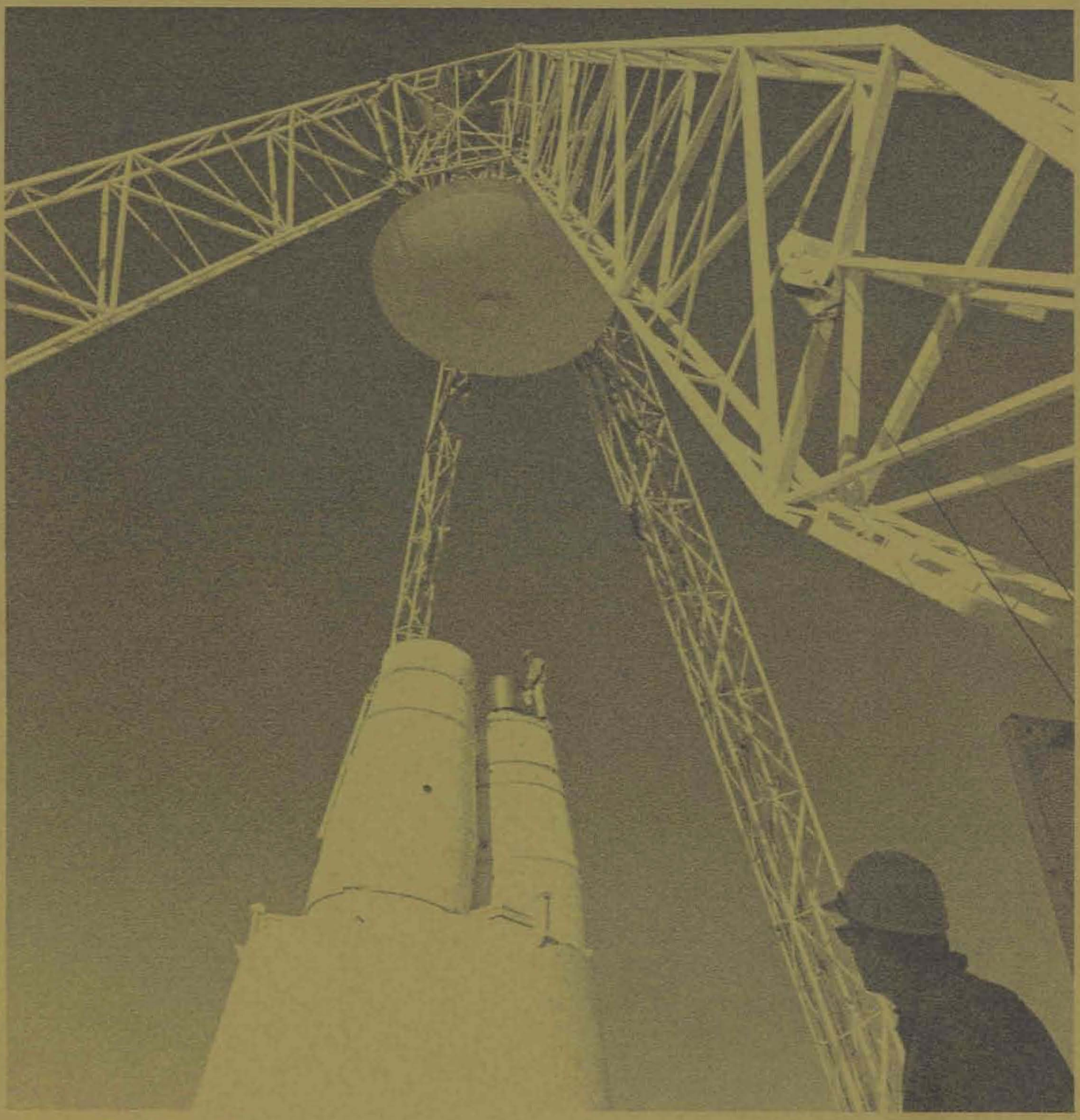
Jet Propulsion Laboratory
1970 Annual Report



Cover: Use of the 210-foot-diameter antenna, equipped with a new high-power S-band transmitter and sequential-acquisition ranging system, made possible the accurate tracking of Mariners VI and VII to a record distance of 2.6 astronomical units. This capability made a vital contribution to the year-long experiment to test Einstein's general theory of relativity *(see p. 11).*

Jet Propulsion Laboratory
1970 Annual Report

A description of work accomplished under Contract NAS 7-100 between the California Institute of Technology and the National Aeronautics and Space Administration for the period January 1, 1970, to December 31, 1970

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Jet Propulsion Laboratory

CALIFORNIA INSTITUTE OF TECHNOLOGY

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PASADENA, CALIFORNIA 91103

CENTRAL
ENGINEERING
180

Dr. M. J. Zucrow, Chairman of the JPL Visiting Committee, with Dr. Pickering.

DIRECTOR'S MESSAGE

During 1970, the Jet Propulsion Laboratory continued the planning and development of its deep space exploration programs and committed increased resources to the problems of the civil sector.

The new decade promises an active program of exploration of both the terrestrial and the outer planets with instrumented, automated spacecraft. The Mariner 1969 mission was extended to include a scientifically important experiment involving the solar effect on radio signals: the first time that the Einstein theory of general relativity has been tested under controlled conditions.

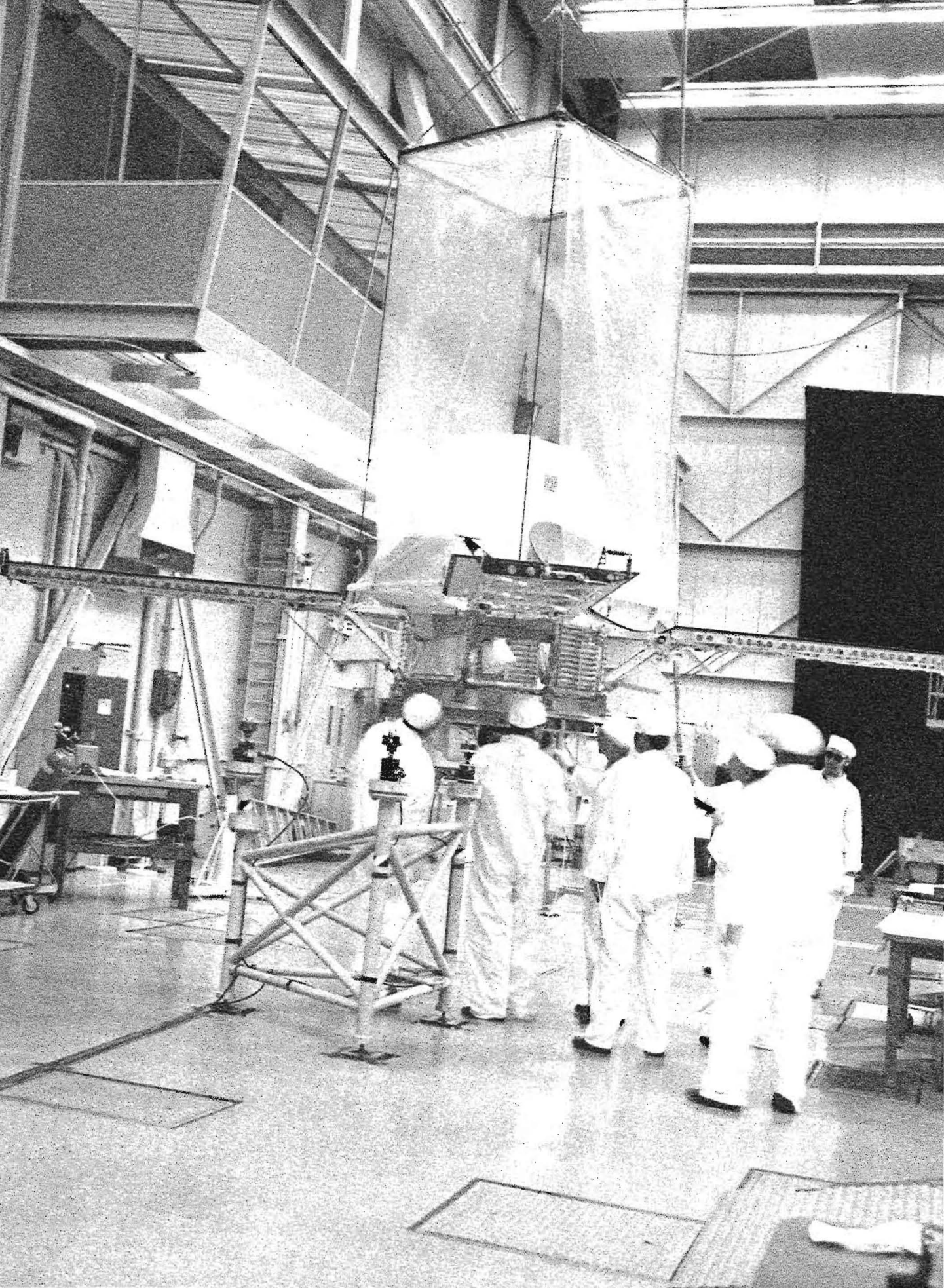
The Mariner 1971 spacecraft — designed to orbit Mars in an extended surveillance of that planet — were fabricated, assembled, and tested by the end of the year. The 1973 Mariner Project, in which the gravitational-assist effect of Venus will be used to send a spacecraft to Mercury, was formally organized, and a preliminary science payload and mission description were selected. Because of scheduling modifications, the Viking Project, a mission that will orbit and land instrumented capsules on Mars, was postponed to a 1975 launch; however, the Laboratory continued to work with other NASA centers on the program.

During the year, JPL accelerated the study of potential missions for the Grand Tour to be launched to the outer planets before the end of the decade. An active program also was pursued to design and develop specific items of hardware, currently beyond the state of the art, that would be critical to these missions.

The Laboratory expanded its efforts in 1970 to apply systems analysis and engineering to such fields as environmental pollution, social and urban problems, public safety, medical engineering, and educational technology. A project was established through the Department of Transportation to design and develop a computer-controlled system to move people within the city of Morgantown, West Virginia.

These projects, and programs of advanced research in such disciplines as the physical and radio sciences, electronics, telecommunications, ground operations computers, flight computer systems, and chemical and electric propulsion techniques, ensure that the Laboratory will continue to make significant contributions to the science and technology of space, and to the application of those capabilities to improve the quality of life for all of mankind.

W. H. Pickering
Director



Flight Projects

MARINER VI AND VII

Following the successful flybys of Mars in July and August of 1969, the Mariner VI and VII spacecraft continued in orbit around the sun. With both spacecraft still functioning, it was possible during the past year to perform an experiment testing Einstein's general theory of relativity. This experiment has been successfully concluded and the results, described elsewhere in this report, have corroborated one important thesis of the theory of relativity.

MARINER MARS 1971

The Mariner Mars 1971 Project encompasses the launching of two identical spacecraft to orbit Mars for close-in surveillance and high-resolution mapping and studying of the time-variable features of the Martian surface and atmosphere.

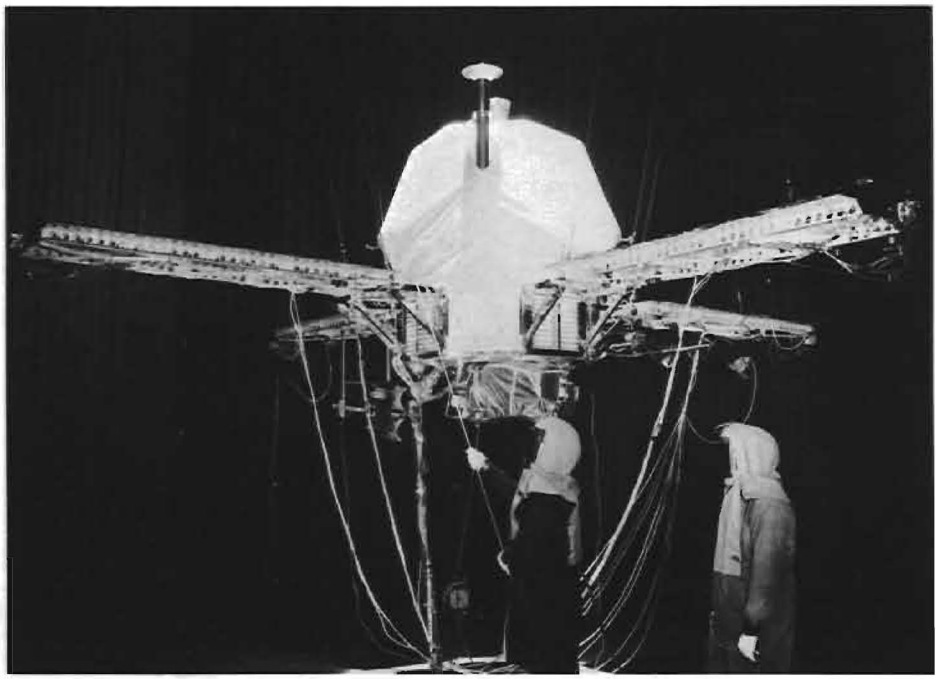
A proof test model and two flight spacecraft were fabricated and assembled during the past year. System and environmental testing on the three spacecraft was nearly completed at year's end.

The first shipments of equipment to Cape Kennedy began in the final months of the year, starting the build-up for launch operations in May.

Development of the extensive computer programs required for mission operations continues as a major project effort.

Mission support areas in the JPL command center, the Space Flight Operations Facility, were prepared for occupancy early in 1971 by the teams being trained to handle the complex functions of mission control.

Following launch in May of the two flight spacecraft, training will be conducted during the summer and early fall of 1971 for the orbital operations, which begin with



Opposite: Mariner Mars 1971 spacecraft being prepared for center-of-gravity tests in the Spacecraft Assembly Facility.

Right: One of the two Mariner spacecraft to be launched in May 1971 undergoing environmental testing in space simulation chamber.

the insertion of the spacecraft into orbit around Mars in November 1971.

While no major change has been made to the mission plan, refinements in the orbital elements for Mission A and Mission B have been made to enhance the quality of the science data to be gathered. Periapsis has been lowered to 1250 kilometers for Mission A and 850 kilometers for Mission B. Inclination of the orbits (relative to the Martian equator) is 80 degrees for Mission A and 50 degrees for Mission B. This makes Mission A virtually a polar orbit.

Development and qualification of the large bipropellant propulsion system for the spacecraft were significant accomplishments in the past year. Previous Mariner spacecraft employed small monopropellant propulsion systems to execute one or two trajectory correction maneuvers prior to planetary flyby. For the 1971 Mariners, a larger, more powerful propulsion system was needed to decelerate the spacecraft into orbit about Mars, as well as to perform trajectory corrections and orbit modifications. The new subsystem contains a 300-pound-thrust rocket engine that burns nitrogen tetroxide and monomethyl hydrazine. A larger version of this system is currently under development for the Viking orbiter, to be launched to Mars in 1975.

Approved mission plans call for 90 days of orbital operations at Mars, with each spacecraft performing six experiments: (1) visual imaging, using the television cameras, (2) ultraviolet spectroscopy, (3) infrared spectroscopy, (4) infrared radiometry, (5) S-band occultation, and (6) celestial mechanics. The last two experiments use the spacecraft radio link and do not require special instruments aboard the spacecraft.

MARINER VENUS–MERCURY 1973

A single mission, to be launched in the fall of 1973, has as its primary objective exploratory investigations of the atmosphere, surface, and body characteristics of Mercury. Interplanetary experiments and further investigations of Venus are also planned as a part of this first dual-planet, gravity-assist type of mission.

During 1970, the major events which occurred were the formation of the JPL Project Office, the industry briefing for, and a series of meetings with, potential spacecraft systems contractor candidates, the selection by NASA of the science payload, and the issuance by the Project of a Request for Proposal (RFP) to the spacecraft systems contractor candidates.

The preliminary spacecraft and mission description upon which the RFP package was structured resulted from the mission design activities. Systems contractor selection is scheduled for the spring of 1971.

The launch window for the flight opens October 12, and closes November 20, 1973. Arrival at Venus will occur in early February 1974 and Mercury arrival in late March or early April. A single spacecraft will be launched.

The science payload selected in June includes instruments to be provided by five principal investigators for the charged particle, infrared radiometry, magnetic fields, plasma science, and ultraviolet spectroscopy experiments. Two science teams were selected corresponding to the Project-supplied science instruments—television and the S-X-band radio system.

An operational Science Steering Group, consisting of the Principal Investigators and Science Team Leaders and chaired by the Project Scientist, has now been formed. This group is an essential element in mission and spacecraft design and planning, providing scientific guidance and participating with the Project in the conduct of science-related tradeoff decisions.

The science payload, although structured to meet the primary scientific objectives of investigating the planet Mercury and its environment, is also expected to yield important information concerning Venus and the interplanetary medium.

Continuous in-flight measurements will be obtained from the magnetic fields, plasma science, and charged particle telescope experiments. All of the instruments will view Venus and its vicinity, obtaining data supplementary to those returned by earlier Venera (Russian) and Mariner spacecraft.

Observations at Mercury will provide data concerning the nature and evolutionary history of the planet's surface, including its physiography and thermal properties; the presence and composition of its atmosphere; and the nature of the interaction between Mercury and the solar wind. The latter observations will contain information concerning planetary properties.

An important scientific consideration is the conducting of magnetic, plasma, and charged particle measurements at 0.4 astronomical units nearly simultaneously with similarly instrumented spacecraft operating at different solar radial distances (Pioneers F and G, IMP H or J), up to 5 astronomical units.

VIKING ORBITER

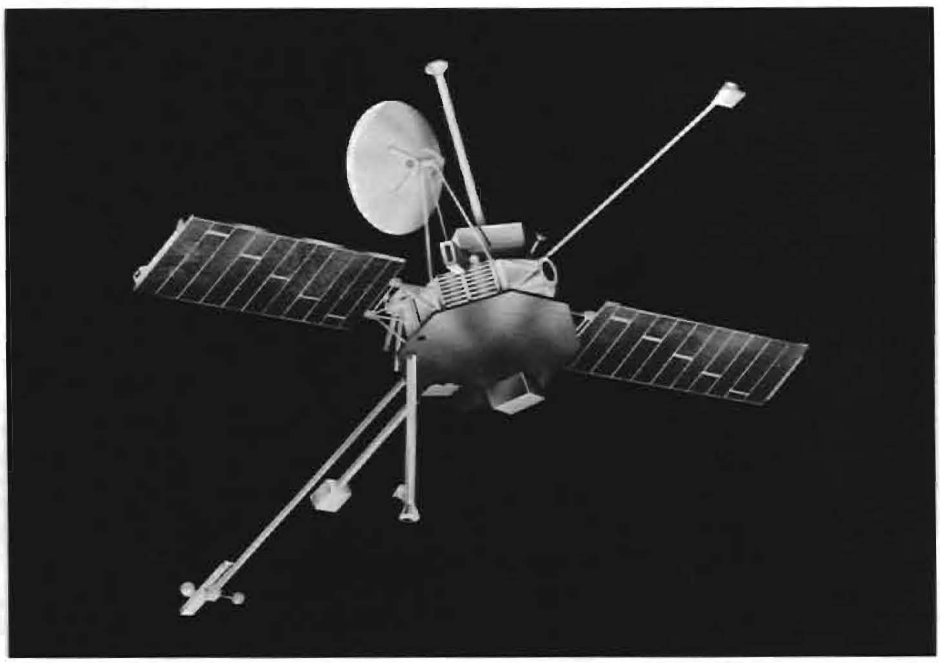
Two spacecraft, each consisting of an orbiter and a sterilized lander capsule, will be launched separately during the 1975 launch opportunity. The two spacecraft are to provide complementary data about Mars and perform complementary functions as well as provide redundancy.

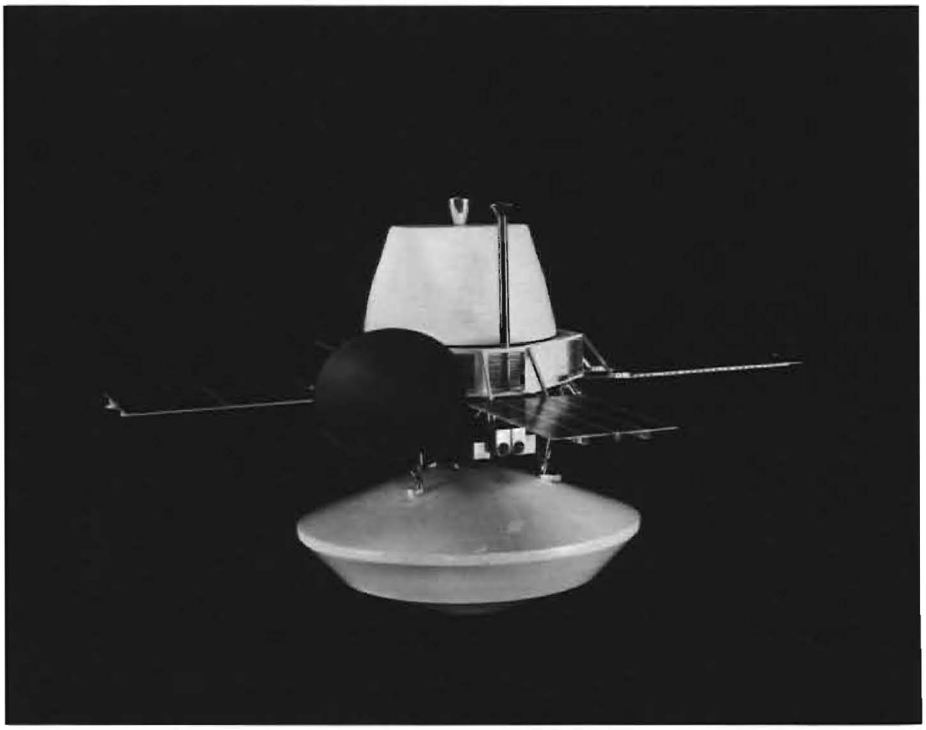
The orbiters will insert the landers into descent trajectories from orbit about Mars. Scientific instruments aboard the orbiters will be used, in part, to obtain data to confirm the selection of landing sites for the landers or, if necessary, to select more advantageous landing sites.

Within a 50-day period following injection into Mars orbit, the landers will separate from the orbiters, perform a de-orbit maneuver, make scientific measurements during entry, and soft-land in the designated landing areas. Each lander is designed to have an extended surface life of 90 days in which to obtain scientific data.

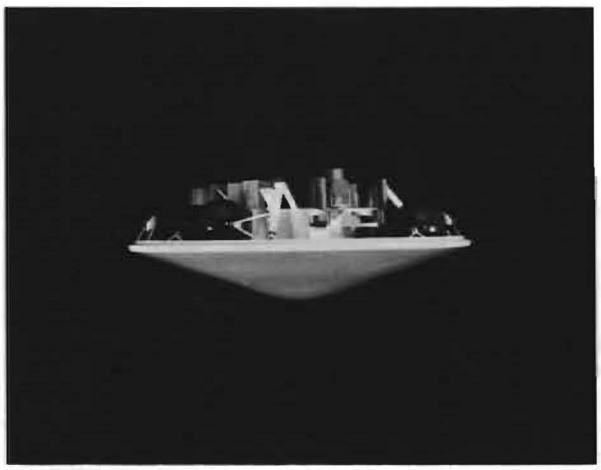
The lifetime of the orbiters is to be at least 140 days following orbit. The orbiters will act as communications relay stations between the landers and earth as required to obtain periodic coverage of the lander

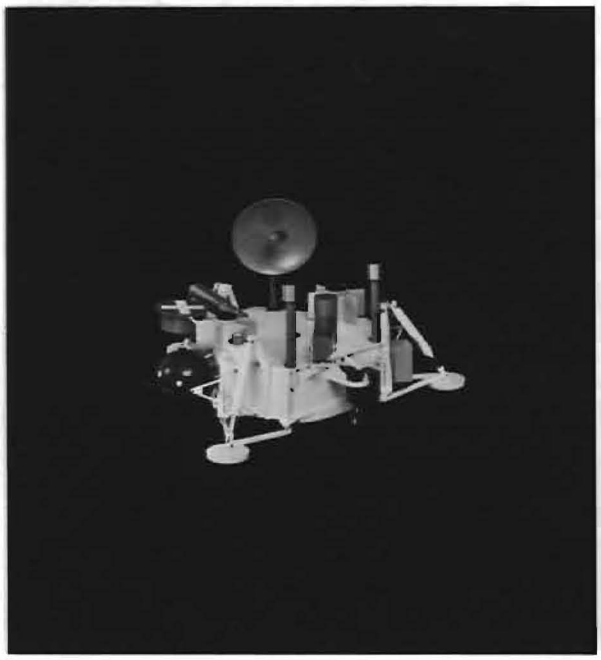
Mariner Venus-Mercury 1973 spacecraft.

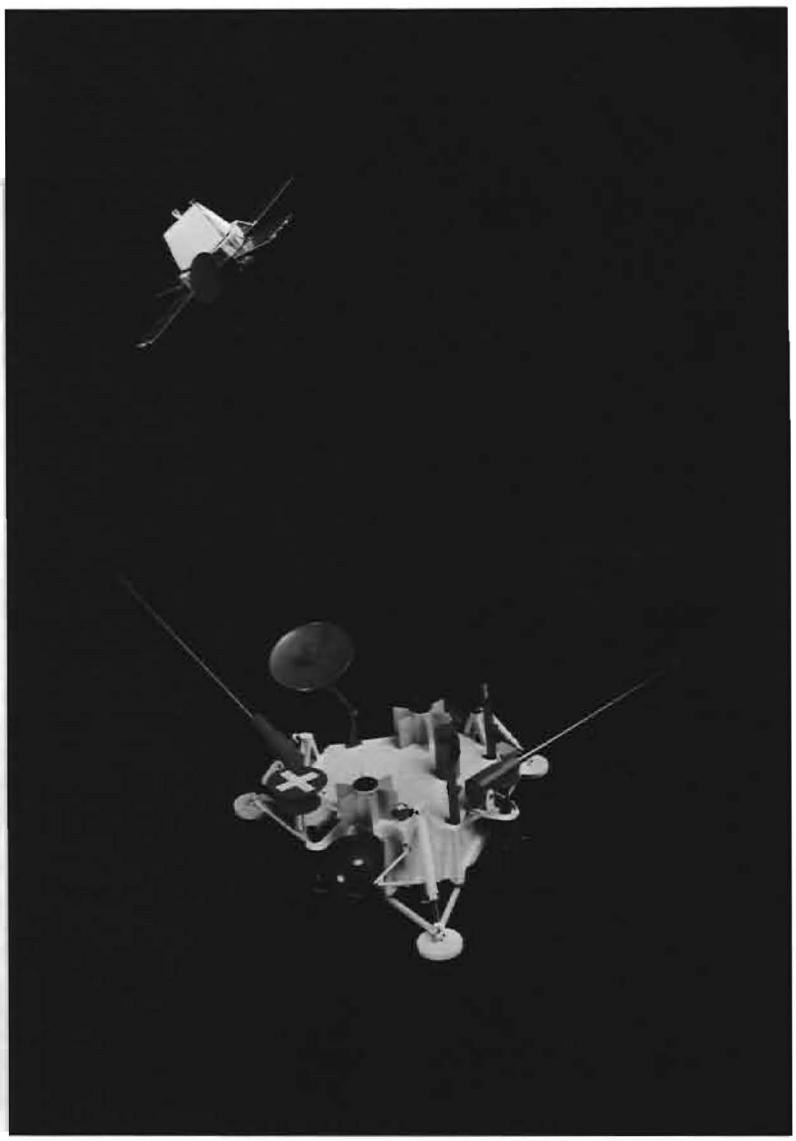


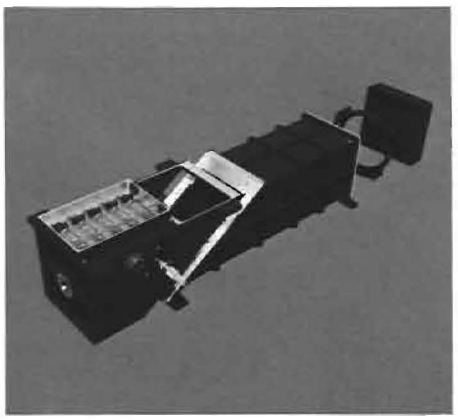


Model of Viking spacecraft in various mission configurations. Top: Orbiter with encapsulated lander. Center: Lander with protective heat shield. Bottom left: Landed instruments ready to observe Martian surface and atmosphere. Right: Orbiter, shown separated from lander, will operate as a relay station, conduct experiments, and map the planet photographically.









Mars atmospheric water detection spectrometer developed for Project Viking.

surroundings, make scientific measurements for the selection of landing sites for future missions, and study the physical and dynamic characteristics of Mars.

The Viking Project was initiated by NASA late in 1968, with two launches originally scheduled for mid-1973. However, in January 1970, NASA postponed the dual mission until late summer of 1975, with arrival at Mars approximately 11 months later.

The Langley Research Center has overall management responsibility for the Viking Project. The Lander System is being developed under contract to Langley by the Martin Marietta Corporation in Denver, Colorado. The Orbiter System development and Tracking and Data Acquisition are responsibilities assigned to JPL. In addition, Langley Research Center has responsibility for the Launch Flight Operations System, and Lewis Research Center for the Launch Vehicle System.

A gas chromatograph/mass spectrometer, that will perform organic analyses of the surface of Mars, is also being developed by JPL.

The basic objective of the Viking Project is to advance the knowledge of the planet Mars by direct measurements in the atmosphere and on the surface, and observations of the planet during approach and from orbit. Particular emphasis will be placed on obtaining information concerning biological, chemical, and environmental factors relevant to the existence of life on the planet at this time, and in the past, or the potentials for the development of life in the future.

The orbital objectives to be accomplished in satisfying the basic objectives are to obtain visual, thermal, and water vapor information, both in orbit and at the landing areas, to be used in selecting sites for the landers and for future missions as well as in the study of dynamic characteristics of the planet and its atmosphere, and to conduct scientific investigations using the orbiter radio subsystem.

ADVANCED PLANETARY MISSION TECHNOLOGY

During 1970, the Advanced Planetary Mission Technology Program continued to provide support to the Laboratory and to NASA in the evaluation, definition, and planning of potential planetary missions.

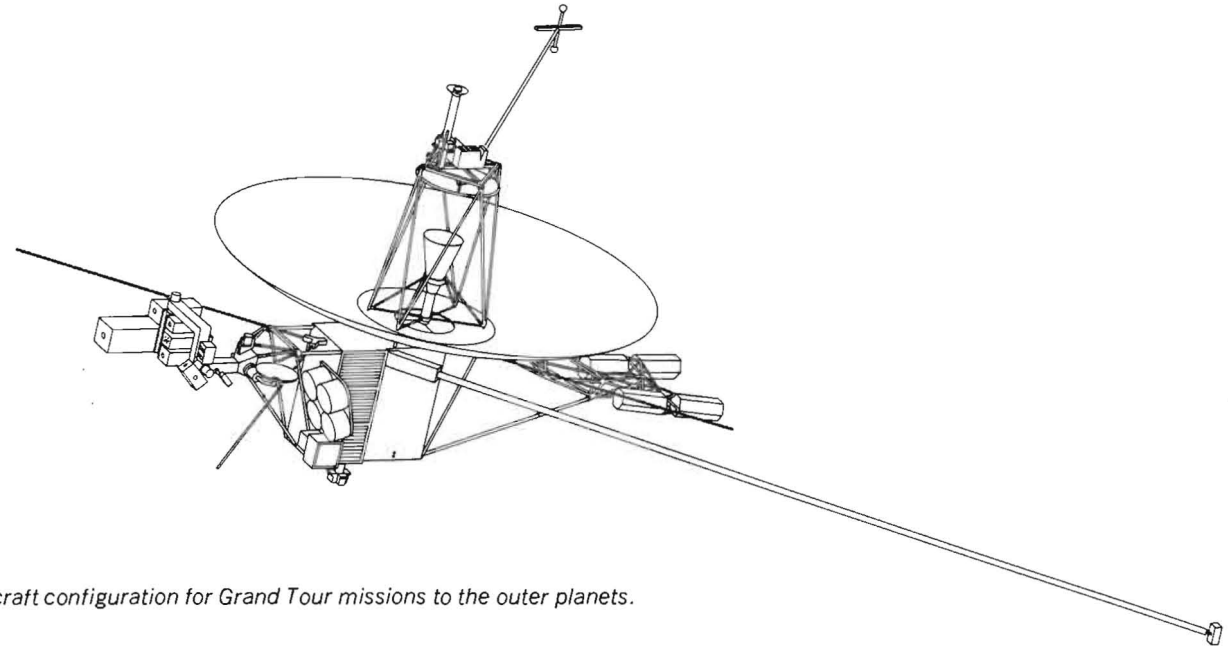
Studies of possible missions to the outer planets were continued during 1970. In midyear, a report was given to NASA detailing a proposed set of Grand Tour missions and their implementation. The set consisted of a 1975 Jupiter flyby, with the spacecraft subsequently going out of the plane of the ecliptic and passing back over the sun, dual flights in 1977 to fly by Jupiter, Saturn, and Pluto, and dual flights in 1979 to Jupiter, Uranus, and Neptune. Flight times to Neptune range from 7 to 9.5 years.

Programmatic considerations, including funding and a possible interference with the 1975 Viking launches, led to dropping the 1975 Jupiter out-of-the-ecliptic flight from the proposed set and shifting one of the 1977 Jupiter–Saturn–Pluto flights to 1976.

One of the major points revealed by this study was that in order to have a payload of maximum scientific value available for the first flight, development of specific scientific objectives should be undertaken in 1971.

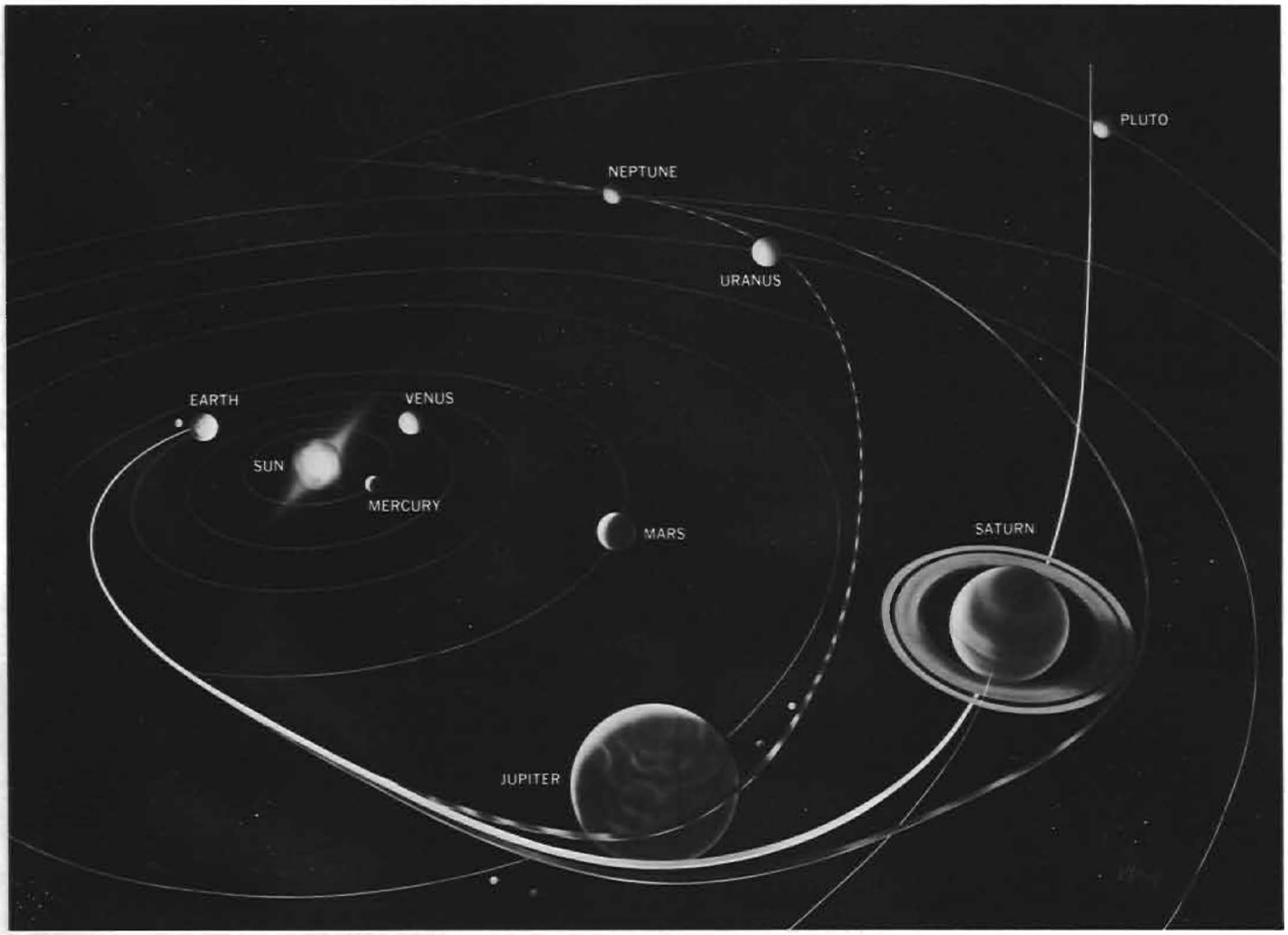
Accordingly, an invitation to participate in the mission definition activities for the Outer Planet Grand Tours was issued to the scientific community in October 1970, calling for proposals from interested scientists. In November 1970, a preproposal briefing was held to inform potential proposers of the mission set and the implementation plan.

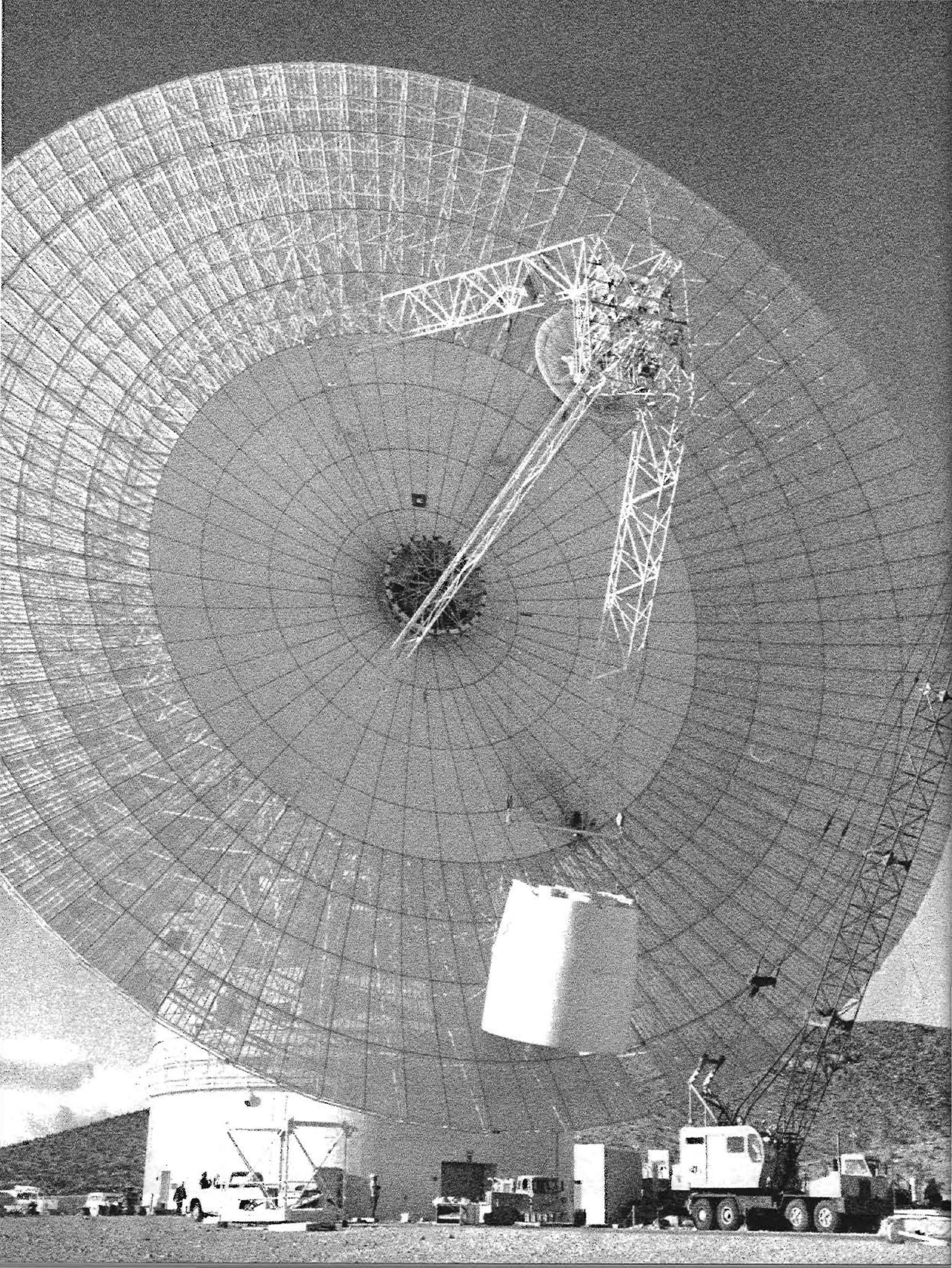
In order to interface with and support this scientific mission definition activity, JPL initiated the formation of a Grand Tour Project Office and established a mission preliminary design team.



Spacecraft configuration for Grand Tour missions to the outer planets.

Artist's concept of three-planet trajectories considered for Grand Tour missions.





The Deep Space Network

OPERATIONS

The 210-foot antenna at Goldstone provided the principal support for the Mariner VI and VII extended mission The standard 85-foot network and the 210-foot antenna provided tracking for the Pioneer 6 through 9 spacecraft in orbit about the sun The DSN supported the Manned Space Flight Network (MSFN) in communicating with Apollo 13 Network operational tests continued in support of Mariner Mars 1971 Interface engineering and operations planning continued for the Pioneer F and G missions to Jupiter, the Mariner Venus–Mercury mission in 1973, the Viking missions to Mars in 1975, and the Helios missions in 1974–75

MANNED MISSION SUPPORT

The recovery from the in-flight failure of Apollo 13, which made great demands on the ground system, was supported by the 85-foot network and the 210-foot antenna at Goldstone. Operational planning was completed for the Apollo 14 launch in January 1971. An additional experiment on this mission involving bistatic radar measurements of the moon will require special configuration at the 210-foot station at Goldstone.

MARINER VI AND VII EXTENDED OPERATIONS

The DSN-provided capabilities made achievable the primary objectives of the Mariner VI and VII extended operations. The primary requirement of achieving accurate tracking at a distance of 2 6 astronomical units (approximately 242 million miles) could only be met by use of the 210-foot antenna at Goldstone equipped with a new high-power S-band transmitter and a new experimental sequential-acquisition ranging system. The combination of the capabilities of this equipment made possible the tracking to the record distance of 2 6 astronomical units in March 1970.

The superior conjunction of the sun and Mariner VI on April 29 and Mariner VII on May 10 was the midpoint of a year-long experiment to test Einstein's general theory of relativity by measurement of the gravitational effects of the sun on radio signals passing near it. These measurements were sought to distinguish between the predictions of the Einstein theory of gravitation and that proposed by Brans–Dicke Important corrections to the observations had to be made for the effects of charged particles both in the earth's atmosphere and in interplanetary space These corrections were obtained by a method designated as differenced range versus integrated doppler (DRVID) The sequential acquisition ranging equipment was designed to provide a measure of the DRVID correction directly

PIONEER EXTENDED MISSIONS

The DSN continued the regular tracking and data acquisition of the Pioneer 6, 7, 8, and 9 spacecraft Pioneer 7 was tracked by the 210-foot antenna station at Goldstone, as were Pioneers 6 and 9. Pioneers 6, 8, and 9 were also supported by the 85-foot antenna stations at Goldstone, Spain, South Africa, and Australia.

During the year, the DSN celebrated the fifth anniversary of the tracking and data acquisition support of Pioneer 6 This spacecraft was launched on December 16, 1965, and has completed six revolutions around the sun. Pioneer 6 is getting relatively closer to earth and was within range of the 85-foot antennas toward the end of 1970. Pioneer 9 passed the limit of the standard 85-foot antennas, and the S-band signal was occulted by the sun in December 1970

Total Pioneer data acquisition support during the year was approximately 12,000 hours, during which time the DSN collected

Opposite: Installation of tri-cone structure on Goldstone 210-foot-diameter antenna.

over 3.5 billion bits of telemetry data containing information on fields and particles, thus further defining the solar environment. This information was collected by more than 20 scientific instruments carried by the four Pioneers traveling in the ecliptic plane. The telemetry data also contained engineering measurements made on board the spacecraft which were necessary to maintain the earth-controlled housekeeping functions. More than 7000 commands were transmitted to the four Pioneers by the Project's Flight Operations Team.

Improvements in the S-band receiver and certain hardware changes have extended the capability of the 85-foot antenna stations, increasing coverage of Pioneers 8 and 9, and obtaining earlier than anticipated 85-foot antenna tracking for Pioneer 6.

High points of the year were Archimedes spiral alignment, solar radial alignment, and earth radial alignment of Pioneers 6 and 8, and the Pioneer 9 solar occultation.

The DSN has started the design and planning activities necessary for the tracking and data acquisition support of the Pioneer F and G missions, with launches planned in 1972 and 1973. These missions are managed and operated by the NASA Ames Research Center and will explore the interplanetary medium, the nature of the asteroid belt, and the environmental and atmospheric characteristics of Jupiter.

210-FOOT ANTENNA NETWORK

Construction of the 210-foot network has progressed consistently with the forecast schedule.

Site construction work at Canberra, Australia, was started in December 1969, and the remainder of the 2800 cubic yards of concrete was placed in early October 1970. Fabricated steel assemblies were delivered to the site late in the year, and the 320-foot guy derrick is in place ready to handle the heavy structural steel members.

In Spain, pedestal excavation began in July. The first concrete placement for the pedestal footing was made in November 1970.

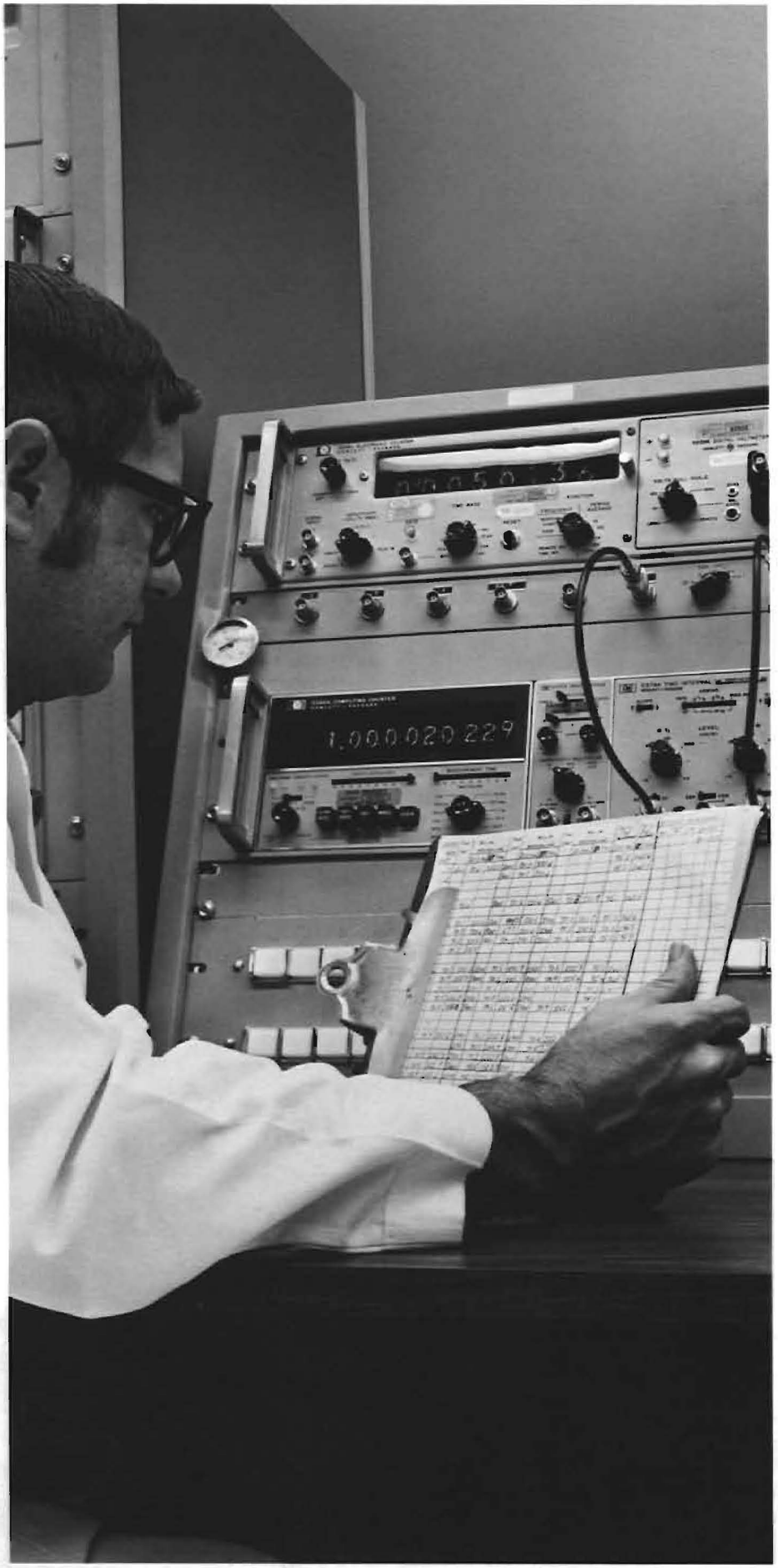
FACILITY MODERNIZATION

Multiple-mission telemetry and command equipment was incorporated into the DSN to meet requirements for the Mariner Mars 1971, Mariner Venus–Mercury 1973,

Opposite: Atomic clock at Goldstone Time Standards Laboratory, accurate to ±2 millionths of a second, is the master clock for the Deep Space Network stations. Clocks at overseas tracking stations are synchronized with this clock by a unique, JPL-developed moon-bounce technique.

Elevation wheel for new 210-foot antenna being constructed at Canberra, Australia.

Construction site of Canberra 210-foot antenna.



and Viking 1975 flights and to provide continuing support for later missions. Development and implementation of this equipment provide, in conjunction with the Space Flight Operations Facility (SFOF) and the Ground Communications Facility (GCF) capabilities, real-time command and telemetry capability to and from spacecraft from the mission control center.

During 1970, the Deep Space Instrumentation Facility (DSIF) expanded its multiple-mission telemetry capability with the installation of symbol synchronizer and block decoding equipment at all stations. These devices operate in conjunction with the subcarrier demodulator and telemetry and command processor to provide uncoded or block-coded real-time data processing capability up to 2000 bits per second at 85-foot stations and up to 30,000 bits per second at the Goldstone 210-foot station. In addition, multiple-mission command capability was introduced into the DSIF through development and installation of command modulator equipment at all stations. This equipment operates in conjunction with the telemetry and command processor to provide real-time command capability from the SFOF to the spacecraft. In order to support station testing and training, general-purpose telemetry data-generation equipment was developed and installed at all stations. The new equipment also provides network training for telemetry operations in conjunction with the DSN Simulation Center.

High-power (200-kilowatt) diplexed operation at the Goldstone 210-foot-diameter antenna provided extended mission support to the Mariner VI and VII spacecraft to verify Einstein's general theory of relativity. A tri-cone structure was implemented for the 210-foot antenna which provides rapid transfer of operation to any one of three Cassegrain feed cones. Operation of the 210 with a polarization diversity feed on the tri-cone structure provided data on the solar corona using Pioneer spacecraft signals to measure Faraday rotation.

Significant changes were made during 1970 in the Space Flight Operations Facility to provide test and flight support for the Mariner Mars 1971 and Pioneer F Projects. These changes will also provide continued flight support for the on-going Mariner Mars 1969 and Pioneer 6 through 9 Projects. Two IBM 360 Model 75 digital computers were installed to form the nucleus of the SFOF Mark IIIA central processing system. Expansion of the SFOF processing capability and development of specialized interface equipment provide the capability of meeting the requirements of the DSN command, telemetry, tracking, monitor and operations control, and simulation systems.

Unlike the Mark II configuration, the new SFOF Mark IIIA configuration includes (1) a multi-jobbing capability that allows the concurrent processing of non-real-time

Opposite: Project personnel in Space Flight Operations Facility observing mission status board

background jobs with the processing of real-time data during mission support, (2) the transmission of data over outbound high-speed data lines, (3) the reception of wideband data, (4) the processing and display of high-rate telemetry data, (5) the incorporation of a multi-channel digital television assembly, and (6) the development of an interface with the Scientific Computer Facility (SCF) to implement the transfer of orbital and trajectory data between programs in the IBM 360/75 and the Univac 1108 computers in the SCF

Innovations associated with technical facilities include an uninterruptible power supply to guard against critical period power outages and the redesign of the physical plant to provide expanded capability for DSN and project users

The Ground Communications Facility concentrated its modernization efforts on the high-speed data and wideband data systems The high-speed data system interconnects the SFOF with each of the deep space stations As the state-of-the-art has improved, the GCF's high-speed data transmission rate was increased from 550 to 600 bits per second, then to 1200, and finally, two years ago, to 2400 The state-of-the-art now permits up to 4800 bits per second to be transmitted over a standard international voice-grade communications channel During 1970, the GCF upgraded the high-speed system to provide 4800 bits per second per circuit in order to meet the DSN's data transmission needs between the SFOF and DSIF This upgrading also included GCF equipment which permits several computers to share the same high-speed circuit simultaneously, each transmitting and receiving its own data

The second major GCF effort was the development of a wideband 50,000-bit-per-second capability between the SFOF, the DSN Simulation Center, the Compatibility Test Area (CTA 21), and the Goldstone 210-foot station This system, which was designed last year, was developed, tested, and placed in an operational status during 1970 It employs a broad-spectrum (48 kilohertz) circuit and detects its own transmission errors It is used to send spacecraft digital video data between locations As in the high-speed system, several computers can use the same wideband circuit simultaneously, thus decreasing the number of such circuits required

The DSN Simulation Center was upgraded to provide the capability of simultaneously simulating two spacecraft and three deep space stations. To allow this, the Simulation Center EMR 6050 was expanded from 16,000 to 32,000 words of main memory and the Univac 1108 computer was electrically interfaced with the EMR 6050 Command-responsive spacecraft math models now exist in the Univac 1108 which dynamically change spacecraft commutator parameters The GCF interfaces have approximately doubled in number, with a factor of two upgrade in their speed of operation The control and display mechanism has been enhanced by the addition of general purpose cathode-ray tube (CRT) interactive terminals

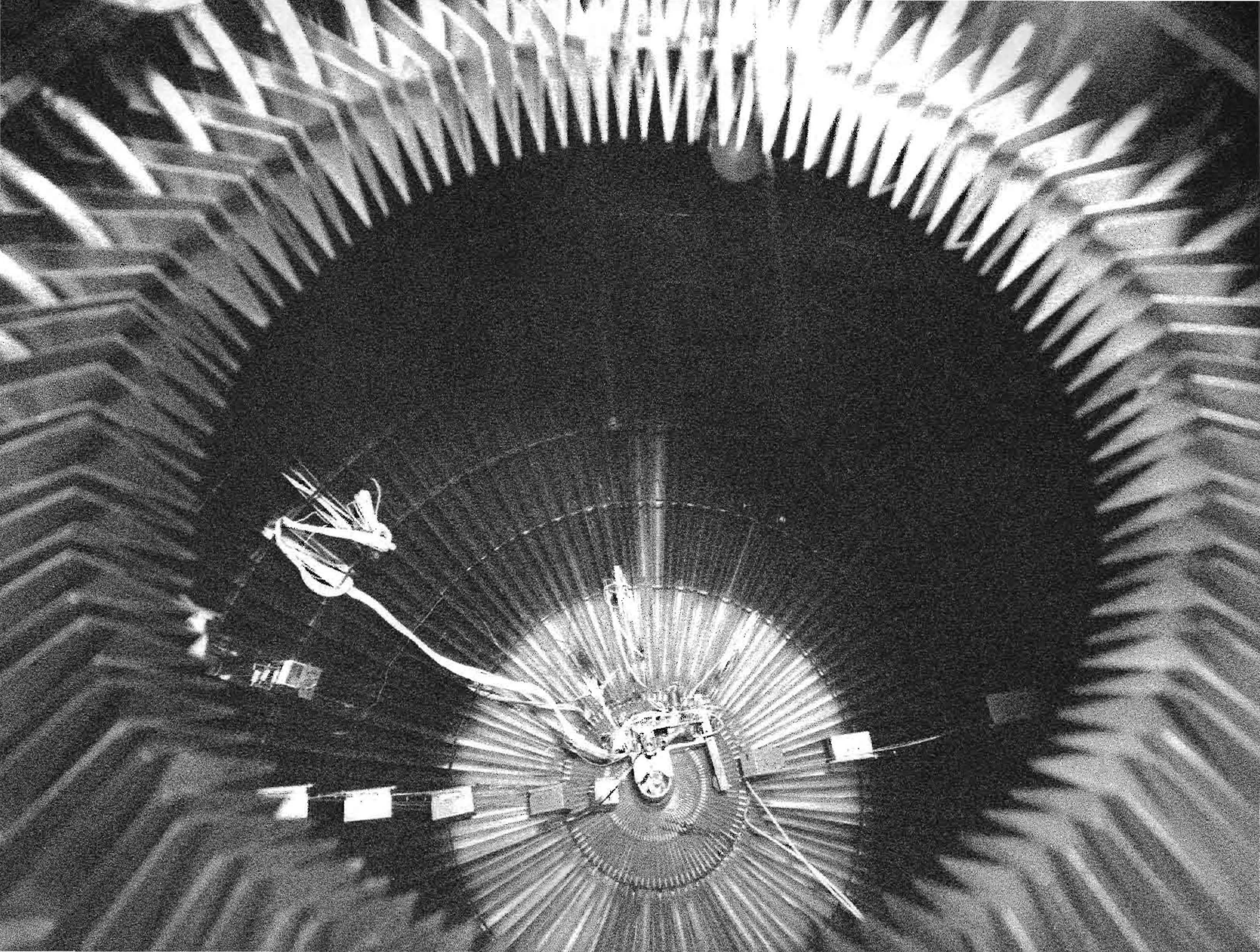
RADIO SCIENCE SUPPORT

A number of radio science experiments were performed using DSN facilities Experimenters from the Weapons Research Establishment of Australia, the California Institute of Technology, and JPL investigated the angular size of radio sources at S-band using the 210-foot antenna at Goldstone in conjunction with the 85-foot antenna at Tidbinbilla to perform a very long baseline interferometry (VLBI) experiment The 210-foot antenna was used with the 120-foot Haystack antenna by JPL and the Massachusetts Institute of Technology to perform a VLBI experiment at X-band to test the Einstein versus the Brans–Dicke relativity theories Measurements were made of the angular displacement of the radio sources in 3C279 and 273 when the former was occulted by the sun. The VLBI technique, using the 210-foot antenna and the 140-foot National Radio Astronomy Observatory (NRAO) antenna, was also employed by NRAO, Caltech, and others to investigate the detailed structure of about 50 quasi-stellar objects

Using the 210-foot antenna alone, Caltech experimenters obtained polarization measurements of pulsar emissions at S-band and made the first measurements of the radiation characteristics of pulsars at X-band

Extensive observations of the x-ray source SCO-XR1 were made by the University of California to determine the variability of its radio emissions

The 85-foot antennas in Australia and South Africa were used by experimenters of those nations to make radio astronomy observations The Australian Weapons Research Establishment continued investigations of the structure and angular size of radio sources in the Southern Hemisphere and of the variability characteristics of some 55 radio sources. The same experimenters collaborated to perform a VLBI experiment between stations at Johannesburg and Woomera in making high-resolution measurements of the structure of Southern Hemisphere radio sources



Research and Advanced Development

PHYSICAL SCIENCES

During 1970, 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.

Analog Magneto-Optic Recording

Recent experiments to demonstrate the feasibility of analog Curie-point recording on manganese bismuthide films yielded linear recording densities of 25,000 bits per inch, and showed track densities of 10,000 tracks per inch are possible. Recording speed is expected to exceed 10 million bits per second. These features, plus selective reading and writing and the low volatility of the information stored, make this technique attractive for 10-billion-bit mass storage systems.

In Curie-point recording, a focused laser beam is moved across the film to raise successive portions of a track above the Curie temperature. These regions, upon cooling, acquire an average magnetization dependent on the magnetic field applied at the instant of cooling. The variation in magnetization along the track is determined microscopically with crossed polarizers showing the variation in optical density of the film.

Magnetogasdynamic Laser

First definitive experimental results were obtained using a magnetogasdynamic laser operating with helium–xenon and argon–xenon fluids. In this laser, the electron temperature is effectively pulsed in a plasma moving with a supersonic velocity relative to an applied steady-state electromagnetic field, causing population inversions of the electronic excited states of atomic xenon.

Using a fixed diagnostic continuous-wave laser, amplification of the order of 100% at a wavelength of 3.5 microns was measured in a direction parallel to the flow velocity. Compared to corresponding pulsed laser experiments where lasing occurs at 3.5 microns in the plasma afterglow, it is believed that amplification in the magnetogasdynamic laser takes place downstream of the applied electromagnetic field in a region of relatively low electron temperature.

Thermionics Research

A detailed understanding of the cesium ionization mechanism in thermionic converters was obtained. In the transition from the unignited to the ignited mode, cesium ions are generated in the anode sheath of the converter. These ions favorably influence the electron transport from the cathode to the anode.

A new mode of converter operation shows promise for future converters. Space charge neutralization is achieved by ions that are generated in the sheath but not in the interelectrode space. With this mode, an improvement of up to 30% in conversion efficiency can be realized.

Research thermionic energy converter during laboratory test.

Opposite: View, looking up, of fluted walls of JPL Molsink facility, including special equipment used in mapping plume flow from small rocket nozzle.

Air Pollution

A study was made of the gas phase reaction of ozone with acetylenic hydrocarbons. This work is part of a program to determine the role of hydrocarbon gasses in the air pollution process. A detailed reaction mechanism was formulated, employing the intermediate formation of a short-lived acid anhydride, corresponding to the original alkyne. This mechanism provides a simple, unifying description of the ozonation of all simple alkynes, and also shows how these reactions are related to the more commonly studied ozonation of olefins.

Boundary-Layer Transition Studies

It is important for high-speed aircraft designers to know whether the boundary layer of air adjacent to aerodynamic surfaces is laminar or turbulent. Tests of scale models in supersonic wind tunnels do not reliably indicate the laminar-to-turbulent transition zone. An experimental investigation conducted in the JPL 20-inch supersonic tunnel showed that flow noise generated within the tunnel forces turbulence upon the boundary layer on a test model, even ahead of the zone where the flow is dynamically unstable and able to self-amplify flow unsteadiness. A theoretical study offers the possibility of indicating ways in which the effects of flow-generated sound waves may be reduced on boundary-layer transition.

Mathematics of Theoretical Physics

A study of the relation of Hilbert transforms to other similar transforms produced, surprisingly, a new transform. Most important, a new method of numerically evaluating Hilbert transforms was devised which could be more convenient than direct numerical integration.

Many special functions of mathematical physics are special cases of the confluent hypergeometric function. The indefinite integrals of the confluent hypergeometric function using the elementary functions and simple reduction formulas were tabulated and evaluated.

The theta functions study resulted in new theorems now being applied to the dynamics of superfluid vortices, evaluation of thermodynamic functions of gases, and structure of crystals.

Mathematics of General Relativity

A new mathematical method was developed for finding exact solutions of sets of coupled nonlinear partial differential equations. Such sets occur in—and, in fact, define—such various fields as fluid physics, electrodynamics, plasma physics, and general relativity. The method uses the mathematics of exterior differential forms in a novel way to determine the invariance group of the differential system, and various classes of exact solutions are then shown to be generated with this group. The noncommutative algebra and analysis of exterior differential forms have been programmed for symbolic manipulation by high-speed computer. Routine operations of the new method can thus be performed rapidly and without algebraic error.

Molecular Interactions

The Ion Cyclotron Resonance (ICR) Lab developed transient techniques for studying ion–molecule reaction rates as a function of ion impact energies at very low velocities. A packet of ions is produced with a thermal distribution of velocities in the crossed-field ion trap of the ICR spectrometer by a short burst of electrons. Immediately after formation, a pulse of rf is applied at the cyclotron frequency of a particular ion which heats the ions to a known velocity from thermal to 100 electron volts. The variation of reaction cross-sections with kinetic energy yields fundamental information concerning the dynamics of ion–molecule interactions at the molecular level.

This new technique has been used to study the ion–molecule reaction of CO_2 and CO systems. Such experiments may yield clues to ion–molecule reactions in the atmospheres of Mars and Venus.

Astrodynamics

A new second-order general perturbation theory was derived for plotting ephemerides for natural or artificial satellites. The most essential feature of the new theory is the employment of a rotating intermediate orbit, which considerably shortens the length of the perturbation series. A perturbation method developed by a Japanese astronomer was combined with the intermediate trajectory to yield an accurate general theory. Collaboration with celestial mechanicians at Yale and Tokyo Universities also produced significant work on satellite motion.

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.

Extreme-Temperature Requirements

A study of expected thermal extremes for electronic parts for any mission likely to be conducted in this century was completed. Thermal analysis was made for flyby or orbiter missions to Venus, Mercury, and the outer planets, and lander missions on the apparent surfaces of Jupiter and Venus. In each case, except for the Venusian lander, it was concluded that existing technology could provide a thermal environment consistent with existing electronic parts. To prolong the mission duration of a Venus lander, either improved thermal control techniques or high-temperature parts must be developed.

Film Microminiaturization

The microminiaturization capabilities of thick film technology were demonstrated in the fabrication of logic circuits destined for possible use on future planetary missions. Two of these circuits are the binary tree switch and its associated driver. The binary tree switch uses 60 transistors mounted on a 1 by 2-inch ceramic substrate, while the driver is mounted on a 1 by 1-inch substrate. Both circuits use interconnections of thick-film conductors and resistors and are being tested for use in future data-handling systems.

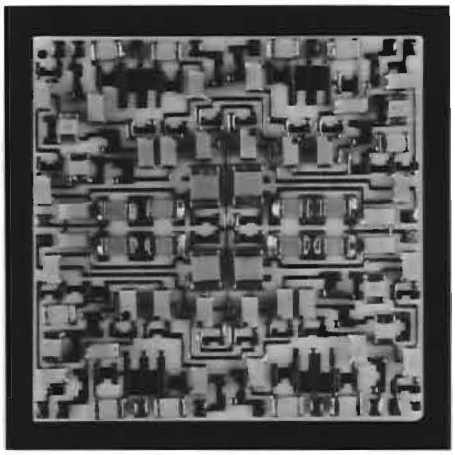
Another microminiature circuit, small enough to be mounted on the head of a rat, is being used in a Caltech medical research project to measure brain waves.

Microcircuit Packages

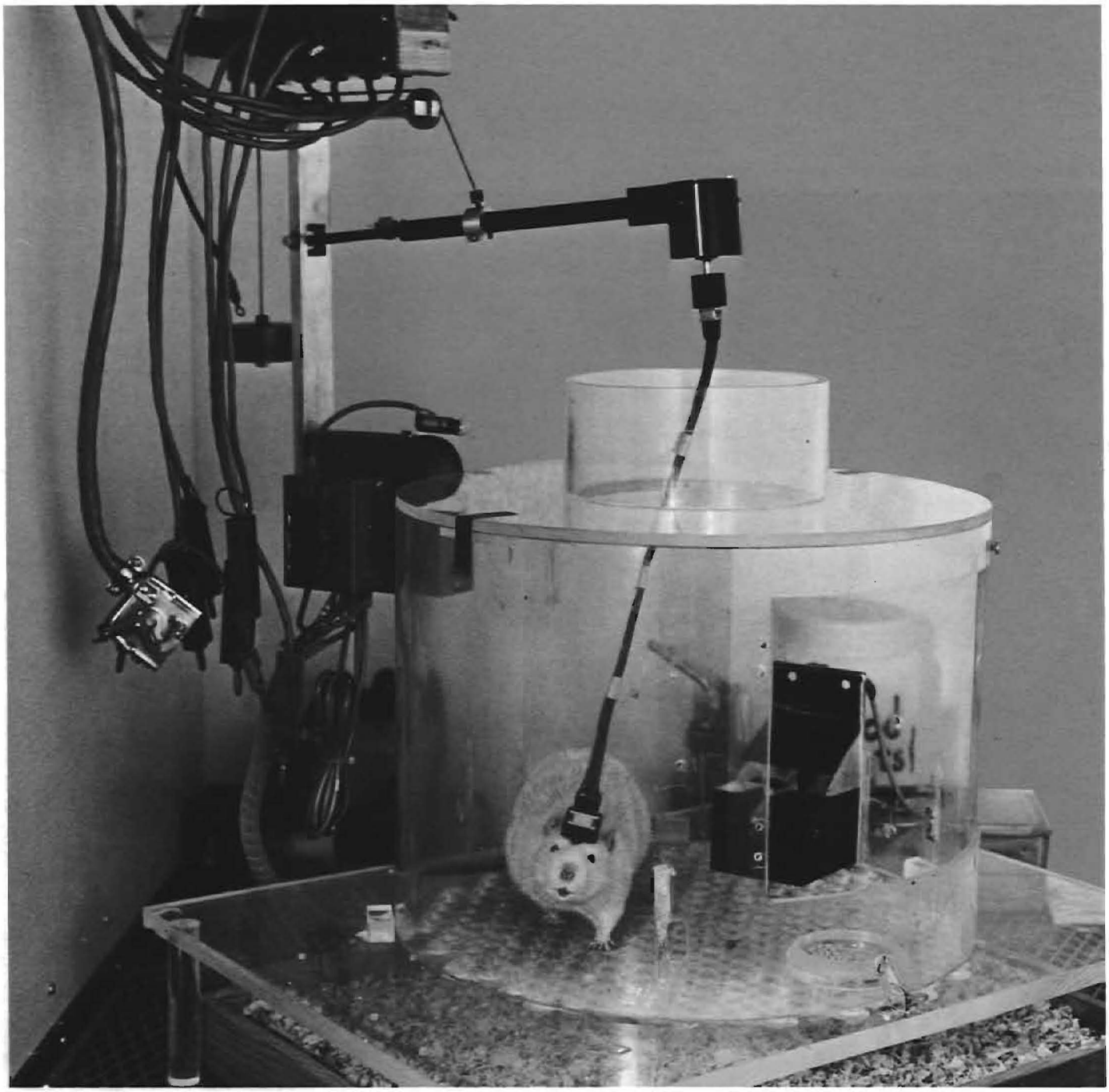
A nonmagnetic, radiation-resistant, hermetic package is being developed for several microcircuit devices, including integrated circuits of various sizes and hybrid film interconnecting circuits.

The goal is to provide a family of ceramic microcircuit packages having gold-plated copper leads, step-up bonding from chip to a minimum package pad size, controlled chip mounting area for a given chip size, and minimum sealing area suitable for use with a controlled machine sealer.

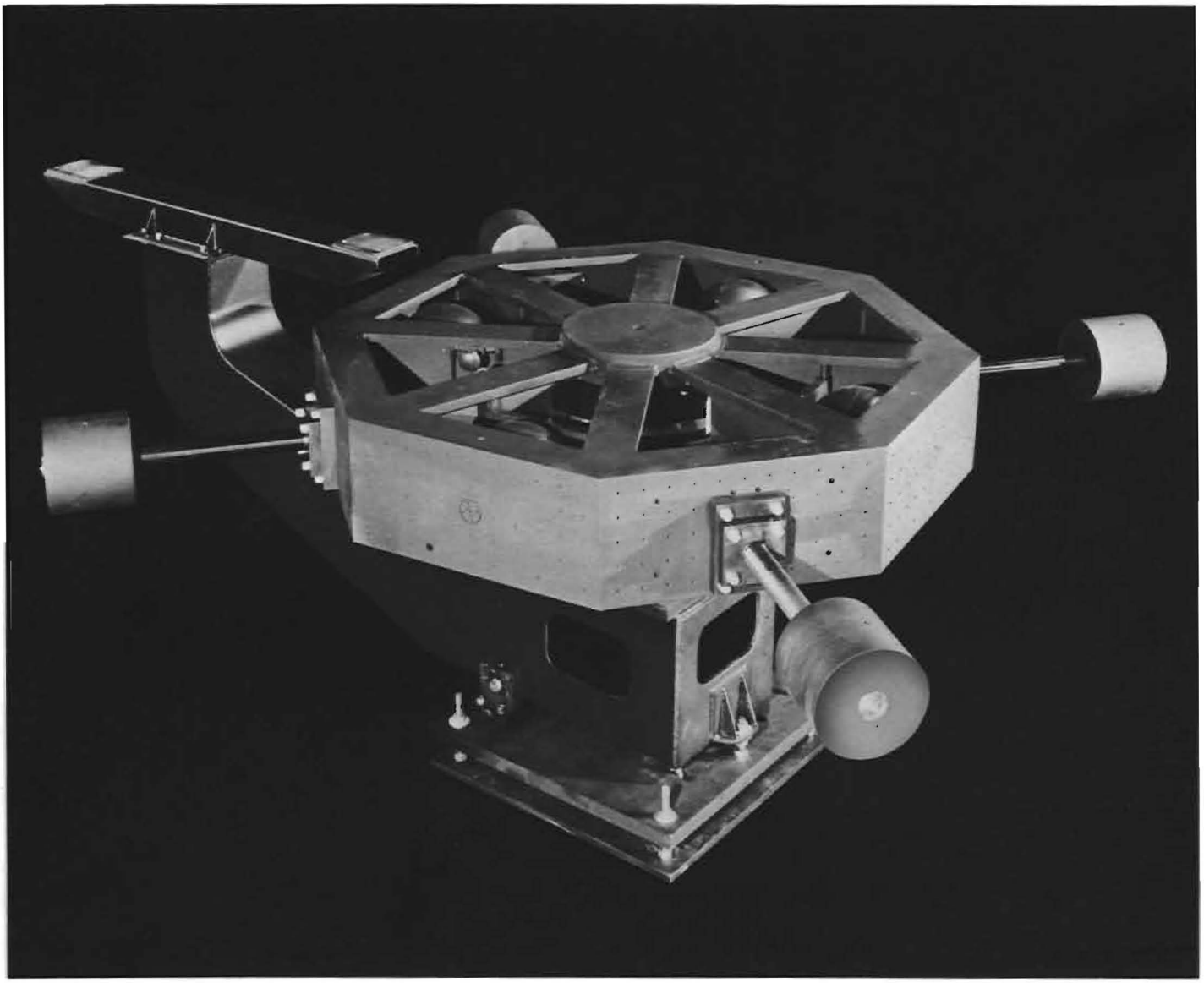
Microminiaturized thick-film hybrid driver, mounted on 1 × 1-inch substrate, designed for future planetary missions.



Laboratory rat fitted with microminiature circuit that transfers brain wave patterns to computer memory for studies of the interaction and function of different areas of the brain.



Attitude controller designed for solar-electric spacecraft.



GUIDANCE, CONTROL, AND DATA HANDLING

Program objectives in these important areas are being expanded to meet the navigational and scientific needs of outer planet missions, whose extended lifetimes impose new demands for long-lived, or redundant, systems.

Self-Testing-and-Repairing (STAR) Computer

A computer capable of automatic fault detection and repair without loss of computing time is undergoing continuing development Software programs for correcting transient errors in computations are designed to return the computation to preset program steps, where the program can be automatically restarted regardless of the computer state at the time the error occurred This "rollback" technique was recently implemented in the STAR computer It is now possible to turn the power to the computer on and off at random and have the computer continue to print the correct results In the complete machine, rollback operations will be monitored to enable the condition of the machine to be determined and to undertake repair action when permanent faults cause perpetual rollback loops

Thermoelectric Outer Planet Spacecraft Project (TOPS) Data Handling

A computer-aided telemetry system (CATS) was developed for long-term space flights to the outer planets CATS forms the nervous system for this spacecraft, collecting data from science instruments and engineering sensors, processing it, and routing it to an on-board general-purpose computer CATS can adapt itself to emphasize measurements of interest at a particular time and to compensate for system malfunctions or changing mission requirements Data processing can be tailored individually to various data sources

Data Compression

An adaptive variable-length coding system was developed for the compression of digital TV data for pictures taken on the Grand Tour missions The compressor adapts to changes in the statistical characteristics of individual pictures by switching between alternative variable-length codes The codes can be simply generated and thus require no memory for storage

Magnetic Tape/Head

Considerable progress was made in magnetic tape recorders for spacecraft data storage application. Research has revealed new and significant information on the effects of variation in environmental parameters, tape-to-head speed, and tape and head material composition

A technique was developed by which minute instantaneous perturbations in tape speed at the head can be related directly to changes in the period of a cycle of recorded signals, being independent of tape transport design or configuration This provides a valuable tool for comparison of the mechanical performance characteristics of tapes and heads and facilitates the prediction of their reliability in tape recorder applications This work was particularly successful in optimizing the magnetic tape recorder for the Mariner 1971 data storage subsystem

Solar-Electric Spacecraft Attitude Control

Solar-electric propulsion is under development for future planetary missions A spacecraft using such a low-thrust propulsion system requires a unique attitude control system A suitable controller was developed which translates the electric propulsion thruster array relative to the spacecraft center of mass to develop control torques about two axes Two of the thrusters are gimballed to obtain control torques for the third axis This mechanism consists of electronics for signal processing and hardware to accomplish the thruster translation and gimballing

Very large solar arrays will be required on this type of vehicle to provide the required electrical power A technique called hybrid coordination formulation was developed to analyze the interaction of the flexible solar array with the control system

Outer Planet Approach Guidance

A current radio tracking study indicates that spacecraft-based guidance measurements will be required for accurate navigation at the outer planets Each spacecraft must include an instrument that observes planetary natural satellites and star backgrounds during approach These observations, when analyzed on earth, should provide the flyby trajectory several days before encounter A guidance instrument has been designed, using either an extremely sensitive television camera or a channel plate image intensifier–vidicon sensor combination. The latter combination, if it proves compatible with 12-year mission lifetimes, may yield better photographs of faint stars near bright objects.

Star Sensor

A star sensor was demonstrated, using the refractive properties of a crystalline optical element to produce an electrical

signal depending on the direction to a distant light source. Labeled the EODS, for electro-optical direction sensor, the device can be used as a single-axis star tracker. It could also be used for roll-axis stabilization of a spacecraft.

TELECOMMUNICATIONS

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

Spacecraft Ranging

A prototype model for an improved ranging transponder was developed for use with a sequential code component ranging system. Current transponders amplify and transmit both the received ranging signal and the spacecraft receiver noise, thereby expending most of the transmitter power on transmitting noise when the signal-to-noise ratio is low. In the new system, called a cleanup loop, the ranging signal is extracted from the receiver noise. Only the regenerated ranging code signal is transmitted, with a resultant improvement in downlink signal-to-noise ratio of up to 46 decibels. The system will enable accurate ranging on outer planet missions.

Advanced Spacecraft Antenna

A conical antenna for furlable reflectors was developed that combines the mechanical advantages of a cone and the rf advantages of a point source feed. The conical main reflector converts an incoming plane wave to a converging conical wave, and the subreflector converts the conical wave to a spherical wave converging to a small spot where the energy is collected by a simple conventional feed. The singly curved conical reflector opens up new and interesting possibilities for furlable designs, which were not possible with conventional doubly curved paraboloidal reflectors.

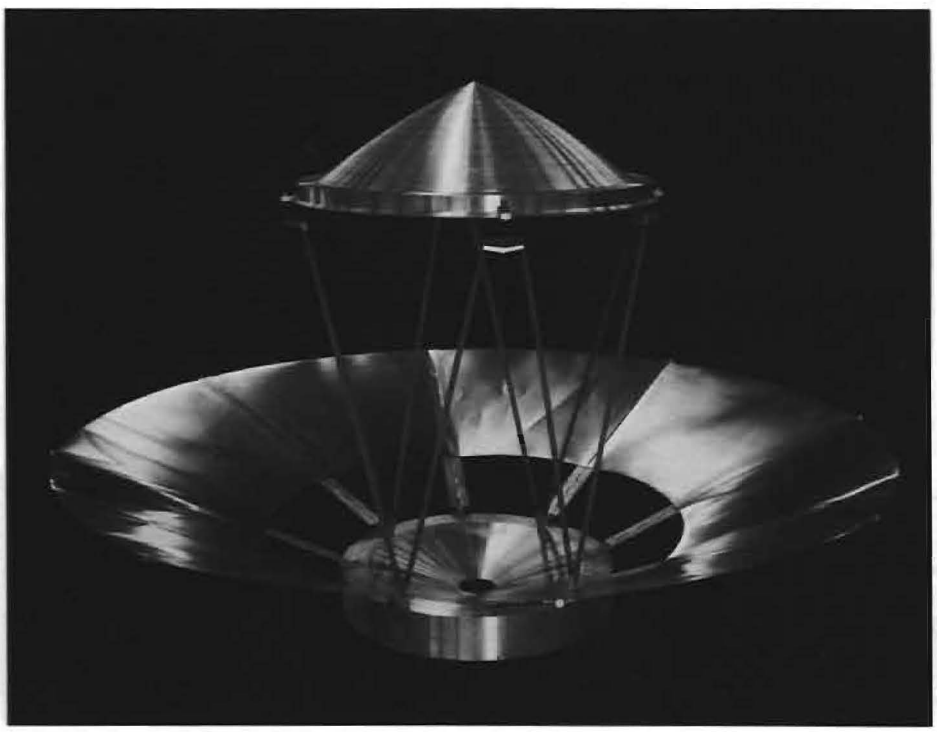
Efficient Telemetry

A more efficient telemetry system, Interplex, was invented. The interplex system preserves all the advantages of the two-channel system of Mariners VI and VII, especially the facility to receive the science and the engineering data with separate equipment, and is compatible with all existing Deep Space Network equipment. Increased efficiency results from a novel modulation technique which reduces the cross-modulation loss. The same concept also yields more efficient multichannel systems.

SPACECRAFT 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

Furlable reflector antenna shown with reflector open (left) and furled (right).



components and materials, plus rigorous testing of spacecraft and components under simulated flight conditions.

Thermoelectric Outer Planet Spacecraft Project

The Thermoelectric Outer Planet Spacecraft Project was established in 1968 and is aimed at developing the technology required for unmanned spacecraft with long life, environment immunity, and emergency adaptability characteristics. To allow mission and spacecraft design to proceed, the TOPS Project has assumed multiple planet flyby (Grand Tour) missions occurring in the 1976–1980 period.

During 1970 the TOPS effort was heavily oriented toward the development and demonstration of selected items of hardware critical to a Grand Tour type of spacecraft. Efforts expected to reach fruition in 1971 are:

1. The design and development of a high-efficiency X-band traveling-wave transmitting tube. The goal is to obtain efficiencies in the region of 40–50% as contrasted to the contemporary 20–30%.
2. The performance of a single-axis attitude control test to demonstrate the feasibility of a system involving digital celestial sensors, digital control, hot-gas thrusters, and momentum wheels, all of which constitute an advance in attitude control technology.
3. The interconnecting of the STAR computer breadboard with the measurement processor subsystem through a two-port memory, for demonstrating the core of the TOPS central data subsystem.
4. The fabrication and testing of a 14-foot-diameter deployable paraboloidal reflector surface to serve ultimately as the TOPS high-gain antenna.
5. The development of concepts of manufacturing process control and quality control screening to be applied to microelectronic circuits. The principles are being incorporated in the development and procurement of a custom metallized multigate array (CMMA) and other microelectronic devices expected to be widely used in TOPS.

Jupiter Aerothermodynamics

The atmosphere of Jupiter requires consideration of aerodynamic braking and subsequent heating of a probe entering the atmosphere at velocities from 48 to 61 kilometers per second. Simulation of the fluid flow, coupled with the intense radiant heating that such a probe would encounter, requires a significant advance in test facility technology. Existing electric-arc shock tubes, which have been adequate to simulate entry into the atmospheres of Venus, earth, and Mars, produce maximum shock velocities of about 16 kilometers per second.

Extensive redesign and development of electric-arc shock tube drivers during the past year have made it possible to obtain shock velocities up to 45 kilometers per second, almost three times that realized by past methods. This shock tube will be used to study plasma radiation characteristics at speeds approaching those of Jupiter atmospheric entry probes.

Jupiter Environment

Space vehicle design criteria were established for the planet Jupiter. Detailed engineering models were developed for the atmosphere and for electrons and protons trapped in the relatively intense magnetic field. Based on observed synchrotron radiation, electrons having relativistic energies typically much larger than that corresponding to electrons contained in the earth's Van Allen belts are trapped in the Jupiter magnetic field.

An analysis of the radiation levels encountered indicates that both the trapped electrons and protons constitute a hazard to spacecraft which fly by or orbit Jupiter.

Rocket Case Composites

A rocket motor case fabricated of boron–epoxy advanced composite material was statically tested in hydroburst. Advanced composite materials are under study for design of spacecraft antenna and pressure vessels.

The design, fabrication, and testing of a full-scale boron–epoxy rocket motor case marks the first time that an advanced composite material has been so used. This is the largest rocket motor chamber of its type yet built. Further tests will be held under actual firing conditions.

Molsink

The unique space vacuum characteristics of the 10-foot Molsink test chamber recently were applied to a study of jet spreading, or pluming, of the exhaust of rocket nozzles in space. The resulting knowledge will help avoid contamination of sensitive surfaces during space missions.

Another application of the Molsink is the evaluation of competing candidate lunar atmosphere mass spectrometers. Equipment was developed to expose these instruments to very small, but known, molecular fluxes of varying density and species while the sensors reside in the molecular void of the Molsink. The instruments' comparative responses to these fluxes will be evaluated.

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.

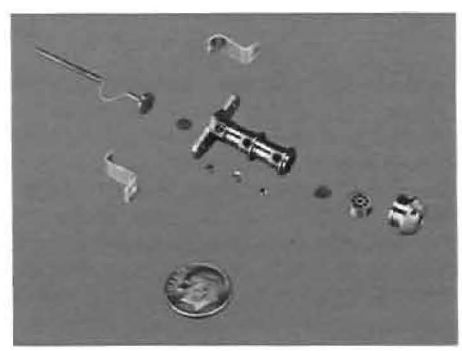
Miniature Liquid Propellant Rocket Engine

In support of the TOPS Technology Program, JPL has developed and tested an extremely low-thrust liquid propellant rocket engine. This minithruster uses hydrazine as a monopropellant and develops a thrust of 225 millinewtons (0.05 pound force).

In the TOPS mission, such thrusters will be employed to gain attitude control of the spacecraft after it leaves the launch vehicle, to unload saturated momentum wheels (used for primary attitude control), and to enable recovery from a transient excursion outside the momentum wheel control band. The thrusters will also serve as backup attitude control devices in the event of a double momentum wheel failure in a single axis.

The heart of the minuscule engine is a catalytic reactor fed by a precision capillary penetrant injector. Its delivered performance in vacuum is about two to three times greater than the performance obtained with an inert nitrogen cold-gas system.

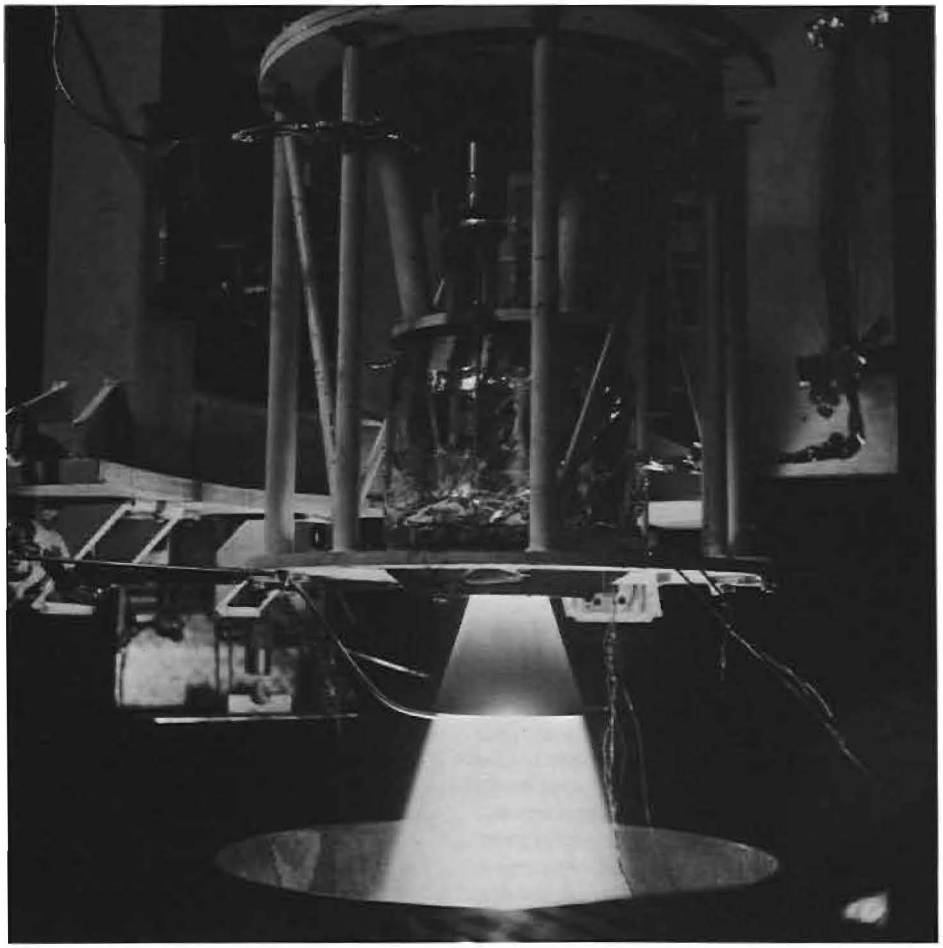
Exploded view of world's smallest (4/5-ounce thrust) liquid propellant rocket engine.



Rocket Nozzles Using Pyrolyzed Materials

High-performance solid rocket motors with long burning times (300 seconds) require the development of new, non-ablating nozzles to save weight and maximize performance. A radiation-cooled nozzle appeared to offer the best performance. Pyrolyzed composite materials are at present the most applicable for radiation-cooled nozzles. These materials are a family of carbon or graphite fibers bonded together in a carbon or graphite matrix. Nozzles made from them use the high-strength fibers as the principal load-carrying element.

Two experimental nozzles were fabricated from one type of pyrolyzed material. The first was fired successfully on a flight-weight motor containing a case-bonded,



Rocket nozzle using pyrolyzed materials shown after ignition.

end-burning propellant (60-pound) grain for 47 seconds at sea-level. The nozzle performed in a radiating (white hot) mode for approximately 35 of the 47 seconds. After the firing, the nozzle was in such an excellent condition that it was tested again, without refurbishment, on a similar motor for another 45 seconds. Equally favorable performance was obtained.

The second radiating nozzle also was fired successfully on a 60-pound flightweight endburning motor, for 47 seconds at simulated altitude conditions (135,000 feet). This nozzle, too, was in excellent condition after the test.

During radiation, the nozzles had a surface temperature of 2765°F, measured by infrared radiometer. These nozzles weigh only 52% as much as a comparable ablative flight nozzle designed to fire for 20 seconds.

The tests have proved that radiating pyrolyzed materials can be utilized effectively for lightweight rocket nozzle applications requiring long burning times.

Restartable Solid Rocket

A high-energy solid propellant rocket motor with restart capability is being developed as an upper stage for medium-class launch vehicles. In the 3000-pound class, the motor — designed for economy missions where larger launch vehicles would normally be required — incorporates a two-burn thrust system with a command liquid quench.

During the past year, the first (full-scale) motor was fabricated and tested successfully by Hercules, Magna, Utah, the propulsion development contractor. The atmospheric static test in January at Eniwetok Atoll was limited to demonstrating the first termination only. The motor incorporated a high-energy, berylliumized solid propellant grain.

Approximately 13 pounds of fluid (80% water, 20% Glycol mixture, by weight) was injected on command after 34 seconds of burn time to quench combustion and terminate thrust. An explosive-actuated valve and a 2800-psi helium gas supply mounted at the head end of the motor case were used to inject the fluid onto the burning surface of the propellant. The program is continuing into the next motor demonstration phase, to be conducted under simulated altitude conditions.

Material-Testing Ampules

For future Grand Tour missions to the outer planets, compatible longer-lasting materials will be needed to contain spacecraft propellants. Such materials are now being tested with propellants in sealed glass ampules in a new automated materials-compatibility facility.

Up to 2000 ampules can be contained in the temperature-controlled test chamber. Ampules are individually monitored by means of stress gauges. Samples can be stored for periods corresponding to outer planet missions, that is, up to 15 years. Excess pressure rises imply adverse chemical reactions and indicate need for new designs and, occasionally, new materials.

Also included in the testing program are materials being used in more immediate projects, including Mariner Mars 1971, Mariner Venus–Mercury 1973, and Viking 1975 (Mars).

Low-Acceleration-Rate Ignition

An ignition system for solid propellant motors was designed to prevent damage to fragile spacecraft sensors or structural members by producing, from an initial spacecraft acceleration transient of 0.3 g, a controlled buildup in thrust that results in a gentle acceleration rate of about 0.3 g per second. The system, called "G-dot," consists of a controlled-flow igniter that burns for 3 seconds with decreasing pressure.

The main propellant charge is highly inhibited to give a satisfactory overall starting transient when combined with that of the igniter. The igniter operating in the hard vacuum of outer space must sustain burning of the uninhibited portion of the propellant below its normal low-pressure combustion limit through mass addition and heat transfer, until the propellant surface and motor pressure increase sufficiently to provide a stable chamber pressure. Small-scale motor tests demonstrate that this approach is technically feasible. A torus-shaped igniter has been designed and fabricated and is scheduled for proof tests.

Sealed glass ampule for testing long-duration materials needed to contain spacecraft propellants for Grand Tour missions.

Improved solid propellant binder having higher specific impulse and lower burning rate than present hydrocarbon binders and tensile properties equal to polyether-based propellants.

Following these, a static test firing will be conducted at simulated high altitude in a motor containing 800 pounds of propellant.

Solid Propellant Binder

An improved solid propellant binder employing a polyunsaturated hydrocarbon was developed that appears to combine the advantages of the two principal classes of present binders — polyether and polyunsaturated carbon chains, generally cross-linked. The new material shows tensile properties equal to the best polyether-based propellants. Moreover, it has the hydrocarbon advantages of moderately higher specific impulse and lower burning rate.

The attainment of both strength and high extensibility in composite solid propellants based on cross-linked polymeric binders depends on the chain-extending capacity of the difunctional prepolymers. The new hydrocarbon prepolymer has a functionality of at least 1.9, equaling polyether prepolymers and bettering other hydrocarbons which average 1.7.

Microwave Measurement of Solid Propellant Burning Rates

An improved high-resolution microwave measurement technique was developed which permits the measurement of solid propellant burning rates under conditions of rapidly changing pressure. Tests show that the technique has a surface resolution of at least 50 microns and time response in the millisecond range. It is the first technique known to be capable of obtaining data with sufficient resolution to validate theoretical models propounded for transient combustion of solid propellants.

The technique consists of transmitting a continuous microwave beam in the X-band region to the base of a burning propellant sample cast in a metal waveguide tube. The microwave signal is reflected from the regressing propellant burning surface at a different frequency due to the doppler shift. A microwave network analyzer and a high-resolution digital data acquisition system continuously measure the phase difference between the incident and reflected signals. The propellant burning rate is proportional to the time differential.

SPACE POWER AND ELECTRIC PROPULSION

With expanding planetary goals, the need for advanced power systems will be encountered in the 1970s. Development continues in the areas of nuclear power as well as solar and battery power to satisfy upcoming requirements. Significant progress was recorded in making electric propulsion ready for application.

Solar-Electric Multimission Spacecraft (SEMMS) Start

The SEMMS effort was begun in September with these objectives:

1. To develop solar-electric propulsion (SEP) to be operational and flight-ready in the mid-1970s.
2. To devise an SEP craft of multimission capability.
3. To demonstrate flight worthiness of the spacecraft and subsystem.
4. To demonstrate the capability of an SEP craft to return science data.

The project envisions a multimission design employing Mariner 1973 and TOPS technologies.

Solar-Electric Mission Studies

The possible use of solar-electric propulsion for scientific exploration of Saturn and Mercury (by orbiters) was studied. The possibility of rendezvous with the comets d'Arrest and Encke and several asteroids also was reviewed. A survey mission to the asteroid belt using solar-electric spacecraft seems promising.

Electric Propulsion Applications

Effort was concentrated on assembling a demonstration system with the functional capabilities of an unmanned interplanetary spacecraft. These include automatic matching of the propulsion system load to available solar panel power, three-axis attitude stabilization using the electric thrust system, and automatic failure detection and correction. Electronic elements were designed to simulate vital functions. A breadboard power conditioner, modified to operate a thruster incorporating a new, long-lived cathode, was successfully tested.

TOPS Power Source

Design and evaluation studies indicated the feasibility of a multi-hundred-watt radioisotope thermoelectric generator (RTG) as the power source for TOPS. Interface, integration, and test problems were investigated, with close support from the Atomic Energy Commission, which will develop the RTG. Safety and operations problems were identified, and a procedure plan was prepared leading to RTG flight approval.

Radiation Studies

Experimental and analytical studies were performed to determine the radiation interference of the RTG with spacecraft experiments or subsystems. The experimental work involved gamma-ray interference measurements with Geiger–Mueller tubes, silicon (surface barrier and lithium-drifted) solid-state detectors, and channeltrons.

The basic equations and a computer program were developed for determining the gamma-ray self-shielding parameters of nuclear heat sources. A solution was obtained for the gamma-ray self-absorption in a SNAP-27 plutonium source.

Radioisotope Power Conversion

Three thermoelectric generators, a SNAP-27 and two SNAP 19s, have undergone performance and life testing, in support of the Atomic Energy Commission and the NASA Goddard Space Flight Center. Nuclear thermionic diodes were also tested.

In the field of isotope thermionics, several improved ring-type cylindrical thermionic converters were built and tested. These converters were designed to be capable of integration with a heat pipe to form an isotope-heated thermionic power supply of high power output.

Reactor Power Conversion

Direct conversion of heat to electricity can be accomplished in a nuclear thermionic reactor by means of electron emission from a hot emitter and collection of these electrons on a cooled collector. The JPL thermionic reactor—an external-fuel design — has several externally fueled, 10-inch-long thermionic converters. This design eliminates electrical insulator material, reduces nuclear fuel operating temperatures, and provides redundancy in the reactor cooling system.

A thermionic converter prototype and its components have been operated for nearly 1000 hours with efficiencies above 12%. After 1000 hours of operation with electrical heating, the converter will be operated with nuclear heat until failure occurs.

Solar Arrays

A program to develop 30-watt-per-pound roll-out solar arrays resulted in the design, development, test and analysis of a full-size, 250-square-foot prototype panel. Flexible solar panels are being considered for several NASA vehicles, including manned space stations and ion-engine-propelled spacecraft.

Science

A Science Office was established during 1970 to coordinate 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.

Lunar rock from Mare Tranquillitatis returned to earth by Apollo 11 crew.

LUNAR SAMPLE STUDIES

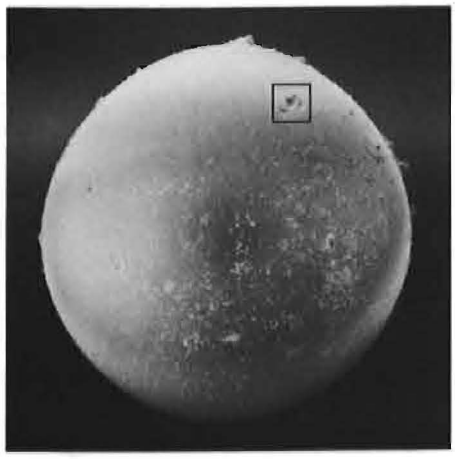
Luminescence, albedo, and spectral reflectance measurements were made on Apollo 11 and 12 lunar samples in order to determine the effects of solar irradiation and impact vitrification (glass formation) on the moon's surface. Results indicate that solar irradiation cannot produce luminescence on the moon that would be detectable from earth. Low-energy proton irradiation does not significantly affect the albedo and spectral reflectance of lunar material, while vitrification may be an important darkening mechanism.

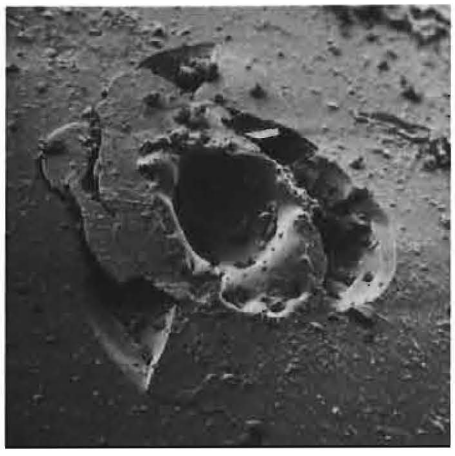
The fission track method was used to map the distribution of uranium in lunar rocks and meteorites. Uranium is found in high concentrations in zircons, phosphates, and certain zirconium–titanium-rich phases. The conditions of lunar rock formation are inferred from these distributions. A search for fossil fission tracks from an extinct plutonium isotope continues. Such fossil track evidence will provide a measure of the age of the local nucleosynthetic event which triggered the formation of the solar system.

The organic solvent extracts of the Apollo 12 lunar sample were examined for the presence of porphyrins and any other fluorescent compounds. No fluorescence that might be attributed to the presence of porphyrins was found in any extract of the lunar sample. Porphyrins, either indigenous or contaminant, would have been detected had they been present in the amount of 10^{-15} moles per gram.

Some controversy exists regarding the initial identification of the strong electron spin resonance (ESR) signals observable in the Apollo soil samples as being ferromagnetic and due to metallic iron. A detailed treatment has been carried out which supports these conclusions and from which it is possible to estimate the average particle size, average particle geometry, and weight percent of metallic iron in a lunar sample. The ESR intensity was measured as the temperature was increased. As would be expected in the presence of ferromagnetism, these measurements showed no change with rising temperature. There appears to be an approximate correlation between metallic Fe content of surface samples and geological age as determined by other means in the Apollo 11 samples. Although this observation needs further testing, it appears that ESR could be a useful survey tool for screening lunar samples according to age. ESR signals caused by Mn^{+2} were observed in two Apollo 12 samples. The line widths of these signals are characteristic for the octahedrally coordinated Mn $(H_2O)^{+2}$ ion. Intensity calibration

Opposite: Lunar soil samples collected by Apollo astronauts being examined for effects of solar irradiation and vitrification.





Top: Glass sphere, about ½ millimeter in diameter, from Apollo 11 soil showing tiny impact craters.
Bottom: Enlargement of one of the craters visible in upper right portion of glass sphere.

suggests the presence of 140 ppm water tied to Mn^{+2} in these samples. It appears that Mn^{+2} may act as a trapping site for water formed by or present in the lunar materials.

INFRARED ASTRONOMY

During the 1969 Mars apparition, some 20 hours of useful observation were obtained with the JPL Fourier interference spectrometer installed at the Coudé focus of the 107-inch McDonald Observatory telescope. Because of the extreme faintness of Mars in the 3–4 spectral region, the individual spectra are of little value. However, 16 of the best runs were averaged to produce one composite spectrum with a resolution of 0.6 cm^{-1} and a signal-to-noise ratio exceeding 50. This spectrum has been carefully examined, and some 40 features have been tentatively identified as being of Martian origin. Of these, roughly one-half manifest an unmistakable regularity. Although the features have defied identification despite both theoretical and experimental efforts, it is clear that they would represent a hitherto unknown component of the Martian atmosphere.

In a joint program of stellar spectroscopy, JPL and University of Texas astronomers have obtained an excellent spectrum of Alpha Orionis in the 3–4 micron region. Approximately 20 lines in the 1–0 band of OH and several lines in the 2–1 and 3–2 hot bands were identified. This marks the first conclusive observation of the OH molecule in the spectrum of any star.

OPTICAL ASTRONOMY

The analysis of the spectra showing the presence of precipitable water on Mars was continued. Enough good spectra have been

JPL engineer examining Surveyor III camera to determine effects of extended exposure to lunar environment.

Table Mountain Observatory.

obtained to reveal a correlation between the amount of water and the Martian season.

A study of the Connes Mars spectrum was completed. A CO_2 rotational temperature of 203°K, a surface pressure of 5 to 6 millibars, and a CO_2 abundance of 72 meter atmospheres were obtained from CO_2 lines. The CO lines in the same spectrum yielded a similar temperature of 205°K and an abundance of 0.15 meter atmosphere.

Excellent spectra of Saturn were obtained with the new Table Mountain Coudé spectrograph, establishing the presence of ammonia in the planet's atmosphere. It had been felt by astronomers that ammonia must be a constituent, but the evidence had been indirect. It is believed that the amount present is small and probably variable. The program will be continued to determine the extent of the variability.

TABLE MOUNTAIN OBSERVATORY

The Coudé spectrograph became operational this year upon the receipt of two master gratings. Initial use of the instrument with the new gratings indicated that the desired speed and spectral resolution had been achieved.

MARINER VI AND VII GENERAL RELATIVITY EXPERIMENT

Soon after Mariners VI and VII passed by Mars in 1969, an experiment to test general relativity theories was initiated. Both spacecraft were tracked at regular intervals from August 1969 to the end of 1970. The experimental data included time-integrated doppler and radar range data obtained from the 210-foot antenna at Goldstone, California. As the spacecraft reached superior conjunction in May 1970, the general relativistic time delay in the ranging signal reached a maximum of 200 microseconds for Mariner VI and 180 microseconds for Mariner VII. Preliminary analyses of the range and doppler data yielded measurements of these delays with an accuracy of from 2 to 4%. As a result, the Mariner data provided the most precise verification of the Einstein theory of general relativity yet announced.

APOLLO 12 TRACKING DATA ANALYSIS

Analysis of radio tracking data from the Apollo 12 Lunar Module as it descended to the lunar surface revealed gravity variations over several large craters. These observations are the first gravity measurements from low altitude. The results show that the regions defined by the craters Ptolemaeus and Albategnius have less than mean lunar gravity as defined by a triaxial ellipsoid. The implications are that these craters have a deficiency of mass, which is consistent with a meteorite impact vaporizing and ejecting material. This also indicates that only partial isostatic compensation has occurred. In conjunction with the mascon results, a 50–100 kilometer thick lunar crust can be inferred if a hot interior is assumed.

PLANETARY ATMOSPHERES

Photolysis of CO_2 in the 1700–1950 angstrom wavelength region is important in the lower regions of the Mars atmosphere, since shorter wavelengths are selectively filtered out in the upper regions. While the short-wavelength photolysis has been studied in some detail, it had not been determined previously whether or not the longer wavelengths were effective in photodissociation of CO_2. A study has now been made of CO_2 photolysis at 1849 angstroms, with the object of determining the primary quantum yield of dissociation, the fate of carbon monoxide and atomic oxygen produced, and the possible roles of O_3 and CO_3 in subsequent reactions. Results obtained to date show that the primary quantum yield is unity, but that in laboratory apparatus atomic oxygen, O_2, and CO can be lost from the system by secondary processes. By means of experiments capable of distinguishing the roles of $O(^3P)$ and $O(^1D)$, it has been shown that the loss of atomic oxygen occurs only at very high pressures, and involves formation of CO_3 by the reaction $O(^1D) + CO_2 + M \rightarrow CO_3 + M$. Losses of CO and O_2 appear to involve surface reactions and do not involve CO_3. Further work is in progress to determine whether similar processes may be important on the planetary surfaces.

VOLATILE HISTORIES OF EARTH AND MARS

A theoretical study of the history of earth and Martian volatiles has led to several conclusions. First, the primitive earth developed a massive atmosphere in chemical equilibrium with the extensively molten mantle and crust, as the direct result of rapid accretion; the atmosphere was highly reducing and methane-rich, and on cooling constituted the setting for abiotic organic

synthesis. Second, Mars developed a substantial reducing and methane-rich atmosphere on accretion which may have served as a suitable setting for spontaneous organic synthesis; Mars could not have developed or sustained such an atmosphere by continuing orogenic activity. Finally, the present Martian atmosphere reflects almost total alteration of the initial atmospheric composition and pressure by exospheric escape, solar wind sweeping and accretion, and interaction with surface material.

RADAR STUDIES OF MERCURY

Radar observations of Mercury made in May and June 1969 were used in 1970 to discover and locate radar-bright surface features on that planet. Such features show up best in depolarized spectra, because with such spectra the highly reflecting front cap of the planet is de-emphasized. Areas of high radar reflectivity, called spectral salients, are located along bands of the planet. These bands are the loci of those points on the planet having a doppler shift corresponding to the frequency offset at which the spectral salient occurs. As the aspect of Mercury with respect to the earth changes, the same feature produces a different band on the planetary surface. The intersections of these bands locate the feature, except for a North–South ambiguity. An additional experiment performed in mid-1970 showed that the features are permanent, since they reappear at the same location on the planet. Furthermore, a more precise estimate of the rotation rate of Mercury could be made, using the assumed coincidence of the 1969 and 1970 features. This measurement confirmed the 59-day sun-locked rotation of the planet.

PALLADIUM/HYDROGEN SYSTEMS

Investigations have been conducted into the unique properties of palladium alloys that allow the selective permeation of hydrogen through the metal. As an outgrowth of these studies, several practical devices have been designed, fabricated, and tested that may be used to perform gas analyses. These devices include a combination hydrogen generator–separator, used to generate hydrogen as a carrier gas to transport samples to analytical instruments and there to remove the hydrogen, thus enriching the sample prior to analysis. The generator–separator may also serve as a gas chromatographic detector. Using the palladium systems, a conceptual design for a microminiature gas chromatograph has been completed. These developments have application in the analysis of diverse gas samples such as planetary atmospheres and air pollutants.

FLIGHT SCIENCE EXPERIMENTS

Flight science activity involves participation of JPL personnel as scientific investigators on missions assigned to other laboratories or centers and may require the development, production, and qualification of flight instrumentation. The activity provides the practical application outlet for scientific research efforts at JPL. During 1970, work was conducted on 16 tasks, among which were the following.

ALSEP Solar Wind Spectrometer

Data returned by the Apollo 12 ALSEP (Apollo Lunar Surface Experiments Package) solar wind spectrometer show that the solar wind reaches the surface of the moon with little hindrance from lunar electromagnetic fields. However, the solar wind has occasionally been observed on the dark side of the moon, up to 20 degrees beyond the lunar terminator, which indicates that there are some fairly strong local magnetic fields on the moon. The instrument also obtained data on the plasma cloud generated by the impact of the third stage of the Saturn rocket on the moon. A second solar wind spectrometer has been delivered to be flown on Apollo 15, scheduled for launch in August 1971.

OGO Solar Wind Spectrometer

Analysis of the plasma data obtained by the Orbiting Geophysical Observatory satellite (OGO 5) has led to several important discoveries: (1) There is an electric field at the upstream edge of the earth's bow shock which accelerates the solar-wind electrons and decelerates the protons. A subsequent resonant interaction of the accelerated electrons with electromagnetic waves at the electron cyclotron frequency is also often observed. (2) A new type of plasma instability was observed to occur at a tangential discontinuity in the solar wind. (3) The electrostatic waves often observed upstream of the earth's bow shock were shown to be generated, on some occasions, by collisionless interaction of the solar wind with suprathermal protons flowing upstream from the shock. (4) During one very large magnetic storm, the dayside cusp region of the earth's magnetosphere was observed to move toward the equator, reaching a magnetic latitude of only 45 degrees.

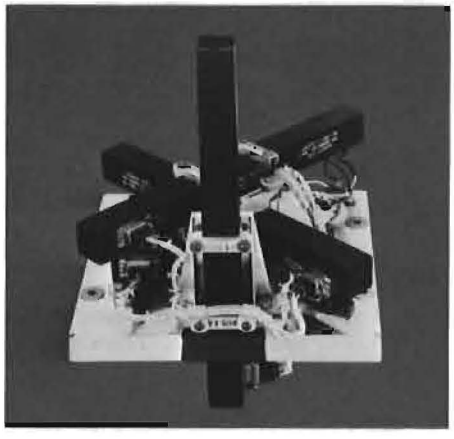
Surveyor III/Apollo 12

In 1967, Surveyor III disturbed small areas of the lunar surface in Oceanus Procellarum and sent back TV pictures of these areas. Thirty-one months later, the Apollo 12 astronauts photographed the same areas. Comparison of the two sets of pictures showed that no changes had occurred; vertical walls in the lunar soil remained vertical, dark ejecta remained dark, and no new meteorite craters, even as small as 1.5 millimeters in diameter, could be seen.

The landing of Apollo 12 near the Surveyor III spacecraft also provided an opportunity to study the effects of extended exposure to space and the lunar environment on spacecraft hardware. The astronauts brought back the TV camera and other structural members of the Surveyor camera for engineering and scientific evaluation. The scientific evaluation was aimed at investigating any effects of the 31-month lunar exposure that may have started or developed on the moon. The results of this investigation, which is still in progress, will be highly valuable to future space programs. Most of the components, materials, optics, and devices survived the vacuum, radiation, and temperature extremes encountered well beyond design requirements. Detailed results will reduce uncertainties associated with the effects of operation and long storage in the lunar and space environment.

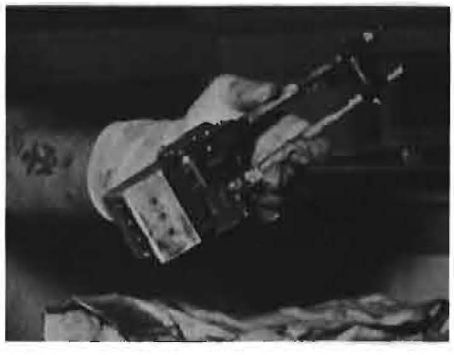
OGO Search Coil Magnetometers

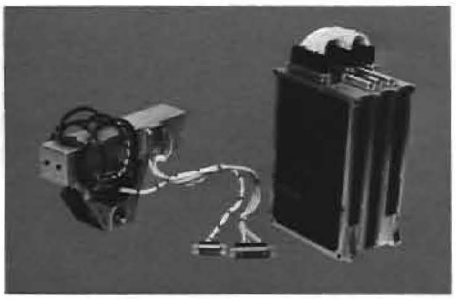
Search coil magnetometers have been flown on all six Orbiting Geophysical Observatories launched once each year since 1964. The experiment provides data on magnetic field variations in the frequency

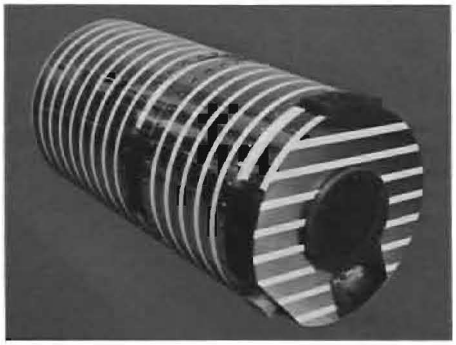


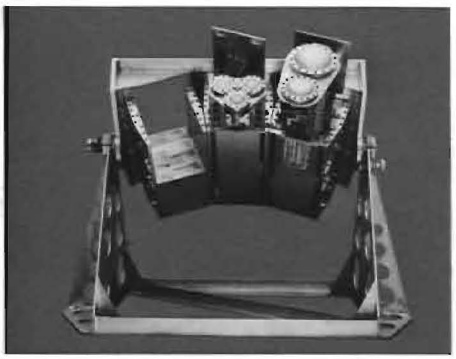
Top: OGO search coil sensors and preamplifier assembly mounted on spacecraft boom package.

Bottom: Surveyor III soil sampling scoop brought back to earth after 31 months on the lunar surface.









Top: Pioneer F / G magnetometer prototype designed for Jupiter study missions.

Center: Gamma-ray spectrometer to be flown on Apollo 15 spacecraft.

Bottom: Engineering model of Nimbus E microwave spectrometer.

range of 0.01 to 1000 hertz occurring within the earth's magnetosphere, magnetosheath, and magnetic tail as well as in interplanetary space. OGO 5 and OGO 6 remain in operation in earth orbit.

Pioneer Celestial Mechanics

Using tracking data from the solar orbiting spacecraft Pioneers 6, 7, 8, and 9, the masses of the earth and moon have been refined. Similar experiments designed to determine the mass of Jupiter and its moons are planned for Pioneer F and G scheduled for launch in 1972 and 1973.

Future Experiments

Future flight science experiments include a gamma-ray spectrometer for the Apollo 15 mission, the Nimbus E microwave spectrometer, and a vector helium magnetometer experiment to be flown past Jupiter by Pioneers F and G.

DIRECTOR'S DISCRETIONARY FUND ACTIVITIES

Insulating Thin Films

Investigation of the electrical properties of insulating films of aluminum nitride in the thickness range of 100 angstroms has demonstrated their suitability for use in charge-storage transistors. If successfully incorporated into a metal-insulator/metal-oxide-semiconductor field-effect transistor, such films would make possible a nonvolatile semiconductor memory element with long-term storage (more than 1 year) and with submicrosecond operating speeds. Such memory elements would be competitive with or superior to those of existing memory cores and significantly better than those of metal-nitride-oxide semiconductor charge-storage transistors presently under development in industry. A device based on aluminum nitride would be the first step toward a low-cost, low-power, high-speed semiconductor memory.

Nuclear Magnetic Resonance of Solids

Progress has been made in developing techniques that would allow an increase of two to three orders of magnitude in the precision with which nuclear magnetic resonance (NMR) parameters can be measured in solids. Recent developments include the completion of an NMR spectrometer capable of utilizing the Waugh multiple-pulse technique for reducing the effects of dipolar broadening in solid-state NMR spectra. In addition, NMR probes were developed that are capable of operation at very high pressure—150,000 psi for truly hydrostatic pressures, and 1,500,000 psi with some internal pressure gradients.

University Access to Nuclear Magnetic Resonance Laboratory

A trial program was initiated under the Director's Discretionary Fund to increase the accessibility of JPL's unique nuclear magnetic resonance facilities for use by the university community. Since the inception of this program, 24 valid requests for access to the facilities have been received, and thus far 16 non-JPL scientists and their students and associates have used the facilities. A number of publications by outside investigators have acknowledged substantial contributions from this program in accomplishing the research and teaching goals of those involved.

Ion–Molecule Reactions

Gas-phase ion–molecule reaction experiments were completed through a joint effort with scientists and personnel from the University of California at Santa Barbara. The study of the dependence of ion–molecule reaction rates on kinetic energy was emphasized. Some of the systems studied to date, H_2–Ar, H_2–N_2, and H_2–CH_4 mixtures, are pertinent to understanding ion–molecule reactions that occur in the upper atmospheres of the planets. The ion-cyclotron resonance spectrometer lends itself to these experiments because it operates best at or near the thermal ion energies that would be found in planetary atmospheres.

Superfluid Helium

The objective of current superfluid helium experiments is to investigate the collective modes of the vortices in a superfluid helium drop, their coupling with the free oscillations of the drop, and their effect on fission of the drop. Preliminary investigations are being conducted as a prelude to possible experiments on an earth-orbiting laboratory. One of the initial problems is how to produce vortices in a freely floating drop. One method utilizes superconducting particles suspended in the drop. Calculations show that suspended superconducting particles can indeed be used to generate vortices in the helium drop. Laboratory experiments will be performed to confirm this. Other results of the calculations show that a superconducting sphere can be used as a magnetometer in arbitrary magnetic fields. They further indicate that if a superconducting sphere or shell could be completely shielded from external magnetic fields, it could be used as an accelerometer.

Aerodynamic Braking

Aerodynamic braking of high-speed vehicles is a critical area of concern because of the large amounts of kinetic energy which will be developed in the various high-speed ground transportation systems currently being studied. It is possible that the use of aerodynamic braking to augment other braking may be a desirable approach for decelerating trains traveling at speeds of 200–300 miles per hour. Since the effectiveness of a series of spoiler-type aerodynamic brakes located along the entire length of a train is not adequately defined, it is not possible to define an optimum braking system. An experimental program was initiated in order to determine the relative effectiveness of several configurations of aerodynamic brakes along a long cylindrical body. In conjunction with this investigation, a secondary objective is being pursued: to develop testing methods required to obtain meaningful data. It is not practical to simulate the relative velocities of the train, ground, and air in a wind tunnel. To date, wind tunnel tests have been performed using three different methods. The data indicate that these testing methods result in significant differences in apparent aero brake drag effectiveness. Preparation is well under way for the final series of tests, in which relative velocity simulation will be achieved by dropping a model down vertical wires with and without a fixed ground plane.

Other Activities

PLANS AND PROGRAMS

The Office of Plans and Programs provides staff support to the Director in the formulation of operational plans and the coordination of resource allocations, the conduct of studies relevant to Laboratory goals and objectives and potential areas for application of future effort, and the investigation of candidate missions and spacecraft systems in support of JPL and NASA program objectives.

Operational and Resources Planning

Resources planning culminates in budget documentation and manpower allocation plans, and is a continuing and fundamental aspect of operational planning. During the past year or two, this work has involved unusual difficulties as a consequence of the unsettled national economy and the uncertain direction of the future national space program. In order to improve the accuracy, or at least the understanding, of future projections, 5-year forecasts of the national economic environment were prepared, and studies were undertaken to identify economic indices that would correlate with project costs and be useful in preparing or analyzing future estimates. Improved understanding of a different sort in the area of resources allocations will be provided by a careful analysis and compilation of JPL historical data.

Planning Studies

Planning studies have concentrated on assessments of NASA's future programs and identification of possible implications for the Laboratory. Subjects of concern in these studies included not only the more immediate changes that are occurring in the NASA program emphasis as a result of the phasing out of Apollo, but also the general influences that may evolve from a re-ordering of national priorities and from the generally declining public interest in and support for the space program. The Laboratory's interests and capabilities outside of the Planetary Program, in which it is primarily involved, were re-examined from the point of view of possibly developing broader support by JPL of the total NASA effort.

Advanced Technical Studies

During 1970, the lunar and planetary advanced study groups continued their work in defining future mission goals and in identifying and solving problems expected in future projects. Studies of mobile missions on the surfaces of the moon and Mars were accompanied by laboratory experiments on some of the required imaging, navigation, and remote analysis techniques. Studies of flyby missions to the outer planets were completed, and the work was taken up by other Laboratory groups in preparation for the Grand Tour project. Studies of missions to comets, satellites, and asteroids are continuing, as are studies of missions which involve orbiting the outer planets or probing their atmospheres.

The Laboratory's advanced studies relate particularly to those objectives that are extremely demanding of automated space flight technology, or closely coupled to the progress of science in understanding the origin and evolution of planetary systems and life forms.

Some study results obtained in 1970 include the following: (1) landmark navigation of automated roving vehicles was demonstrated, (2) a questionnaire was circulated among interested scientists, and the results analyzed to define requirements for mobile lunar surface scientific investigations, (3) rock and mineral identification via television was demonstrated, (4) design requirements for basic and extended outer planet missions were set forth, (5) problems of a 1976 mission to the comet D'Arrest were investigated and a mission analysis was prepared, (6) Jupiter atmospheric entry

probes were analyzed, and (7) updated mission requirements were prepared for Mars orbiters and rovers.

CIVIL SYSTEMS

In its first year of operation, the Civil Systems Project Office considered various avenues of applying space techniques to earthly problems. The Space Technology Applications Office dealt with urban, public safety, and medical engineering proposals, and the Transportation Technology Office provided research and development support to the U.S. Department of Transportation (DOT).

Computer-Controlled Cars Project

The first transportation development effort—the Morgantown, West Virginia People Mover Project—was initiated, with JPL's selection as system manager for the DOT's Urban Mass Transportation Administration. This major demonstration project will comprise about 100 electrically powered, computer-controlled cars operating on an elevated guideway.

It will be designed to connect, over about 6 miles of guideway, the three campuses of West Virginia University in hilly Morgantown. Most of the passengers will be students, although the system will be available to the general public. Stations will be offline, so that a passenger entering a station can select his destination and be transported there automatically.

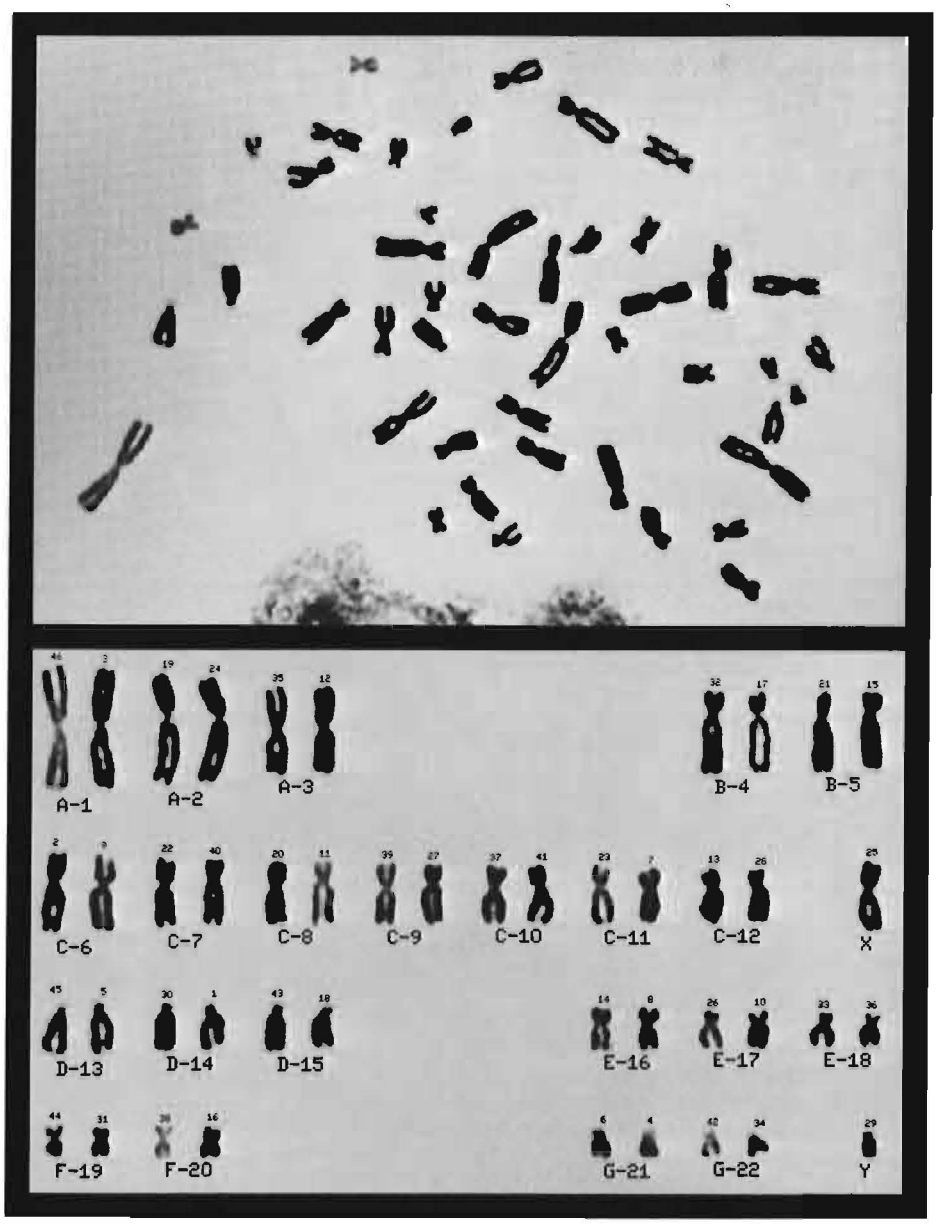
In designing and developing the system, JPL will make use of industrial contractors with applicable experience.

Train-Tunnel Studies

Many rapid transit systems require trains to operate in tunnels in which the train occupies half or more of the tunnel cross-section area. In such a system, the train drag force can be ten to a hundred times greater than outside of a tunnel; hence, a substantial amount of motive power is required to overcome the aerodynamic resistance.

To study the air-flow phenomena about the train and through the tunnel, an experimental program was initiated at JPL in conjunction with theoretical work being performed by the Aeronautics Department at Caltech. Tests are being conducted in a 70-foot-long, 2-inch-diameter, vertically oriented tube that simulates a tunnel about a mile long. A general understanding of the aerodynamic principles involved has been achieved.

Chromosomes in a human blood cell shown highly magnified before (top) and after (bottom) being sorted, numbered, and classified (karyotyped). Using the same computer that enhances photographs of the moon and Mars, researchers can produce a karyogram in one tenth the time required by other methods. Karyotyping is presently used to detect hereditary disorders in patients. The goal is to develop a computer system small and economical enough so that the process could be applied in such areas as the detection of genetic defects in infants, premarital blood tests, and the investigation of the genetic effects of environmental and industrial poisons, drugs, and atomic radiation.



The Department of Transportation has made funds available to continue the theoretical and experimental studies.

PUBLIC AFFAIRS

Open house, conducted in May, drew 20,000 Laboratory and contractor personnel and their families, and an additional 10,000 visitors from communities surrounding Pasadena. A bus tour included NASA walk-in space exhibits, historic JPL spacecraft on the mall, and a variety of science and engineering displays.

Public Educational Services established a series of seven specialized seminars for neighboring high school students and faculty. Each seminar treated a different discipline in science. Video-tape recordings were made of all seminars to form a library for use by schools and educational television facilities for supplemental instruction purposes.

The Public Information Office, with the Photography Section's motion picture group, produced two color documentary films during the year, "The JPL Story" and "Mariner Mars '69."

PERSONNEL

The Employment Group coordinated a Minority Skills Survey of the Northwest Pasadena–Altadena community, which resulted in the establishment of an Urban League Skills Bank. Details on skills available in the community had not previously been centrally recorded.

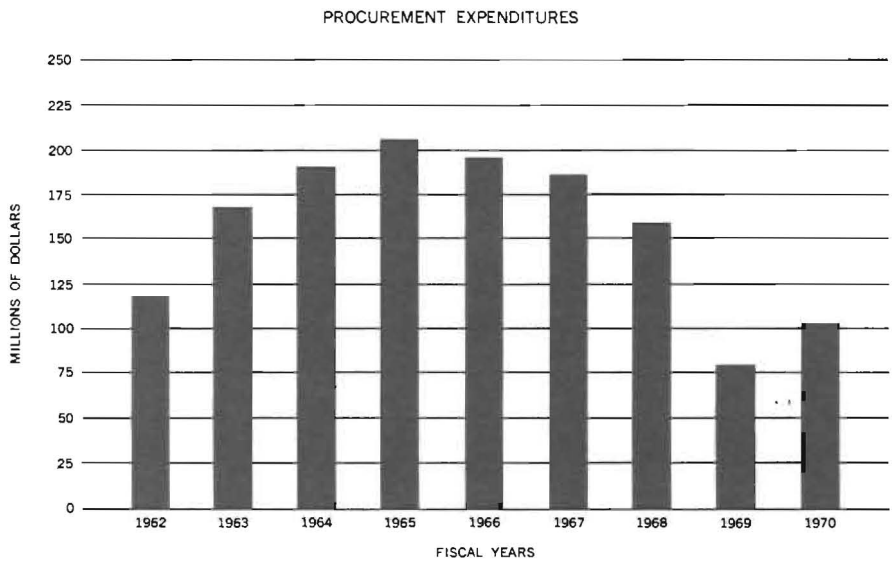
The academic part-time employment program has proven successful in promoting campus exposure to space technology. During the year, over 200 students and professors were employed in this program.

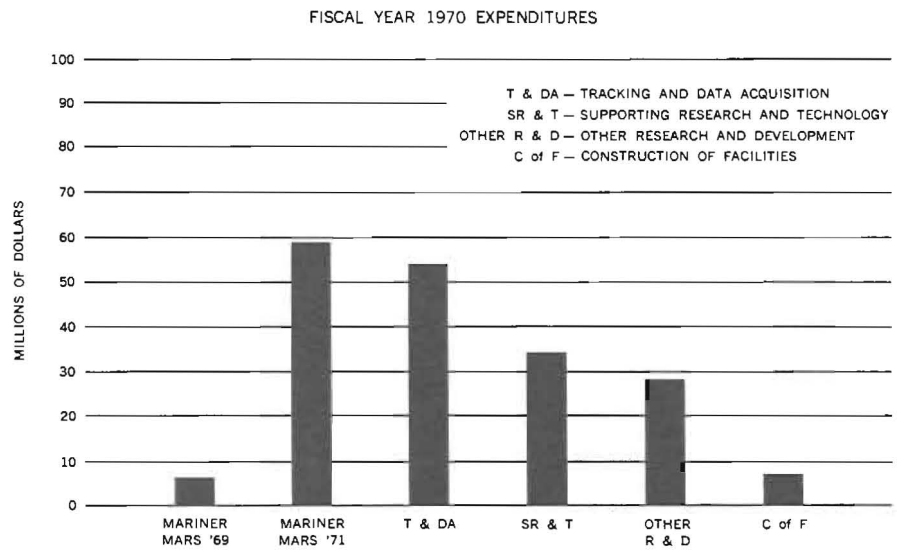
Two hundred and thirty-five persons were employed under the Summer Employment Program. As in the previous year, 45 of these were young people hired under the President's Youth Opportunity Program.

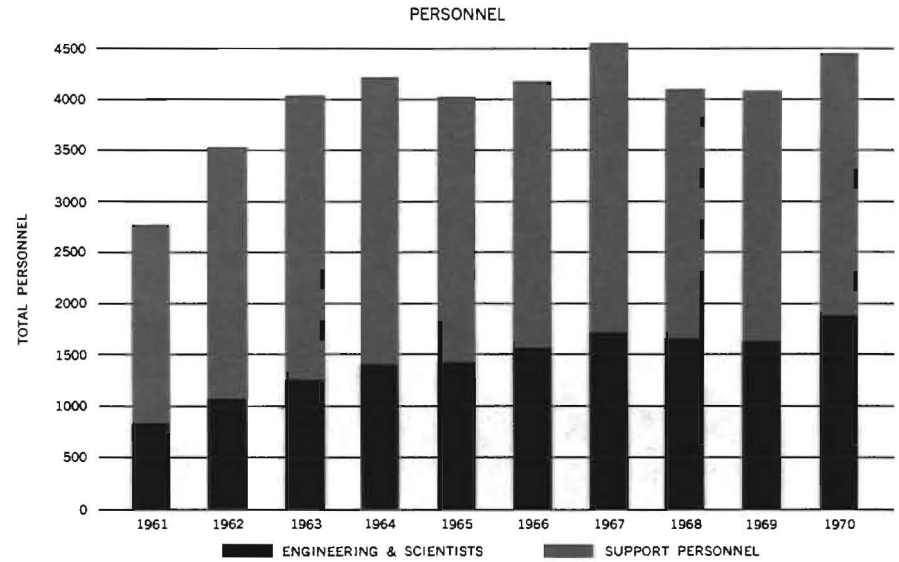
Following an Employee Development Survey, the emphasis in management training was shifted from general principles of management to basic communications skills. Courses are offered in how to conduct meetings, how to write clearly, how to communicate, and how to make an effective presentation. Management courses were condensed into shorter time periods to conserve the work time of participants and to intensify the impact of the courses.

Technical courses were enhanced by making greater use of demonstration equipment, and one classroom was remodeled to provide for more effective use of video and other audio-visual equipment.

Courses in the computer area were offered to familiarize employees with the capabilities of the Univac computer. JPL employees served as instructors. Closed-circuit television was extensively used as a medium of instruction.







FACILITIES

Construction was started on the Systems Development Laboratory in September 1970. To be completed by July 1, 1971, the building will be two stories high, with the capability of adding six stories at a later date, and will contain 30,000 square feet of space. The second floor of the building will be occupied by the Mission Support Area for the Mariner Mars 1971 Project.

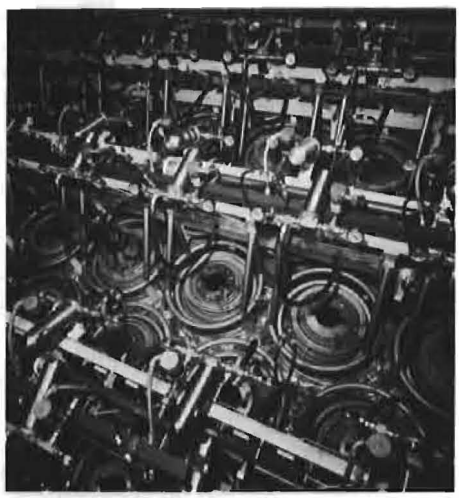
An 8000-square-foot addition to Building 241 was completed in November 1970. The two-story addition will house financial management offices and a quality assurance area, and will enlarge the stores receiving area.

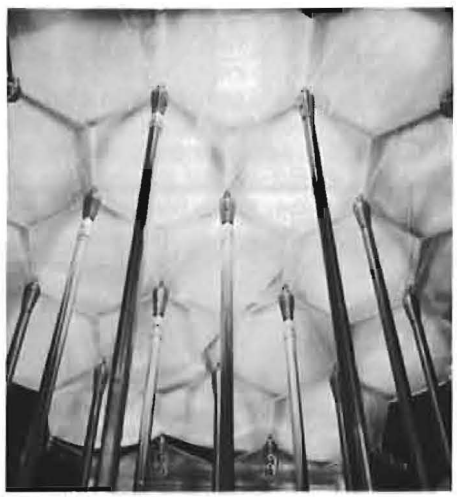
Funds were received for the design of two technical facilities, both of which will be built during 1971. The first, a modification to the JPL 25-foot space simulator, will increase the intensity of the solar simulation system to the level expected to be encountered by the 1973 Venus–Mercury flyby spacecraft and will provide a test capability for the West German Helios spacecraft. The second facility 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 spacecraft. Construction is expected to start early in 1971 and to be completed in the spring of 1972.

Construction was completed on a new permanent Headquarters Building at the Table Mountain Facility. The Headquarters Building will house the site manager and will provide a kitchen, dining–lounge, conference room, library, and four sleeping rooms for astronomers.

Design was started on a two-story addition to, and proposed remodeling of, Building 190 to provide larger and more adequate housing for the Procurement Division.

Approval was received from the City of Pasadena and other concerned agencies to construct a new two-lane concrete bridge across the Arroyo Seco stream bed to replace the old one-lane Bailey Bridge.





Elements of the modified solar simulation system in the 25-foot space simulator. Top left: Array of 37 xenon arc lamps mounted in a water-cooled reflector (seen from below). Top right: One of two arrays of 19 lenses each which condense, project, and integrate the illumination from the lamps. Bottom: 23-foot-diameter spherical collimating mirror (seen from spacecraft test position).

SPECIAL RECOGNITION

This list of awards and appointments is illustrative rather than complete. It is intended to indicate the involvement of JPL personnel in the government, academic, and professional communities and to reflect recognition of their accomplishments and contributions.

NASA Awards

W. H. Bayley, NASA Exceptional Service Medal for outstanding and sustained leadership and management of the Deep Space Network.

P. F. MacDoran and W. L. Martin, NASA Exceptional Scientific Achievement Medal for their contributions in the design, development, and operations of the fast-acquisition ranging machine which made possible the general relativity experiments of the Mariner 1969 extended mission.

M. Neugebauer and C. W. Snyder, NASA Exceptional Scientific Achievement Medal for the conception and execution of major experiments in interplanetary space designed to detect and measure the properties of the solar wind.

E. J. Smith, NASA Exceptional Scientific Achievement Medal for outstanding scientific leadership in the exploration of magnetic fields in interplanetary space and of Venus and Mars.

H. J. Stewart, NASA Exceptional Service Medal for significant contributions to the planning of NASA space missions.

E. V. van der Wyk, NASA Exceptional Service Medal for exceptional effort, dedication, and initiative resulting in the timely publication of the scientific data obtained by the Surveyor and Mariner VI and VII spacecraft.

Academic Honors and Appointments

W. H. Bayley, 1970 Distinguished Alumnus Award, School of Engineering, University of Southern California.

M. F. Easterling, Research Associate in Applied Science, California Institute of Technology.

R. M. Goldstein, Visiting Associate Professor, Planetary Sciences, California Institute of Technology.

A. C. Ludwig, Research Associate, Laboratory of Electromagnetic Theory, Technical University of Denmark.

R. T. Menzies, Research Fellow, Electrical Engineering, California Institute of Technology.

R. F. Miles, Jr., Visiting Assistant Professor, Aeronautics and Environmental Engineering Science, California Institute of Technology.

E. C. Posner, Visiting Lecturer in Electrical Engineering, California Institute of Technology.

Professional Recognition

M. Geller, Fellow, American Physical Society.

S. Gulkis, Member, International Astronomical Union.

R. F. Landel, Fellow, American Physical Society.

D. D. Lawson, Member, American Academy of Forensic Scientists.

Jet Propulsion Laboratory Executive Council

W. H. PICKERING, *Director*

J. E. CLARK, RADM—USN (Ret), *Deputy Director*

W H. BAYLEY	*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*
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*

Jet Propulsion Laboratory Visiting Committee

M J ZUCROW—*Chairman*
Santa Barbara, California

K A ANDERSON
University of California at Berkeley

J H BOLLARD
University of Washington

W BOLLAY
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