Cover: Mariner 9 spacecraft.
JET PROPULSION LABORATORY
1971 ANNUAL REPORT

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DIRECTOR'S MESSAGE

The successful orbiting of Mariner 9 around the planet Mars and the subsequent imaging and data return were the most significant achievements of the Jet Propulsion Laboratory during 1971. This feat required precision tracking and trajectory correction and orbital maneuvers of unprecedented complexity.

Mariner 9 was placed in position to transmit more than 5000 pictures of well over 75% of the surface during a minimum 90-day mission. The optical, spectral, occultation, and celestial mechanics data were expected to produce a dramatic redefinition of the scientific model of the planet. Despite a severe dust storm, by the end of December, prospects for accomplishment of essentially all phases of the original dual mission were excellent.

Project effort continued on the 1973 mission to fly by Mercury following gravity acceleration from the field of Venus. The spacecraft system design was essentially completed, and the system contractor was selected during the year.

JPL also released a preliminary design of the orbiter system for the 1975 Viking Mars project. A system contractor was selected to design and develop the gas chromatograph/mass spectrometer for organic analysis of Mars' atmosphere and surface materials.

The three-year TOPS (Thermoelectric Outer Planet Spacecraft) Project was concluded in December, having demonstrated the technologies required for designing and flying an automated spacecraft to the outer planets.

With the reduced emphasis on new starts in planetary programs, the Laboratory increased efforts to apply its capabilities in non-space fields, such as studies of the chemistry of air pollution, solid-earth physics, physical oceanography, public safety, medical engineering, and environmental management. Specific programs included a police air patrol system, a school alarm system, monitoring systems for hospitals, and studies of water pollution and energy management.

In general, 1971 was a year of solid accomplishment in many fields without general expansion. It was a period in which the Laboratory sought to firm up its position in research and development in space and the basic sciences, while establishing a foundation in the application of technology among the broad-based problems of the civil sector.

FLIGHT PROJECTS

MARINER MARS 1971

Mariner 9 was successfully launched from Cape Kennedy on May 30, 1971, 22 days after a failure in the launch vehicle caused the loss of Mariner 8. Five days later, a trajectory correction maneuver was performed as planned, demonstrating for the first time the operation of the new propulsion subsystem and autopilot in a true space environment. The precision of this maneuver obviated the second trajectory correction maneuver originally planned for October, shortly before arrival at the planet. On November 13, 1971, Mariner 9 was inserted into Mars orbit to become the first man-made satellite of another planet in our solar system.

Upon arrival at the planet, the dust storm, previously observed by earth-based telescopes, was found to be more severe than anticipated. Except for a few high-elevation areas and the south polar cap, dust obscured the surface of Mars. The first orbit trim maneuver, performed successfully on November 15, 1971, lowered the periapsis altitude and adjusted the time of periapsis passage to the view period of the Goldstone 64-meter antenna.

However, because of the dust obscuration, the original mission plan, calling for systematic mapping of 70% of the Martian surface, could not be followed. Instead, the mission was adapted to accommodate requests from the scientists based on analysis of the returned data.

All on-board science instruments have been functioning properly. Although the dust storm reduced the lower atmospheric and surface data anticipated from the ultraviolet and infrared experiments, a better understanding of the dust cloud, its constituents, and its structure is evolving from the data obtained.

The infrared radiometry and spectroscopy experiment suffered some reduction of visibility, but surface features could be seen. Portions of the ultraviolet experiment dealing with the upper atmosphere were not affected by the storm, and neither the occultation nor the celestial mechanics experiment was impaired.

High contrast in the south polar region permitted studies to be made of the recession of the thin solid carbon dioxide frost layer. Also observable through the dust cloud were apparent high-elevation features such as a crater near Nix Olympica. This feature has raised the speculation that some of the Martian craters may not be impact craters and may be of volcanic origin. Photographs of this feature taken after the dust storm cleared confirm the hypothesis of volcanic formation.

Several pictures were taken by the narrow-angle TV camera of the two natural moons of Mars, Deimos and Phobos. Studies of the best Phobos picture, taken from a distance of 5541 kilometers, indicate that it is a very old body possessing considerable structural strength.
During the first few weeks of orbital operations, the celestial mechanics experiment determined that the Martian gravity field is rougher than either the earth's or the moon's. Mars is triaxial in shape and has flattened poles and an elliptical equator. This caused the orbital period of Mariner 9 to vary slightly in a sinusoidal manner over a 20-day period. Since the first orbit trim maneuver was performed before a good characterization of the Mars gravity field had been obtained, the time of periapsis passage was drifting away from Goldstone zenith.

Indications began to appear in December that the dust storm obscuration was diminishing, particularly in the southern latitudes of Mars. As a result, the original plans of mapping 70% of the planet's surface again became a mission objective.

Prior to initiation of the mapping, a second orbit trim maneuver was required. This maneuver, performed on December 30, 1971, raised the periapsis altitude from 1388 to 1650 kilometers and changed the average orbit period from 11 hours, 58 minutes, 13 seconds to 11 hours, 59 minutes, 28 seconds. The former change was necessitated by the need to cover larger areas with each wide-angle picture in order to complete contiguous mapping within the limited high-data-rate communications time remaining; the latter change, lengthening the average orbit period, corrected the time of periapsis passage to compensate for the effects of the irregular gravity field and thus maximized data acquisition by the 64-meter (210-foot)-diameter antenna at Goldstone.

Thus far the systematic mapping, begun January 2, 1972, has been extremely successful and scientifically fruitful. While understanding of Mars and appreciation of its dynamic qualities increase daily, unique surface formations observed by Mariner 9 raise many new, as yet unanswered questions.

Vast canyons, some larger and deeper than the Grand Canyon of Arizona, have been seen by the TV cameras and depth-probed by the ultraviolet spectrometer. The origin of a long serpentine canyon is not understood, even though in appearance it resembles a dry California arroyo. As measured by the infrared interferometer spectrometer, Mars at present has only small amounts of water vapor in its atmosphere.

Another mystery is a bright, irregular equatorial feature reminiscent of the carbon dioxide south polar cap of Mars. However, temperatures of this feature measured by the infrared radiometer preclude the presence of solid carbon dioxide.

About 60% of the dust cloud appears to have been composed of silicon dioxide. In addition, the interferometer spectrometer is obtaining temperature profiles of the atmosphere which can be related to those measured by the S-band occultation experiment. Variations of surface temperature at many locations and different times of the Martian day are being collected by the infrared radiometer.

Surface elevations and pressures computed by S-band occultation measurements taken at numerous locations are providing excellent planet-wide coverage. Additional occultations may be obtained during the May and June 1972 occultation periods. These measurements are being correlated with relative altitude results from the ultraviolet spectrometer, infrared interferometer spectrometer, and television experiments, and ground-based radar, amplifying the understanding of the data provided by the individual experiments.

Data exchange was initiated between Soviet and JPL scientists. Messages were transmitted describing significant Mariner 9 findings, and information was received about the Soviet Mars 2 and Mars 3 spacecraft placed in orbit around Mars subsequent to Mariner 9.
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. Interplanetary experiments and further investigations of Venus will also be carried out as the spacecraft proceeds toward Mercury.

The launch window for the flight opens late in October and closes in 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 arrival at Mercury in late March or early April.

Scientific instruments will be provided by five principal investigators to permit carrying out experiments involving charged particle, magnetic field, and plasma science measurements, infrared radiometry, and ultraviolet spectroscopy. In addition, two science teams have been appointed to oversee and analyze the data expected to be returned by the Project-supplied television and S/X-band radio subsystems.

During 1971, the Boeing Company was selected as the spacecraft system contractor, and the design of the spacecraft system has been essentially completed. Unique features incorporated to meet mission requirements include a two-degree-of-freedom, 137-centimeter, parabolic high-gain antenna, a two-channel telemetry system capable of handling data rates as high as 117.6 kilobits per second for the television while simultaneously returning 2450 bits per second of nonimaging science data, a propulsion subsystem capable of performing multiple burns to provide for four midcourse maneuvers to permit accurate targeting at Mercury, and solar power panels which can be articulated about their long axis for thermal control purposes. The spacecraft separated weight, including all scientific instruments, is estimated to be approximately 500 kilograms.

Mission sequence and mission operation system activities have both been major activities during 1971. Detailed plans for the conduct of the science experiments have been formulated to cover both the cruise and encounter phases. Instrument design and preliminary fabrication were also initiated, and mechanical, electrical, and thermal interfaces between the science instruments and the spacecraft were defined.
VIKING MARS ORBITER

Two missions, both to orbit and land on Mars in midsummer 1976, will be conducted by the Viking Project. 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 Mars missions is to advance our knowledge of the planet Mars by means of observations from a Martian orbit and measurements on the planet's surface. Particular emphasis will be placed on obtaining information concerning biological, chemical, and environmental factors relevant to the existence of life on the planet at the present time or in the past and the potentiality for the development of life in the future.

The Langley Research Center has overall management responsibility for the Viking Project. The Orbiter System development, and tracking and data acquisition are assigned to JPL. The Lander System is being developed under contract to Langley Research Center by the Martin-Marietta Corporation. The Lewis Research Center has responsibility for the Launch Vehicle System.

The objectives to be accomplished by the Orbiter System are to obtain visual, thermal, and water vapor information from orbit of potential landing sites and other areas of Mars. The results of this information will be used in selecting sites for the landers and for future missions as well as in the study of the dynamic characteristics of the planet and its atmosphere.

The science experiments to be performed by the orbiter are (1) visual imaging of the surface, (2) infrared radiometry, (3) infrared spectrometry, and (4) radio experiments to obtain data that will improve planetary navigation capability and provide measurements of radio propagation properties and Mars atmospheric data.

During 1971, significant strides were made toward the development of an orbiter design to meet the mission requirements as established by a Mission and System Requirements Review held in 1971. A preliminary design review of the Orbiter System was held in October.

An additional area that has received considerable attention in the development of the Orbiter System design is the expansion of the redundancy capabilities that have existed in previous Mariner spacecraft to ensure that no single failure in the spacecraft will cause the loss of more than one experiment. Considerable progress has been made, although some areas still exist, notably in the structural and propulsion elements, in which it has not proved feasible to fully meet the desired redundancy capabilities. In these areas, suitable design margins will be provided.

Functional requirements for the Orbiter System and subsystems have been developed and are being used in support of the subsystem procurement activities which began early in the year. To date, ten major orbiter procurements have been initiated and four subsystem-level contracts have been negotiated.

Considerable effort was also expended during the year in developing operating procedures which in a number of instances are unique to the JPL Viking effort as contrasted with those used on other JPL projects. Some ten major policy documents, such as the Viking Orbiter Design Book, Configuration Management Plan, and Data Management, were prepared and issued to provide policy direction and requirements to the various elements working on the Orbiter System.

The Laboratory is also providing the gas chromatograph mass spectrometer (GCMS) for the Viking Lander. This instrument will perform organic analyses of both the surface material and the atmosphere at the surface of Mars.

GCMS activities during 1971 included establishment of a GCMS management office, separate from the Orbiter Office, and the selection of Litton Systems, Inc., as the contractor to produce the instrument. A major effort through the end of 1971 was to establish and document the functional design. Early in 1972, project management responsibility for GCMS was transferred to Langley Research Center.
OUTER PLANETS PROJECT

Conceptual planning of an Outer Planets Project, to consist of a series of four flyby missions, including two to be launched in the late summer of 1977 to investigate Jupiter, Saturn, and Pluto, and two to be launched in the fall of 1979 to investigate Jupiter, Uranus, and Neptune, was essentially completed during 1971. Information concerning the characteristics of interplanetary space, the asteroid belt between Mars and Jupiter, the rings of Saturn, and the moons of Jupiter, Saturn, and Uranus would also be obtained during the missions.

The four spacecraft would eventually escape from the solar system and would be tracked to the limits of the Deep Space Network 64-meter antenna system to obtain as much scientific information as possible as they proceed into the Milky Way galaxy. Mission designs were evolved with the intent of maintaining communications with each of the spacecraft to a distance of at least 40 astronomical units (AU) from earth.

Flight times to the farthest planets, Neptune and Pluto near the edge of the solar system, would be from 9 to 14 years, depending upon the launch dates and trajectories selected. The spacecraft would then proceed beyond the solar system and recede from earth at a velocity of about 3 AU per year.

Activities in support of the Outer Planets Project were cooperatively carried out by a number of organizational elements both outside and within the Laboratory, including the Advanced Planetary Missions Office. The major and continuing effort during the past year has been an iterative process of defining the spacecraft functional requirements and design, the mission parameters, and the scientific objectives to be accomplished in order to evolve a low-cost but still scientifically worthwhile program consistent with anticipated budgetary and schedule constraints. The effort was carried out in conjunction with the cognizant Headquarters elements of NASA and involved the Space Science Board of the National Academy of Sciences and a select international group of over 100 scientists. The scientists were organized into 13 science teams, each operating under a team leader, the 13 leaders comprise the Outer Planets Science Steering Group.

To maximize the scientific returns from the missions, responsibility was placed on this Science Steering Group to assist the Project at an early stage in the development of spacecraft and mission plans to ensure a match between mission capability, scientific requirements, and the known schedule and budgetary constraints. The team leaders of the Group and their respective areas of cognizance are shown below.

<table>
<thead>
<tr>
<th>Science Team</th>
<th>Team Leader</th>
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<tr>
<td>Imaging</td>
<td>M J S Belton</td>
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<td>Kitt Peak National Observatory</td>
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<th>Radio Science</th>
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<td>Photopolarimetry</td>
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<td>Energetic Particles</td>
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<td>Plasma</td>
<td>J H Wolfe</td>
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<td>UV Spectroscopy</td>
<td>T. M Donahue</td>
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<td>Radio Physics</td>
<td>J W Warwick</td>
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<td>Meteoroid</td>
<td>R K Soberman</td>
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<td>IR Spectroscopy</td>
<td>C B Farmer</td>
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<td>Hydrogen Lyman Alpha</td>
<td>J E Blamont</td>
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<td>Planetary X-Ray</td>
<td>K A Anderson</td>
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Other significant events that occurred during 1971 include the establishment of a Project Office at JPL, formulation of preliminary project plans, and conducting of a series of briefings for industry on the results of the Thermoelectric Outer Planets Spacecraft (TOPS) Project, a precursor effort on the design of an outer planet spacecraft.

A series of intensive briefings on the TOPS Project was held in September to provide industry with an up-to-date account of the studies, designs, and developments that evolved from over 3 years' effort on the Project at the Laboratory. Over 50 companies throughout the country were represented at these briefing sessions.

The activities described above were predicated on an outer planets program including a four-flight mission set involving spacecraft with operating lifetimes of 10 to 12 years and designed to fly by the outermost planets. The NASA budget for FY 1973, revealed in January 1972, indicates, however, that the outer planets program will initially consist of a two-flight mission designed for flyby explorations of Jupiter and Saturn. In keeping with this plan, the Laboratory is now engaged in project planning efforts with redefined science objectives and directed toward the launching of two spacecraft in the late summer of 1977. Each spacecraft will fly by Jupiter in the spring of 1979 and Saturn in the spring of 1981.

*This project, aimed at developing the technology required for unmanned spacecraft having long-life, environmental immunity and emergency adaptability characteristics, is described in the Research and Advanced Development section of this report.
THE DEEP SPACE NETWORK

OPERATIONS

During 1971, the Deep Space Network (DSN), with its world-wide facilities, provided the tracking and data acquisition for the launches of Mariner 8 and 9 and the flight and initial orbital operations of Mariner 9 at Mars. The standard 26-meter-diameter network and the 64-meter-diameter antenna at Goldstone, California, provided support for extended mission activity of the Pioneer 6, 7, 8, and 9 spacecraft in orbit around the sun. DSN facilities around the world were utilized in joint operation with the Manned Space Flight Network in support of the Apollo 14 and 15 missions. Planning and preparation for DSN support of the following flight projects continued throughout the year: Pioneer F and G missions through the Asteroid Belt and past Jupiter, scheduled for launches in 1972 and 1973; Mariner Venus–Mercury 1973; the Viking missions to Mars in 1975; and the Helios sun-orbiting flights, a project of NASA and the Federal Republic of Germany, in 1974-1975.

MARINER 9

The major operational effort of 1971 for the DSN was Mariner 9 tracking and data acquisition. Last-minute preparations and final ground system checkout consumed all available resources until the launch of Mariner 8 in early May. Failure of the second stage of the launch vehicle caused termination of the mission during powered flight. After the launch of Mariner 9 on Memorial Day, the Network did double duty: near-continuous Mariner 9 cruise phase tracking and data acquisition and final planning and preparation for the single-spacecraft Mars orbital mission. That orbital mission began on November 13, and the daily torrential flow of science data from the spacecraft to the Deep Space Stations, to the command center, the Space Flight Operations Facility (SFOF), and to the experimenters continued into 1972.

The resources of the Space Flight Operations Facility were spread thin among mission support, training during the cruise phase for orbit operations, and continuing development.

Mariner 1971 support involved significant changes in the DSN. New capabilities included

1. An automatic command system with remote control from Mission Control in the SFOF.
2. A coded science data reception and processing capability at all primary Deep Space Stations.
3. Higher-speed data lines (4800 bits per second) connecting all Deep Space Stations with the Network and Mission Control Centers in SFOF.
4. A 50,000-bit-per-second data link between the Goldstone Mars Station and the SFOF to handle the high-rate science data.
5. Two new IBM 360/75 computers and new programming of all the computers in the SFOF.

The DSN will continue in 1972 to acquire data transmitted from Mariner 9, to transmit commands, and to generate radiometric data for spacecraft orbit determinations.

PIONEER EXTENDED MISSIONS

The DSN continued the regular tracking and data acquisition of the Pioneer 6, 7, 8, and 9 spacecraft. Pioneer 6 was supported by the 26-meter-diameter antenna.
stations at Goldstone, Spain, South Africa, and Australia. Pioneers 7, 8, and 9 were tracked by the Goldstone 64-meter-diameter antenna station.

All four Pioneer spacecraft have been in solar orbit for 3 years or longer. Pioneer 6 was launched on December 16, 1965, and is in its seventh orbit around the sun. During the year, it was again within the range of the 26-meter antenna stations and operated most of the time on telemetry rates of 16 and 64 bits per second. When the Pioneer 7 spacecraft was in superior conjunction, Faraday rotation measurements of the S-band link were made during the entrance and exit phases.

**RADIO SCIENCE SUPPORT**

The 64-meter antenna at Goldstone was used for support of a number of radio astronomy experiments at 3.5- and 13-centimeter wavelengths. The unusually low-noise temperature of the antenna, together with a hydrogen maser frequency standard, make it a unique instrument in sensitivity and stability. This capability was used by a number of groups of experimenters to study the structure and other characteristics of quasars. The Massachusetts Institute of Technology, JPL, and others investigated the structure of quasars 3C273 and 3C279 using an interferometer consisting of the 64-meter antenna at Goldstone and the 37-meter Haystack antenna in Massachusetts. The millisecond-of-arc resolution of the interferometer permitted identification of the structure of 3C279; subsequent observations indicated an anomalous expansion rate of the components of the quasar. These observations generated considerable interest and a desire to continue and extend them. A related observation with a view to an explanation of the result was begun by Caltech in the mapping of nearby spiral galaxies.

Very long baseline interferometry (VLBI) observations at 3.5 centimeters of more than 30 sources were conducted by Caltech and the National Radio Astronomy Observatory (NRAO) in Greenbank, West Virginia. In these experiments, the 64-meter antenna was used in conjunction with the 43-meter antenna at the NRAO. In June, simultaneous observations were made with these antennas and the 22-meter paraboloid of the Crimean Astrophysical Observatory. Digital magnetic tape recordings from all three stations were taken to the NRAO for computer processing.

At 13-centimeter wavelengths, various VLBI observations were made by investigators from Caltech, Cornell, and Australia, with various interferometer baselines. A 26-meter antenna at Goldstone and the 43-meter antenna at NRAO were used in one set of observations. These experiments utilized wideband recording systems supplied by NRAO. A trans-Pacific baseline between the 64-meter antenna at Goldstone and the 26-meter antenna at Woomera, Australia, employed standard DSN recording equipment with appropriate computer programs and minor ancillaries.

**64-METER-DIAMETER ANTENNA NETWORK**

Progress on the two overseas 64-meter antenna systems has been commensurate with project schedules issued two years ago. The operational readiness date for both stations remains June 30, 1973.

During 1971, the installation near Canberra, Australia, has progressed from the circular concrete pedestal to the erection of the over 900,000-kilogram steel alidade structure which supports the reflector assembly. The reflector backup structure has been completed to approximately 50% of the total reflector diameter. At the beginning of the year, the Spanish site near Madrid was a mere excavation. The 25.3-meter-diameter, 4.5-million-kilogram concrete pedestal is now complete. The azimuth bearings and drive systems have been installed, and the erection of the heavy alidade steel structure (2529 kilograms per linear meter) has begun.

**FACILITY MODERNIZATION**

The Deep Space Stations, operating in conjunction with the other elements of the DSN, provides real-time command and telemetry capability to and from spacecraft from the mission control center as well as highly accurate doppler (range rate), range, and angular direction for radio navigation. The telecommunications capability implemented and installed at the deep space communication stations during 1970 has provided support to the Mariner Mars 1971 mission.

During 1971, the Deep Space Stations continued expansion of their telemetry capability with the installation of data decoder assemblies. This equipment, operating in conjunction with the subcarrier demodulator and symbol synchronizer assemblies, provides (1) sequential decoding up to 2048 bits per second, (2) uncoded data detection up to 118,000 bits per second, and (3) block decoding up to 2500 bits per second. The data decoder assembly will provide sequential decoding for the convolutional coded telemetry received from the Pioneer F and G spacecraft and block decoding and uncoded data detection for the interplex telemetry planned for Mariner Venus–Mercury 1973.

During 1971, development of the SFOF Mark IIIA Central Processing System, necessary to provide test and flight support for the Mariner 1971 mission, was completed. Additional capabilities were developed to support the Pioneer F mission. These included interfaces with the Mission Support area, installed in the Systems Development Laboratory, and the Remote Information Center at the Ames Research Center.

Two IBM 360, Model 75 digital computers form the nucleus of the SFOF Mark IIIA Central Processing System (CPS) configuration. The software operating system, JPLS, allows the concurrent processing of real-time input data for mission support and the execution of non-real-time background jobs. User programs have been developed to satisfy the requirements of the DSN Telemetry, Command, Tracking, and Monitor and Operations Control Systems Mariner 1971 programs, including the Adaptive Mode Planning System (AMPS) and Library Set (LIBSET), have been developed and are running on the 360/75 computers.

The multi-channel Digital Television (DTV) assembly, accepting data from the 360/75, was installed and is providing a
Australian 64-meter antenna under construction near Canberra will be ready for operation in 1973.
display capability for the DSN and Project users in both the SFOF and Systems Development Laboratory. The high-speed data capability was expanded to enable both 360/75 computers to interface with eight full duplex circuits.

In 1971, the Ground Communications Facility completed all communications capabilities required to support the Mariner Mars 1971 launch and flight operations. Facilities were also completed for the support of the Pioneer F operations in 1972.

The high-speed data system, which connects the SFOF to the Deep Space Stations and to other data interchange points, is the GCF's principal data transmission medium. In 1971, the upgrading of this network from 2400 to 4800 bits per second was completed, and it was placed in operation and used to support Mariner 1971 operations and Pioneer F testing. High-speed circuits interconnecting the SFOF, the Ames Research Center, and the University of Colorado at Boulder were also installed and placed in operation. These circuits form the beginning of a distribution network which will forward SFOF-processed data directly and instantaneously to interested scientific personnel in widely separated locations.

1971 marked the completion and operational use of the wideband system interconnecting the SFOF, the DSN Simulation Center, the Compatibility Test Area, and the Goldstone 64-meter station. The system operates at 50,000 bits per second and is designed to provide the low error rates desired for the transmission of digital video (television) data from the stations to the SFOF. This capability was used to support Mariner 1971.

DSN DEVELOPMENT

Range-Doppler Planetary Radar

The 1971 Mars Radar Topography Experiment was conducted between June 1 and October 12, with a track every third or fourth night using the Goldstone 64-meter Mars Station antenna for transmission and reception. The receiver output was sent by microwave link to the Goldstone Venus Station for range-gated spectrum analysis using a combination of high-speed, special-purpose digital equipment and an XDS-930 general-purpose computer. The special-purpose equipment, including computer-controlled coders, digital demodulators, and a hardware spectrum analyzer, yielded 32 spectra separated by 3 microseconds in range, each spectrum having 64 frequency points separated by 10 hertz. The spectra were recorded on digital magnetic tape for later processing and displayed in real time on a storage oscilloscope to allow operator control of the experiment.

X-Band Weather Project

The objective of the weather project is to determine the effects at X-band of the earth's atmosphere and changing weather conditions on the performance of a typical earth-spacecraft telecommunications link. For this purpose, two classes of measurements are being made at the Goldstone Mars Station: (1) meteorological parameters at ground level and (2) microwave sky temperatures using the 64-meter antenna at S-, X-, and K-bands. These microwave data are collected continuously without interfering with normal tracking operations. Weather effects on antenna gain are also under investigation.

Mariner Venus–Mercury 1973 S/X Capability

Mariner 1973 will have coherent S- and X-band, two-frequency transmit capability. Simultaneous doppler and range measurements of the received signals on the ground will result in accurate, unambiguous, integrated electron content measurements along the signal propagation path. This offers an opportunity for obtaining more accurate Venus and Mercury occultation data as well as continuous monitoring of the interplanetary medium. An extended mission capability will provide additional data on the solar corona during the solar occultation. The experiment is jointly supported by NASA's Offices of Advanced Research and Technology and Tracking and Data Acquisition. The dual-frequency ground receiving scale model of dual-band antenna feed in anechoic chamber.
equipment for Mariner 1973 will have better dynamic stability than that of present systems. New low-noise maser amplifiers for S- and X-band will have internal superconducting magnets to reduce instability contributed by the masers. Prototype superconducting magnets for these new masers are presently being tested in the laboratory.

Low-Noise K-Band Receiving Capability

The 64-meter antenna at Goldstone recently obtained a receiving capability at higher frequencies than were previously available. The new system will provide for antenna performance information, spectral line measurements, and other ground-based radio science experiments in the frequency range of 14.3 to 16.3 gigahertz (2-centimeter wavelength). The high sensitivity and tuning range of this system are due to optimized antenna feed components and a new low-noise maser amplifier — the first built by JPL to use an internal superconducting magnet. Comparative measurements with another antenna-mounted maser have demonstrated a large improvement in dynamic stability resulting from the use of the new magnet.

Radio Star Absolute Flux Calibration

For several years, JPL has had a program of calibrating flux values of selected radio stars at Goldstone to allow the DSN stations to measure antenna efficiency. This year, an advanced phase became operational. The new scheme employed a horn antenna as a primary gain standard. This type of antenna is presently being given an absolute gain calibration in cooperation with the National Bureau of Standards. Using the moon-based Apollo Lunar Surface Experiments Package (ALSEP) as a far-field beacon, the horn calibration is transferred to the 26-meter antenna at the Goldstone Venus Station. This allows the absolute flux density of the calibration radio stars to be determined. The absolute flux calibration was improved by virtue of advanced standard horn measurement techniques. The DSN will benefit from improved accuracy tolerance as a result of the new calibration scheme.
PHYSICAL SCIENCES

During 1971, research continued in the physical sciences, broadening our understanding of physical phenomena and providing a basis for future developments in various phases of space technology.

Gas-Phase Ion–Molecule Reactions

Ion-cyclotron resonance techniques are used to study gas-phase ion–molecule reactions important to an understanding of the radiation chemistry of gases in planetary atmospheres, in comets, and in interstellar space. Significant findings made during the year bear on the ionization phenomena in the early solar nebula and the present Jovian atmosphere. For example, it has been found that the \( \text{H}_3^+ \) ion plays an important role in certain key gas-phase chemical reactions.

Copper Vapor Laser

A repetitively pulsed, supersonic, copper vapor laser was designed and put into operation. It is excited by passing a current pulse through a supersonic jet composed of a mixture of copper vapor and helium. A plasma arc heater is used to supply the energy to vaporize the copper and impart kinetic energy to the helium carrier gas. A key element in the laser system is a device used for injecting copper particles into the arc-heated helium flow. With further development, this laser could provide high-power laser energy in the visible spectrum comparable to power outputs currently attained with gas dynamics and chemical lasers operating in the infrared.

Elastomer Longevity

Methods were developed to predict time to failure of elastomers over protracted time periods. A new discovery made is that the crosslink density of an elastomer diminishes in a manner measurably analogous to the time–temperature equivalence. Tests are carried out on a conventional tensile tester, where elastomer specimens are pulled at a constant rate of deformation until they fail. Typically, these tests last from several seconds to 2 hours. By using a range of test temperatures and specimens of different degrees of vulcanization along...
with the time-reduction principle, a failure curve is predicted.

Experimental points from both static and dynamic tests representing a range in real time from 1 minute to about 6 months fall along the predicted curve. Thus, the predictive test method has been verified over this time range. The verification experiments are continuing.

Superconductivity at High Temperatures

The high-temperature limit of present superconductors is 21 °K. The mechanism of these superconductors is based on the interaction of an ionic lattice with electrons. Purified ore and crystals cleaved from natural molybdenite were intercalated with sodium, potassium, and rubidium. An onset of superconductivity in the range of 4 to 6.5 °K was observed in all intercalated samples.

Superconducting Electromagnetic Detectors

Experiments have been initiated to investigate the feasibility of using thin-film superconducting structures as detectors of infrared radiation. Theoretical studies indicate that infrared detection based on quantum-mechanical effects in these superconductors would be several times as sensitive as any present method.

Such detectors would improve astronomical observations — either at earth-based observatories or in spacecraft instrumentation. Prototypes are being developed and studied in cooperation with Caltech's Low Temperature Physics Laboratory.

Supersonic Jet Noise Investigations

An anechoic chamber facility is now being used to evaluate noise-generating mechanisms in aircraft propulsion systems.

Jet exhausts of supersonic jets, at gas temperatures comparable to those encountered in aircraft jet engines, are probed with crossed laser beams. Fluctuating density is evaluated by analyzing the signals recorded from laser beams transmitted through and perturbed by the jet. The intensity and distribution of the noise sources are determined from signals recorded by an array of microphones placed outside the jet.

ELECTRONIC COMPONENTS AND TECHNIQUES

Virtually every aspect of spacecraft technology depends on or is influenced by electronic components and packaging techniques. Research and development in this area provide support for much of the forward thrust of space technology in electronics.
Electronic Packaging

A new electronic packaging system for the Thermoelectric Outer Planet Spacecraft (TOPS) Project features a separable electronic compartment with single-side access plug-in assemblies. Microminiature connectors with 0.127-centimeter contact spacing, and small-gage wires (26–30 AWG) with thin insulation cut down weight and volume. The principal features of the development are the use of a composite module package and discrete multilayer interconnection techniques.

Integrated Circuit Components

A low-power, large-scale integrated circuit was developed for implementing digital functions of spacecraft data systems. The circuit employs 116 logic gates on a silicon chip measuring $0.39 \times 0.43$ centimeters. These gates can be interconnected for varying user needs during the fabrication process to arrive at an integrated circuit providing nearly any logic function desired. The device — called a custom-metallized multigate array — reduces the weight and volume of the data system as well as increasing its reliability.

TELECOMMUNICATIONS

Telecommunications advanced development is progressing steadily on high-data-rate communications with future spacecraft at the extremes of our solar system.

Spacecraft Transponders

A breadboard model of a multimission spacecraft transponder receiver in which more than 80% of the active elements are monolithic integrated circuits was developed for evaluation. Significant characteristics of this receiver include a 5-hertz threshold carrier tracking loop bandwidth, a power drain of only 1.5 watts, and a reduction in volume to half that of the present receiver.

Telemetry Modulation

Interplex, a method of modulating several kinds of data onto a single radio link which minimizes distortion and still permits independent control of the several data channels, was adopted by Venus–Mercury 1973 to increase the overall data rate at Mercury encounter by 60%. Interplex allows the use of two separate channels with independent error rate control and no interchannel interference. Spacecraft modifications involve only the relocation of one small component called the phase multiplier. Changes to the ground radio are also minor.

Furlable Superhigh-Frequency Antenna

A 1.8-meter, furlable, conical Gregorian antenna was demonstrated at K-band. In addition, a new concept (the conical Quadreflex antenna) using a conical main reflector and two stacked subreflectors was devised and a 0.75-meter model built and successfully tested. These antenna designs will permit NASA earth satellites, both manned and unmanned, and planetary spacecraft to communicate at higher data rates by permitting higher-frequency operation. The antenna was demonstrated on the Mesa range at JPL.

Right: Superhigh-frequency Gregorian antenna being tested on JPL Mesa range.

Monolithic integrated circuit for multimission spacecraft transponder.
SPACELAB DEVELOPMENT

Successful scientific experiments in space depend largely on unimpaired functioning of spacecraft hardware throughout all phases of a mission. The improved design of spacecraft, in turn, involves continued development of better individual components and materials, plus rigorous testing of spacecraft and components under simulated flight conditions.

Thermoelectric Outer Planets Spacecraft Project

The TOPS Project, established in 1968 for the purpose of developing and demonstrating the technology required for the development of unmanned spacecraft, was completed on December 1, 1971. All activities related to these missions have now become the responsibility of the Outer Planets Project Office.

The following are some of the major accomplishments of the TOPS Project:

1. A spacecraft system design was completed which could result in a significant scientific mission.
2. A single-axis attitude control test was performed to demonstrate the feasibility of a system involving digital celestial sensors, digital control, hot-gas thrusters, and momentum wheels.
3. A 4.25-meter-diameter, lightweight, deployable, parabola-shaped reflector surface was fabricated to serve as the TOPS high-gain antenna.
4. A Jupiter radiation belt model was developed.
5. Selected parts intended for the outer planet spacecraft were tested in radiation environments expected on the mission.
6. A large integrated-circuit component which will be the building block for the computer and many other TOPS subsystems was developed through the prototype stage.
7. A flexible data-processing subsystem was breadboarded.
8. An improved-performance and highly reliable S-band receiver, S-band solid-state exciter, X-band solid-state exciter, and S-band solid-state power amplifier were breadboarded and evaluated.
9. The command demodulator was breadboarded.
10. The complete power subsystem was breadboarded and evaluated.
11. A high-density subsystem and system packaging compartment was fabricated, demonstrating the feasibility of this lighter-weight approach.
12. A comprehensive 6-day technical briefing was given to industry in September 1971 on TOPS technology and remaining problem areas.

TOPS Spacecraft Data Storage

The formulation of a new spacecraft data storage tape recorder concept may minimize TOPS tape recorder problems. It con-
sists of a simple tape transport mechanism completely immersed in a chemically inert fluid to avoid direct contact of moving parts. Hydrostatic bearings and tape suspension provide for wear-free operation. The mechanical system is simplified by buffering the data input and output of the tape recorder. Design features are under mathematical and experimental study.

TOPS Approach Guidance

A demonstration of approach guidance, a required part of an outer planet navigation system, was successfully made during the Mariner Mars 1971 approach to the planet. Images of Mars' two moons against a star background were transmitted to earth from the spacecraft television cameras for ground-based computer processing to obtain navigation information. This demonstration provided a firm technology base for outer planet mission navigation system design.

Self-Testing and Repairing (STAR) Computer

A computer capable of automatic detection of its own failures and of self-repair by switching of redundant elements is undergoing continuing development. Capability to recover from transient faults was achieved. STAR is currently being used as a research tool to examine the validity of the concepts on which it is based as well as to determine techniques for improvement. The hard core of the machine is the test and repair processor, which must never perform an incorrect action. Alternative configurations for this processor have been developed with a view toward simplification.

TOPS Sun Sensor

A digital sun sensor is being developed to control and stabilize the spacecraft in outer planet missions. During the mission, the spacecraft (including antenna) is continuously pointed toward earth by using signals from the sensor. The sensor's accuracy must be maintained over the entire field of view of approximately 6 x 38 degrees. The sensor expresses the sun error angle in a digital computer output word.

A single-axis (pitch axis) breadboard sensor having 0.025-degree resolution over a 6-degree field of view was fabricated and tested. The tests verified design concepts and demonstrated that the sensor is capable of functioning regardless of sun distance.

TOPS Spacecraft Command

A sampled-data, second-order, digital tracking loop was developed for the command detector to be used on Viking Orbiter and outer planet spacecraft. This technology offers increased reliability, stability, and predictability of performance over conventional analog tracking loops. Digital implementation should mean lower flight project costs because a smaller design margin is needed to cover performance uncertainties and, as a result, lengthy experimental tests are not required. The digital loop reduces signal acquisition time by a factor of five. For example, a command sent to Mariner 9 is delayed up to 8 minutes before execution; the digital detector will require only 1.6 minutes under the same conditions.

TOPS Spacecraft Transmitters

A solid-state, 20-watt, S-band power amplifier was developed to replace traveling-wave-tube amplifiers in spacecraft for missions requiring 10-year lifetimes. Semi-lumped circuitry is employed in the amplifiers. The outputs of four amplifiers are combined in a hybrid combiner built on an aluminum oxide substrate using microstrip technology.

TOPS Power System

The goal is to integrate a nuclear power system into an outer planet spacecraft. The specific problems of power system development include the design and development of a lightweight, high-performance, ultra-reliable, fault-tolerant set of power processing equipment arranged in the proper configuration to meet the stringent requirements imposed. Another major area of effort concerns the design and evaluation of the power source.

Fabrication of all of the major power processing elements was completed, and the elements have been assembled into a system configuration now in test. Design and evaluation studies were completed with the selection of multi-hundred-watt radioisotope thermoelectric generators (RTG's) as the power source for TOPS. An investigation was made of RTG mockups to simulate the mechanical, thermal, magnetic, electrical, and nuclear radiation properties of fueled RTG's. Use of such simulated RTG's would minimize exposure of operational personnel to radiation during spacecraft testing. Handling and operations studies resulted in a decision to request the AEC to select a prefueled RTG design concept for outer planet missions. In such a design, the fuel capsule remains integral with the generator at all times after completion of flight qualification testing, thereby enhancing reliability.

Mission Design Graphics

Computer-animated films were developed to illustrate the geometry of a planetary encounter and to simulate the appearance of the target planet and its satellites as seen from the spacecraft. The films cover the Mariner Venus-Mercury 1973 mission, the Outer Planets Project, and a 1978 comet Encke rendezvous flight.

Outer Planet Satellite Flybys

It has been determined that it is possible for an outer planet spacecraft to pass close to several of the many satellites of the outer planets. Larger outer planet satellites, comparable in size to the moon and Mercury, may have fundamental significance in the formation of the solar system. A number of opportunities were found for encounters with several satellites while the spacecraft is on a Jupiter-Saturn-Pluto or Jupiter-Uranus-Neptune trajectory. Close-up studies of both the planets and their satellites could double the number of bodies investigated by a single spacecraft.

Deployable Antenna

Telecommunications requirements for outer planet missions may dictate antenna sizes not compatible with existing or contemplated launch vehicle nose fairings. Hence a deployable antenna, measuring 4.25 meters at full extension but only 1.5 meters folded, has been designed and an experimental prototype fabricated. This concept employs tapered tubular-aluminum ribs supporting a reflective surface of gold-plated chromel-R mesh. Testing is underway to ensure accuracy and folding repeatability of the paraboloid profile. Future work will involve deployment and folding techniques and radiofrequency testing.

Jupiter Entry Research

Research advanced for predicting the entry heating and dynamic environment that a probe would encounter during a Jupiter atmospheric mission. By using an electric-arc-discharge shock tube capable of shock-heating gases to speeds of 45 kilometers per second, temperature and electron density measurements were made in hydrogen.
to temperatures over $12,000^\circ$K. These experimental results, in conjunction with a computer program for the ion and electron density and temperature behind strong shock waves in helium-hydrogen gas mixtures, indicate that the nonequilibrium flow in expected Jovian atmosphere gas mixtures is significant in determining the thickness required for the heat shield of an entry probe.

Fairly accurate calculations have been made for the weight of a heat shield necessary to ensure the survival of conically shaped probes entering the Jovian atmosphere. The predicted heat shield weight is about one-fourth of the total weight of a typical probe entering the atmosphere in a near-grazing trajectory. The entry mission at Jupiter appears feasible from the heat-protection point of view.

**CHEMICAL PROPULSION**

The basic aim of chemical propulsion research is to improve liquid and solid propulsion subsystems. Other studies seek to refine propulsion equipment and adapt it to improved propellants. These efforts, in turn, require a steadily increasing understanding of physical and chemical phenomena associated with rocket propulsion.

**Bimodal Rocket Engine**

Spacecraft on missions to the planets, to their satellites, and to the asteroids require versatile on-board propulsion systems. Low thrust is desired for trajectory corrections; high thrust and high specific impulse are needed for orbital entry and the initial phases of landing. Finally, low-thrust, throttleable operation is required for the landing phase. JPL is testing a novel rocket engine, which can meet all of these requirements, thus greatly simplifying spacecraft design and improving on-board propellant utilization.

The key element of this new concept is the bimodal rocket engine, currently undergoing feasibility testing. In the monopropellant mode of operation, hydrazine fuel is decomposed in a catalytic reactor, yielding a thrust of about 163 kilograms. The engine is readily throttleable in this mode. In the bipropellant mode, nitrogen tetroxide oxidizer is injected into the effluent reactor gases, producing secondary combustion and a thrust of 453 kilograms at high specific impulse.

Tests to date have demonstrated close to theoretically attainable performance and low heat transfer to the rocket chamber walls in both modes. These results promise success for the ensuing development of a flight-type engine.

**Irradiation Tests**

An investigation was begun of radiation exposure effects on solid propellants and pyrotechnic materials. Neutron, gamma-ray, proton, and high-energy electron radiation exposures stemming from interplanetary radiation fields as well as the active radioisotope thermoelectric generators on board the spacecraft will be encountered during long-duration missions to the outer planets.

Various materials were irradiated to a predicted Outer Planets Project radiation profile and put through high-temperature tests. Radiation-conditioned materials were compared to control specimens for determination of physical chemical and performance changes. The results showed potential degradation in performance after a 10- to 12-year exposure to radiation, indicating that engineering precautions should be taken to protect pyrotechnic devices and propellants used on spacecraft for long-duration missions.

**Solid Propellant Research**

A new concept is being studied for distributing the metal fuel additives uniformly throughout the solid propellant by incorporating the additives into the oxidizer particles. This scheme would reduce local concentrations of the metal which cause agglomeration, or coalescence, during burning. It is believed that the reduced agglomeration will, in turn, reduce two-phase flow losses and therefore improve delivered specific impulse.

The metal is added to the oxidizer by crystallizing it from a chemically saturated oxidizer solution containing suspended metal particles. Small propellant batches have been made at JPL, burned at various pressures, and observed by high-speed photography. When compared with propellants in which the metal was added separately, the occluded metallized propellants showed little or no metal agglomeration. Motor firings are planned to determine whether the expected increase in specific impulse is realized.

**Polymer Analysis**

Significant progress has been made toward the development of a theory-based method for determining the functionality distribution of prepolymer structures. Significant progress has been made toward the development of a theory-based method for determining the functionality distribution of prepolymer to be used for synthesizing elastomers, such as solid propellant binders. The ideal prepolymer is

**Remote-controlled manipulator for handling solid propellants.**
bifunctional, it has two reactive groups. Most commercial prepolymeres are zero-, mono-, bi-, trifunctional, or higher mixtures. Knowledge of the distribution is important to the formulator because of the effect this characteristic has on the cross-linked structure of the product, and thus on its mechanical properties.

The theory on which the proposed analysis scheme is founded is based on cross-linking probabilities. Polymerization studies conducted with model compounds in a specially designed reactor-measuring system yielded excellent agreement with theory. The next step in the development was to subject simple prepolymeres to the method in place of one of the model compounds. This was done with two such materials, with results that were in agreement with values obtained by previously used qualitative methods.

SPACE POWER AND ELECTRIC PROPULSION

Electric propulsion offers a unique capability to perform difficult high-energy missions of increasing scientific interest. The technology of solar-electric propelled spacecraft is being studied for these applications. Development of spacecraft power continues, so that future requirements, especially long lifetime, can be satisfied.

Solar-Electric Spacecraft

This effort embraces mission analysis, navigation studies, spacecraft design studies, and development of both the thrust system and the associated power system. The high-energy missions which are particularly suitable for such spacecraft include rendezvous with and orbits of small bodies such as comets and asteroids, and several classes of orbits of the outer planets. In-depth studies with the comet Encke and the small asteroid Eros were accomplished. Planetary studies were conducted on orbiters of Mercury and Jupiter. The Jupiter studies demonstrated the flexibility in orbit selection and launch period available through solar-electric propulsion. Related studies for these missions covered navigational aspects, mission operations, flight software, and exploration strategies based on scientific objectives.

Spacecraft design visualizes a modular solar-electric propulsion system attached to an existing Mariner-type spacecraft.

The first demonstration model of a fully automatic electric propulsion system for interplanetary spacecraft was tested. Elements of the test system include the thruster array, which is movable to provide spacecraft attitude control; the power-conditioning equipment, and a computer which simulates a spacecraft control computer and sequencer. The power conditioning equipment represents a significant improvement in the state-of-the-art of spacecraft power processing equipment, with a specific mass (kilograms per kilowatt of power processed) only one-fourth that of previous units. The computer is programmed to provide fully automatic startup and shutdown, power utilization control, and, in conjunction with the switching matrix, system failure detection and correction.

Solar Arrays

Solar cells, which convert sunlight to electricity, are susceptible to damage by both the proton and electron radiation encountered in space. Several years of investigation show that damage can be reduced by enhancing the radiation-resistant properties of cells, for example, by diffusing lithium into the cells. Lithium solar cells were fabricated in the laboratory with good control, and test data indicate that, at temperatures above 30°C, they are over three times more radiation-resistant to electrons and ten times more resistant to protons than conventional cells. Still to be resolved is the production of flight-quality cells at reasonable cost in the quantities required for commitment to flight hardware.

Batteries

There is no battery system at the present time which is capable of reliably supporting 8- to 12-year missions. Although the nickel-cadmium battery has come closer to meeting the requirements than any other battery, this system must be improved in two areas: control of gassing and the prevention of leaks.

Development of both a nongassing nickel-cadmium battery and a new compression-type, injection-molded seal for the electrical terminals was initiated. Electrodes for the nongassing battery and the leak-proof seals have been designed and delivered. These accomplishments are significant for spacecraft batteries, and for the many other uses of sealed nickel-cadmium cells where high reliability and long life are required.

Silicon-Germanium Technology

The nuclear power supply (RTG) for outer planet mission applications uses thermoelectric elements made of a silicon-germanium (SiGe) alloy. The system must operate reliably for 10-year periods. Extensive experiments to determine the long-term behavior of this material in an RTG environment are under way. The sublimation and reaction/gasification rates of the SiGe/insulation system are being measured. The tests of the RTG configuration show that silicon and germanium vapor species attack the silica fiber insulation, causing it to gasify and corrode. The foils which are part of the insulation show substantial deposits that will affect the thermal conductance.
The Science Office coordinates all science activities at the Laboratory. These include the science experiments conducted on JPL-managed flight projects, radio science support of the Deep Space Network, JPL flight science participation in non-JPL projects, and research in the physical, biological, and space sciences pursued in the Laboratory's continuing research and development program. The Office also coordinates activities with the university community.

INFRARED ASTRONOMY

The infrared astronomy program uses principally a Connes-type Fourier spectrometer at the McDonald Observatory 273-centimeter telescope. Part of the program is a joint undertaking between JPL and the University of Texas.

Observations of Venus in the 3–4 micron region during the winter 1970-1971 have confirmed the existence of a strong phase effect. The detailed analysis of these data is still in process, but two broadband absorptions have been tentatively identified as being due to bound HCO\textsubscript{3} in the cloud material.

Observations of Jupiter in the 3–6 micron interval have established the presence of CH\textsubscript{3}D in the atmosphere — the first time deuterium has been observed in any astronomical object. The calculation of the H:D ratio is not complete.

New observations of Mars have been obtained covering the 3–6 micron (1700–3400 cm\textsuperscript{-1}) region at a resolution of better than 0.1 cm\textsuperscript{-1}.

Analysis of the spectrum of the M supergiant star Alpha Orionis was completed. The analysis of the OH bands near 3.5 microns has led to the conclusion that the CNO bi-cycle of nucleosynthesis in this star has essentially been driven to completion.

Spectra have recently been obtained of the archetypal Mira variable Omicron Ceti. Analysis of these data will be undertaken when more of the cycle of variability has been covered.

OPTICAL ASTRONOMY

High-dispersion spectroscopic observations of Venus were continued both at Table Mountain and McDonald Observatories. Comprehensive observations of the CO\textsubscript{2} bands from 7158 angstroms to 1.2 microns as a function of phase angle were extended to the critical phase angles near 180 and 0 degrees. These observations were fundamental in the recent work which has provided an explanation of the observed phase curves and their behavior as a function of line strength. There is strong evidence that the visible clouds of Venus consist of at least two layers: a dense cloud whose top is in the troposphere at a pressure of \(\sim 0.2\) atmosphere, with a diffuse haze extending from this level to a pressure of \(\sim 5\) millibars in the stratosphere.

Opposite: Photograph taken on the moon of Apollo 15 astronaut deploying second JPL-built solar wind spectrometer on the lunar surface.

Left: Solar telescope being used for infrared astronomy experiment is adjusted at McDonald Observatory.
FIELDS AND PARTICLES

The solar wind magnetic field was studied using Mariner 5 magnetometer and plasma data. The propagation of sector boundaries — current layers separating regions of opposite magnetic polarity — has been shown to be strongly affected by the interaction of adjacent solar wind streams. The sector boundaries frequently appear to be surfaces across which shearing motions occur in the solar wind. Another aspect of solar wind dynamics studied is the nature of discontinuities or abrupt changes in the field directions within tens of seconds. The observed discontinuities have been successfully classified into two basic types: rotational, in which there is a propagating “kink” in the magnetic field lines, and tangential, where typically the magnetic field changes in magnitude as well as direction. Both types of discontinuities have been predicted by hydromagnetic theory.

Electron-molecule and electron-atom collision processes were studied with the aid of two unique electron-scattering spectrometers. Data relating the energy levels of target molecules and negative ion molecules or the probabilities of different possible processes are obtained in the form of electron energy-loss spectra. These data are required for understanding and prediction of the behavior of systems where free electrons are present. Such systems include earth and planetary atmospheres, plasma, lasers, and materials exposed to β-radiation. The performance of magnetohydrodynamic generators and nuclear and magnetogasdynamic lasers depends critically on the nature of the nonequilibrium properties of their working fluids such as excitation, recombination, and ionization rate processes. Only a very limited number of measurements have been made on the rates of these important processes, and the recent measurements indicate that the cross sections estimated and used for previous model calculations were in error by a factor of 50 in some cases, leading to incorrect conclusions. Measurements are being made utilizing the most advanced techniques, and a number of important cross sections have been determined for the first time.

The high data-acquisition rate of the Orbiting Geophysical Observatory 5 (OGO-5) field and plasma instruments has made it possible to analyze the internal structure and dissipation mechanisms of large-amplitude solar wind discontinuities. An event was observed in the OGO-5 data which, at the lower data rates typical of previous spacecraft instruments, would have been interpreted as a single tangential discontinuity but which the OGO-5 data rate shows to be two sharp, closely spaced dis-

Spectroscopic observations of Venus are made with the Table Mountain Observatory's Coudé spectrograph.
continuities. Emanating from these discontinuities are small-amplitude fluctuations that are presumably fast-mode magnetohydromagnetic waves, whose rapid decay is consistent with theoretical expectations. Explanation of the considerable magnetic turbulence associated with the second discontinuity and extending toward the first has led to generalization of the usual theory of magnetic drift wave instabilities. An intriguing possibility is that the two discontinuities together represent the first observation in the solar wind of the so-called Petschek mechanism, in which rapid merging of magnetic field lines occurs between two standing waves.

MARS RADAR TOPOGRAPHY

Radar examination of several planets was conducted with the help of Goldstone transmitting facilities and advanced DSN Development signal-processing devices. In particular, a narrow belt on the surface of Mars centered at 16°S latitude was examined in the summer and early fall of 1971, with special processing developed to investigate topographic variations. Such information is needed to help interpret and enhance Mariner 1971 photos of Mars, and, in addition, is crucial to choosing a landing site for Viking 1975. The data show a rugged terrain for Mars, with altitude excursions of more than 13 kilometers. The measurements are repeatable to 40 meters, with 100-kilometer resolution on the surface of the planet. Individual craters are clearly resolved and their depths unambiguously measured. Altitude scans superimposed on Mariner 7 Mars pictures show excellent correlation with visible craters.

PLANETARY ATMOSPHERES

Atmospheric Pollutants

Previously developed JPL laser receiver technology is being applied to the detection and estimation of atmospheric pollutants. Calculations were made that showed that atmospheric pollutant-sensing systems using infrared heterodyne radiometry are sensitive and selective in identifying molecular constituents. These systems are based on overlaps between an infrared laser line and a pollutant absorption line. Because of the very narrow spectral bandwidths of the laser and the heterodyne receiver, high resolution is obtained, leading to advantages in selectivity over standard radiometers and spectrometers. Laboratory work thus far has demonstrated the effectiveness of a carbon dioxide laser heterodyne radiometer in sensing warm carbon dioxide in a gas cell. Sensitivity measurements are close to the theoretical predictions for this case. Present efforts will lead to the use of other laser lines to detect several atmospheric pollutants with spectral lines within the tuning band of the carbon dioxide laser.

Rare Gas Abundances

A physical-chemical explanation was found for (1) the low abundance of Xe in earth-atmospheric nonradiogenic rare gas, as opposed to its higher abundance in primordial rare gas found in meteorites, and (2) the anomalously high relative concentrations of Xe recently reported in shales.

Differences between the relative abundances of primordial rare gases in (1) the sun, (2) meteorites, and (3) the earth's atmosphere have long served as one of the most important sources of information concerning the history of earth-forming material and the origin of the earth's atmosphere. It is normally assumed that, once degassed to the earth's atmosphere, rare gases are conserved therein, and that the total amount of each rare gas degassed from the solid material that formed the earth is the same as the amount presently observable in the atmosphere. A well known exception is He, which is light enough to escape efficiently from the earth's gravitational field to space.

It is also assumed that the other rare gases, including primordial Ne, Ar$^{36}$, Kr, and Xe, are conserved since rare gases do not interact to form chemical compounds with earth surface material. Experimental studies recently completed indicate that this assumption is not entirely correct.

Surface area measurements and Freundlich adsorption plots for Kr and Xe adsorption at 25 and 0°C were obtained for shale samples. The results, together with geological considerations, indicate that Xe — but not Ne, Ar, or Kr — has been significantly depleted from the earth's atmosphere by physical adsorption on terrigenous sediments. If the removed Xe is hypothetically restored to the atmospheric inventory, an almost perfect match to the elemental composition (Ne: non-radiogenic Ar:Kr:Xe) of the primordial rare gas component as it occurs in normal chondritic meteorites is obtained.

JUPITER RADIATION STUDIES

A noise-adding radiometer, developed to calibrate the sensitive receiving facilities of the DSN for spacecraft tracking applications, was used in 1971 in Jupiter passive radio experiments. Jupiter is presently being observed with this system on the DSN Venus site 26-meter antenna at S-band. The antenna temperature due to Jupiter, although only 0.3°K, varies in a systematic manner, with an amplitude variation of less than 10%.

A new theory of Jovian decametric radio emissions has been proposed based on a novel emission mechanism. External agents such as Io and the solar wind generate hydromagnetic disturbances which propagate, with little damping, along the lines of the Jovian magnetosphere and produce a local plasma instability that leads to induced emission of decametric radiation. In the proposed theory,

1. The typical source size of decametric emissions is explained in terms of the size of the agent generating hydromagnetic disturbances.

Atmospheric pollutant-sensing system based on laser receiver technology developed for space applications.
2. The observed frequency drifts of decametric emissions can be understood in terms of the motion of hydromagnetic disturbances along the magnetic field lines.

3. The structure of observed emission bands can be qualitatively explained as being due to an on-off switching effect of plasma instability as the local magnetic field gradient changes in sign.

4. The observed variation of the intensity of emitted radiation as a function of frequency can be qualitatively understood on the basis of a loss-cone distribution of the electrons of the emitting plasma.

Other analyses of S-band radio observations of Jupiter, taken at the Goldstone Venus station in 1971, revealed that Jupiter’s flux density has decreased approximately 20% since 1964. Data from earlier epochs provide strong evidence that Jupiter’s decimetric flux and, hence, its relativistic radiation belts are modulated by solar activity.

**VLBI EARTH PHYSICS**

Studies of the use of the Deep Space Instrumentation Facility antennas in an interferometric mode for applications to earth physics are in progress. Initial experiments performed over short distances have demonstrated the potential for measuring intercontinental baselines with an accuracy of 30 centimeters or better by observing extragalactic radio sources. A series of very long baseline interferometry (VLBI) experiments were conducted between stations at Goldstone, California, and Madrid, Spain, using high-precision frequency systems developed by JPL and the Smithsonian Astrophysical Observatory. These experiments are designed to measure irregularities in the earth’s rotation rate (variations in Universal Time). Preliminary computer data reduction indicates a measurement precision of approximately 0.005 second. In addition, the separation of the stations at California and Spain will be determined within 2 meters.

**LUNAR STUDIES**

A model, developed using Orbiter photography, Apollo 12 multispectral photography, earth-based spectrophotometry, and thermal IR and radar data, suggests that the high-albedo central region of the Descartes Formation was formed by Copernican-age volcanism. The bright surface is either littered with abundant centimeter-sized rocks or has formed from an insulating debris layer overlying a surface with an abundance of rocks in the 1-20 centimeter size range. Based on these data, the bright unit is thought to be a young pyroclastic deposit mantling older volcanic units of the Descartes Formation. The Apollo 16 target point is only 50 kilometers northwest of the central part of this unit, so material associated with this unique highland formation may be found in the returned soil and rock samples.

In previous magnetic resonance studies of the returned lunar samples from Apollo 11 and 12, it was demonstrated that the broad, asymmetric electron spin resonance (ESR) signals centered at Q = 2.09 are ferromagnetic resonances caused by metallic iron particles whose average shape is spherical and whose average diameter is 1 micron. Metallic iron contents ranging from 0.001 to 0.50 weight percent were determined for a selection of lunar samples. A correlation between metallic iron phase concentrations and lunar sample ages was more firmly established in these measurements. This correlation has potential application in dating lunar samples. It now appears that the ESR method of metallic iron determination is superior in sensitivity and accuracy to other methods.

Electron spin resonance signals characteristic of radiation damage in a lunar rock (12021-42) have been observed for the first time. Irradiation and thermal annealing experiments were carried out with portions of this sample. These experiments have made possible an estimate that the radiation accumulated in this lunar sample is about 5 x 10^4 Rankines. It takes about 5 x 10^4 years to reach this dosage without thermal draining. Thus, the natural radiation dose that accumulated in this sample is below the saturation level. The ESR results also show that more than one electron trapping site exists. Work is in progress to ascertain whether the extent of lunar radiation damage, provided it can be detected by ESR, might not be used to estimate lunar surface exposure ages.

**BIOSCIENCE**

Lyophilized microbial cultures, including specimens of algae, bacteria, fungi, and yeast, were subjected to analysis by pyrolysis–gas chromatography–mass spectrometry. Some detailed comparisons of the various pyrolysates suggest that it is possible to establish, by this technique, the extent of differentiation among several classes of organisms of interest. Results so far indicate that, with respect to the individual specimens analyzed, unique sets of major pyrolys products may exist for each of the four groups of organisms studied, a possibility which could be of great use in the identification of microorganisms, both on earth and in space.

An Antarctic field trip was made during austral summer 1970-1971 to the farthest south area of exposed rock and soil at Mt. Howe, 225 kilometers from the South Pole (elevation 2800 meters, 87°21'S, 149°18'W). Environmental measurements were made for approximately 1 week, air samples were collected, and eleven soil samples were taken from a 64-kilometer area of moraine and bluffs. Analyses of the soils showed that some samples did not contain any viable populations of microorganisms, whereas others contained approximately ten bacteria or yeasts per gram of soil. Mt. Howe is the farthest south soil microorganisms have been found. The soil in which they were found was developed in the La Gorce Mountains (86°45'S, 146°00'W), algae were found in a frozen pond. Further analyses are being made to substantiate the toxicity, inhibitory, and sterility factors of Antarctic soils.

In the interpretation of several of the Viking experiments, it is important to consider sources of ambiguity and interference with data that will be scrutinized in an effort.
to unravel the chemistry and/or biochemistry of the Martian surface. Work has been carried out which for the first time demonstrates the abiogenic synthesis of organic compounds under simulated Martian atmospheric and ultraviolet irradiation conditions. These results are of great planetary and biological significance. When mixtures of $^{13}$CO and water vapor diluted with $^{12}$CO or N$_2$ were irradiated with ultraviolet in the presence of soil substratum, $^{13}$CO was found to be converted to $^{13}$C-organic products, recoverable from the substratum. Thus far, the organic molecules formaldehyde, acetaldehyde, and glycolic acid have been tentatively identified using very sensitive radio-chemical labeling techniques. It has been proposed that this organic synthesis results from adsorption of carbon monoxide and water on a surface, with excitation of one or both molecules occurring at wavelengths longer than those absorbed by the free gases. This process may occur on Mars and may have been important on the primitive earth.

Work is in progress on the detection of porphyrin molecules in a billion-year-old Nonsuch shale, processed by some recently developed procedures that yield an organic solvent extract. This extract was fractionated by silicic acid column chromatography and characterized by means of spectrophotofluorometry and high-resolution mass spectrometry. Reasonably firm identifications have been made of three fundamental types of porphyrin: alkyl porphyrins, cycloalkanoporphyrins (of the deoxophyloerythroporphyrin type, which possess the isocyclic ring of chlorophyll), and porphyrin macrocycles having increased aromaticity. Although identification of porphyrins in this rock unit has been claimed previously, the work accomplished at JPL represents the
first successful separation of the porphyrin component into classes and the identification of several specific molecular species. The presence of three fundamental types of porphyrin in the same rock body is suggestive of a precursor–product relationship, whose clear understanding is geochronologically very significant.

In other work, a number of carotenoid pigments of the algae crusts of a hot desert soil were isolated by extraction and characterized by means of chromatography and high-resolution mass spectrometry. This work is the result of a unique collaborative effort in soil microbial ecology and several chemical disciplines.

A technique developed at JPL for fractionating complex mixtures of biologically important compounds from geochemical samples at the microgram and submicrogram levels by direct introduction into the ion source of a high-resolution mass spectrometer has led to the discovery of some potentially important "bio-indicators" in the extracts from these and other geological samples. A variety of alteration products of β-carotene in the hot desert soil were identified unequivocally, although they were only present at the nanogram level (10⁻⁹ grams). Positive identification by any other analytical technique is impossible. The carotenoids, as phytochemical indicators, showed that these desert surface organisms were principally nitrogen-starved cyanophytes.

FLIGHT SCIENCE EXPERIMENTS

Flight Science Tasks during 1971 covered seventeen scientific investigations designed to be performed from non-JPL spacecraft. While some of these tasks involve only the use of tracking data from the spacecraft to derive scientific information, others include the development of hardware to be flown on the spacecraft.

Hardware design began this year on a 204-kilogram gamma-ray spectrometer, to be flown on HEAO-B, the largest and heaviest scientific instrument that JPL has ever developed. Hardware for a scanning microwave spectrometer to be carried on Nimbus F was also in the design phase.

Experiments flown in 1971 and instruments that have been delivered for flight in the near future are described below.

Apollo Gamma-Ray Spectrometer

A gamma-ray spectrometer was flown successfully on Apollo 15, acquiring data from lunar orbit on the surface composition of a large portion of the moon. Significant variations in the concentration of naturally radioactive elements were observed that correlate with mare and highland areas. Measurements taken in the lunar space provided new information on the diffuse cosmic gamma-ray flux from 4 to 25 million electron volts. The same instrument will be carried on Apollo 16, scheduled for launch early in 1972.

Apollo ALSEP Solar Wind Spectrometer

The solar wind spectrometer of the Apollo 12 Lunar Surface Experiments Package (ALSEP) has completed its second year of continuous operation on the lunar surface, and has been joined by an identical instrument deployed by the Apollo 15 astronauts about 1100 kilometers away.

The first instrument has shown that the properties of the solar plasma as it strikes the lunar surface are almost the same as in space. Investigation of the subtle changes in properties resulting from plasma interactions with the lunar surface or the lunar magnetic field has been hampered by the scarcity of simultaneous plasma measurements in near-lunar space, but some effects have been detected. The velocity of positive ions appears to be lower at the Apollo 12 site than in space by as much as 70 kilometers per second, probably because of the presence of a local magnetic field. Compression of the horizontal component of this field roughly in proportion to the plasma pressure is measured by the magnetometer.

Some interesting phenomena are observed near sunrise and sunset, including a surprising delay in the "solar wind rise." Large clouds of plasma are observed from the impacts of the Saturn rocket stage, and both the energy and the direction of motion of the clouds are different from what would be expected.

Data from the Apollo 15 instrument should clarify the meaning of these observations, but as yet, only a few hours of these data have become available for analysis.

Apollo S-Band Transponder Experiment

Analysis of radio tracking data from both the Apollo 14 and Apollo 15 Command and Service Modules while in low orbit (perigee altitude of 15 kilometers) for 24 hours prior to the Lunar Module descent has revealed detailed gravity information. All seven craters observed near the surface tracks have negative gravity anomalies. These craters range in diameter from 150 to 90 kilometers. The implications are that the craters have a mass deficiency due to the ejection of material during the impact event and that isostatic compensation has not been complete. Gravity profiles over the mascons in Mare Serenitatis, Mare Crisium, and Mare Nectaris show that fairly good models for these mascons are surface disks with a mass distribution of approximately 500 kilometers per square centimeter. This is equivalent to 2 kilometers of rock spread over the maria (>500-kilometer diameter for Serenitatis). To support such a load for billions of years, a crust of at least 200 kilometers must exist if a hot lunar interior is assumed.

Additional gravity information is being obtained from the small subsatellite ejected by the astronauts on the Apollo 15 mission and still orbiting the moon. The satellite is expected to have a lifetime of over a year, during which time its perigee altitude will periodically be low. These low orbit passes will provide additional opportunities for high-resolution gravity measurements.

Additional Experiments

A microwave spectrometer experiment is ready for flight on Nimbus E, and a vector helium magnetometer has been delivered that will be flown past Jupiter on Pioneer F.

DIRECTOR'S DISCRETIONARY FUND ACTIVITIES

Oil-Absorbing Polymers

A variety of special polymers are being synthesized with the aim of producing an agent that will extract significant amounts of cholesterol, bile acids, and other lipids from the intestine. The approach is to exploit a property peculiar to cross-linked amorphous polymers. Such polymers, when placed in a compatible liquid, will imbibe large quantities of the liquid and yet retain their solid character.

A general process was developed for making a variety of polymers with high absorption capacities and free from components that can be released to the local environment. The process consists of synthesizing the polymers in a manner that will produce a low degree of cross-linking, followed by solvent extraction and drying.

Four different polymers with high absorption capacities were made. The best absorption measurements obtained so far ranged from 1600 to 2600%, based on the polymer dry weight, for oils such as oleic acid, a liquid triglyceride (vegetable oil), and mineral oil.

The technique was mastered for making micellar solutions containing egg lecithin, sodium cholate, cholesterol, and water. This composition is an approximation of mammalian bile. A program of testing the ability of the specially prepared polymers to absorb these lipids from the model bile solution was begun. Limited tests showed absorption of the lipids from micellar solutions to be considerably more difficult than in the free condition.

Further exploratory syntheses were begun to make polymers containing chemical adsorbs designed to enhance polymer–micelle interaction.
Kerr-Effect Light Modulation With Organic Liquids

The Kerr response of a number of organic liquids was investigated. Particular attention was given to nematic liquid crystals, and two were found to have an unusually large Kerr effect immediately above their nematic-isotropic transition temperature. The maximum observed Kerr response was 40 times that of nitrobenzene, with a time constant of 22 nanoseconds. These results indicate the possibility of obtaining a low-voltage Kerr shutter, at a penalty in terms of reduced bandwidth. The Kerr response of several nematic substances in their isotropic phase exhibited a Curie-Weiss behavior near the transition, the Kerr constant increasing proportionately to $1/(T - T_c)$ as the transition temperature was approached. The time constant of the Kerr effect in two substances was near 20 nanoseconds, indicating that their molecules move fairly independently, while one substance had a Kerr time constant of 1–3 microseconds, suggesting a very high degree of molecular association. Kerr effect measurements of this type will be of interest in basic studies of the liquid crystal state because the results depend on the nature of the inter-molecular forces that create the nematic ordering.

Superfluid Helium Experiments

The work of this task has led to two new tasks supported by NASA to conduct experiments on the properties of superfluid helium in weightlessness. One task is aimed at exploring the fundamental behavior of superfluid helium in the absence of constraining walls. This is accomplished by studying the superfluid in the form of a large drop suspended in a weightless environment. The second task is aimed at exploring more typical behavior of weightless superfluid helium to provide engineering data for the design of superfluid helium cooling systems for spacecraft.

In addition, the thickness of weightless superfluid helium film has been under theoretical study. In weightlessness, ordinary liquids evenly cover the walls of their container. In the case of superfluid helium, however, there is the possibility that this may not happen and that part of the container wall at least would be covered by a superfluid film of characteristic thickness. The reason is that, unlike ordinary fluids, the zero-point energy of helium is considerable and may be lower in the film than in bulk, tending to stabilize the film.

Visualization of the Coronary Microcirculation

In an affiliated effort between JPL-Caltech and the Huntington Institute for Applied Medical Research, a task was initiated to investigate the feasibility of a servo-controlled, microscopic, cinematographic approach to the study of the coronary microcirculation in the functioning heart muscle. Such a capability will make possible for the first time the continuous observation of the microcirculatory bed in a moving target tissue without loss of focus or of the site of interest from the field of view.

An experiment was conducted to measure the typical frequency composition in the motion of a cat's heart. The data were collected using an electro-optical sensor and processed in real time on a computer system. Knowledge of the frequency composition of the target tissue motion is needed to determine the feasibility of the considered servo-controlled capability.

General Relativity Feasibility Study

A 1-year study was undertaken to determine the potential of future deep space missions for significant tests of general relativity. To accomplish this objective, it was necessary to compute error covariance matrices for various orbital and relativistic parameters, and for reasonable tracking patterns and error sources of the NASA/JPL Deep Space Network.

The relativistic parameters for the error analysis were selected on the basis of careful consideration of all possible metric theories of gravity. As a result, it was decided that the essential elements of relativistic tests could be encompassed by the two parameters $\beta$ and $\gamma$ in the Eddington–Robertson–Schiff metric.

Six future missions were selected for study, including orbiter missions of Mercury, Venus, and Mars and interplanetary missions of the Mariner Venus–Mercury and Helios class. It was concluded that a measurement of $\gamma$ within the next few years, probably by Mariner Mars 1971 and the Viking Orbiter, would yield a test of relativity to $\pm 0.6\%$. The parameter $\beta$, although equally important, proved more difficult to determine. Of the six missions that were studied, only the Mercury orbiter emerged as an obvious candidate for a significant measurement of $\beta$ to the level of $\pm 1.5\%$.

Air Pollution Chemistry

Studies were made of the chemistry of zwitterionic intermediates in the reaction of ozone with olefins. The behavior of these species is one of the least understood aspects of air pollution chemistry. By means of gas phase experiments at low temperatures and over a wide range of pressures, techniques based on infrared and gas chromatographic analysis have been developed to measure the relative rates of zwitterion reactions, including fission, rearrangement, and collisional stabilization.
OTHER ACTIVITIES

PLANS AND PROGRAMS

The Office of Plans and Programs continued its role in the formulation of operational plans and the coordination of resource allocations, and in the investigation and assessment of potential areas for the application of future Laboratory effort.

Operational and Resources Planning

Efforts during the year were divided between (a) carrying out the continuing processes involved in the preparation of budget documentation and the coordination of resource allocations (funds and manpower) among the various Laboratory activities and (b) exploring methods for streamlining and improving these processes. The manpower reporting system was studied in detail with the objectives of reducing the number of reports and improving the consistency among them. In a companion study, manpower planning activities were reviewed in search of ideas that could simplify procedures so as to reduce the time and numbers of people involved in the manpower planning and allocation steps and possibly increase the flexibility of the operating organizations in the deployment of manpower. Another major study of importance in resources planning dealt with the effects of inflation on flight project costs. It developed a relatively simple cost model based on published and authoritative economic indices.

During the year, NASA undertook a comprehensive and critical appraisal of the size and composition of its institutional base in the light of its changing programs and work force adjustments. The Laboratory supported this appraisal with a careful review of its own roles and missions, management philosophy and practice, and future objectives.

The Laboratory shares with industrial and other academic research and development organizations a serious interest in and concern for the continued intellectual vigor and expertise of its professional staff and the avoidance of obsolescence among professional personnel. A study was initiated during the year to identify effective means by which to ensure preservation of institutional vitality, particularly in a period of nonexpansion.

Advanced Technical Studies

Technical studies are carried out continuously at the Laboratory to evaluate possible future missions and candidate spacecraft systems consistent with JPL and NASA interests and program objectives. Current planetary mission studies continue to emphasize the exploration of the outer planets. Studies of flyby missions to the outer planets have now been largely completed, and this work has proceeded to the early project development stage as the Outer Planets Project. Follow-on studies now in progress are devoted to orbiters and atmospheric entry probes, particularly with respect to their utilization in investigations of the planet Jupiter. These studies are coordinated with the activities of the Science Advisory Group, a working group of some 23 space scientists which was formed to study and advise specifically in matters of science rationale and strategy for the exploration of the outer planets. A further aspect of planetary mission studies, initiated during the year, is concerned in broad terms with the automated exploration and scientific examination of the surfaces of distant bodies.

Studies of comet and asteroid missions continued and are expected to grow in importance as the strategy for the exploration of these bodies is further developed. A specific study in progress is concerned with the objectives and spacecraft system requirements for a rendezvous mission to the comet Encke in 1984.

Advanced studies in support of the Lunar Program were suspended at JPL in June 1971 because NASA was unable to provide funding in this area for the 1972 fiscal year. Work during the early part of calendar year 1971 continued the development of programs for the scientific exploration of the moon using automated orbiters and surface rovers. Candidate instrument packages were examined in terms of the scientific objectives of missions designed to accomplish surface traverses over long distances. Data from the Apollo 12 and 14 missions were used in analytical and experimental investigations of surface imaging and landmark navigation techniques.

In support of the Space Applications Program, planning studies were initiated to examine the areas of earth physics and physical oceanography. Five specific topics were identified in the range of JPL's competence and interest: (1) global gravimetry, (2) oceanic altimetry, (3) global magnetic surveys, (4) application of laser devices and long-baseline interferometry to the measurement of motions of the earth's crust, and (5) applications of earth satellites as...
data relays from buoys at sea. Mission definition studies have been initiated relative to the first three topics.

A final area of current interest in advanced studies concerns the experimental investigation of theories of general relativity and gravitation for which space flight technology offers several promising techniques. During the year, particular attention was given to the evaluation of studies sponsored by the European Space Research Organization (ESRO) dealing with the experimental potential of a sun-orbiting, drag-free spacecraft. Publication of the Proceedings of the NASA/ESRO/JPL/Caltech-sponsored Conference on Experimental Tests of Gravitation, November 11–13, 1970, was completed.

OFFICE OF COMPUTING AND INFORMATION SYSTEMS

In recent years, computing technology has performed an increasingly important role in the Laboratory’s overall capabilities. Large-scale general-purpose computing services now consume an appreciable portion of the total JPL budget. Computing technology is a crucial factor in a successful planetary program, as well as in the technical and administrative programs.

Because of the growing importance of computing to the Laboratory’s activities, the Office of Computing and Information Systems (OCIS) was established in July 1971. The Manager of OCIS reports to the Office of the Director and is a member of the JPL Executive Council.

OCIS has responsibility for the technical and programmatic management of large-scale general-purpose computing activities at the Laboratory involving the Space Flight Operations Facility (SFOF), the Scientific Computing Facility, the Administrative Computing Service, and the Mission Test Complex. The 350-man organization responsible for the operation of these activities and the associated computers, the Data Systems Division, was transferred to the Office of Computer and Information Systems.

Creation of the new office is necessitating certain interface changes, particularly among the Tracking and Data Acquisition (TDA) Office, Flight Projects, and OCIS. Under the new interface, TDA will be responsible for supplying mission data to the SFOF. The OCIS will process these data to meet Flight Projects mission-independent as well as mission-dependent requirements. The intent of the new responsibilities is to establish clearly visible TDA/OCIS/Flight Projects interfaces.

Functional elements within OCIS will include computing planning, committing computing resources to the Flight Projects, computing resource management, and the Automatic Data Processing Requirements Office. Computing operations, software development, and the implementation of OCIS computing plans will be performed in the Data Systems Division, the operational arm of OCIS.

CIVIL SYSTEMS

Transportation Technology

SUBWAY AERODYNAMICS

The Vehicles In Constrained Spaces (VICS) project is being operated 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. The contract calls for a theoretical, experimental study of the aerodynamics of vehicles traveling in tubes.

The experimental part of this investigation, being carried out at JPL, has required the design and construction of a ten-story, high, pressurized facility (VICS-120). This fully instrumented facility tests moving models at uniform or varying velocities in a vented or unvented 5.08-centimeter-diameter test-section tube. The effects of scaling and variations in model-vehicle and tube configurations are being investigated in preparation for the analytical modeling work at Caltech.

MORGANTOWN

Development of a computerized rapid transit system was undertaken for the United States Department of Transportation to be demonstrated on the West Virginia University campus at Morgantown. A total system analysis was performed prior to construction, and JPL work was concluded in September 1971 with the accomplishment of the preliminary system and subsystem designs. Work on the automatically operated transportation system is now being completed by a team of industrial contractors.

Space Technology Applications

The Space Technology Applications Project continued to apply space-derived analysis and development techniques to civil sector problems in the areas of public safety and medical engineering. In addition, a study was performed to evaluate potential efforts in the field of environmental management.

PUBLIC SAFETY SUPPORT

The major effort within Public Safety Support has been concentrated in the areas of law enforcement air patrol systems and school emergency communications.

Law Enforcement Air Patrol Systems. An evaluation of helicopter patrols instituted by the Los Angeles Police Department (LAPD) in 1969 was completed. Helicopter patrols were shown to be effective in reducing offenses in theft, robbery, and auto theft as well as significantly increasing the probability of arrest. The helicopter patrols were more effective in suburban areas than in areas with multi-story buildings. The
results of the evaluation have been disseminated to the law enforcement community through presentation to the International Association of Chiefs of Police and the Airborne Law Enforcement Association.

A breadboard visual aid system that will provide significantly improved night and day visual capability to observers on police patrol helicopters was designed, fabricated, and ground tested. The system provides a magnified, full-color daytime display for the observer and utilizes an infrared search light coupled to an image intensifier for nighttime display. Arrangements have been completed with the Los Angeles Police Department to flight test this model early in 1972 in order to complete the evaluation of feasibility. A proposal to design, develop, test, and evaluate an engineering prototype model has been developed jointly by JPL and the LAPD and submitted to the City of Los Angeles for approval to submit it as a grant request for Omnibus Crime Control Act funds.

School Emergency Communication. Operational testing of the Private Alarm Signaling System was successfully completed at John F. Kennedy High School (JFK) in Sacramento. The system provides teachers with a pocket-size device to signal for help in the event of a classroom disturbance or to summon medical assistance for an ill or injured pupil. The system was tested throughout the 1970-1971 academic year and has been strongly endorsed by school authorities, particularly in providing early indication of potential major disorder situations. A modified system has been developed and installed in the John Muir High School in Pasadena and is presently undergoing operational testing. Interest in the system has been expressed by the Department of Housing and Urban Development, the Office of Education, and a large number of school districts throughout the country. NASA has been requested to provide nonexclusive licenses to two small businesses to market the system.

The Automated Attendance Accounting System, consisting of 82 classroom terminals and a central data processing subsystem, was also installed at JFK in Sacramento. This computerized system eliminates time-consuming paper work in attendance reporting and compilation of individual reports. The system software and hardware are presently being reconfigured in preparation for resumption of operational testing in early 1972.

MEDICAL ENGINEERING

Medical Engineering activities have been carried out primarily in the fields of materials and prosthetics and medical instrumentation. Other efforts carried on this year include an analysis of the health care delivery system in Southeast Los Angeles in conjunction with the Martin Luther King, Jr.,
General Hospital, evaluation of a new technique in ultrasound imaging, and development of a heat-sterilizable, intermittent, positive pressure breathing apparatus.

**Materials and Prosthetics** A major medical need exists for materials, membranes, and tubing that will not cause clotting (thromboresistant) when placed in contact with blood, for example, in an artificial kidney machine. Currently, the drug heparin is administered to patients to prevent clotting. A demonstration of thromboresistant, heparinized membranes and tubing surfaces was completed. The thromboresistance of heparin complexes on polyurethane tubing was successfully demonstrated through in vitro and in vivo testing. Heparin complexes were found to be thromboresistant on cuprophane membranes in vitro; however, blood flow perturbation precluded satisfactory evaluation in tests performed in vivo.

A new technique employing the scanning electron microscope was developed and utilized to assess the blood platelet deposition on surfaces following in vivo testing.

A joint USC/Los Angeles County Hospital/JPL study of artificial heart valves has continued. Efforts included (1) developing methods for predicting the fatigue life of prosthetic valve poppets, (2) improving methods for accelerated fatigue bench testing, (3) developing criteria for estimating the effects of the physiological environment on prosthetic valve materials, (4) post mortem inspection and analysis techniques for evaluating valve condition, and (5) formulation of a viscous, time-dependent model of flow through an aortic prosthetic valve.

**Medical Instrumentation** A miniaturized radio telemeter developed at JPL using hybrid circuit techniques was demonstrated on a live rat in the Caltech Behavioral Biology Laboratory. The instrument has 10 channels of brain neuron firing signals for hi-fi transmission and analysis by a receiver-decommutator-computer system. Each channel is 5 kilohertz wide and can distinguish between signatures of up to 20 neurons. The system is designed to replace a hardware cable system and will provide the researcher with a tool which permits more free-ranging behavioral experiments. The telemeter, including batteries, weighs 16 grams and has a volume of 12 cubic centimeters.

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**FINANCIAL MANAGEMENT AND PROCUREMENT**

The Prime Contract between NASA and Caltech for the operation of the Jet Propulsion Laboratory has been extended 3½ years through June 30, 1975. The extension continues the basic contract for the Laboratory's research and development and associated efforts relative to space science, technology, and space exploration, and for the application of space technologies to civil systems and problems.

In 1971, JPL's support to federal agencies other than NASA, state and local governments, and a public utility totaled 20 tasks valued at approximately $1,600,000. Some of the organizations supported were the National Institutes of Health, National Science Foundation, Department of Transportation, Federal Republic of Germany (Helios spacecraft project), State of California, County of San Diego, Cities of Los Angeles and Pasadena, and the Southern California Edison Company.

A significant increase in the public's interest in reported new technology items was indicated during 1971. More than 4000 requests for new technology information were received, doubling the number averaged in prior years.

A contract in excess of $47 million was placed with the Boeing Company, Seattle, Washington, for the design, fabrication, and testing of the Mariner Venus-Mercury 1973 spacecraft. The flight spacecraft is due to be delivered in time for launch in October 1973.

During the calendar year 1971, JPL executed approximately $1.5 million in contracts with educational institutions in 19 states. Contractual efforts entailed scientific activities on Mariner Mars 1971 and 1973 missions, participation in experiments developed for various NASA centers, and basic research and development for future planetary missions.

As part of the overall JPL Small Business Subcontracting Program, an increased emphasis has been placed on utilizing minority-owned firms. Efforts are under way to assess qualifications of such firms and to determine how and when JPL might utilize these capabilities.

**PERSONNEL**

The total number of personnel remained almost constant during the year. Recruiting activities concentrated on the employment of engineering and scientific personnel and minorities.

In a continuing effort to attract qualified minority employees, recruiting teams visited five predominantly black campuses, and three colleges with high Chicano enrollments were added to the Laboratory's college recruiting program.

The academic part-time employment program has continued to give over 225 students and professors the opportunity to participate in advanced space technology.
The Summer Employment Program remained at the same level as the previous year, with 45% of the 235 persons employed in this year's program being of minority ethnic origin.

Employee Development activities continued at about the same level as in the preceding year, with a strong offering of on-Laboratory courses in the management, general, technical, and computer fields. There was an increased use of television, films, programmed instruction, and computer-assisted instruction. A video tape speech test station was also established.

The Affirmative Action Program at JPL was newly organized as a Project at the beginning of 1971. At that time, the employees of minority races represented 7.2% of the JPL population. In order to achieve a more integrated and balanced work force, a goal of increasing the minority percentage to 8.3% was set. This goal was surpassed with an increase to 9.3%, nearly one-fourth of the persons hired during the year being members of minorities, compared with one-tenth the previous year.

Near the end of the year, the Affirmative Action Program Office was established as a permanent organization, reporting to the Director. In 1972, increased emphasis will be placed on Affirmative Action for women.

FACILITIES

Construction on the Systems Development Laboratory was completed on July 1, 1971. It is two stories high, with the capability of adding six stories at a later date, and contains 30,000 square feet. A $650,000 modification to the 7.6-meter space simulator is under construction to increase the intensity of the solar simulation system to the level expected to be encountered by Mariner Venus–Mercury and to provide a test capability for the West German Helios spacecraft. It will be operational in April 1972.

A second technical facility being constructed is the Isotope Thermoelectric Systems Application Laboratory (ITSAL), which will provide shielded rooms for research and advanced development efforts involving radioisotope thermoelectric generators. These units are planned as primary power sources for outer planet mission spacecraft. Construction will cost $1,250,000 and will be completed in the spring of 1972.

Construction approval has been received for an addition to the north side of Building 249, the Visitors Reception Building, which will be used to house part of the Personnel Section.

PUBLIC AFFAIRS

The Public Affairs Office scheduled 31 three-hour briefing tours of the Laboratory to better acquaint JPL employees, prime contractors, and their families with preliminary results of the Mariner Mars 1971 mission. In addition to 5661 family members, more than 2500 special guests of Caltech and JPL visited the Laboratory.

The Public Information section supported the Mariner 1971 mission at Cape Kennedy, in press room and broadcast activities, and at JPL and Washington, D. C., press conferences.

The section completed two documentary films, "Mariner Mars '69" and "Space in the 70's—Exploration of the Planets."

Public Educational Services introduced a model program for career education counselors under special developmental programs funding through the U.S. Office of Education. Counselors in neighboring high schools participated in the 6-week program to familiarize themselves with available careers for their counseling programs in the schools.

Specialized seminars were conducted for high school students in the field of technical and industrial education. Each session consisted of an all-day program of lecture-seminars, followed by tours of selected Laboratory facilities.

More than 280 pre-arranged guided tours of the Laboratory were provided for audiences exceeding 10,000 persons. Over 4400 requests for educational literature pertaining to space flight missions and research programs were received by mail from throughout the United States and many foreign countries.

Mailings of current educational literature were made to 700 schools and public libraries in Los Angeles County during the year. One hundred sixty-seven speaking engagements were made, with an audience reaching over 52,000 persons. Over one million publication units were distributed by all educational services combined.

Educational displays were provided for educational and public exhibits in the Los Angeles area and in other cities nationwide. NASA overseas exhibits programs were also supported.

SPECIAL RECOGNITION

This brief list of awards is illustrative rather than complete. It is intended to recognize the accomplishments and contributions of JPL personnel.

C. R. Gates, NASA Exceptional Service Medal for contribution and leadership in space navigation.

P. M. Muller and W. L. Sjogren, Magellanica Premium Award, American Philosophical Society, for the discovery of mascons.

F. I. Roberson, NASA Exceptional Scientific Achievement Medal for the Apollo Orbital Science Experiment.


R. Stevens, NASA Exceptional Service Medal for development and effective use of Deep Space Stations.
Jet Propulsion Laboratory Executive Council

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

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Assistant Laboratory Director—Tracking and Data Acquisition

J P. CLICK  
Assistant Laboratory Director—Financial Management and Procurement

F H. FELBERG  
Assistant Laboratory Director—Plans and Programs

A FINERMAN  
Manager—Office of Computing and Information Systems

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

H J. STEWART  
Advanced Studies Advisor

C W CRAVEN  
Executive Assistant to the Director, Secretary to the Council

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