physical makeup of magnetic tapes has brought JPL to the forefront of belt and tape technology. The Laboratory was asked to assist the Skylab astronauts in deciding how to handle Earth Resources Experimental Package (EREP) tapes exposed to high temperatures.

**Spacecraft Development**

**Space Vehicle Design Criteria**

Under a NASA program, models were established for planetary and interplanetary environments to aid in the design of space vehicles. Particular attention was devoted to environments expected to interact strongly with a spacecraft. Charged particle radiation environments were described. Models of the solar wind, galactic cosmic radiation, and energetic solar flare protons were developed and exercised to establish design criteria. The models were published, with the resulting criteria describing intensities, fluxes, and fluences in terms of time, position, and energy dependence for electrons, protons, and other ions.

**Outer Planet Aitherothermodynamics**

Major advancements were made in the knowledge of radiative heating for probes being considered for atmospheric entry missions to the outer planets. Experiments in high-performance electric shock tubes demonstrated that reaction rates are much slower than originally anticipated in heated mixtures of hydrogen and helium. This indicates less radiative heating for probes entering the
atmospheres of Saturn and Uranus, reducing heat shield weight requirements by up to one-half. The performance of the shock tubes is being increased to simulate conditions expected on entry missions to Jupiter.

A closed-form theoretical study has resulted in an improved understanding of the radiative viscous flow field for a blunt probe entering the Jovian atmosphere, permitting evaluation of the regions of applicability of several simple competing analytical approaches currently in use. In the area of flight dynamics, initial computer studies have shown that unsymmetrical ablation of the heat shield can compromise the mission objectives for a probe entering the Jovian atmosphere.

Guidance, Control, and Navigation

**Attitude Control Electronics**

A significant advancement in spacecraft attitude control electronics was accomplished with the development of HYPACE (Hybrid Programmable Attitude Control Electronics). This new design uses programmable digital computer technology to provide functions normally executed by inflexible hardwired designs. Besides flexibility, HYPACE offers a viable approach to low-cost, multi-mission applications. Programmable electronics for the first time allows control changes to be made during flight to cope with unplanned events. The Mariner Jupiter/Saturn 1977 Project will benefit directly from the HYPACE development.

**Optical Navigation Demonstration**

Satellite-star optical navigation was initiated successfully on the Mariner 9 mission. During the Mars approach, 21 pictures of Deimos and Phobos were taken by the spacecraft camera and transmitted to Earth. Angle measurements of the satellite positions relative to background stars were extracted from the imaging data. The data, calibrated and processed with orbit determination software, improved the approach trajectory estimate of the spacecraft.

The orbits of Deimos and Phobos, too, were more accurately determined by the Mariner 9 images. Optical navigation technology has been adopted by the Viking Project as a backup to the radio tracking system during Mars approach. Mariner Jupiter/Saturn 1977 also will use satellite-star measurements to meet navigation requirements.

**Planetary Robots**

A research program in robotics and artificial intelligence was started to develop semi-autonomous machines that can carry out exploratory tasks on planets without step-by-step human direction from Earth. Success would obviate communication time delay problems and possibly increase the amount of scientific data obtained. The first goal is a laboratory breadboard that will integrate the functions of locomotion, manipulation, vision, and decision-making. The first machine should at least be able to store a command, move to a designated site, and pick up a rock.

**Chemical Propulsion**

**Remote Laser Pyrotechnic Ignition**

Remote ignition of pyrotechnic initiators by a solid-state, pulsed laser has been successfully demonstrated. A small, flight-size neodymium laser (2.5-joule output) was used to ignite insensitive propellants under a range of conditions. In addition, a facility was developed to prepare and test pyrotechnic materials used in chemical propellants at JPL.

**Below:** Toxic propellant facility at JPL is equipped for the preparation and testing of toxic materials used in chemical propellants.
output, 1.5-millisecond pulse width) was used to ignite a pyrotechnic device at a distance of approximately 20 meters. The laser-initiated pyrotechnic device consisted of a simple glass window mounted in a small charge holder containing approximately 100 milligrams of an ammonium perchlorate-zirconium pyrotechnic material. The laser, which measured 5.0 by 7.6 by 12.7 centimeters and weighed 0.9 kilograms, was completely self-contained.

Conesphere Propulsion

A multi-stage, solid rocket propulsion system design called "Conesphere" was conceived for use in high-energy missions. The system consists of two or more conically shaped motors of ascending size, connected directly to each other. Each motor is a scale model of the largest one. The concept utilizes an advanced carbon material, with high strength at high temperature, for the total structure. The advanced carbon material permits the structure to function not only as a motor chamber but also as the nozzle of the next motor in the sequential system. Cutting of each motor chamber, at a predetermined location, subsequent to the operation of each motor, is accomplished with a linear-shaped charge attached as a band around the chamber structure. The remaining portion of the chamber thus becomes the nozzle of the next motor to be fired.

Analysis has shown this concept to be more efficient than present multi-stage, solid propellant rocket motor propulsion systems for high-energy missions to outer planets or solar system escape.

High Back-Pressure Propulsion

Propulsive maneuvers within dense planetary atmospheres pose new challenges to the spacecraft propulsion designer. Difficulty is encountered with conventional chemical rockets because of the sharp decrease of the expansion of the combustion products as the ambient pressure is raised. This reduction in turn causes the impulse delivered per unit mass of propellant to decrease drastically.

The concept of using a chemical propellant which detonates (rather than deflagrates) has been developed to meet such a challenge. The system investigated would operate in a pulse mode by using the output of a high-power compact laser to fire remotely a charge of detonating propellant. The shock wave is then directed by means of an expansion nozzle to provide thrust. The nozzle is designed to effect an energy-conserving momentum exchange with atmospheric gases contained in the nozzle. The very high pressures of a detonation make this system insensitive to ambient pressure up to several kilobars, and the pulsed operation provides quiescent periods during which scientific observations and measurements can be made with minimum disturbance.

Experiments have verified laser ignition of the propellant in near-vacuum conditions, at high pressure, and in simulated atmospheres.

Small Hydrazine Thrusters

A technique was developed to extend significantly the operating life of pulsing 0.44-newton monopropellant hydrazine, catalytic thrusters for spacecraft limit-cycle attitude control applications. This development provides such thrusters with a viable option for long-life missions. A recent series of exploratory and life tests showed that preheating the catalyst bed to approximately 200°C, at the cost of about a watt per thruster, permitted the simulation of a long-life spacecraft attitude control duty cycle of $2.5 \times 10^5$ starts without thruster performance degradation.
Nozzle Plume Analysis

Tests were conducted in the JPL Molecular Sink ultrahigh-vacuum facility to trap and measure the mass flux in the far-field of a nozzle plume, with special emphasis on turning angles up to 140 degrees, using a unique cryogenic quartz crystal micro-balance design. Gaseous mass fluxes not predictable by present theories were encountered and quantitatively measured in the region behind the nozzle exit plane. This knowledge is significant if materials or sensing surfaces that are incompatible with the gaseous exhaust products are used in this vicinity.

Bimodal Rocket Engine

JPL is testing a novel bimodal rocket engine which could meet all planetary space flight requirements with a single engine. Such a development would greatly simplify spacecraft design and improve on-board propellant utilization. In the monopropellant mode of operation, hydrazine fuel is decomposed in a catalytic reactor, yielding a thrust of about 158.7 kilograms. The engine is readily throttled in this mode. In the bipropellant mode, nitrogen tetroxide oxidizer is injected into the reactor effluent gases, producing secondary combustion and a higher thrust of 453.6 kilograms with a higher specific impulse.

Tests demonstrate good performance and low heat transfer to the rocket chamber walls in both modes. Results are promising for a flight-type engine.

High-Energy Propulsion Module

High-energy propulsion systems using fluorine or FLOX \((\text{F}_2 + \text{O}_2)\) as an oxidizer can improve spacecraft propulsive performance by 30%. A self-contained fluorinated propulsion module, JPL-developed and vacuum-tested, could permit payload improvements and higher-energy accomplishments for longer space missions. Two engines were tested with JPL's high-energy module: a 4448-newton engine for 400 seconds and a 2669-newton engine for 420 seconds.

Space Power and Electric Propulsion

Solar-Electric Spacecraft

Solar-electric propulsion (SEP) has unique capabilities for accomplishing a wide range of scientifically interesting missions, including a slow flyby of the Comet Encke in late 1980. The technology of SEP spacecraft is being developed for these applications. Development of spacecraft power is continuing, with emphasis on long lifetime, low cost, and high reliability.

Navigation of solar-electric-propelled spacecraft requires new techniques, and studies were conducted to evaluate navigation technology for potential application to SEP missions. The continuous...
fluctuation of thrust magnitude and pointing angles caused by electric thrusters produces small, unpredictable variations in the nongravitational accelerations acting upon the spacecraft. Models for the random components of nongravitational accelerations were developed and incorporated into navigation data-processing algorithms. In addition, it was found that simultaneous radio tracking from widely separated stations produces a data set that is much less sensitive to these acceleration effects than conventional single-station tracking, making SEP navigation potentially competitive with ballistic spacecraft navigation.

**Solar Arrays**

Progress has been made toward reducing the cost of solar power sources. JPL techniques to determine analytically the stress concentration in solar cell arrays were successfully applied in developing the Viking Orbiter solar array design. Application of these array modeling techniques greatly reduced the development effort required to produce a successful design.

A major factor associated with array design is the cost of silicon photovoltaic converters, much of it being incurred in the processing of polycrystalline silicon into single-crystal blanks for the solar cells. Hand labor is presently required to grow, slice, lap, and etch a piece of single-crystal silicon to the proper dimensions, a process that wastes over 50% of the silicon. A significant advance was made in the manufacture of silicon ribbons directly from a polycrystalline silicon melt. Ribbons of single-crystal silicon, more than 30 centimeters long, were produced (illustrating the feasibility of growing ribbons continuously) and sized to the desired dimensions, thus eliminating manufacturing steps and reducing waste of the high-quality polycrystalline material.

**Batteries**

To meet the requirement for a 6- to 12-year operational life, a nongassing nickel-cadmium battery concept and a compression-type, injection-molded seal for electrical terminals were developed and successfully tested. The battery design eliminates gas formation while charging or discharging, thus preventing build-up of pressure within the battery and obviating charge control devices. The terminal seal is inexpensive and withstands many thermal cycles without leaking.

**Radioisotope Power Sources**

The evaluation of isotope thermoelectric power sources continued under a technology study of solar-independent spacecraft power. Nine thermoelectric generators are under long-term evaluation, several for over 5 years. A materials program was initiated to investigate degradation within a thermoelectric thermopile. Experiments include sublimation and reaction-gasification rates of silicon-germanium and various insulation materials. An AEC plutonium-fueled SNAP-19 thermoelectric generator was used for radiation experiments in both neutron and gamma spectra.

**Telecommunications**

**Line Source Antenna Feed**

A line source feed was developed for a conical reflector antenna providing exceptionally high performance at a single frequency. It outperforms designs using subreflectors and a conventional antenna feed. Efforts are underway to develop a similar feed for the two frequencies used in JPL space communications. The line source feed and conical reflector significantly increase the practicality of large, high-efficiency unfurlable antennas for spacecraft.

**Spacecraft Transponders**

The feasibility of microminiaturizing the multimission spacecraft transponder/receiver in beam-leaded technology has been demonstrated. Beam-leaded active and passive devices are thermal-compression bonded directly to gold interconnect circuit traces on ceramic submodules. Another significant new achievement is the incorporation of surface acoustic wave filters in the difficult VHF region. Resulting improvements, as compared with Viking hardware, are: 34% reduction in cost; 6:1 reduction in power drain, weight, and volume; and 10:1 improvement in phase and group delay stability. The improved stability will reduce target inaccuracy at Jupiter from the present 60 to only 6 kilometers.

**S/X Experiment**

A 200-milliwatt X-band transmitter (XTX) was developed for use in a dual-frequency (S/X-band) dispersive charged particle experiment on the MVM'73 spacecraft. The unit uses microstrip RF circuitry. The new transmitter and the pre-existing S-band transponder will provide simultaneous coherent range and doppler on two microwave frequency links from spacecraft to Earth. The S/X experiment on MVM'73 will be the first JPL use of a coherent dual-frequency telemetry system.

Opposite: Conical reflector antenna with line source feed.

Below: S-band receiver to be used in S/X-band experiment on Mariner Venus/Mercury 1973 spacecraft.
Science

JPL computer resources have been applied in the image processing of terrestrial survey data and in microwave spectrometry of the interstellar medium. Planetary atmosphere work during the reporting period included temperature profiles, ionization studies, and infrared spectroscopy. Radar and radio astronomy techniques were used to investigate asteroids and the planets Venus, Saturn, and Jupiter. Lunar projects included laser ranging, topographical surveys, and other experiments flown on Apollos 15, 16, and 17. Several promising research and development projects were supported by the Director's Discretionary Fund.

Geology

A combined JPL/Caltech–U.S. Geological Survey research team has been investigating the use of Earth Resources Technology Satellite (ERTS) photographs in regional geologic mapping. Because of the wide view of these photographs, it is possible to trace linear features over long distances. Several new features were discovered through emphasis by computer filtering. One set, near Flagstaff, Arizona, outlines an area that may be favorable for the drilling of new water wells for the city. Another set, correlated with a new state aeromagnetic map, offers clues to the underlying structure of the pre-Cambrian basement rocks.

JPL's digital image processing techniques have been applied to the study of other earth resources. A thermal anomaly near Lordsburg, New Mexico, was mapped by thermal-infrared overflight film. The computer enhancement technique also enabled recognition in ERTS color pictures of various mineralized areas, particularly limonite stains, near Goldfield, Nevada.

Planetary Atmospheres

Dual-Frequency Technique

A dual-frequency and multiple field-of-view technique has been developed to determine vertical temperature profiles in cloudy atmospheres from radiance observations alone. The dual-frequency principle uses the Planck function of the dependence of intensity on frequency. Cloud-sounding frequencies are used to reconstruct their clear column radiance in the presence of multiple layers of broken clouds in all fields of view. The new technique can be used to reduce infrared and microwave radiance data simultaneously, and leads to the same degree of vertical resolution permitted under cloudless conditions.

Ionization

The ion cyclotron resonance spectrometer has been modified for use as an ion trap in which ions are formed and stored. This mode of operation allows accurate measurement of absolute rate constants, with the mass spectrum of the ions taken as a function of time. A new device makes possible the detection of electrons and more efficient detection of low-mass ions. Ionization processes taking place in the Jovian atmosphere, and the ion–molecule reactions occurring in many gaseous mixtures, have been identified and their absolute rate constants measured.

Radar Science

Asteroid Study

Radar scattering properties of the asteroid Toro were successfully measured in August 1972 when that small body came
within 20 million kilometers of Earth. When radar and optical data are combined, they suggest an irregular rocky surface, slightly smoothed by a mantle of loose material.

**Saturn's Rings**

Radar echoes at 12.6 cm have shown that the rings of Saturn are very efficient reflectors. The received power was unexpectedly strong, corresponding to over 60% of lossless isotropic scattering by the visible rings. It follows that the particles are likely to be rough, with diameters on the order of 1 meter or larger. Depending on the density with which the rings are filled, hard rock and metal fit the data well.

**Venus Mapping**

A high-resolution radar brightness and altitude image of a small area (a 150-kilometer section of Venus; right: elevation contours of same area as revealed by radar.)
Radio Astronomy

Jupiter's 13-centimeter flux density was monitored to investigate the relationships of the planet's synchrotron radio emission, solar activity, and orbital position with respect to the Sun, the Earth, and the solar wind. The total flux density has remained 20% below the 1964 value and no significant weekly or monthly variations have been seen during the 2½-year program. The distribution of relativistic electrons in the belts is being studied from Jupiter maps made at 3.7 and 11.1 centimeters using the three-element interferometer at the National Radio Astronomy Observatory. Comparison with earlier maps should reveal temporal variations of the belt structure. A theoretical study of Jupiter's decimeter wavelength radiation is progressing toward a model for the diffusion of high-energy electrons in the magnetosphere.

The brightness temperature of space in the microwave region of the spectrum has been observed to be approximately 3K. This thermal radiation is believed to have been produced during the initial phase of the expanding universe. Some irregularities in the uniformity of the microwave radiation could have been caused by material that ultimately formed galaxies and clusters of galaxies. A search was made for small-scale irregularities at 3.56 centimeters using the 64-meter Goldstone antenna.

Quasar Patrol was established to monitor monthly variations in structure of 10 quasars and radio galaxies. The technique uses very long baseline interferometry employing the 64-meter antenna and one or more antennas located in Massachusetts, West Virginia, Sweden, or Australia. Significant changes in the visibility functions of the Seyfert galaxy 3C120 and quasars 3C273 and 3C279 were observed from month to month, suggesting highly relativistic motions in the rest-frames of the source. To provide increased resolution, the observing wavelength was decreased from 3.8 to 2.1 cm for recent observations.

Interstellar Microwave Spectroscopy

Microwave transitions of interstellar molecules were investigated by astronomers from the University of California at Berkeley, JPL, and the University of Maryland. The Goldstone 64-meter antenna was used to study spectral lines of interstellar molecules and atoms at S-band (2 gigahertz), X-band (8 gigahertz), and K-band (15 gigahertz). The program also employs a computer-controlled microwave spectrometer. Laboratory measurements of line widths and intensities for both the ground and first vibrational states of ammonia were obtained. Work is now in progress on formaldehyde and acetaldehyde.

Lunar Laser Ranging

Retroreflectors placed on the Moon by the Apollo 11, 14, and 15 astronauts have been hit by laser beams for the past 3 years, providing highly accurate range measurements from McDonald Observatory based on the measurement of the elapsed time between the firing of a laser at these targets and the reception of the reflected beam. JPL-analyzed data fixed the coordinates of the observatory and the arrays, and the orbit and mass distribution of the Moon, to within 3-meter accuracy. Further analysis should enable measurements to be obtained of small irregularities in the rotation and orientation of the Earth, and tests to be made of relativity theories. Future range data may achieve 3-centimeter accuracies and permit measuring continental drift.

Infrared Astronomy

The planetary infrared spectroscopy program and the joint JPL–University of Texas stellar infrared spectroscopy program produced the first astronomical detection of deuterium (heavy hydrogen) in the atmosphere of Jupiter in the form of singly-deuterated methane. It was determined that the deuterium/hydrogen ratio is significantly lower than on Earth (by a factor of between 2 and 6). Since the Jovian D/H ratio is probably unchanged from the time of formation of the solar system, the result has lent strength to the argument that the terrestrial ratio has been enhanced by chemical fractionation and appears to support the predicted nucleosynthesis of a "big-bang" cosmology.

VLBI Earth Physics

Very long baseline interferometry (VLBI), using quasars, is being developed to achieve three-dimensional Earth distance measurement with an accuracy of within a few centimeters. The objective is to produce a technique for studying earthquake mechanisms. Relative motion measurements of points near Earth's tectonic plate boundaries could yield information on plate motion and strain buildup within a quake fault zone.

Feasibility of VLBI for this purpose was confirmed by an 8400-kilometer Goldstone–Madrid (Spain) test, which provided a catalog of 10 quasar sources with accuracies of within 0.1 to 0.01 arc seconds. Demonstrations of Earth distance measurements to within 4 centimeters were made in preliminary tests between two Goldstone antennas 16 kilometers apart.

Fields and Particles

Magnetic field and solar wind data from Mariner 5, under continued analysis, show that solar wind speed apparently depends on the solar latitude where it originated—the higher the latitude, the
higher the speed. Plasma waves in the Earth's magnetosphere have been studied with the help of Orbiting Geophysical Observatory satellites. Persistent plasma wave turbulence results from instability of Van Allen particles. Chorus, an electromagnetic disturbance caused by energetic electrons from Earth's tail during magnetospheric substorms, appears to be accompanied by precipitation of energetic electrons into auroral zones.

**Apollo Flight Science**

JPL has helped to complete topographical profiles of the Moon from laser altimeter readings taken from Apollos 15, 16, and 17. Observations were taken every 20 seconds, covering some 30 kilometers of surface with a precision of 2 meters at inclinations of 26, 9, and 20 degrees to the lunar equator. The profiles show that mare surfaces average 3 kilometers below the highlands, with 11 kilometers difference between lowest and highest lunar altitudes.

A lunar sounder experiment flown on Apollo 17 used three-frequency coherent radar and an optical recorder to measure elevations and detect subsurface features. Subsurface layers were found from 25 to 2000 meters deep. Radar evidence will be coupled with photography to evaluate the Moon's surface formation processes.

Radio tracking data taken from Apollos 15, 16, and 17 corroborated gravity anomalies (mascons) found on Lunar Orbiter flights. They appear to be caused by lava fills that flooded large ringed basins after the Moon's active volcano period some 3 billion years ago. The Moon's outer surface has since cooled to rigidity down to about 600 kilometers.

Gamma ray spectrometer experiments on Apollos 15 and 16 indicate that the Moon has large regional contrasts in surface radioactivity. The spectrometer results tend to prove that the Moon underwent much differentiation early in its history.

**Nimbus**

Global-scale temperature profiles of the Earth's atmosphere are being obtained by a JPL microwave spectrometer aboard the Nimbus 5 satellite. Cloud water vapor readings also are being provided to aid in weather forecasting. The microwave instrument is largely unaffected by cloud conditions which impair infrared sensors and, thus, is producing improved data for global weather predictions.

**Director's Discretionary Fund**

The Director's Discretionary Fund provides seed money for research and development projects that show promise of obtaining early outside support. Typically, projects are funded for 1 year at from $15,000 to $40,000. In the past year, several projects have been brought to a close, and funding has been provided for 19 new tasks, which include:

An experimental study of techniques for reducing oxides of nitrogen produced during coal combustion, with variables such as excess air, air preheat, and fluegas recirculation. Early results show that reduction in NOx levels can be obtained, but the problem is more difficult than in gas or oil combustion.

A combination of the techniques of multispectral photography and computer image processing to discriminate algae blooms in fresh water bodies. A software system from Purdue University was modified to perform multispectral data analysis, enabling pattern classification.

Development of a servo-controlled photomicroscopy system, incorporating JPL focus controls with Caltech and Huntington Institute equipment, for filming the microcirculation of blood in a living heart. The feasibility of using the automated system for heart microvascular photography was first demonstrated on cats.

Below: Microwave spectrometer aboard Nimbus 5 obtains temperature profiles of the Earth's atmosphere to aid in weather forecasting.

Right: Spectrally filtered photograph of kelp beds along the Santa Monica coast (left), computer-processed to show multispectrally classified regions (right). Key (bottom) indicates classifications.
Civil Systems

The Civil Systems Program experienced a significant increase in tasks sponsored by non-NASA sources, complementing the applications technology efforts conducted for NASA. Strong program focuses were developed in materials and computer-based image processing for biomedical applications, low-pollution internal combustion engine technology, wastewater purification techniques for environmental systems, and public safety systems for schools.

Biomedical Systems

During the past 18 months, the biomedical systems area has grown steadily and is now receiving almost 80% of its sponsorship from non-NASA sources. Many projects have been undertaken for the National Institutes of Health and such medical institutions as the University of Southern California School of Medicine, University of Nebraska Medical Center, and the City of Hope National Medical Center.

The expanding program includes projects in image processing, biomaterials, biomechanics, bioinstrumentation, sterilization technology, and health care systems. Selected examples of biomedical projects follow.

A Regional Health Care Technology Resource

As a consequence of growing collaboration with local hospitals and medical research centers, JPL represents a potential resource for medical institutions in this region. A project to develop the concept of a regional health care technology resource has been initiated in collaboration with the Hospital Council of Southern California. The objective is to apply the Laboratory's unique capabilities to the solution of common hospital problems.

Needs-analysis surveys have been initiated with six local hospitals. Two of these have been completed, and have resulted in general technology support contracts for small clinical and research tasks with the City of Hope National Medical Center and Huntington Memorial Hospital.

Flow Studies of Atherosclerotic Arteries

A major cause of death is vascular disease—particularly atherosclerosis, which often results in severe localized restriction or total occlusion of vital arteries. JPL, in conjunction with the USC School of Medicine, has initiated research to investigate the effects on hemodynamics (blood flow) of the arterial wall roughness generated by atherosclerosis. An experimental flow-test system has been constructed to perform pulsatile flow experiments on castings of diseased human coronary arteries.

An arterial casting consists of a channel within a polymeric block of material replicating the internal arterial dimensions. Pulsatile flow test results were compared experimentally to a smooth-tube equivalent. Results showed that castings of moderate roughness exhibit higher pressure drops at the same flow rate than smooth-tube equivalents. This effect becomes more pronounced as the pulse rate increases.

Operating Room Contamination

A study was undertaken to investigate the application of NASA clean room technology to orthopedic surgery. Microbiological-particulate contamination at the operation site was determined under the following conditions: (1) air filtered through high-efficiency particulate air filters and patterned in a unidirectional flow to the surgical field, (2) surgeon body exhaust systems to control nasopharyngeal exhaust and particle shedding from exposed skin areas, and (3) protective garments worn by surgical personnel.

In collaboration with St. Luke's Hospital, Denver, an evaluation was made of a horizontal unidirectional-flow operating room developed by Martin-Marietta Corporation under NASA funding. The 6-month study monitored 129 orthopedic operations. Significant reductions in contamination were attributed both to the room and the body exhaust system. A companion study was begun at Hollywood Presbyterian Hospital in a vertical-flow operating room.
Heat Sterilization

Spacecraft sterilization technology has been used to produce a breathing machine which can be sterilized entirely by dry heat to prevent the transfer of infectious organisms among users.

Ventilators, currently in use by asthma, emphysema, and other respiratory disease sufferers, have parts that cannot withstand heat sterilization. As a result, chemical sterilizing agents are used which are less efficient and reliable than heat.

Prototype units built by a medical equipment manufacturer, incorporating design and materials changes made by JPL, were successfully subjected to more than 300 hours of thermal testing at 127°C in JPL's sterilization ovens. Similar units were field-tested in several Los Angeles area hospitals in March 1973.

Heart Muscle Research

In cooperation with the Cardiovascular Research Group of the Cedars-Sinai Medical Center, miniature force transducers—developed for solid propellant stress analysis—are being adapted for in vivo animal tests. In these open-chest tests, transducers are implanted in the myocardium (heart muscle layer), which is subjected to selective occlusion of the coronary arteries. The force field at the site of implantation is recorded before and during occlusion and after reperfusion. The primary goal is to measure changes in myocardial contractile force before and during induced trauma and the effects of mechanical and pharmacological therapy on force recovery. Another objective is myocardial force field mapping during tests.

Coronary Microcirculation

In an affiliated effort between JPL/Caltech and the Huntington Institute for Applied Medical Research, a task has

Breathing machine for respiratory disease patients, modified to use space age materials that can withstand heat sterilization.
Flexible rubber heart-assist bypass pump developed for the National Institutes of Health has been tested on calves. The rubber bladder is implanted between the left ventricle of the heart and the aorta to bypass parts damaged by disease.

The first real-time focus-control (one axis only), closed-loop servo-microscope prototype was built and is now being used by the Huntington Institute to investigate the effects of drugs on cats' coronary microcirculation. A proposal for the support of the complete three-axis system development was submitted to the National Institutes of Health and is presently under consideration by the National Heart and Lung Institute.

Heart Valve Evaluation

A 3-year heart valve evaluation program was concluded with the Cardiology Section of the Los Angeles County-USC Medical Center. The JPL effort probed three major areas: (1) problems of durability and materials degradation in the body environment, (2) fluid dynamics performance, and (3) examination and evaluation of valves recovered post-mortem.

Much of the materials work was conducted on silicone rubber, which is widely used for prosthetic valve poppets. Silicone rubber exposed to the blood stream has a tendency to absorb some fatty constituents of the blood. JPL tests show that this process leads to a softening of the material and a lessening of its useful life. In some cases of apparent chemical degradation, severe physical changes in the silicone rubber may cause valve malfunction.

Clinical testing of the flow performance of prosthetic valves may now be enhanced by the JPL-developed theoretical analysis of time-dependent viscous flow through an aortic prosthesis. This analysis allows for a moving body (the valve poppet) within a channel that has arbitrarily moving walls. A solution was achieved by numerical computer methods.

More than 30 prosthetic valves recovered at autopsy were furnished by the Los Angeles County Hospital for evaluation at JPL. Several types and models of valves, with implantation times varying from a few days to 8 years, were assessed in the NASA-sponsored program.

Human Chromosomes

Development was nearly completed of a system for the automatic analysis of conventionally prepared human chromosomes. The system accepts a microscope slide containing the homogeneously stained metaphase chromosomes and produces a 10-group pictorial karyotype. This work will be extended under a contract award from the National Institute for Child Health and Human Development (NICHD) to develop a clinical prototype of the system. Research also continues to develop a system that will analyze chromosomes stained by the recently developed banding techniques. This will allow resolution of the karyotype into 20 homologs and two sex determinants.

A technique for the study of chromosomes condensed prematurely in the process of cell division was developed. This technique will provide the basis for gene mapping studies. Image analysis of prematurely condensed chromosomes may advance the diagnosis of genetic disease beyond what would be possible in the banded metaphase chromosomes.
Arterial X-Ray Processing

In collaboration with the USC Specialized Center of Research on Atherosclerosis, an X-ray image processing technique to measure blood vessel plaque was tested in a post-mortem study of 30 patients from the Los Angeles County-USC Medical Center. Computer estimates of arterial disease, as derived from the X-ray films, were compared with cholesterol analysis of the corresponding arterial tissue, and a close correlation was observed. On the basis of these results, a clinical evaluation study was initiated, analyzing yearly angiograms of myocardial infarction patients at Rancho Los Amigos Hospital.

Transportation Systems

A number of technological developments have been undertaken and completed for transportation system design, more efficient engines, and establishment of pollution characteristics of supersonic aircraft.

Subway Aerodynamics

The experimental portion of the Vehicles in Confined Spaces Project has been completed. The work was carried out under a contract between Caltech and the Institute for Rapid Transit, which has a grant from the Department of Transportation to produce a handbook on the ventilation aspects of subway design.

This work was used by Caltech to develop theoretical models. Small-scale tests carried out at JPL simulated conditions expected in a subway-train system. Scaling laws predicted by the theory were verified, and the aerodynamic-related effects in the design and operation of rapid transit systems utilizing tunnels, including power and ventilation requirements, can now be included with greater confidence.

Motor Analysis

Linear induction motors for high-speed (500 kilometers per hour) ground transportation are dominated by end-effects which defy traditional analyses used for rotary induction motors. A numerical mesh computation method predicted the variation of reaction-rail current and magnetic field along the motor and through the magnetic wake region behind the motor. Calculated motor thrust and efficiency agree with vehicle data from the Department of Transportation Ground Test Center. Thrust increases of 50–100% appear possible.

Aerodynamic Braking

A preliminary experimental study of the use of a series of aerodynamic surfaces for braking high-speed trains indicates that the approach is feasible for decelerating trains traveling at 160–480 kilometers per hour. The interference effects from the wakes of upstream brakes make it mandatory to examine their efficiency as a complete series of brakes rather than a single aerodynamic surface. The study could lead to a test program for optimizing aerobrakes.

Low-Pollution Engine

A mixed fuels concept is being investigated for its feasibility in reducing pollutants emitted from automotive and aircraft engines. Early tests show potential for meeting 1976 Environment Protection Agency (EPA) requirements. The system also appears to be capable of improving fuel consumption in internal combustion engines.

The benefits of low fuel consumption and low pollution are achieved in an engine basically similar to today's designs. The fuel system is modified to use one more fuel. No exhaust aftertreatment devices appear to be necessary. Feasibility will be demonstrated by modifying and thoroughly testing two automobiles in simulated road use.

Opposite Low-pollution engine based on the use of mixed fuels being tested in the laboratory prior to demonstration in simulated road use
Stratospheric Observations

In support of the Department of Transportation Climatic Impact Assessment Program, a number of stratospheric observations were conducted using a JPL-developed high-speed interferometer spectrometer. The stratospheric background composition was determined from analyses of absorption spectra obtained by observing the Sun at low elevation angles. The instrument, installed in a Concorde aircraft flying at stratospheric altitudes (10 to 18 kilometers), obtained spectral coverage of the wavelength regions where molecular transitions of trace gases occur over a wide range of latitudes in the northern hemisphere. Among significant preliminary results were the detection of nitric oxide at a concentration of one part per billion by volume in the 11- to 20-kilometer altitude region, latitudinal variation of methane, variation of carbon monoxide with latitude and altitude, and the verification of previous measurements of water vapor and nitrogen oxide concentrations.

Public Safety Systems

In the area of Public Safety Systems, two tasks produced systems with potential for alleviating problems in school safety and juvenile delinquency. These developments are being transferred to the commercial sector.

Private Alarm Signaling System

Testing of this emergency school communication system was completed at John Muir High School, Pasadena, confirming earlier results obtained at the John F. Kennedy High School, Sacramento. Industry was licensed by the government to manufacture and market the system, and the transfer to industry was completed.

To date, the manufacturer has installed several systems in California, Georgia, and New York schools, and interest has continued to increase in the education sector. Another application has been tried by the Department of Housing and Urban Development, in which the manufacturer installed the alarm system in an Operation Breakthrough apartment project for the elderly in Sacramento.

Student Attendance Information System

The Student Attendance Information System—originally known as the Automated Attendance Accounting System—passed a year-long test at John F. Kennedy High School in Sacramento. The system demonstrated its capability for registration, accommodating student program changes, enrollment accounting, class-size management, and student accountability, as well as attendance accounting. Results
elicited praise from school officials, who received several hundred inquiries from various educational organizations. The system is in continuing operation at the school to accumulate additional performance data.

Environmental Systems

The Environmental Systems Office addresses tasks in three fields: environmental, energy, and community systems. The program includes non-NASA-sponsored work performed for the Environmental Protection Agency, the Southern California Edison Company, and cooperative efforts with the Caltech Environmental Quality Laboratory (EQL).

Wastewater Purification

Application of space technology to the insulative properties of carbonaceous materials led to the development of a new charcoal sewage treatment process. Pyrolytically prepared, this charcoal possesses the ability to adsorb dissolved contaminants from sewer water. Laboratory work indicated that a similarly active carbon char material could be prepared from the suspended or undissolved solids in sewage. Carbon, after purifying the water by adsorbing the dissolved solids, is recycled back into the raw sewage. Recycled carbon promotes settling and filtering of the undissolved solids.

The process could replace present biological systems in municipal treatment facilities. It promises cleaner water at a competitive cost. A mobile, small-scale processing facility is being constructed to demonstrate feasibility in treating raw sewage, and possibly agricultural and industrial wastewater as well.

Project SAGE

A JPL–EQL group found that water heating is one of the most significant energy usages in Southern California. A project to investigate the commercial potential for solar-assisted gas energy (SAGE) water heating was established under sponsorship of the Southern California Gas Company.

The cost of solar water heating was found to be within an economically feasible range for a 32-unit apartment used for a design study. A final design will be selected for a demonstration installation in a 50-unit apartment building.

Nitrogen Oxide Studies

A study was made of the effects of combustion process modifications on emissions of oxides of nitrogen (NOx) from natural gas-fired boilers. Sponsored by the Southern California Edison Company, the study showed that fuel-rich combustion was one of the most easily implemented and most effective NOx reduction methods. A technique of gas recirculation achieved further reduction of nitrogen oxides.

In another nitrogen oxide research effort, JPL is investigating emissions from multi-burner arrays in fossil-fueled furnaces for EPA. The goal is to determine air–fuel combustion dynamics and time-space temperature conditions that produce nitrogen oxide emissions.

California Four Cities Program

A 2-year experiment, under JPL project management, is evaluating the potential of science and technology in helping solve urban problems in the California cities of Anaheim, Fresno, Pasadena, and San Jose. Each city is paired with a high-technology corporation, which provides a senior advisor to serve on the city manager's staff.

The program, jointly sponsored by the National Science Foundation and NASA, has demonstrated the effectiveness of the assistance of a scientist or engineer in day-to-day city operations. Major applications of science and technology undertaken in the cities have been improvement of communications through cable television in Anaheim, solid-waste management in Fresno, suggested revised managerial procedures in city administration in Pasadena, and development of a municipal information system in San Jose.
Other Activities

Plans and Programs

The Office of Plans and Programs continued to serve as the focal point at JPL for 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 concerned with the analysis and evaluation of possible future missions and candidate spacecraft systems.

Operational Planning

In activities connected with the application and allocation of resources, Laboratory planning has been impacted by the continuing squeeze on the NASA budget and the shrinking of its institutional base. In January 1973, NASA-wide budget reductions to limit spending for the remainder of fiscal year 1973 resulted in the elimination of some JPL research and development tasks and in substantial cutbacks in others. One effect of these adjustments was a 5% reduction in Laboratory manpower which, when added to earlier reductions, brought the total reduction in 1973 to about 7%. Furthermore, current planning anticipates additional manpower reductions of about 5% during fiscal year 1974. The reductions have appeared most severely in the allocations available to research, advanced development, scientific investigations, and supporting service-type functions, and relatively less so in the flight project activities.

Special Planning Studies

Periodic assessment of NASA’s likely future programs and identification of possible implications for the Laboratory are important factors in planning and often provide the background and motivation for other assessments and special studies. Recent studies, for example, identified the Earth and Ocean Physics Program in the Space Applications area as particularly appropriate to the strengths and scientific interests of JPL and Caltech. As a consequence, the Laboratory is now developing a significant activity in this area, possibly including the implementation of Earth satellite projects at the appropriate time. Other recent studies assessed the state of development of solar-electric propulsion and examined the prospects that missions for which it would be a preferred technique will be authorized.

The Office of Plans and Programs and other elements of the Laboratory devoted substantial efforts to re-examining the nature of project costs and seeking means by which they can be minimized consistent with acceptable risks. The most important factor to be reckoned with is that non-recurring engineering design and development costs predominate in a typical project when only a few flight units are involved, the costs of the actual spacecraft hardware are relatively small. The conclusion was that policies that would lead to standardization of spacecraft designs and, additionally, would permit advance procurement of hardware (combining orders and inhibiting subsequent changes) could have a significant effect in reducing costs by spreading the non-recurring investments over a larger number of flights.

Advanced Technical Studies

Advanced Technical Studies in 1972 and 1973 continued in the development of strategies for scientific exploration of the solar system and the evaluation of possible programs, missions, and candidate spacecraft systems. Study results were reported in such general areas as comet and asteroid rendezvous missions, earth physics satellite programs, remotely manned systems for planetary exploration, and outer planet missions including orbiters and atmospheric probes. Specific investigations which seemed especially promising, and on which additional work is planned in the immediate future, include the imaging of Venus by synthetic-aperture radar from orbit, the return of samples from Mars, and the use of solar-electric propulsion to achieve a slow flyby of the comet Encke. In studies relevant to the exploration of the Moon,
an integration and summary of Apollo results was prepared, and planning was begun for possible future unmanned missions.

In a somewhat different category, two studies were made to provide data for choices affecting future launch vehicle and propulsion development programs. These were undertaken in collaborations with the Battelle Memorial Institute and the NASA/AEC Space Nuclear Propulsion Office. Only a few of the more significant results from these studies can be mentioned here. The Mars sample return study, which was conducted jointly with the NASA Langley Research Center, demonstrated that the automated return of samples from Mars has become technically feasible and may be achievable at a cost low enough to make this mission a serious contender among planetary enterprises in the future. The Venus orbiter study showed that a side-looking radar (similar to the lunar sounder radar developed at JPL) carried by a Mariner spacecraft into a relatively low orbit around Venus could provide a global map of the planet's surface at a resolution of 200 meters, with spot coverage (3% of the surface) at a resolution of about 50 meters.

Particularly noteworthy among study results is an increased interest in the use of solar-electric propulsion for missions to comets. With the growing realization that cometary material may hold clues to the early formation of planetary systems, scientists are eager to deliver measuring instruments to a comet and through its coma and tail. However, such missions are technically difficult. Either the spacecraft must be accelerated into an orbit the same as that of the comet (which requires advances in both propulsion and navigation), or it must intercept the comet with a high relative velocity (which, to obtain useful measurements during the brief encounter, requires advances in instrumentation and data handling). For an initial exploratory mission, it appears reasonable to use solar-electric propulsion to attain a moderate intercept speed, and to employ existing types of instruments to make these measurements. Later missions, again using solar-electric propulsion, could achieve a true rendezvous, remaining in the vicinity of the comet indefinitely.

Office of Computing and Information Systems

Computing technology continues to perform an ever-increasing role in the work of the Laboratory. JPL's large-scale general-purpose computing facilities, and their support of flight projects, scientific and engineering tasks, and administration, are the responsibility of the Office of Computing and Information Systems (OCIS). The operating arm of OCIS is the 330-man Data Systems Division. Its computing equipment, personnel, facilities, and associated resources are referred to collectively as the Mission Control and Computing Center (MCCC).

During 1973, the MCCC supported the extended Mariner Mars 1971 and Pioneer flight missions; conducted ground test and preparation activities for the Mariner Venus/Mercury 1973, Viking 1975, and Helios 1974/1976 Projects; and provided for the science, engineering, and administrative computing needs of the Laboratory. Additional equipment and improved techniques have been extending the capability of the MCCC. A computer performance evaluation project (COMPEP) has carried out a continuing investigation of techniques designed to improve performance based on detailed analyses of operational and utilization data for each system. Many of the computing improvements of the past year have resulted from this effort.

The Mission Control and Computing Center consists of three functional and interrelated elements: the General Purpose Computing Facility (GPCF), the Mission Control and Computing Facility (MCCF), and the Mission Test and Computing Facility (MTCF). The GPCF has two Univac 1108s for general scientific and engineering service and shares an IBM 370/158 with the Caltech campus for administrative work. The MCCF employs three IBM 360/75 computers in mis-
Mission control flight operations support and planetary data processing. The MTCF uses Unvac 1230s and other computers for spacecraft preflight testing and flight telemetry processing.

General Purpose Computing Facility

The 1108s of the GPCF, which processed an average of 17,000 jobs per month during Fiscal 1973, also provided navigation computing to the flight projects. The system operates (1) in the conversational mode, with access from more than 150 remote terminals, and (2) in the batch mode at the central processor or from any of six remote job entry stations. Recent facility improvements include more extensive high-level language capability, increased storage, faster storage-access techniques, and a front-end processor to improve the system efficiency for handling remote-terminal communications.

Administrative computing provides financial and other accounting services, assists personnel record-keeping, and supports indexing and other library functions, as well as project management information systems. During a typical month, approximately 3000 administrative jobs are processed, 300,000 punched cards are used, and 900,000 pages of printed output are produced and distributed.

Mission Test and Computing Facility

During the reporting period, the MTCF grew from a single mission test system to three systems to meet the simultaneous needs of Mariner Venus/Mercury and Viking. In addition to spacecraft system test operations and in-flight engineering information, the facility provided quick-look picture processing for the Mariner 9 experimenters.

Caltech Medical Sciences Laboratory

The basic objectives of the Caltech Medical Sciences Laboratory are to establish joint Caltech/JPL biomedical tasks and, with the assistance of outside medical scientists, lay the basis for a major new program in this area. The program has included the following activities in the 10 months since its inception:

- A workshop on genetic and molecular disease was held in December 1972, sponsored in large part by the California Chapter of the Committee to Combat Huntington's Disease and attended by several nationally prominent medical scientists and administrators. Conclusions reached at the workshop, with the advice and encouragement of the attendees, led to the decision to plan a Caltech/JPL Medical Sciences Laboratory, with its main emphasis on attacking genetic and molecular diseases.
- Two major proposals submitted to the National Institutes of Health are now under active consideration. Both proposals are joint Caltech/JPL endeavors, one has as its principal investigator a member of the faculty of Caltech, the other a JPL scientist.
- Numerous outside experts in biomedical engineering have visited Caltech and JPL to provide a better understanding of the problems and potentials in this field, and to identify potential biomedical leaders whom we might wish to place on the permanent staff.

Administrative Divisions

Funding for JPL's ongoing tasks and new effort in research and development amounted to $286,839,000 during the 18-month reporting period, including 95 new tasks. Funding for ongoing and new construction of facilities amounted to $3,374,000.

An increased national emphasis has brought about new efforts in technology transfer to industry and the public sector. Requests from the public sector for Technical Support Packages on items of new technology reached a new high during the period.

During calendar year 1972, JPL conducted in excess of 33,000 procurement transactions, representing obligations of approximately $146,000,000. Principal activities centered about the Mariner Mars 1971, Mariner Venus/Mercury 1973, and Viking Orbiter 1975 missions.

The NASA/JPL plan for securing greater utilization of minority business capabilities in the Southern California area was implemented and has proven to be very effective. Almost $4 million of actual and anticipated awards were identified as directly traceable to a limited trial run of the plan. The Los Angeles Federal Executive Board has adopted this program as a primary objective and has secured funding from the Office of Minority Business Enterprise for full-scale implementation.

The Technical Information and Documentation Division conducted information retrieval and dissemination projects on behalf of two federal agencies. The first was a study of communication and dissemination of research results sponsored by the Office of Intergovernmental Science and Research Utilization of the National Science Foundation. This study, looking toward the sharing of federally sponsored scientific work with interested state and local governments, developed a concept for identifying items likely to be of value to such users, and a system for dissemination of the information to them. Further development and application of the system was undertaken by the National Science Foundation.
The second project involves the operational support of Department of Transportation information control and indexing activities by the JPL Library. Since July 1972, the Library has been indexing, abstracting, and processing literature entries for the National Highway Traffic Safety Administration's automated data collection and their announcement journal, *Highway Safety Literature*. In addition, the Library prepared an *Index to the Hazardous Materials Regulations*, to be published by the Government Printing Office, for the Department of Transportation Office of Hazardous Materials.

**Special Recognition**

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

- R. J. Parks, elected to National Academy of Engineering
- W. H. Pickering, Edison Medal, Institute of Electrical and Electronic Engineers
- D. Schneiderman, National Space Club Astronautics Engineer Award
- W. L. Sjogren and P. M. Muller, Special NASA Prize for discovery of lunar mascons

With the conclusion of the Mariner 9 Mars orbiting and Apollo lunar landing projects in late 1972, numerous NASA medals were awarded to JPL personnel, including the following:

- D. Schneiderman, NASA Distinguished Service Medal
Jet Propulsion Laboratory Executive Council

W. H. PICKERING, Director
C. H. TERHUNE, Jr., Lt. Gen. USAF (Ret.), Deputy Director

W. H. BAYLEY
Assistant Laboratory Director—Tracking and Data Acquisition

J. P. CLICK
Assistant Laboratory Director—Administrative Decisions

F. H. FELBERG
Assistant Laboratory Director—Plans and Programs

F. E. GODDARD
Assistant Laboratory Director—Research and Advanced Development

J. N. JAMES
Assistant Laboratory Director—Technical Divisions

W. H. PADGHAM
Assistant Laboratory Director—Personnel Administration and Supporting Services

R. J. PARKS
Assistant Laboratory Director—Flight Projects

D. G. REA
Assistant Laboratory Director—Science

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