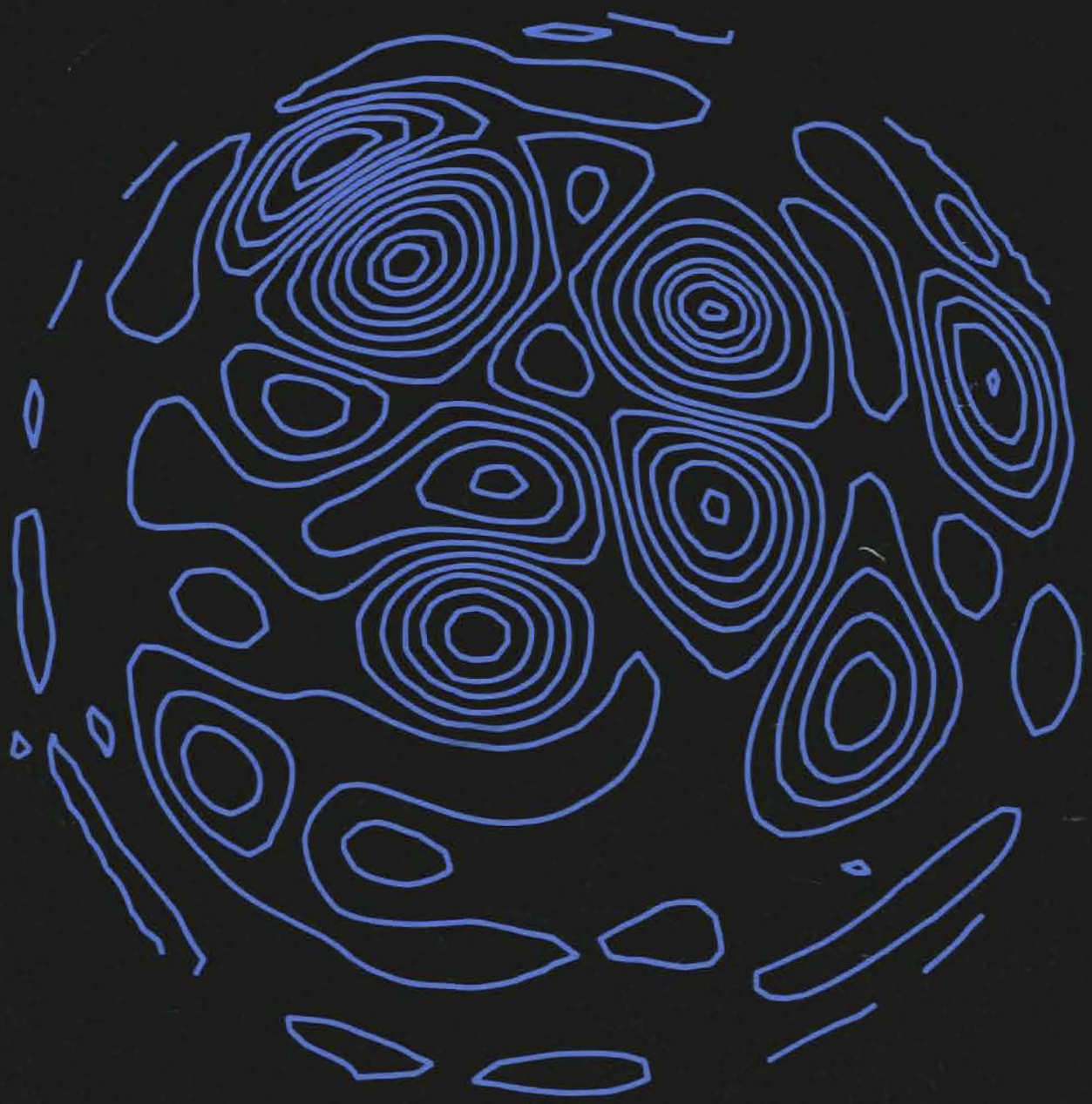
JET PROPULSION LABORATORY
1968 ANNUAL REPORT



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, 1968, to December 31, 1968

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Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive, Pasadena, California 91103

Front cover: Gravimetric map of the moon's near side outlining areas of mass concentrations (mascons) of dense material beneath the lunar surface (see p. 13)

1968 began and ended with the participation of the Jet Propulsion Laboratory in major U. S. space flights. In January, the Laboratory conducted the mission of Surveyor VII — the last of five highly successful soft landings on the moon that helped prepare the way for the manned lunar landings planned for 1969. In December, JPL's Deep Space Network supported the nation's first manned lunar orbital flight, the Christmas mission of Apollo 8.

In addition to providing tracking and data acquisition for these missions and for three earlier Apollo flights made during the year, the Deep Space Network also supported four Pioneer interplanetary probes and the extended phase of the Mariner V Venus flyby mission. Pioneering pulsar observations at S-band, radar observation of the asteroid Icarus, and detailed mapping of the planet Venus are typical of the radio science support activities engaged in by the Deep Space Network, in most instances using the 210-foot antenna at Goldstone, California. Authorization was received to construct two additional 210-foot antennas at overseas locations to complete a worldwide subnetwork.

Progress was made toward the final phases of engineering and development of the Mariner spacecraft scheduled for Mars flyby flights early in 1969.

Research and development continued to spearhead the Laboratory's efforts. For example, a new, highly accurate mathematical method for determining atmospheric structure by measuring the intensity of outgoing radiation was developed and then applied to the reduction of data obtained from a balloon flight during July. This method not only has broad implications in worldwide weather prediction but can be used to determine the atmospheric structure of other planetary atmospheres.

In some respects, 1968 marked the end of an era for the Jet Propulsion Laboratory, as it did for the nation and for the California Institute of Technology. Caltech's new president, Dr. Harold Brown, will take office at about the same time President Nixon is inaugurated; for the Laboratory, 1969 begins a new agreement extending the existing JPL contract between NASA and Caltech for 3 years. Supplementing the contract is a memorandum of understanding which establishes new principles for the operation of the Laboratory. For example, impetus will be given to developing relations between the Laboratory and the academic community. Discretionary funds established to support research and development will be used to increase faculty and student participation in JPL programs and also to explore new fields of research appropriate to the Laboratory's capabilities.

Having made significant contributions to the early stages of space exploration, the Jet Propulsion Laboratory is prepared to continue its participation in the nation's space program and anticipates the opportunities of the new era with confidence.

W. H. Pickering
Director

Dr. L. A. DuBridge, President, California Institute of Technology, and Dr. W. H. Pickering on the occasion of Dr. DuBridge's resignation from Caltech to accept the position of Science Advisor to the President

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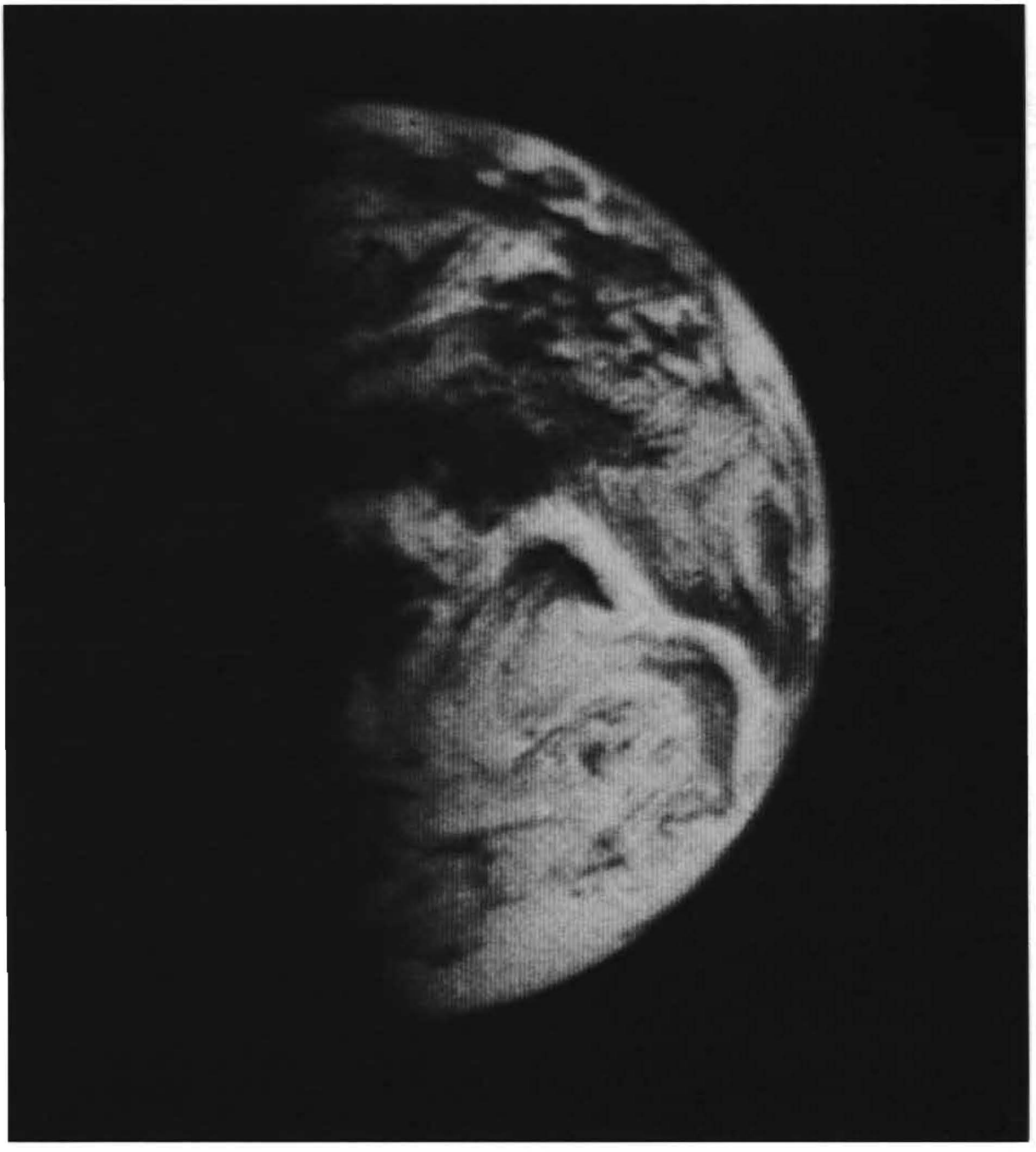


Meteorological photograph of the earth taken by Surveyor VII in January 1968 shows the North American continent.

SURVEYOR

The Surveyor flights were brought to a successful conclusion with the landing of Surveyor VII on the moon in January 1968 The missions explored lunar mare as well as highland terrain and provided significant topographic and scientific information about the moon

Surveyor VII

Surveyor VII was launched from Cape Kennedy on January 7, 1968 As the launch guidance parameters had to be fixed some months in advance, before the landing site was chosen, a large midcourse maneuver, equivalent to over 1000 kilometers at the moon, was necessary This maneuver was performed so accurately that the spacecraft touched down within 1 5 kilometers of the center of the target circle The site, chosen for its scientific interest, was in the southern highlands, on the outer rim of the crater Tycho, in an area expected to be different in character from the maria in which the earlier Surveyors landed

Surveyor VII was the only spacecraft in the series to carry both an alpha scattering instrument for chemical analysis of the lunar surface and a soil-mechanics surface sampler for determining surface mechanical properties A unique advantage of this combination was revealed when the alpha scattering sensor head failed to deploy normally to the lunar surface The surface sampler was used to free the sensor head and push it down to the surface, thus salvaging the alpha scattering experiment Later it was used twice more to pick up the alpha scattering sensor head and move it to new positions on the lunar surface to obtain additional analyses These provided composition determinations on a total of three lunar samples undisturbed fine surface material, fine subsurface material, and a surface rock

The surface sampler itself performed static and dynamic bearing tests and a number of trenching operations It also picked up, weighed, and broke rocks Magnets carried by the surface sampler picked up a 1-centimeter particle that was evidently magnetic Special sensors on the spacecraft furnished data on thermal and radar properties of the surface (for example, a pile of rocks near the spacecraft cooled much more slowly after sunset than did other surface areas)

The television camera, equipped with polarizing filters, returned over 21,000 pictures, including views of the solar corona and earth. The spacecraft also transmitted pictures of argon ion laser sources located at Kitt Peak, Arizona, and at the JPL observatory at Table Mountain

Surveyor VII operated throughout the first lunar day of its landing and for 80 hours into the lunar night; it resumed operations on the second lunar day, continuing until February 21, 1968

Scientific Results of the Surveyor Project

Surveyor VII was particularly valuable in comparing characteristics of the maria with those of a rather fresh highland area The differences on the whole were found to be relatively small compared to the similarities The Surveyors showed that both mare and highland surfaces consist of a layer of fine particles, weakly cohesive, with larger rocks scattered in and on the fine matrix. The mechanical properties of the soil layer are almost identical in highland and maria, and rather similar to those of a terrestrial garden soil, but change rather rapidly with depth The fine particles have moved across the surface, mostly downhill.

The density of the one rock measured corresponded, within experimental accuracy, to that of solid basalt The rocks examined showed considerable evidence of erosion, presumably by micrometeorite impact

The chemical composition of the soil matches that of a basalt in both highlands and maria, with a lower iron content in the highlands. This points to large-scale differentiation by melting and resolidification. Also, the difference in iron content suggests a lower density in the highlands, with the implication that at least partial isostasy exists on the moon.

Some other differences between highland and maria were noted For example, rocks larger than 10 centimeters were much more common at the highland site than in the maria, and the depth of the soil layer was more variable

In addition to providing information on the solid body of the moon, the Surveyors proved useful in studies of solar system mechanics and astronomy Surveyor data have permitted verification of an improved lunar ephemeris, for example Observations have shown that the polarization of earthlight arises primarily from reflection off the oceans at angles close to specular, and that the outer solar corona (F-corona) extends out to distances which match those for zodiacal light.

MARINER

At the end of 1968, having successfully concluded the Mariner V flight, JPL was preparing for three additional Mariner missions to Mars In 1969, two 900-pound

Liftoff of Surveyor VII from Cape Kennedy on January 7, 1968. Last of the Surveyor series, the spacecraft landed in the rugged southern highlands of the moon on the rim of the crater Tycho.

Mariners will fly by Mars; in 1971, two 2000-pound Mariners will orbit the planet; and in 1973, two 6000-pound Mariner-class spacecraft (Project Viking under the direction of Langley Research Center) will orbit Mars and detach soft landers that will explore the surface.

Mariner V

The Mariner mission to Venus in 1967 was launched from Cape Kennedy on June 14, and closest approach occurred on October 19. Analysis of the data, completed during 1968, indicated that (1) the magnetic field of Venus cannot be larger than 0.005 to 0.001 that of the earth, (2) there are no detectable radiation belts, (3) an atomic hydrogen cloud is present, but there is no atomic oxygen, (4) the ionosphere stops abruptly at 370 miles above the surface on the day side, and (5) the surface pressure is between 60 and 100 earth atmospheres if the U. S. radar measurements of the planet diameter are correct.

Radio contact was re-established with Mariner V on October 14, 1968. The signal was weak and displaced from the expected frequency. The spacecraft was tracked for a period of approximately 3 weeks, during which time it was determined that no further telemetry or command capability could be established with the spacecraft. Therefore, effective November 5, the mission was declared terminated.

Mariner Mars 1969

The Mariner Mars 1969 Project will launch two 900-pound spacecraft in early 1969 for mid-summer flyby encounters. Mission objectives are exploration of the planet and establishment of a basis for future experiments, particularly those related to the search for extraterrestrial life.

During 1968, three sets of flight-qualified spacecraft subsystems and scientific instruments were completed, tested, and assembled into spacecraft, which were shipped to Cape Kennedy at the close of the year. The spacecraft design and the individual flight articles were qualified through an intensive program of environmental and functional tests, and the scientific sensors were calibrated.

In addition, the two Atlas/Centaur launch vehicles were completed, tested for compatibility with the spacecraft, and shipped to the Cape; modifications were made, and training and test programs were conducted to develop tracking and data acquisition support by the Deep Space Network and other ground facilities; programming and planning of the mission operations were carried out;

design of the flight mission, particularly of the complex Mars encounter sequence, was prepared and reviewed.

No continuous cruise science operations are included in the 1969 Mariner mission. The six scientific experiments, four of which use special instruments aboard the spacecraft, will obtain their data at the planet.

Television pictures in three groups (long-range approach pictures of the disk of Mars, wide-angle, medium-resolution surface pictures, and narrow-angle, high-resolution surface pictures) are to be obtained. An infrared radiometer will track the center of the picture swath. Infrared and ultraviolet spectra will be taken to obtain atmospheric composition data. A radio occultation experiment similar to that performed by Mariner IV will seek additional information on atmospheric physical properties, and a celestial mechanics experiment will use spacecraft tracking data to improve the accuracy of the mass, orbital, and spatial parameters of Mars. An attempt will be made to detect general relativistic effects on the spacecraft.

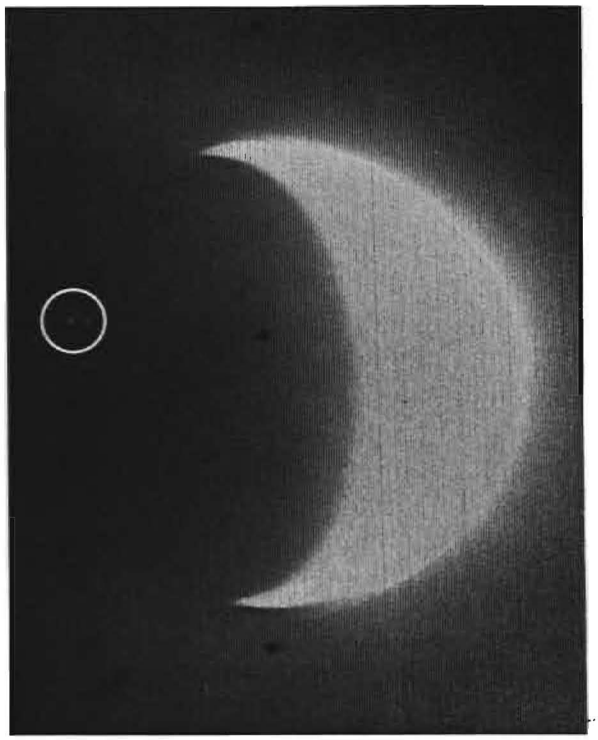
More than two dozen scientists and engineers, representing eleven universities, government, and corporate laboratories, serve on the various experimenter teams.

The scientific investigation of Mars will be greatly enhanced by new communications and control features on the Mariner 1969 spacecraft. An experimental high-rate telemetry system (16,200 bits per second) will speed the return of data as well as allow more information to be returned from the planet, while a large increase in the data storage capacity will permit the storage of a great quantity of television and other complex data. The development of a two-degree-of-freedom scan platform large enough to mount all the scientific sensors provides great flexibility in instrument pointing and scanning. Mariner Mars 1969 will be the first planetary spacecraft to use a programmable computer which permits in-flight changes and additions to the planetary observation sequence to be made with nearly the flexibility of real-time remote operations.

Thus, at the end of 1968, the next step in the exploration of Mars is about to be taken in the form of a difficult, sophisticated, and ambitious mission.

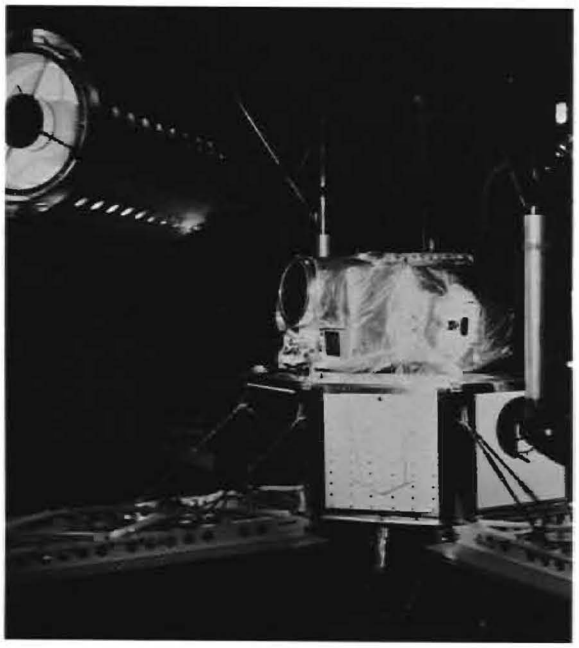
Mariner Mars 1971

The Mariner Mars 1971 Project was authorized in November 1968 and is in the planning and preliminary design phase. As a follow-on to the Mariner Mars 1964 and 1969 Projects, the 1971 Project will draw heavily upon equipment proved and knowledge gained on these earlier missions to perform two Mars orbiting missions.



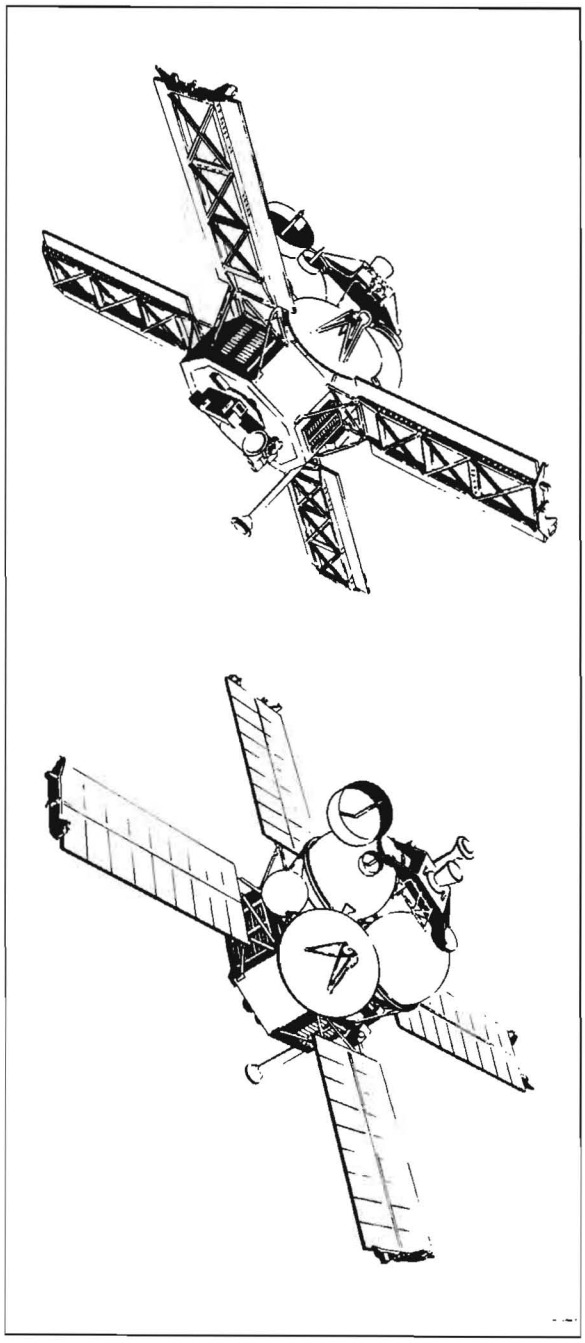
Top: Rocky lunar terrain photographed by Surveyor VII showing crater rim on the horizon

Bottom: Laser beams aimed toward Surveyor VII site from the earth and relayed back by spacecraft TV camera



Top: Surveyor VII's soil sampler freeing jammed alpha scattering instrument

Bottom: Light reflectance test being performed on model of Mariner Mars 1969 spacecraft



Views of Mariner Mars 1971 orbiter — baseline spacecraft configuration

Two identical spacecraft will be launched in May 1971, will arrive at Mars in November, and will be placed into different orbits around the planet. The missions will be designed to study characteristics of the planet from orbit for a minimum period of 90 days. During this period, data will be obtained on atmospheric composition, density, pressure, and temperatures and on surface composition, temperature, and topography. Approximately 70% of the planet's surface will be covered, and time dependence of the various phenomena will be recorded.

The science payload of the Mariner Mars 1971 Project will provide for detailed imaging and spectrographic observations from orbit; additional instruments will perform measurements during the cruise phase prior to planet arrival. Eight major experiments are currently planned, supported by six separate science instrument subsystems and the radio tracking system. Most of the science instruments will be mounted on a Mariner Mars 1969-type movable scan platform.

A major feature of the spacecraft is a large (300-pound- thrust) rocket motor to decelerate the spacecraft and place it into a Mars orbit. The mission will provide rapid transmission of data from orbit, allowing the use of these data to guide subsequent observations.

Because of the similarity of design, the Mariner Mars 1969 spare flight spacecraft will be reworked and converted into one of the Mariner Mars 1971 flight spacecraft; the Mariner Mars 1969 proof-test model (a flight prototype) will be modified for the 1971 Project.

ADVANCED PLANETARY MISSION TECHNOLOGY

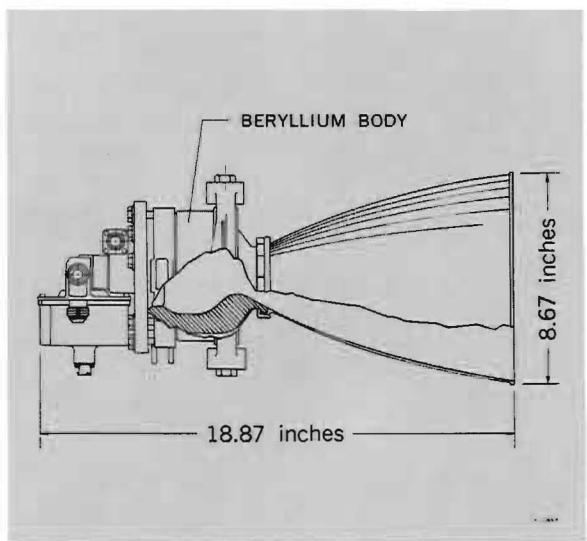
During 1968, the Advanced Planetary Mission Technology (APMT) Program provided support to the Laboratory and to NASA in the evaluation, definition, and planning of potential planetary programs.

Synopses were prepared for a total of 26 candidate missions to Mars, Venus, and Mercury. Detailed studies were completed of Mariner Mars 1971, Titan Mars 1973 (Project Viking), and Mariner Venus/Mercury 1973 missions. Limited studies were conducted on Venus/Mercury 1970 and Venus 1972 missions. In response to special requests from NASA Headquarters, detailed scheduling and resource estimates, based on validated mission assumptions and implementation requirements, were prepared for 20 different missions spanning the period from 1969 through 1981. Additional resource estimates were made for the NASA Planetary Working Group, covering missions and phased programming for the near planets, including Jupiter, and the comets and asteroids.

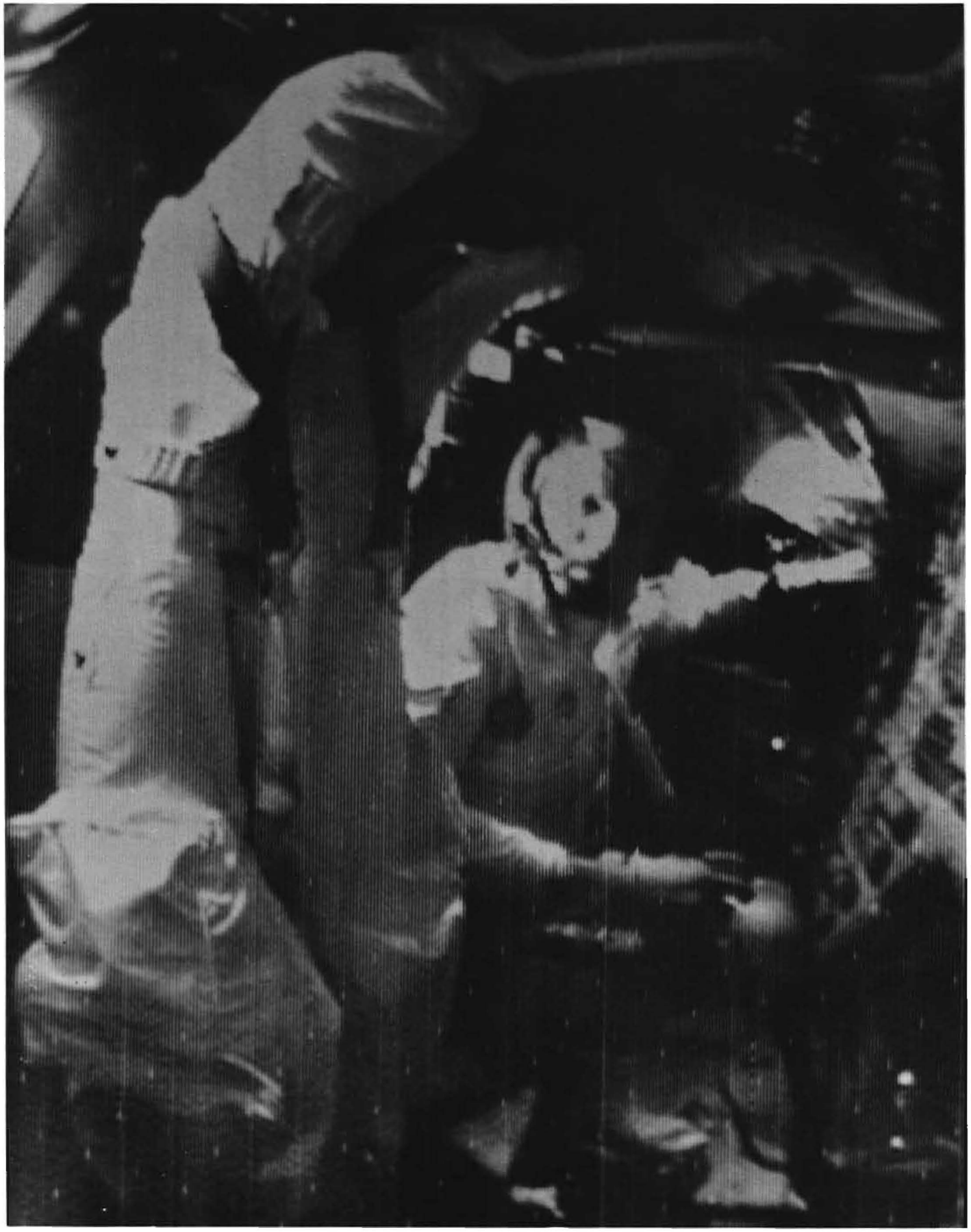
Development programs were conducted to meet the advanced requirements of orbiters/flybys, probes/landers, and surface laboratories for potential Mars, Venus, and Mercury missions. These activities were coordinated with the Supporting Research and Technology effort at the Laboratory and with JPL's planetary lander effort, Capsule System Advanced Development (CSAD).

In the project planning area, APMT activity was directed principally to planning for the Mariner Mars 1971 (Mars orbiter) and Titan Mars 1973 missions (Mars orbiter and lander). An interim organization was established to facilitate the assumption of formal Mariner Mars 1971 Project responsibilities, and preliminary editions were published of project management and technical control documents.

For the Titan Mars 1973 mission, the APMT Program Office supported the Langley Research Center, which has project responsibility for the mission, in defining project and lander system management and technical requirements, and specification of technical criteria and constraints for both the lander and the orbiter systems. This support continued through December 1968, at which time JPL was assigned responsibility for the orbiter spacecraft and established a Laboratory Orbiter System Office in support of the Viking Project.



300-pound-thrust engine under development for Mariner Mars 1971 orbiter mission



The Deep Space Network

OPERATIONS

During 1968, the Deep Space Network (DSN) provided tracking and data acquisition support for the launches and flights of Surveyor VII and Pioneer IX, and DSN facilities around the world were utilized in joint operation with the Manned Space Flight Network (MSFN) in support of the Apollo 5, 6, 7, and 8 missions. In addition, extended mission activity continued with Lunar Orbiter V, Mariner V, and Pioneer VI, VII, and VIII spacecraft. Planning and preparation for DSN support of the Mariner Mars 1969 Project continued throughout the year, and planning for Mariner Mars 1971, Helios (a West German project), and Viking projects was begun.

The DSN now consists of the Space Flight Operations Facility (SFOF) at JPL and ten stations on four continents three 85-foot-diameter antennas and a 210-foot antenna at Goldstone, California, two 85's in Spain; two 85's in Australia, an 85-foot antenna in Johannesburg, South Africa; and a spacecraft monitoring station at Cape Kennedy. During 1968, the Ascension Island DSN station in the South Atlantic was transferred to the Manned Space Flight Network. All overseas elements of the DSN maintain communications with the SFOF through NASCOM, NASA's ground communications system.

Post-photographic readout operation of the Lunar Orbiter V mission early in 1968 and the final Surveyor soft-landing mission (Surveyor VII) in January–February concluded NASA's current unmanned lunar exploration program.

During its final month in orbit around the moon, Lunar Orbiter V was used primarily to support Apollo ground operations system verification. The Manned Space Flight Network used the spacecraft as a training vehicle to test tracking capability, orbit determination, data flow, and voice relay. The DSN utilized Lunar Orbiter V for a bistatic radar investigation of the lunar surface and in the development of sequential decoding equipment.

For the Surveyor VII mission, the DSN supported the 66½-hour flight from launch to touchdown. The Network commanded the TV camera and science instruments and received all data transmitted by the science instruments. During first-lunar-day operations, the stations transmitted to the spacecraft 138,060 commands and received and recorded 20,993 TV pictures and nearly 60 hours of alpha scattering data

Planning and preparation for DSN support of the Mariner Mars 1969 Project emphasized the increasing load on the DSN from planned future deep space missions. These missions are characterized by a high probability of success, higher data rates, and the launching of more than one spacecraft on each mission. As a DSN research and development project, the Mariner 1969 spacecraft and the DSN will test the transmission and reception of video data at a data rate of 16,200 bits per second.

During 1968, the DSN continued tracking and data acquisition support of the Pioneer series, now totaling four spacecraft in orbit around the sun The DSN developed, implemented, and operated all special instrumentation necessary to support the Pioneer VI solar occultation experiment from mid-October to mid-December. The instrumentation measured changes in the direction of the polarization of the linearly polarized S-band spacecraft signal, thus determining the effects of Faraday rotation due to the sun's corona. Pioneers VI and VII were tracked by the high-performance 210-foot antenna at Goldstone, while Pioneer VIII remained within the capabilities of the DSN's 85-foot antenna network. Following launch of Pioneer IX on November 8, the DSN collected data on the definition of the earth's magnetosheath and bow shockwave by tracking the spacecraft through the plasma surrounding the earth Special support was given the Apollo 8 flight through monitoring of the sun's radiation by all four Pioneer spacecraft to enable the prediction of solar flares and their danger to the astronauts.

MARINER V REACQUISITION

On October 14, a weak spacecraft signal was detected by the 210-foot antenna station It was quickly confirmed as originating from Mariner V, circling the sun in an orbit between Venus and the earth However, the signal was very unstable in frequency and low in power level, and no telemetry data were obtained DSN support of the Mariner V reacquisition activity was terminated on November 5.

MANNED MISSION SUPPORT

The DSN has supported, in varying degrees, all four Apollo missions flown in 1968, beginning with the unmanned Apollo 5 that tested the descent and ascent propulsion systems of the Lunar Module in January and concluding with Apollo 8, the Saturn V-launched manned lunar orbiting mission on Christmas

Opposite. Televised view of Apollo 8 astronauts as received at Goldstone

Three of the 85-foot DSN stations—at Goldstone, Canberra, and Madrid—were outfitted with MSFN control room wings to enable the station to support the neighboring MSFN prime 85-foot stations. During Apollo activities, the DSN stations were staffed by MSFN personnel, with selected support from a limited number of DSN personnel to operate the common station subsystems.

The DSN station at Cape Kennedy participated in the Apollo 5 and 6 missions, and the 85-foot stations at Goldstone and Canberra were also used for the latter flight. During America's first three-man mission, Apollo 7, the Madrid and Canberra stations tracked 32 earth orbital passes. Apollo 8, the most complex manned flight to date, was supported by all of the above stations and the 210-foot antenna station at Goldstone.

FACILITY MODERNIZATION

Twenty-four-hour coverage by 210-foot-diameter DSN antennas came closer to reality in December with NASA's request to industry to submit proposals for the fabrication and erection of two 210's to be installed in Spain and Australia. Construction will begin in 1969, and the antennas will become operational in 1973. Including the existing 210-foot antenna at Goldstone, the new network of 210's will provide 6 to 7 times the sensitivity of the comparable network of 85's.

Modernization of the SFOF power distribution system under a three-phase plan was partially implemented during 1968. The modernization program encompasses a solid-state uninterruptible power system (UPS), a standby power-generating facility, and removal of existing leased power-generating equipment. The UPS installation converts alternating current to direct current, which is used to charge batteries and power inverters. The inverters convert the dc back to ac, which can be precisely controlled for frequency, voltage, and waveform. In the event of ac failure, the batteries will continue to provide dc power until standby generating equipment can be started. The standby power plant will have sufficient capacity to carry the SFOF power requirements in the event of a total prolonged failure. Construction of the underground standby power plant adjacent to the SFOF began late in the year. The facility will house up to four 1350-kilowatt

Activity in operations room of the Space Flight Operations Facility during Surveyor VII mission

210-foot-diameter antenna at Mars station, Goldstone, California

dual-fuel (diesel or natural gas) engine generators, a new utility system control room, and auxiliary equipment.

The Compatibility Test Area (CTA 21), designed to test spacecraft telecommunications elements with the DSN, became operational early in 1968. The installation, located at JPL, began supporting the Mariner Mars 1969 Project early in the year. CTA testing included four classes of activity: spacecraft subsystem research and advanced development testing, engineering developmental model testing, proof-test model testing, and flight equipment (full spacecraft and mission-dependent equipment) testing.

RADIO SCIENCE SUPPORT

The unique facilities of the DSN were used throughout the year in the radio and radar astronomy activities undertaken by JPL and other organizations.

The recently discovered pulsating radio sources, or pulsars, were first observed at S-band frequencies in March, using the 210-foot antenna at Goldstone. Dynamic spectrograms of two pulsars (CP 1919 and CP 0834) were obtained also in the 82–85 megahertz VHF band. The spectra were measured to provide information concerning the nature of the immense energy of the pulsating stars. S-band observations of the pulsars will continue in an effort to use the very precise pulses in the development of a time-synchronization technique for clocks at widely separated tracking stations.

Advantage was taken in June of the relatively rare close approach of the asteroid Icarus (6.4 million kilometers from earth) to perform radar experiments. The 85-foot Venus station antenna and the experimental 450-kilowatt transmitter were used to transmit radar signals to the asteroid, and the 210-foot diameter antenna at the Mars station received the echo. From the analysis of the received signal, Icarus' radius was estimated to be 0.6 kilometer and the rotation period about 2.4 hours.

Woomera space communications station, one of two 85-foot antenna stations in Australia, is part of the Deep Space Network.

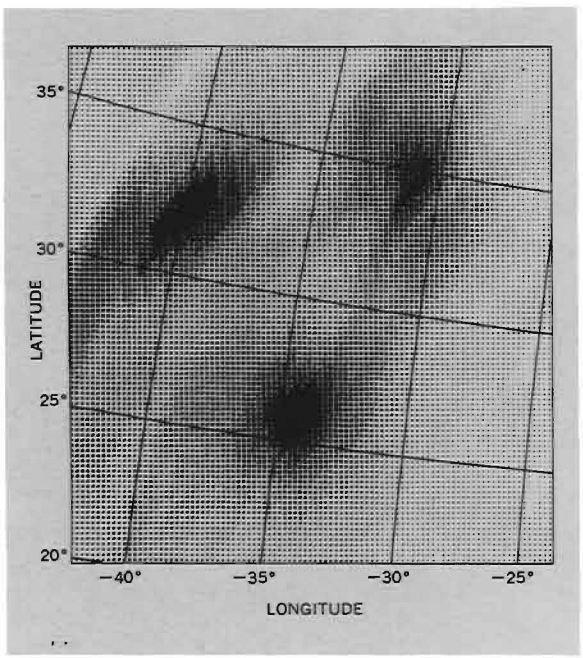
Using the 210-foot antenna, a map of a small area of Venus showing three clearly defined surface features was obtained. The strongest feature, called Beta, appears roughly circular, with a diameter of about 150 miles. The three features, which could be mountains, craters, or boulder fields, form a triangle between 25 and 35° North latitude and −30 and −40° longitude.

Toward year end, the radio signal from Pioneer VI was received as it passed through the sun's corona during a superior conjunction experiment. Data, received from as far as 1.8 AU from earth, are being studied in the areas of spectral broadening of the signal and polarization rotation induced by the solar corona.

A Venus ranging experiment, designed to improve our knowledge of the orbital parameters of Venus and the earth, was carried out at intervals throughout the year. The earth–Venus range was about 1.74 AU at midsummer.

The 30-foot-diameter antenna at Goldstone's Venus station continued to be used for time-synchronization signals at 8.45 gigahertz and for radiometric observations of the planet Venus at 23 gigahertz.

The radius of Venus was obtained by means of two different sets of measurements, which were found to agree within 3 kilometers. The first was based on radar ranging values recorded at different times, distances, and angles over a 3-year period. These measurements yielded the distance between the earth and the surface of Venus as well as the distance between the earth and the planet's center of mass. From these distances, a radius of 6053.7 ±2.2 kilometers was determined. The second radius determination was made from ranging and doppler measurements taken by Mariner V as it passed Venus, together with the earth-to-Venus-surface distance. On the basis of the radius thus established, data from the radio occultation experiment were used to calculate the atmospheric pressure as a function of altitude.



Radar map of portion of Venus' face shows clearly defined surface features that may be mountains, craters, or boulder fields.

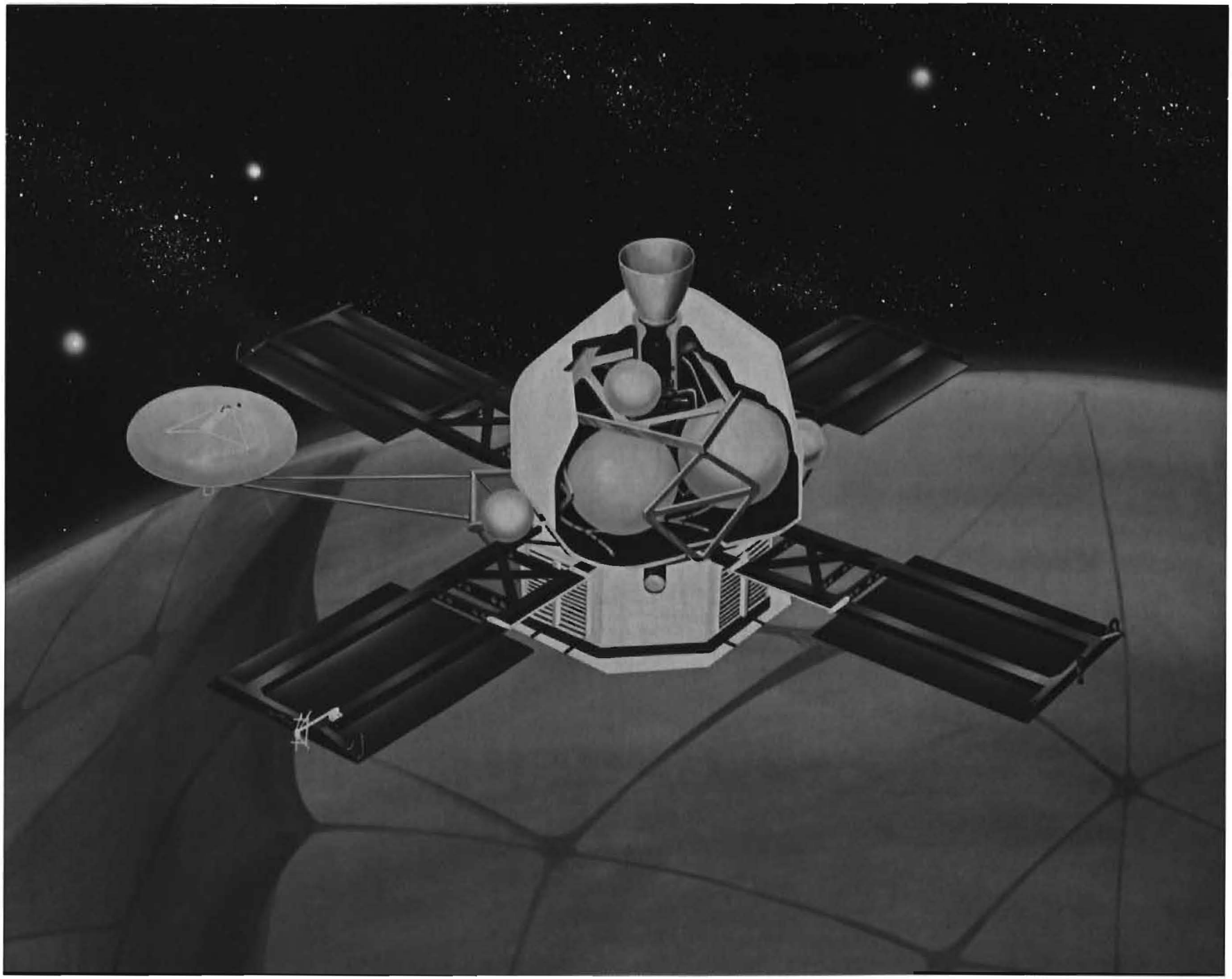
In an experiment conducted with the South African government's Council for Scientific and Industrial Research, the 85-foot antenna at Johannesburg was used to record signals from a radio source partially occulted by Jupiter. The resulting data are now being analyzed.

The extremely accurate radio tracking data provided by the DSN allowed researchers to pinpoint minute velocity changes in the Lunar Orbiter V spacecraft as it circled the moon in a near-polar orbit. Some 9000 individual data points were analyzed. By superimposing the detailed computer output onto a lunar map, a qualitatively consistent gravimetric map of the moon's near side was developed. The map indicated that small, but noticeable, acceleration variations on the orbiting spacecraft correlated with all five ringed seas on the near side of the moon, leading researchers to believe that the moon may contain mass concentrations of dense material. Investigation of the phenomenon is continuing.

ADVANCED DEVELOPMENT

A 450-kilowatt S-band transmitter was installed on the 85-foot antenna at the Goldstone Venus station. The 450-kilowatt klystron amplifier tube, one of the largest and heaviest electronic devices to be mounted on a steerable antenna for operational use, is located in a new electronics room on the antenna. The klystron, focus magnet, and cathode oil tank together weigh 1200 pounds and stand 7 feet high.

Performance of a sequential decoder on data transmitted on a spacecraft link was demonstrated with a series of experiments using Lunar Orbiter V and the Echo station at Goldstone. It was shown that sequential decoding can perform on an actual spacecraft link with the efficiency predicted by theoretical calculations and laboratory experiments.



PHYSICAL SCIENCES

During 1968, research continued in the physical sciences, broadening our understanding of space-related physical phenomena and providing a basis for future developments in various phases of space technology.

Ion Cyclotron Resonance Studies

The ion cyclotron resonance spectrometry technique was employed to investigate ion-molecule reactions. Measurements were made of (1) thermal rates which previously had to be obtained by more complicated methods, (2) energy dependence of ion-molecule reactions; and (3) reaction cross sections. Ion cyclotron resonance spectrometry was applied to the study of reactions occurring in the earth's ionosphere An experimental study of the ion-molecule reactions that take place in mixtures of helium and nitrogen gases has provided a possible explanation for the loss of helium from the earth's atmosphere The previous explanation, based on a dissociative charge transfer reaction between helium ions and nitrogen molecules, did not adequately show how the resulting helium atoms could attain enough energy to escape. A second explanation based on a similar reaction with oxygen molecules was weak because of the very low abundance of oxygen in the upper atmosphere. As a result of recent ion cyclotron double-resonance experiments, it now appears that helium ions can react with nitrogen molecules to produce stable N_2^+, leaving ample energy available for escape of the helium atom.

Photochemistry

The techniques developed over the years in the Photochemistry Task were applied to the problems of air pollution The reactions of excited oxygen atoms and molecules with trace quantities of hydrocarbons were studied in order to ascertain the origin of some of the air pollutants. The excited species are produced from the photolysis of ozone, an atmospheric constituent A spectroscopic search is under way for the elusive CO_3 molecule which could be of significance in air pollution chemistry

De Haas–van Alphen Effect

Experimental studies of the Fermi surface in a number of metallic systems are currently being conducted using the de Haas–van Alphen effect. Digital data handling techniques were developed for processing and performing numerical Fourier analysis of the experimental data to yield accurate values for the frequencies and amplitudes of oscillations of the magnetic susceptibility of the crystals. The experiments to date have resulted in the measurement of the effective masses of the electrons in white tin and indium. In addition, what appears to be magnetic breakdown has been observed in samples of white tin

Quantum Theory

A study was conducted to determine the extent to which the order of levels of a symmetric system is predetermined solely by the symmetry of the system. The methods already developed to demonstrate the existence of such an order for systems having the symmetry of the cubic and tetrahedral point groups were extended and modified to investigate the structure of electronic energy bands in crystals. The investigation led to the discovery of an "invariant" band structure — a portion of the band structure predetermined by the symmetry of the crystal, which therefore can be predicted without any knowledge of the crystal potential Another interesting aspect of the band structure of crystals came to light that allows the band structure of dissimilar lattices to be compared in a precise fashion. This is of great interest in the study of the comparative band structure of different crystalline phases of the same metal

Fast-Response Polarimeter

A specially instrumented polarimeter was constructed and used to measure the electro-optic response of certain crystals The instrument is capable of making time-resolved observations of a repetitive change in the birefringence of a specimen with a rise time approaching a nanosecond Electronic sampling and averaging are used to obtain the time resolution while, at the same time, retrieving the signal from a large noise background The noise is unavoidably present because only a few tens of photons pass through the system during one resolving time. The techniques previously used in polarimetry were either manual, or involved direct oscillographic observation of a photosignal with its accompanying noise, and were limited to much lower bandwidths.

High-Density Magnetic Information Storage

An experimental investigation of laser Curie-point switching in manganese bismuthide (MnBi) films has indicated that their information-storage density may

Opposite: Artist's concept of Mars orbiter spacecraft showing module for space-storable propellant

approach that of photographic film. It was found that, by proper control of the magnetic field applied during switching, 1-micron spots could be switched to a wide range of average magnetizations, and thus to a wide range of grays as seen through a pair of crossed polarizers Such a characteristic is an attractive one for the use of these films as high-density laser recording media

Population Inversions in an Arc-Jet Exhaust

Spectroscopic measurements of the intensities of a large number of argon ion lines in the exhaust of a magnetoplasmadynamic arc jet have revealed similarities to spectra obtained from the spontaneous emission from CW argon ion lasers. The exhaust of the arc jet, operated at ambient pressures of less than 1 torr, is known to be in a highly nonequilibrium condition, and the similarity of the spectra with that of the laser suggested that the condition necessary for population inversion in the laser could also be present in the arc exhaust Because of the high power potential for a flowing laser system, direct evidence of lasing action was sought by directing an argon ion laser beam through the arc exhaust plume and observing the emerging beam for possible enhancement. Preliminary tests have indicated amplification of the primary beam by approximately 5% per meter of plasma path length

Plasma Heat Transfer

The effects of magnetic and electric fields on surface heat transfer from flows of partially ionized gases are of importance in the design of electrode configurations for magnetogasdynamic generators and propulsion devices During 1968, the effect of an applied, transverse magnetic field on heat transfer from a slightly ionized gas to the walls of a channel was studied. Experiments were performed using argon preheated by an electric arc to approximately 10,000°K at pressures varying from 5 to 200 torr and applied magnetic field strengths up to 10 kilogauss. Application of the magnetic field increased the heat transfer as much as 80% from a subsonic gas stream and as much as sixfold from a supersonic gas stream. The trend and magnitude of these results show approximate agreement with a simplified theoretical prediction

Air–Sea Interaction

Air flow over a wavy surface was studied to learn the mechanism by which energy is transferred from the wind to water waves Waves which travel downwind were generated mechanically in a sheet of rubber comprising one wall of a wind tunnel The measurements showed that the pressure drag of the wavy surface is insufficient to explain the wave growth observed on natural bodies of water, and revealed a strong variation of the surface shear stress in phase with the wave motion.

The Microwave Spectrum of OH

A new JPL microwave spectrometer was used for precise measurements of previously unobserved transitions in the free radical OH With these data, a set of improved molecular constants was determined, and new transitions were predicted that may be observed by radio astronomers in interstellar OH. It is anticipated that this work may aid in unraveling the anomalies found in the radio astronomy data taken thus far on OH transitions

Applied Mathematics

An important advance in the computational accuracy of orbit determination programs was made with the application of the little-known technique of Householder transformations This technique is currently being used to enhance data processing.

Generally, high-order methods for the numerical solution of systems of ordinary differential equations are more efficient than low-order methods, but are not commonly used because of the danger of numerical instability An algorithm was developed which tests for indications of instability and adjusts the order of the method to be as high as possible subject to maintaining stability This algorithm was used successfully in a variety of applications and has proven significantly more reliable and efficient than other methods currently in use at JPL

By combining new algorithmic formulations of Householder orthonormal transformations, the projection gradient method, and cubic spline curve parameterization, curve fitting procedures were developed which permit a large amount of flexibility with regard to such special requirements as interpolation, monotonicity, and processing of large amounts of data. One effective application of these procedures was in the mascons investigation reported under the Deep Space Network.

SPACE SCIENCES

Space science is that aspect of physical science devoted to the study of planetary, interplanetary, and solar phenomena and thus includes planetary astronomy

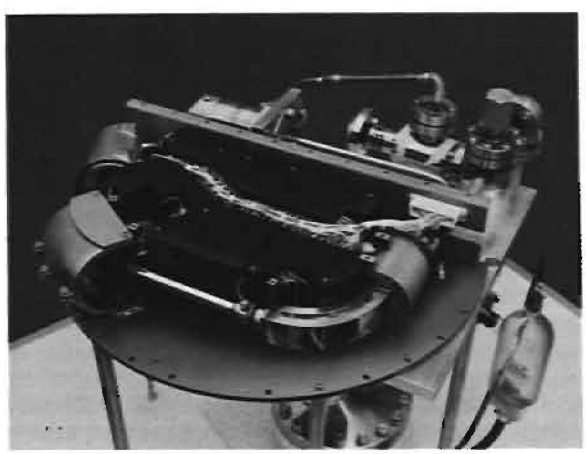
as well as flight experiments. Current efforts are concentrated on developing both experimental and analytical techniques for determining planetary surface and atmospheric properties.

Aerometry/Meteorology

Studies of instruments for the measurement of Mars surface wind velocity and atmospheric temperature have indicated the need for experimental data on the operating characteristics of various types of instruments under Mars surface conditions. A small wind tunnel for use in testing anemometers and thermometers under these conditions was built. The tunnel is contained in a vacuum tank 4 feet in diameter by 16 feet long. A 24-inch vaned axial fan is driven through a rotating sealed shaft by a variable-speed motor located outside the tank. The test section is a 1-foot cube, and wind speeds from 1 to 85 meters per second have been obtained and measured for gas densities of 1×10^{-5} to 4×10^{-5} g/cm^3, the range of atmospheric densities expected near the surface of Mars. The speed profile is flat to ±5% down to a speed of 1 meter per second. Low-frequency turbulence levels are of the order of 1% and could be improved if necessary by the addition of screens and turning vanes. Tests of several anemometer and thermometer instrument types are planned.

Atmospheric Mass Spectrometer

A miniaturized mass spectrometer was designed and developed to measure the composition of the Martian atmosphere from a high-velocity entry capsule. It is a double-focusing instrument utilizing tandem electrostatic and magnetic fields. Through the use of electron-multiplier collection techniques, gas concentrations as low as 20 ppm in the Mars atmosphere can be detected. The spectrometer scans the mass range from $M = 10$ to $M = 90$ every 3 seconds. Based upon current mission profiles for Mars, this would result in a minimum of eight complete mass spectra being obtained. Faster scanning can be accomplished, however, through a reduction in mass range, resulting in significantly more spectra. A minimum resolving power ($M/\Delta M$) of 90 is achieved, allowing precise analysis of all gas species within the spectrometer's mass range. The total weight of the instrument package is 10 pounds, and the average power consumed is 8 watts. Utilization of mass-spectral peak detection methods allows the telemetry of up to 32 mass peaks per spectrum for less than 800 binary bits of data. The mass spectrometer has demonstrated the capability of surviving the necessary heat sterilization required of all early planetary entry experiments.



Laboratory model of mass spectrometer being developed for measuring the composition of planetary atmospheres

Infrared Emissive Properties of Silicate Powders

The emission spectra of a compositionally diversified suite of igneous rocks, rock-forming minerals, and meteorites were studied in the laboratory. In addition to the usual structures associated with strong absorption in these materials, new diagnostic features were discovered in the emission spectra of powdered silicates with particle size on the order of microns. The newly recognized features consist of broad emission minimums adjacent to frequencies of strong absorption, and emission maximums in the regions of anomalous dispersion. The latter are located where the real refractive indices are near unity. For certain basic and ultrabasic rocks, the new features may dominate the powder spectra, thus giving them a completely different character from that usually determined by the characteristic reststrahlen bands. The experimental results suggest that emission spectra of planetary surfaces may contain useful compositional information about the surface material even though it may be freely pulverized.

Exobiology

Two bioscience experiments were developed for missions on the surface of Mars. One is designed to detect life by measuring the biological incorporation of carbon from radioactive carbon dioxide into organic matter in the light and in the dark. The light-dependent assimila-

tion of carbon dioxide is known as photosynthesis — a process which must occur on Mars if there is any life on the planet. Its independence of liquid water makes it unique among the life detection experiments that have been proposed for Mars exploration. For the second experiment, which performs an organic analysis of soil, the utility and limitations of a combined pyrolysis/gas chromatograph/mass spectrometer system were defined. It was established that this system can make both a general survey of soil organic compounds and specific identifications of biologically important classes by analyzing their pyrolysis products. This permits recognition of organic compounds of contemporary biological, fossil, or cosmic origin.

Optical Astronomy

While installed at the Coudé focus of the 24-inch reflecting telescope at Table Mountain Observatory, the JPL Connes-type Fourier spectrometer obtained spectra of Venus at a resolution of 2 cm^{-1} in the spectral region from 2600 to 3500 cm^{-1} (2.9 to 3.8 microns). Solar spectra of 0.06-cm^{-1} resolution were obtained over the same spectral interval. This resolution is about one order of magnitude better than that given in the Solar Atlas. Late in the year, the instrument was removed from Table Mountain and packed for shipment to McDonald Observatory (University of Texas), where it will be installed at the Coudé focus of the new 107-inch reflecting telescope during January of 1969.

High-dispersion spectrographic studies of Venus in the 7000–12000 angstrom region were continued with the Coudé spectrograph of the 82-inch Struve reflector at McDonald Observatory. Small amounts of H_2O were found to be present from plates taken during November and December of 1967, and relatively large amounts (60 microns) were found during September 1968. Negative results on other equally good spectrograms argue strongly for variability in the observable H_2O vapor on Venus.

Beam from 2-watt argon ion laser leaving the 24-inch telescope at JPL's Table Mountain Observatory

Planetary Flight Mechanics

The first N-body relativistic integration of planetary ephemerides fit to optical, radar, and spacecraft data was developed. A confirmation was made of previous radar values of the radius of Venus and the astronomical unit. The former differs from the value of the radius obtained by Venera 4. An anomalous feature in the Venus radar bounce residuals led to a determination of the mass of Mercury.

Radar and optical observations of the minor planet Icarus were analyzed in an attempt to verify the predictions of general relativity and to estimate the dynamical oblateness of the sun, the mass of Mercury, and other parameters. The optical data spanned the interval from June 1949 to August 1968. Seven doppler measurements were taken at the Goldstone, California, station in June 1968 at 0.04 AU. These measurements, which had an accuracy of 0.06 meters per second, were useful in indicating a bias in declination of the optical observations but otherwise had a negligible effect on the solutions. The mass of Mercury was the only astronomical constant for which consistent estimates could be obtained. The solution for the inverse mass was $m^{-1} = 5{,}940{,}000 \pm 50{,}000$.

Laboratory Infrared Spectroscopy

High-resolution laboratory spectra ($\sim$0.1 cm^{-1}) were obtained of the $3\nu_3$ band of CH_4, and a curve of growth was derived for the R-branch from their measurement. The R-branch lines are complex and split to varying degrees, so that their curves of growth differ from those for single lines. Moreover, the strong rotational couplings between levels cause variations in the intensities of the components of the J manifolds, so that simple nuclear spin statistics are not sufficient to describe the intensities observed. Knowledge of the exact form for the curve of growth will make possible an accurate, systematic determination of rotational temperatures on Jupiter and perhaps the other giant planets.

The Earth's Magnetosphere

The shape of the earth's magnetosphere and the distribution of the magnetic flux within it have been deter-

mined by means of potential theory The calculation is an improvement on previous calculations because it takes into account the magnetic neutral sheet — an improvement that also makes the calculation more difficult The rather intricate boundary condition so introduced is solved by a novel use of the theory of conformal mapping Dynamic as well as static aspects of the magnetosphere can be modeled, and changes in the magnetosphere are related to changes in the solar wind. Such information is important in relating geomagnetic disturbances, such as magnetic storms and the aurora, to fluctuations in the solar wind.

X-Ray Astronomy

A successful x-ray astronomy balloon experiment was conducted on January 15, 1968. Its objectives were to gain experience in balloon operations, to make observations of one or more of the x-ray sources reported in Cygnus, to test the effectiveness of a background-reducing shield, and to establish the practicality of flying a beryllium window as thin as 1-mil in spacecraft experiments

Readings were taken of the cosmic x-ray background between 20 and 120 kilo electron volts (keV), of the efficiency of anticoincidence shielding between 3 and 12 keV and between 20 and 120 keV, and of the spectrum of the discrete x-ray source Cygnus XR-1 above 20 keV. The transit of Cygnus XR-1 was seen in the spectral record from 20 to about 60 keV. The atmospheric background between 20 and 120 keV was monitored during ascent The particle flux observed by the anticoincidence shield was monitored continuously.

FLIGHT SCIENCE EXPERIMENTS

Experiments developed by JPL are flown on a variety of space vehicles. Data from such missions have led to a number of significant discoveries and to the development of new experiments

OGO Series Magnetometers and Solar Wind Spectrometer

During the past year, the fifth of six planned magnetometer experiments was launched on an Orbiting Geophysical Observatory (OGO) earth-orbiting mission. The sixth and last flight of the experiment is scheduled for 1969. The objective of these experiments is to investigate the low-frequency magnetic variations in the magnetosphere, magnetosheath, and interplanetary space. The OGO-V magnetometer was launched in March of this year and is still working well. The most significant new feature of this experiment over previous OGO experiments is the capability to transmit information on rapidly changing magnetic phenomena.

A second experiment launched on OGO-V utilizes two solar plasma spectrometers to secure more definitive data on the properties of the solar plasma in interplanetary space and in the magnetosheath than have been provided by earlier space probes.

Apollo Solar Wind Experiment

During the past several years, a solar wind spectrometer has been developed and equipment fabricated for flight with the Apollo Lunar Surface Experiment Package (ALSEP) The purpose of this experiment is to measure the direction and intensity variations in the solar plasma that reaches the lunar surface. The spectrometer is designed to be deployed by an astronaut on the lunar surface and to operate for about 1 year Flight equipment has finished fabrication and test phases and awaits disposition for an early Apollo lunar landing flight

Determination of the Temperature Profile in an Atmosphere From Its Outgoing Radiation

A new, highly accurate mathematical method for precise determination of atmospheric temperature profiles from the intensity of outgoing radiation was devised The method is based on the principle of relaxation, and the solution is obtained by iteration. This new technique provides a reliable tool for practical sounding of temperature under various meteorological conditions, including partial cloudiness. Very little time is required for the reduction of a set of measured radiance values to temperature, a system can be arranged to produce temperature profiles in real-time as data are accumulated.

The method was successfully applied in a high-altitude balloon experiment conducted in Texas by JPL last July. This was the second in a series of flights to develop the experimental technique for meteorological satellite applications. Analysis of the data shows that temperature profiles can be obtained from ground level to balloon altitudes of about 125,000 feet, and that surface temperatures can be obtained to an accuracy of 1 degree The atmospheric profiles are in good agreement with independent temperature measurements made on standard U S. Weather Bureau radiosondes, and the ground temperature measurement was verified independently by comparison with data from local weather stations.

Besides the primary temperature applications, the method has also proven effective in other ways. Among the problems which can be solved by this technique are the determination of surface elevations, cloud height, the percent of cloud cover, and the amounts of absorbing gases in an atmosphere.

In principle, the method can be applied to any frequency region, such as the 15- and 4.3-micron CO_2 bands or the microwave region. The solutions can be achieved without *a priori* knowledge of the temperature profile. Thus, this method is also suitable for unambiguous determinations of temperature in the comparatively unknown atmospheres of other planets.

Pioneer Celestial Mechanics Experiment

Over the past 3 years, four Pioneer spacecraft have been launched into orbits about the sun. Highly accurate doppler data were obtained from each spacecraft by means of ground-based antennas in the NASA/JPL Deep Space Network. These data provide measurements of one component of the relative velocity of the Pioneer spacecraft along a line joining the antenna and the spacecraft to an accuracy of better than 1 millimeter per second. By observing changes in this velocity component, it is possible to obtain information on the masses of the earth and moon and on the orbits of the spacecraft and earth about the sun.

Results obtained from Pioneer VI, launched in December 1965, and from Pioneer VII, launched in August 1966, show that the mass of the earth is 1/332945 that of the sun and the mass of the moon is 1/81.301 that of the earth. The combined mass of the earth and moon is 1/328900 that of the sun.

Scientists examining data from JPL-developed flight science experiments

ELECTRONICS

Virtually every aspect of spacecraft technology either depends on or is influenced by the state of the art in electronics. Research and development in this area provide much of the forward thrust of space technology.

Guidance and Attitude Control

Analytical studies for the control-system design of a roving vehicle for the surface of the planet Mars resulted in two important achievements: a dynamic programming scheme to select optimum paths for travel over the Martian surface, and a minimum-energy controller for an analytically synthesized electric-motor-drive system. An important advance was made in the development of digital computer techniques to analyze the effect of large, flexible spacecraft structures on control systems.

A baseline attitude-control design for a typical outer-planet mission was derived and will be used as the basis for future mission studies. In response to the long-life requirements for an outer-planet mission, a complete triple-redundant majority-voting attitude-control loop was breadboarded. A six-degree-of-freedom digital-computer simulation of a gimballed autopilot control was developed and was successfully applied to the Mariner Mars 1971 orbiter autopilot system design.

A special program to develop a strapdown inertial navigation system using electrically suspended gyros achieved several milestones in the past year, including the completion of all system hardware, a computer simulation of the system, and a preliminary system-integration test.

Both translational and gimbal actuators were developed for an experimental electric-propulsion ion engine. The gimbal actuator achieved a step-resolution accuracy of less than 0.1 milliradian, and the translational actuator performed with a step-resolution accuracy of 0 025 inch.

A computer program was developed for use in the design of spherical pressure vessels required for attitude-control gas systems Other accomplishments in the area of attitude-control gas systems included the first experimental measurement of thrust levels produced by thruster valve leakage and the design of a gas-distribution system capable of both ammonia and hydrazine vapor compatibility.

A new Canopus star tracker with improved capability for automatic identification and acquisition of Canopus was developed This tracker is being used on the Mariner 1969 spacecraft. A special test facility for operation of a laser sensor was completed for use in the development of active optical sensors for obstacle avoidance by automatic roving vehicles. Gyro and accelerometer sensors, developed for thermal sterilization capability, demonstrated their performance ability by surviving multiple cycles of high-temperature exposure

Control and Data Handling

The design and construction of the self-testing and repair (STAR) computer are continuing. Switching of the replaceable units will be accomplished by power-supply control and a switchable transformer using square-loop core material Coding of the command word for error detection will use a 2-out-of-4 code for the operation code part and a residue code for the address part, permitting a very simple check inside individual modules to determine validity of the operation code. The data words are residue-coded; therefore, data and commands are now to a large degree distinguishable, a departure from one of the basic tenets of the von Neumann machine made in the interests of better error detection.

Spacecraft Telecommunications Subsystems

The first complete working model of a 20 – 100 watt electrostatic focused amplifier (ESFA) was demonstrated for possible use in exploratory missions where variable high power is necessary. The amplifier was developed by Eimac/Varian. The 1400° collector dispenses 60% of the tube's waste heat directly to space rather than into the spacecraft. The overall efficiency of the amplifier is 45% at 100 watts

A computational technique was devised to calculate the circularly polarized radiation pattern of a high-gain erectable spacecraft antenna. The gain was measured experimentally and found to agree with theory to within 5% In the area of capsule relay antennas, sterilizable antennas capable of operating at 200 watts in the Martian atmosphere were developed.

A prototype low-data-rate telemetry system using multiple frequency-shift-keying and a fast Fourier transform detector was demonstrated. The system is capable of operating at 0.1 bit per second for a landed capsule direct link

A 3-decibel lowering of the noise temperature of a spacecraft transponder was demonstrated using a tunnel diode preamplifier capable of operating from −30 to +70° C which consumes only 60 milliwatts of power.

Communication Theory

A new theory on the performance of convolutional codes of short constraint length was developed and demonstrated, together with a class of codes. The decoding uses a version of the Viterbi maximum-likelihood algorithm It was shown that a 1.2-decibel improvement over the Mariner 1969 high-rate system can be obtained with the same decoding complexity using a constraint length of 6. Even a constraint length of only 4 gives a 0 2-decibel improvement, and with less complexity on both spacecraft and ground. There are no erasures with Viterbi decoding. Part of the reason for improved performance is the use of non-systematic codes, in which the information bits do not appear "in the clear"

Radio Science

JPL participated with several other organizations in conducting a laser bounce off the Surveyor VII vehicle on the moon.

A solar corona occultation experiment was performed with Pioneer VI. The Faraday rotation as measured by this experiment helps to determine the magnetic properties of the solar corona.

A radar map of the Venus feature Beta was prepared using data taken during the 1967 conjunction.

A radar bounce off the asteroid Icarus during its recent close approach to earth sets an upper limit of 490 meters for its radius and a lower limit of 0.13 for its reflectivity.

The period of several pulsars was determined more precisely than before using their S-band signals received at the Goldstone tracking station, and a theory was developed using the data to determine various astronomical constraints.

Improved Standard for Radiometric Measurement

A new primary standard reference for total irradiance measurement was developed and successfully demonstrated. The high accuracy of the instrument affords the possibility of its acceptance as an international scale of reference. Recent upper atmospheric measurements made with a vacuum enclosed version of the device and corrected for remaining atmosphere and sun's distance provided a new high-confidence figure of 139.0 ±0.9 milliwatts per square centimeter for the mean sun-to-earth solar constant.

Scanning Electron Microscope

Immediate application of scanning electron microscopy techniques to the study of two Mariner 1969 integrated circuit failure modes resulted in the early definition of the underlying mechanisms and subsequent corrective actions.

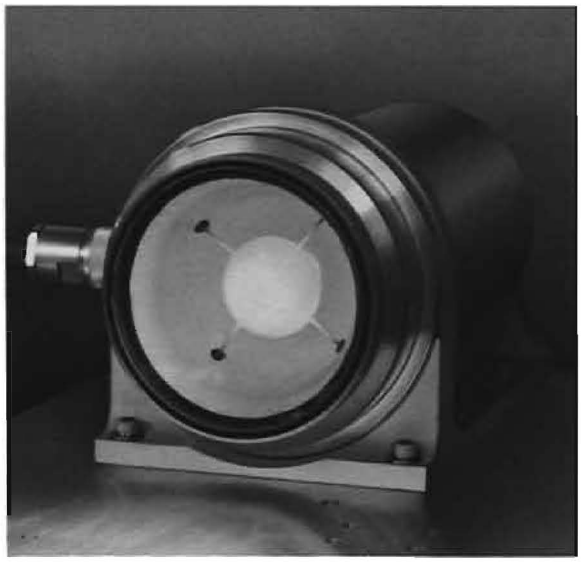
Concurrent with the installation of a Cambridge "Steroscan," two recurring failure modes were under study. One mode, in which circuit interconnects were being corroded open and gold–aluminum bonds were failing, was found to be due to incomplete removal of wire drawing lubricants used in bonding wire manufacture.

The second mode, in which aluminum circuit interconnects were becoming discontinuous, was found to be due to loss of control in the metal sintering process step during manufacture, as well as the existence of a sharp oxide profile which made it difficult to cover the interconnects with metal during evaporation.

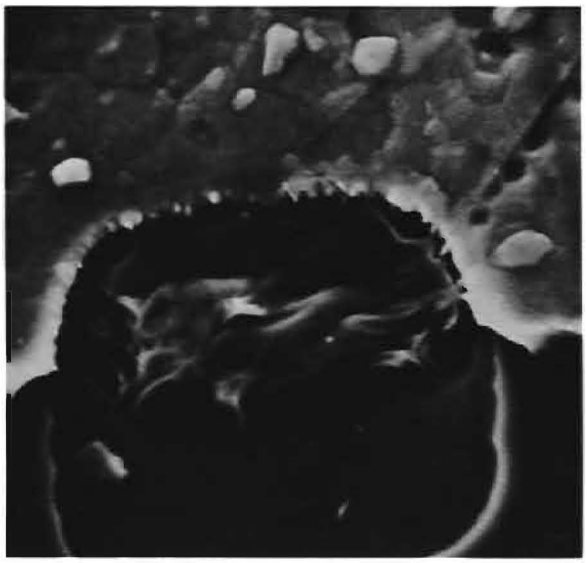
New Circuit Development

An all-solid-state logarithmic electrometer suitable for space-borne instrumentation was developed. The electrometer measures currents ranging from 10^{-5} down to 10^{-11} amperes with 1% accuracy for currents as low as 10^{-10} amperes. This accuracy is maintained from 0 to 50°C and for current pulses with rise times as fast as 1 decade per millisecond.

Recent advances in large-scale integration (LSI) technology were utilized in developing a digitally controlled hyperbolic-function generator having application to a space-borne mass spectrometer. The generator is built around a diode matrix which contains in excess of 15,000 diodes, thus providing a stepwise approximation to the desired function with excellent resolution. This technique has general application to generating a



Electrostatically focused amplifier for use in exploratory missions requiring variable high power



Closeup view of open metal stripe taken through scanning electron microscope

wide range of functions and waveforms that would be extremely difficult if not impossible to generate without resorting to electromechanical methods. Its digital nature gives it the added advantages of ease of control, simplicity in synchronizing related functions, and extremely good repeatability.

SPACECRAFT AND CAPSULE DEVELOPMENT

The successful completion of flight experiments is largely dependent upon the unimpaired functioning of spacecraft hardware throughout all phases of a mission. The design and development of spacecraft involve not only the design and construction of individual components but also the development and use of adequate materials and the testing of the spacecraft and its components under simulated flight conditions.

Mars Entry Capsule and Lander

The design and development of a Mars planetary entry and landing system progressed to the point at which an operating feasibility model of the 350-pound entry capsule was built and subjected to a series of functional and environmental tests, including heat sterilization. In addition, the wheel-shaped, balsa-encased lander operated successfully following two simulated Mars landing impact tests. For these tests, the lander was released from a helicopter at the Goldstone tracking station.

Mars landing capsule and anemometer after 250-foot drop test

The design and testing of the capsule and lander have demonstrated the feasibility of the technology required to perform future Mars entry and landing missions.

Venus Entry Simulation

An earth reentry test is a possible means of testing the design of a Venus entry probe. Analysis of the simulation attainable indicated that a full-scale vertical earth reentry flight test at 36,000 feet per second (11 kilometers per second) should provide an acceptable simulation of deceleration, angle-of-attack envelope, and heat-shield response for a Venus entry at a path angle of about 45 degrees, despite large differences in the atmospheric compositions of the two planets.

Planetary Entry Research

One task now receiving considerable attention is the radiative heating a ballistic vehicle would undergo upon entering the atmosphere of Jupiter. The thermodynamic conditions for a projected 40-kilometer-per-second entry velocity trajectory were experimentally simulated in a shock tube by diluting a possible gas mixture for the Jupiter atmosphere (hydrogen, helium, neon) in argon. Measurements made behind the model bow shockwave agree within 40% of the 2×10^5 watt-per-square-centimeter peak radiation energy predicted by the theoretical model. Since the theoretical model is under development, the comparison is considered satisfactory at this stage. For entry velocities of 60 kilometers per second, the theoretically predicted peak radiative intensity is an order of magnitude greater than at 40 kilometers per second, while the gas temperature is double the 20,000°K peak value. These measurements were compared to previous radiation measurements. The indication is that the radiative heating for Jupiter entry would be less than that encountered during entry at 40 kilometers per second into the atmospheres of earth, Mars, or Venus.

Planetary Entry Test Chamber

This facility, which was completed during the year, provides capabilities for the simulation of Martian entry environments. It will accommodate aeroshell structures or capsule systems up to approximately 7 feet in diameter.

During planetary entry, the structure of the entry aeroshell is loaded by a rapidly increasing and de-

creasing bell-shaped pressure pulse. At the same time, a correlated similarly shaped heat flux pulse acts on the exterior surface of the heat shield. Depending on the atmospheric model utilized, the entry conditions, and the configuration, the pressure levels, and the heat flux levels, as well as their durations between inflection points, may vary considerably. These environmental parameters can be simulated in the facility.

The planetary entry test chamber is the only known facility of its type, and is expected to contribute significantly to the evaluation of planetary entry probes.

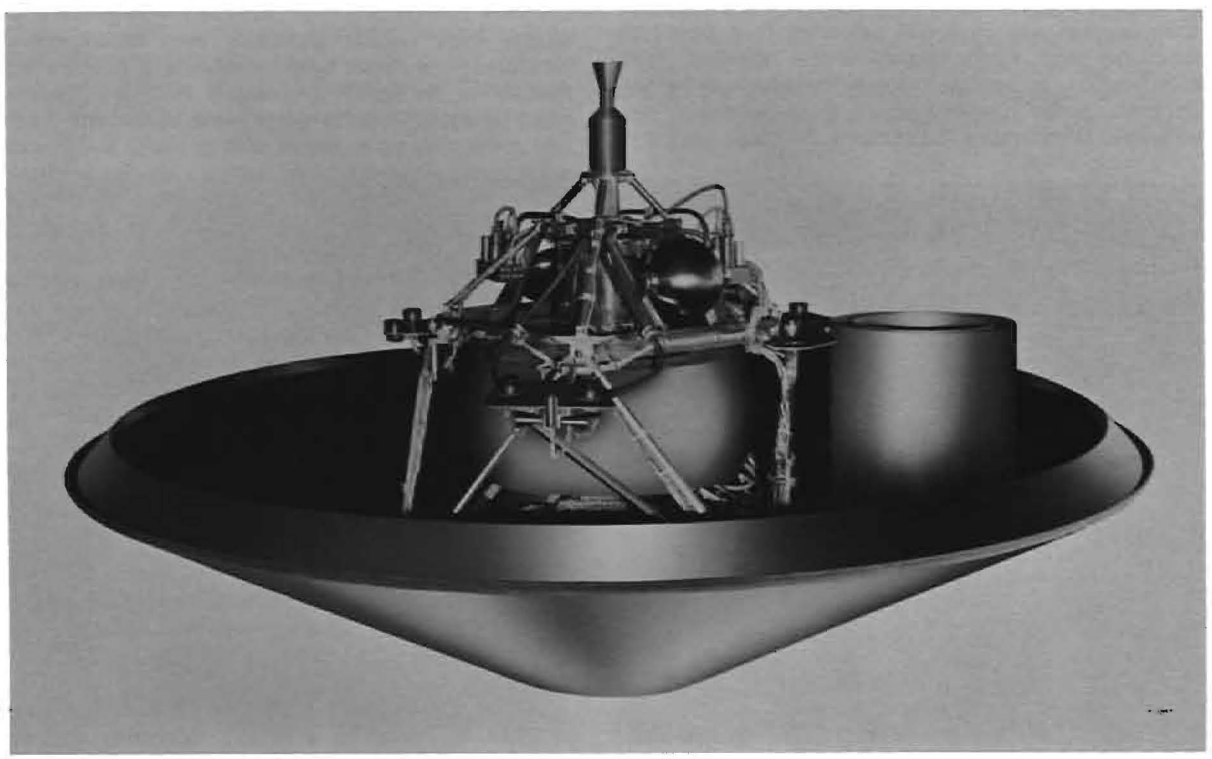
Space Environment Research

The 10-foot Space Molecular Sink (Molsink) simulator became operational early this year. In this facility, only a small fraction (4 out of 10,000) of the molecules that escape from a test item return to it. As a result, Molsink provides a unique capability for the experimental investigation of contaminant migration and such "clean surface" physics problems as cold-welding, material degradation, and evaporation.

During this year, the facility was used extensively for the evaluation of frictional adhesion problems in a number of Mariner 1969 devices. Instrument mechanisms such as camera shutters and gear trains were tested to determine their ability to function through encounter without failure. In several cases, redesigns were made as a result of these tests. Also, experiments were performed in support of the planetary quarantine program to evaluate factors affecting the expiration rates of viable organisms in the vacuum environment of space.

Foam Encapsulants

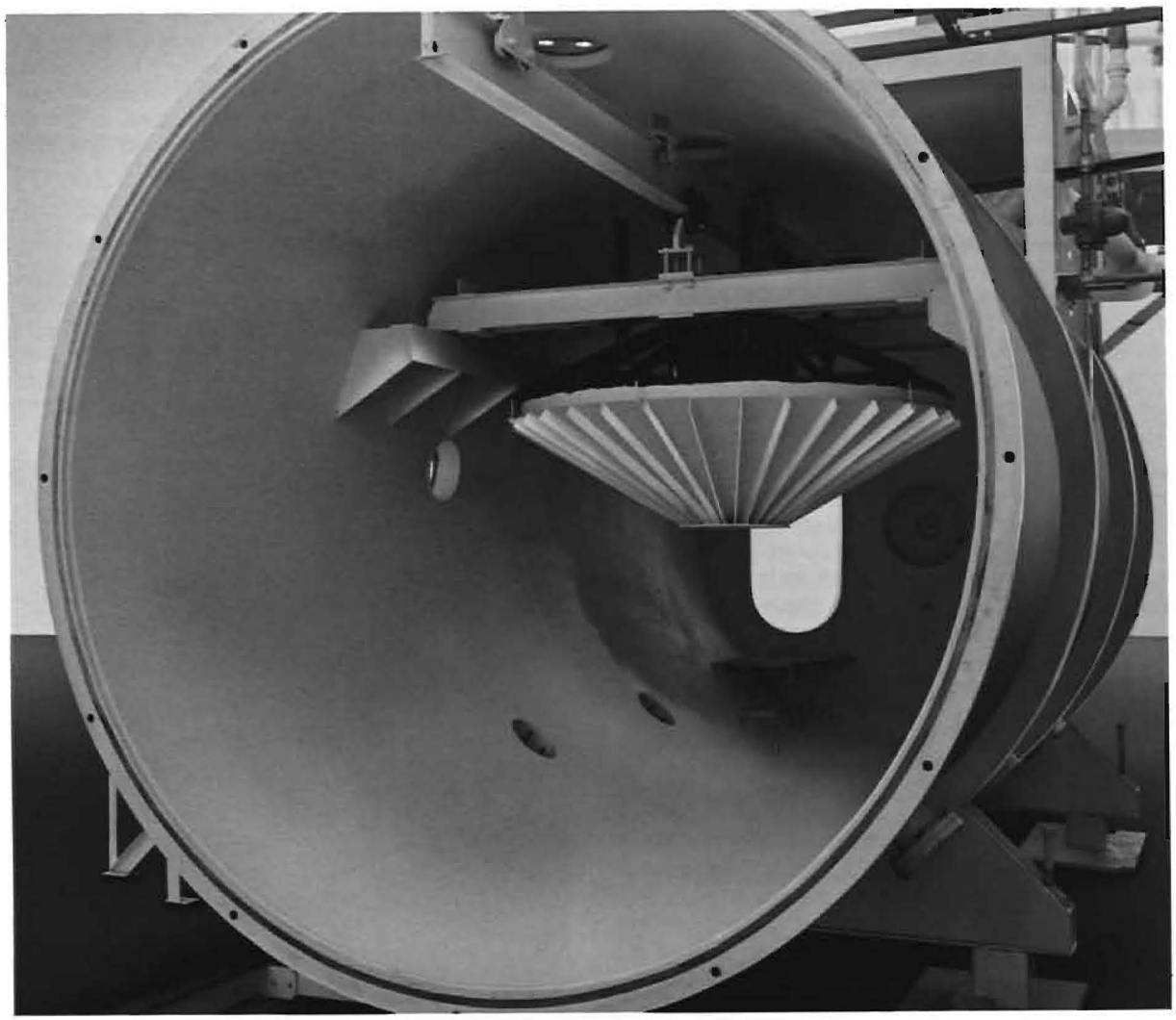
A technique was developed for determining the corona inception voltage in closed-cell foamed plastics. Sulfur hexafluoride gas is used as a "transformer oil" to prevent discharges from electrodes or surface cracks, so that discharges occur only inside the foam. By means of this test technique, structural parameters can be determined which should lead to the development of high-voltage, lightweight foam encapsulants operative at reduced pressure.



Feasibility model of planetary entry capsule

Structures

Computer programs for the analysis of elastic and inelastic structural systems are continuously under development. A program predicting the dynamic response of axisymmetric vehicles during hard landing under general conditions of impact and surface characteristics was completed during the year. A general three-dimensional program for the analysis of structural systems consisting of viscoelastic, rheologically simple materials is in development. In addition, a combined test and analysis computer program system based on the transfer-function concept is in process of checkout; it accepts experimental and/or analytical time data inputs and system characteristics and computes determinate or random system responses. Analog computation capabilities are continuously developed in conjunction with experimental measurement techniques for application in linear vibrations, nonlinear vibrations, and structure-control system interactions.



Mockup of aeroshell installation undergoing heat test in planetary entry test chamber

Two 6½-foot-diameter aeroshells were designed and fabricated for the Mars entry capsule. The conical aeroshells were made of very lightweight phenolic fiberglass honeycomb sandwich material. A planetary entry test chamber was designed and completed for the test of the 6½-foot aeroshells subjected to expected Mars entry pressure and temperature loadings.

Spacecraft Sterilization

A dry-heat sterilization process was developed and applied to the operating feasibility model of the 350-pound Mars entry capsule and lander encased in a biocanister. A thermal analytical model of the capsule was constructed for the process development, and microbiological assays were performed during assembly to estimate the microbial burden on the capsule surfaces.

With these data, using a computer program (SPAN), a sterilization cycle was determined that would achieve the appropriate probability of sterility required by planetary quarantine constraints. In addition, a technique was developed for altering the sterilization cycle to reflect conditions and thermal responses differing from those predicted, which may exist after the processing has begun.

The terminal sterilization cycle was applied to the entry capsule in the operational manner in which it would be implemented for an early Mars mission.

CHEMICAL PROPULSION

The basic purpose of chemical propulsion research is the continued improvement of liquid and solid propellants. Concomitant studies seek to improve propulsion equipment and to adapt the equipment to improved fuels. This, in turn, requires a constantly increasing understanding of the physical and chemical phenomena associated with rocket propulsion.

Space-Storable Liquid Propellant Module

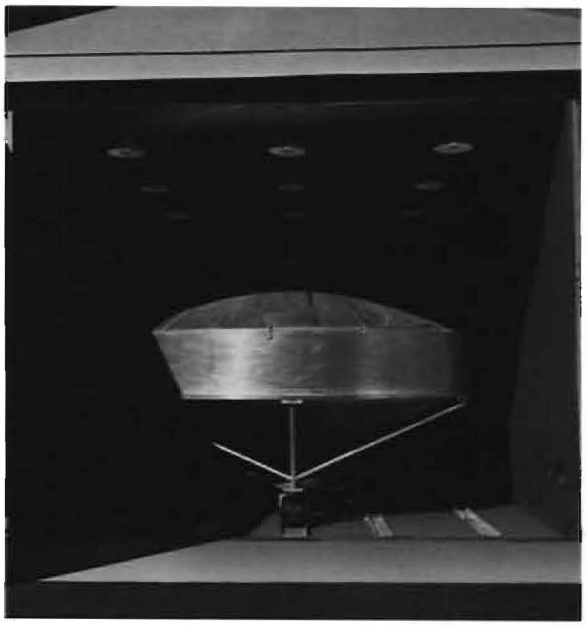
A broad program leading to the design, construction, and testing of a module for space-storable propellant was initiated in 1968. Rocket engines based on carbonaceous materials were tested that are capable of containing the high-temperature (7000°F) combustion gases. Design studies indicate that the module can be maintained in a sealed condition (no propellant venting) during launch operations, in transit, and in planetary orbit.

Liquid Propulsion Motor Development

A new cooling technique using conduction cooling is being developed for liquid propulsion engines capable of long-duration firing required for the Mariner Mars 1971 orbiter mission. Although several metals and alloys possess the thermal conductivity required for the conduction cooling process, beryllium offers the combined advantages of high thermal conductivity, light weight, high heat capacity, and relatively high melting point. The heat transmitted to the chamber walls in the throat region of the rocket motor is conducted by the monolithic beryllium structure back to the vicinity of the propellant injector, where it is absorbed by the latent heat of vaporization of a propellant film supplied by the injector. Development of this concept will provide engines which are low in cost, rugged, long-lived, and operationally simple, and have the versatility to meet a wide variety of propulsion requirements.

Mixture-Ratio Measurement in a Bipropellant Rocket Chamber

A technique was developed for sampling and analyzing the combustion gases in a rocket chamber. A traversing, water-cooled probe continuously feeds a



Thermal analytical model of Mars entry capsule in terminal heat sterilization chamber

local sample of gas into a computer-controlled mass spectrometer for on-line chemical analysis. The distribution of propellant mixture ratio in the chamber can be obtained from the results. This tool was used to obtain the first detailed results on the mixture-ratio distribution of an unlike impinging stream injector element under actual combustion conditions. The results show that, with a hydrazine–nitrogen–tetroxide propellant system and 0 073-inch-diameter orifices, the phenomenon of combustion-induced stream separation takes place A model was devised to predict the presence or absence of stream separation, and a design criteria plot has been made available to the industry The new sampling and analysis technique should prove valuable for the study of a wide variety of combustion processes.

Propulsion for Spacecraft Attitude Control

Planetary spacecraft launched to date have all used cold nitrogen gas for their attitude-control propulsion. The feasibility of two new systems using propellants stored as liquids was demonstrated during the year. The new concepts show significant improvements in system weight and reliability for future spacecraft applications. In the first of these, an electrolysis cell was developed which electrolyzes liquid hydrazine to form nitrogen and hydrogen gas. The performance of this mixture of gases is 50% better than the performance of nitrogen. With this advantage, and the advantage of storing the propellant as a low-pressure, high-density liquid instead of as a high-pressure gas, the system will weigh approximately one-half as much as an equivalent nitrogen system.

In the second system, liquid ammonia is stored aboard the spacecraft and, upon demand, supplies superheated ammonia vapor to the attitude-control thrustors, using waste heat from the spacecraft for the heat of vaporization. Here, also, the system weight would be about one-half of the equivalent nitrogen system. The weight advantage of either of these new systems can be obtained in future long-duration space missions with high reliability and little increase in system complexity.

New Valve-Seat Concept

Of critical importance to long-term space missions of the future are liquid propulsion systems with zero-leakage valves. A new approach to solving the problem of lapped valve-seat leakage is to impregnate the ball-contacting metal surfaces of the seat with ultrafine diamond particles The diamond impregnation increases the lifetime of the valve seat by eliminating galling between the seat and the closure ball and increasing its resistance to erosion and corrosion. The scanning electron microscope has been a particularly valuable tool in evaluating seat surface treatments and in determining seat surface finishes.

Low-Thrust Solid Propellant Rocketry

The major drawback in applying solid propellant rocket motors to planetary spacecraft propulsion is their intrinsically high thrust, which causes large and often intolerable acceleration loads to be imparted to the spacecraft Rocket motors using solid propellants typically burn for short times at the high thrust; longer times and lower thrust are achievable normally at the expense of mass fraction efficiency

Recent studies have shown that a design can be developed which will provide low acceleration loads without the penalty of low mass fraction efficiency The concept involves the use of the JPL-developed Saturethane propellant, which is based on a secondary, saturated hydroxyl-terminated polybutadiene binder and ammonium perchlorate oxidizer with aluminum fuel. The Saturethane propellants as a class have very low burning rates and high elongation, which are very advantageous characteristics for this application. The propellant charge is fully case-bonded; however, rather than having the usual internal burning configuration, the charge burns from the nozzle end.

Fully case-bonded nozzle-end-burning motors were successfully processed by curing the propellant grain at pressures similar to those to be experienced upon firing, or by curing by zones or stages. It was demonstrated that these charges can be temperature-shocked cyclically from 165 to −50°F and pressurized at these extreme temperatures to levels which duplicate the firing pressures, with no indication of charge cracking or unbonding from the motor case

Solid Propellant Rocket Motor Command Termination

A study of solid rocket combustion termination by water quench was initiated to (1) determine the optimum method of water injection to obtain complete extinguishment, (2) better understand the quench

mechanism so that it may be optimized, (3) establish means of predicting water requirements for any given motor, and (4) determine feasibility and performance of water extinguishment of flight motors.

The program consists of two phases: a laboratory-motor phase, which is currently under way, and a small solid propellant motor phase The laboratory motor is a slab-burning window motor capable of accepting several different types of water injectors. In this phase, a knowledge of the efficiency of the different types of injector and spray patterns and an indication of the dominant quench mechanism, or mechanisms, is being acquired. Using this information, a theoretical model will be developed to correlate the data of each injector and provide general extinguishment criteria.

The objective of the second phase of the program is to gain confidence in the extinguishment criteria and the reliability of this type of impulse control. Knowledge of the optimum values of the quench parameters gained in the slab motor will be applied to extinguishment of motors in the 3½ – 60 pound range to determine any motor configuration and size dependency

T-Burner Studies

In recent years the T-burner, a center-vented resonant cavity combustor, has become perhaps the most widely used device for studying combustion instability characteristics of solid propellants. However, there remain questions about the possible effects of the burner itself on the phenomenon it seeks to examine and the equivalence of the various methods of conducting T-burner experiments. Some 200 test firings have now been completed in JPL burners to seek a better understanding of the T-burner and to resolve some of these questions; thus, the results provide a higher level of confidence for the results of future T-burner experiments.

From the JPL experiments, it is now evident that the acoustic admittance, surprisingly, does not vary with burners of different diameters. It is also apparent that the growth-decay and the variable-area methods of conducting T-burner experiments do not provide the same results. In addition, ignition procedures have been shown to have a significant effect on the results obtained from such experiments. Although to date a complete understanding of the chamber acoustic losses has not been obtained, some important aspects of these losses have been observed which should help to provide a better understanding of these and the T-burner itself.

Rocket Exhaust Oxide-Particle Size Measurement

As part of the investigation of solid propellant rocket combustion, a study was undertaken to reconcile the differences in the results of two methods of measuring the particle size of aluminum oxide produced in such motors: a tank-collection and a spectrophotometric method. In the first method, small motors are fired inside a sealed tank, so that the solid exhaust products can be collected and analyzed In the spectrophotometric system, the amount of light at two wavelengths transmitted through the rocket plume is used to obtain a mean particle size Experimental and theoretical analyses led to an understanding of the differences between the two methods, so that they may now be used in a complementary manner

Solid Propellant Binder Development

Solid propellants based on new saturated hydrocarbon polymeric binders derived from linear alpha-olefins are demonstrating improvements in important properties over conventional propellants. The outstanding improvement is in thermal stability, resulting from the chemical ruggedness of the new materials Some new propellant formulations survive at least 300 hours at 275°F with good retention of essential properties. Under these conditions, conventional propellants either liquefy or harden, and they usually swell and crack. Another advantage is the greater tensile capacity, which is a measure of the combined tensile strength and elongation of propellants

Certain properties of the new propellants are inferior to those of conventional propellants, however, these may be improved The saturated hydrocarbon binders are more viscous in the liquid state, making processing of highly filled slurries difficult. In addition, the lower temperature limit of good rubbery properties is high compared to that of propellants based on polybutadiene binders. Based on the theory that both of these properties are dependent on polymer chain microstructure, 1-propylene was substituted for the bulky olefin, neohexene, in the free-radical synthesis of ethylene/olefin prepolymers The expected results were obtained. The glass transition temperature, which is an index of low-temperature properties, was lowered by 25°C, and the viscosity was almost an order of magnitude lower. Subsequent experiments with saturated hydrocarbon polymers derived from longer linear alpha-olefins provided even more improvement.

New Polymers for Solid Propellants and Expulsion Bladders

Although ionene polymers were first prepared to investigate electronic transport in organic polymers, structural variations have been introduced that result in elastomeric materials with good properties and that are flexible to −80°C. These polymers appear promising for solid propellant binders and other applications requiring elastomers with superior low-temperature properties. Two new techniques were developed for the preparation of saturated hydrocarbon prepolymers for propellant binders or other stable castable elastomers: direct monomer polymerization by cationic heterogeneous catalysis, and air oxidation of high-molecular-weight elastomers, followed by reduction.

In the area of nonreactive polymers for low-temperature application to expulsion bladders, two new polymer systems were developed: poly(perfluorobutadienes) and poly(perfluoroalkylene oxides). The latter in particular are unique in having the thermal and chemical stability of Teflon and superior low-temperature properties.

Mechanical Properties of Filled Rubbers

Previous work on the properties of glass-bead-filled elastomer composites was extended to composites containing a carbon-black filler, in which a much greater degree of interaction exists between the filler and the binder. The presence of filler particles having greater adhesion modified the stress–strain response essentially as predicted by theory except that, in addition, both the ultimate strength and ultimate elongation also increased with filler content; the latter effect was not observed with the glass-bead composites. This difference in behavior was attributed to the increased viscoelastic character of the binder conferred by the presence of the carbon-black filler. This work illustrated the strong dependence of filler–binder interaction on the ultimate properties of composites.

SPACE POWER AND ELECTRIC PROPULSION

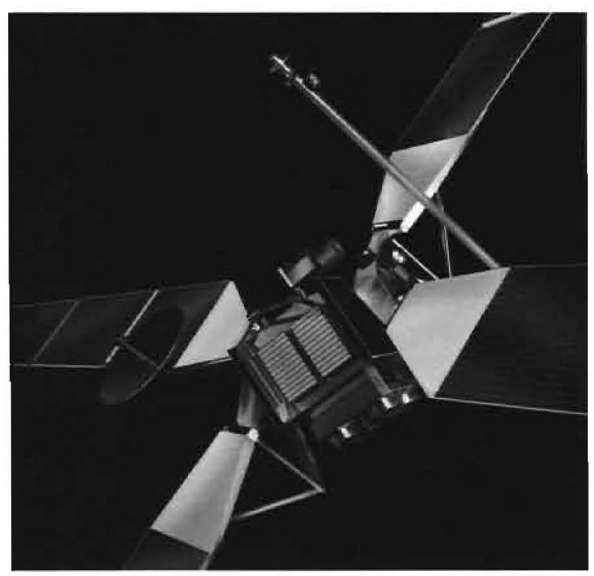
Nonchemical propulsion research is oriented toward long-range application. As the travel times and distances from earth increase, spacecraft propulsion must rely on the conversion of nonchemical energy into electrical power to make such extended missions possible.

Thermionic Diode Power Sources

As a part of a program for developing the technology of direct energy conversion, JPL has sponsored the development of thermionic diodes. These devices produce electrical energy from heat, which in turn comes from solar concentrators, radioisotopes, or nuclear reactors. A thermionic diode has been successfully operated at 2000°K for over 12,000 hours, a significant step in proving the reliability of such a device for use in spacecraft.

Radioisotope Power Sources

Radioisotope power systems produce nuclear radiation, which may interfere with spacecraft experiments. In order to identify, evaluate, and minimize the radiation interference problems for a specific spacecraft design, a collection of computer programs dealing with nuclear radiations and attenuation with the corresponding cross-section libraries was assembled. In addition, establishment of an experimental nuclear radiation facility was undertaken, where particle detectors and isotope radiation interfaces will be correlated to the expected radioisotope emitter nuclear spectrum. With this facility and the computer programs, it will be possible to perform, both experimentally and analytically, the necessary nuclear-detector interference and shielding studies.



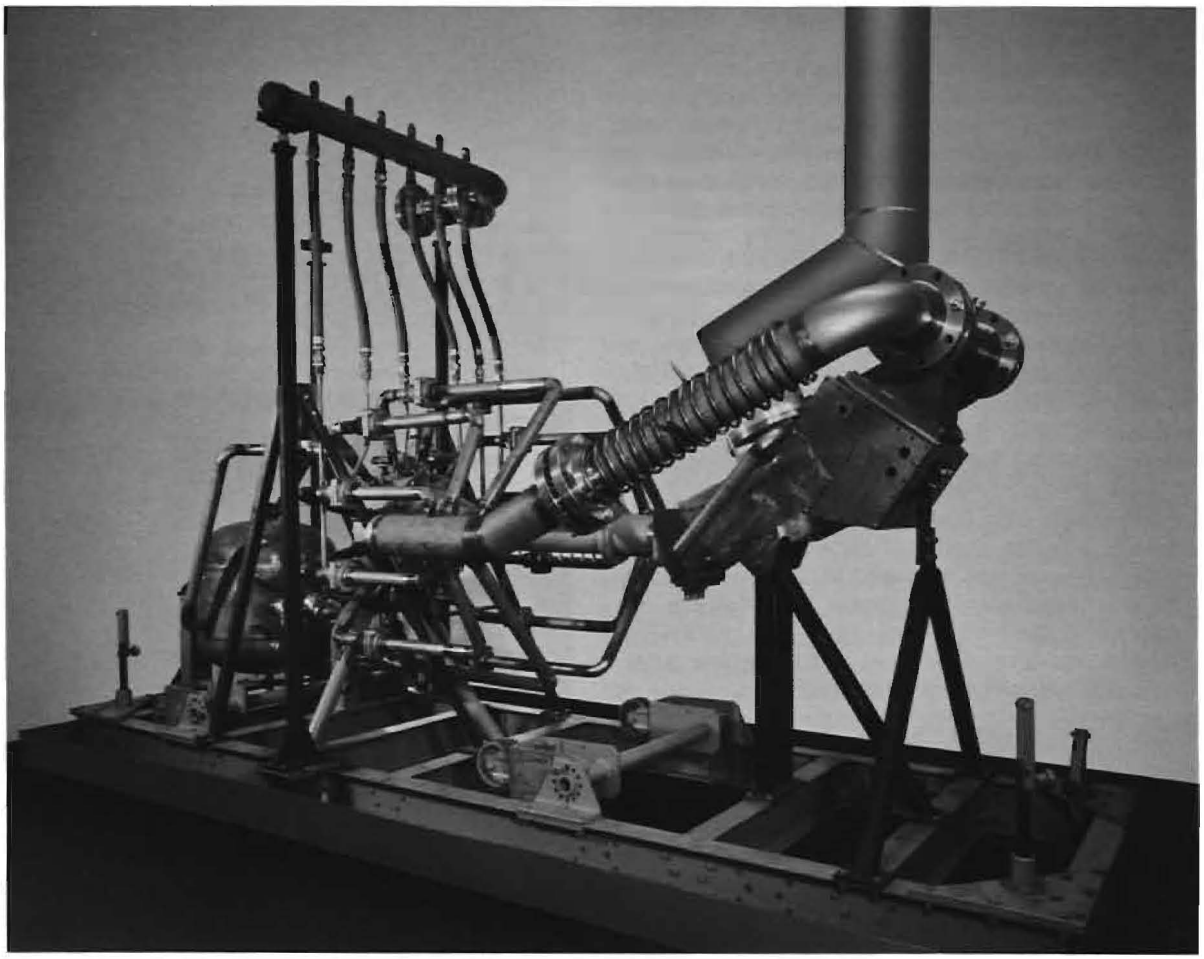
Model of solar-electric spacecraft conceived for Jupiter flyby in 1975

Lithium-Boiling Potassium Rankine Cycle Test Loop

The final phase of operation of the Lithium-Boiling Potassium Rankine Cycle Test Loop included testing of a newly conceived, shellside cross-flow liquid metal boiler.

Potassium boiling occurs outside a bank of lithium flow tubes in a compact, forced-convection, once-through unit; shellside boiling causes the potassium to be directed cross flow to the lithium tube bundle, eliminating the possibility of parallel-path instabilities and improving overall boiler heat transfer.

The performance of the boiler during the final phase of tests proved to be highly satisfactory. The overall heat-transfer coefficient was measured as approximately 3000 BTU/m-ft^2-°F at 100% exit quality (all fluid as dry vapor). Stability of the system was excellent for even the most severe system perturbations. A particularly significant test performed was a simulated space startup of the Rankine cycle test loop. Boiler and system stability and performance during this severe transient test were outstanding, especially when compared to the transient behavior experienced using a previously tested "conventional" tube-side boiler.



50-kilowatt liquid-metal magnetohydrodynamic power conversion system

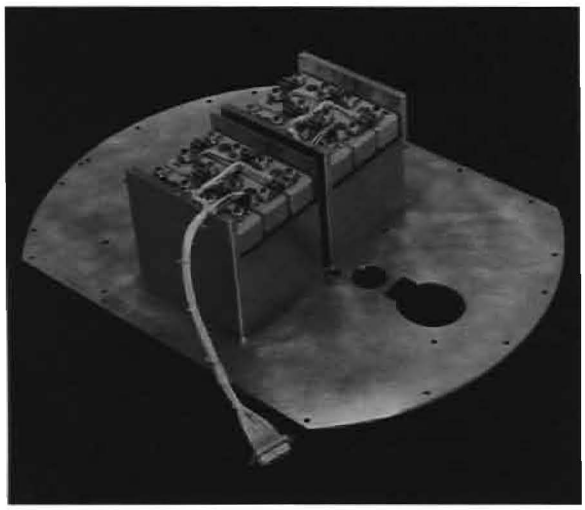
Liquid-Metal Magnetohydrodynamic Power Conversion

A 50-kilowatt conversion system to be operated with sodium–potassium as the liquid metal and nitrogen as the driving gas underwent preliminary hydraulic and electrical tests. In hydraulic tests with water and nitrogen, the system achieved closed-loop circulation of the water. In electrical tests of the generator, the desired traveling magnetic field was obtained. Assembly of the generator with the hydraulic components is in progress. A method of thermally insulating a liquid-metal MHD generator from the high-temperature liquid metal flow with minimum wall thickness was demonstrated, using the high thermal resistance of a vacuum interface to limit the heat transfer between an 1100°C alumina wall and a 70°C nickel block to only 15 watts per square centimeter at a contact pressure of 4 atmospheres.

Photovoltaic Power Sources

The feasibility of a four-wing, 50-kilowatt solar array having a specific power capability of 20 watts per pound was demonstrated. Fabrication techniques making extensive use of beryllium were developed, and an 8 × 13 foot subpanel was fabricated and tested. Deployment tests of a simulated wing were successfully conducted.

An additional development, which has the potential of producing 30 watts per pound through a "roll-out" technique, is under way. The roll-out solar array, when in the stowed or launch condition, is wrapped on a cylindrical drum. Upon command to deploy, an extendable boom is used to unroll the solar array from the drum. Preliminary analysis of the concept is encouraging, and a program leading to the development of a 10-kilowatt array system has been initiated.



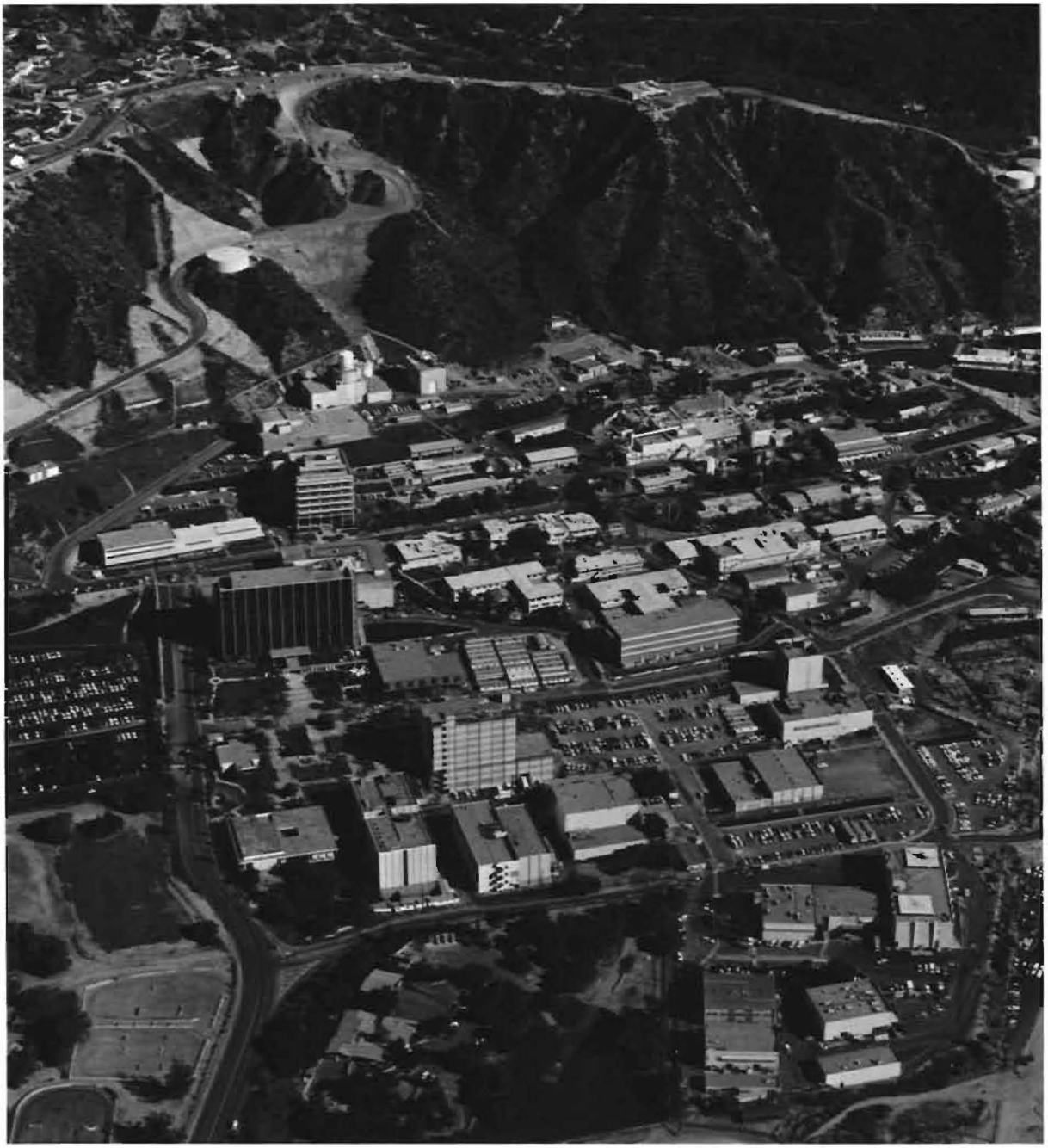
Heat-sterilizable, high impact-resistant silver–zinc battery

Sterilizable Batteries

Heat-sterilizable, high impact-resistant silver–zinc batteries were fabricated for the JPL Capsule System Advanced Development Program and were contained in capsules that were impacted at 1300 and 2500 *g*. All electrical performance requirements were met after the impacts. Work on secondary and large primary batteries continues, with the development of an 80-ampere-hour primary cell being at the most advanced state. The procedure of heat sterilizing after electrical cycling was shown to be practical provided that care is taken before sterilization to discharge the cells to the point at which no zinc metal remains and no mercuric oxide has been formed. In the heat-sterilizable nickel–cadmium battery program, 5-ampere-hour cells were developed which exhibit no capacity losses due to sterilization. Efforts are being directed to the problem of producing cells with uniform performance characteristics and to the design of larger-capacity cells.

Electric Propulsion Applications

Continuing progress in the development of large solar arrays and of integrated propulsion systems makes prospects for solar-powered electric propulsion spacecraft missions in the 1970's quite promising. During the past year, thrustor performance was improved to the point previously projected for attainment in 1970 and maintained over the required two-to-one power range. A first-generation thrust subsystem, including all elements anticipated to be required on a mission, was assembled. The subsystem included two individually gimballed thrustors mounted on a translating structure, a lightweight power-conditioning system connected through a switching network to one of the engines, and a failure-detection network to command the switching. The primary objectives of this phase of the program are to identify and eliminate any unfavorable interactions among the various subsystem elements, and to determine the control characteristics of the thrust subsystem. Testing will continue to the first part of 1969, and will culminate in an abbreviated endurance test.



Other Activities

JPL NAVIGATION PROGRAM

The ability of the Laboratory to navigate space vehicles with high accuracy has contributed greatly to the success of our space missions. The scientific return from some flight experiments has been enhanced, and other science experiments have been made feasible, by our ability to navigate accurately. Important contributions to celestial mechanics have resulted from advances in navigation technology. New challenges to our navigational capability appear imminent (e.g., navigation to the outer planets).

Navigation activities at JPL frequently involve all of the program offices as well as several of the Technical Divisions. The JPL Navigation Program (JNP) Office was established late in 1968 to coordinate and enhance the research and development related to the Laboratory's navigation activities and to provide continuity between flight projects

PLANS AND PROGRAMS

In the first year since its establishment in 1967, the Office of Plans and Programs acquired a staff and organization, and engaged in a number of major planning activities and staff studies As one means of facilitating Laboratory communications with NASA Headquarters in matters of institutional concern, a liaison representative was appointed to be resident in the Office of Space Sciences and Applications in Washington.

Resources Planning

During the year, the Office of Plans and Programs established procedures for implementing the overall coordination and review of the Laboratory's operational plans—that is, budgets, manpower allocations, and the like. This involved developing and analyzing estimates of resource requirements in coordination with the operating elements of the Laboratory, preparing recommendations to the Director for the allocation of available resources, and reviewing final plans and documentation for consistency and for compatibility with overall JPL and NASA plans and objectives. The internal interfaces involved in accomplishing these functions were defined, and the functions were carried on effectively.

Long-Range Planning Studies

A major long-range planning study completed in 1968 was concerned with a general assessment of possible areas of interest for Laboratory effort during the next 5 to 7 years and included both space and non-space programs. The non-space areas of greatest interest were those falling within federal agency cognizance and having a significant technological content. The social and economic environment anticipated during the period was regarded as an important factor in evaluating prospects for federal sponsorship of R&D and was carefully considered. Technical assessments took into account the possible influence of rapid technological developments in such fields as electronics, materials, and computers. JPL's potential interest in candidate programs was evaluated in terms of such factors as compatibility with the Laboratory's capabilities, staff interest, national significance, and the prospects that the Laboratory could become involved to the extent of playing a leading role. A second study, which is continuing, was undertaken later in the year to further examine some aspects of this investigation.

As an outgrowth of these studies, the Laboratory has undertaken a small effort in conducting studies for and providing technical support to the Assistant Secretary for Research and Technology in the Department of Transportation.

Advanced Technical Studies

Technical studies are carried out continuously at the Laboratory to explore potential missions and candidate spacecraft systems consistent with JPL and NASA program objectives. During 1968, three studies were undertaken that deserve special mention.

The problems of exploring the surface of the moon in areas distant from the sites planned for manned landings were examined. Goals for such lunar exploration were formulated, together with priorities, and alternative methods for achieving them were considered. Remotely controlled mobile vehicles and their instrument payloads were given special attention, and tests simulating lunar vehicle navigation problems under probable operational conditions were conducted in the Mojave Desert.

In the field of planetary exploration, the primary mission studies accomplished during the year examined the rationale for and feasibility of various outer planet

missions that can be flown during the 1976–1982 period, taking advantage of favorable positions of the five outer planets relative to one another During this period, the gravitational field of Jupiter can be utilized to accelerate the spacecraft outward to other outer planets, greatly reducing the flight time and injection energy otherwise required for such missions A number of different missions are possible, involving visits to two-, three-, or four-planet combinations. The most complex of these is the four-planet mission encompassing Jupiter, Saturn, Uranus, and Neptune, known as the outer planet "Grand Tour." Multiplanet opportunities occur for 2- or 3-year periods for each planet beyond Jupiter, recurring at intervals ranging from 12 years in the case of Jupiter/Pluto to 23 years for Jupiter/Saturn The unusually favorable coincidence in planet geometry that makes the four-planet Grand Tour possible will occur during the period 1976–1978 and not again for 170 years. The flight times required for these missions range up to about 10 years, which implies a need for great reliability in the spacecraft, but such mission lifetimes are considered feasible.

The objectives of the recent studies were to determine the characteristics of spacecraft systems capable of missions to the outer planets and of carrying payloads weighing from 50 to 200 pounds. Several design concepts were developed, including both three-axis-stabilized and spin-stabilized configurations. The studies showed that either of these stabilization techniques could be employed The on-board power sources considered included radioisotope sources as well as solar cell arrays.

The feasibility of using solar-electric propulsion for the mission was investigated and was found to depend principally on the capabilities of the launch vehicle used. If a new vehicle of Titan III D/Centaur capability or equivalent becomes available, the preferred mission concepts involve ballistic launches and trajectories. With a more limited launch vehicle of the Titan C class, a solar-electric-propelled spacecraft could accomplish the missions

In a more general sense, the studies showed that the outer planet missions are feasible, and that they require no unusual efforts in advanced development prior to implementation. Scientifically, the missions have many exciting aspects, providing a unique opportunity to reach the outer regions of the solar system

The third important area of study was in support of the space applications program. The specific task that was undertaken is the identification and analysis of technological requirements and costs for earth satellites capable of accepting and relaying data from other satellites, manned or unmanned. The time period of interest is 1970–1980 The approach adopted consists of (1) establishing requirements and formulating system concepts, (2) examining such aspects as coverage, replenishment, network control, communications, etc, and (3) performing comparative evaluations of candidate systems.

UNIVERSITY RELATIONS OFFICE

The University Relations Office, formed in 1968, has three basic purposes (1) to interface with the university community, (2) to act as the JPL contact point with the NASA Office of University Affairs, and (3) to facilitate the holding of joint meetings and symposia by JPL and professional societies. The University Relations Office has responsibility for the Resident Research Associate Program, sponsored by the National Research Council, and the Summer Faculty Fellowship Program, sponsored by NASA and the American Society for Engineering Education.

Perhaps the most significant development of the year was the formation of a JPL Visiting Committee of distinguished scientists, primarily from the academic community. This committee is charged with reviewing the JPL programs and recommending to the Director appropriate areas for future emphasis, as well as suggesting actions that would lead to more effective interaction with the university community.

The University Relations Office was also active in several other areas It aided faculty members of local universities in contacting Laboratory staff having similar interests, it provided assistance in expediting transfer of surplus equipment to universities and in locating equipment and facilities that could be shared with universities, it pressed for policies and procedures that would facilitate faculty participation in JPL activities; it represented the Director at university-related meetings and symposia; and it helped individual faculty members with a variety of problems.

During 1968, 21 faculty members were consultants to the Jet Propulsion Laboratory. Several faculty members of local universities cooperated informally with the

JPL technical staff on research problems of mutual interest. There were 29 active research contracts with various academic institutions. In addition, the Laboratory supported seminars, lectures, and technical presentations at various universities. Three JPL employees held joint appointments at Caltech; two Caltech faculty members held joint appointments at JPL. A total of 30 JPL employees had teaching appointments at local colleges and universities.

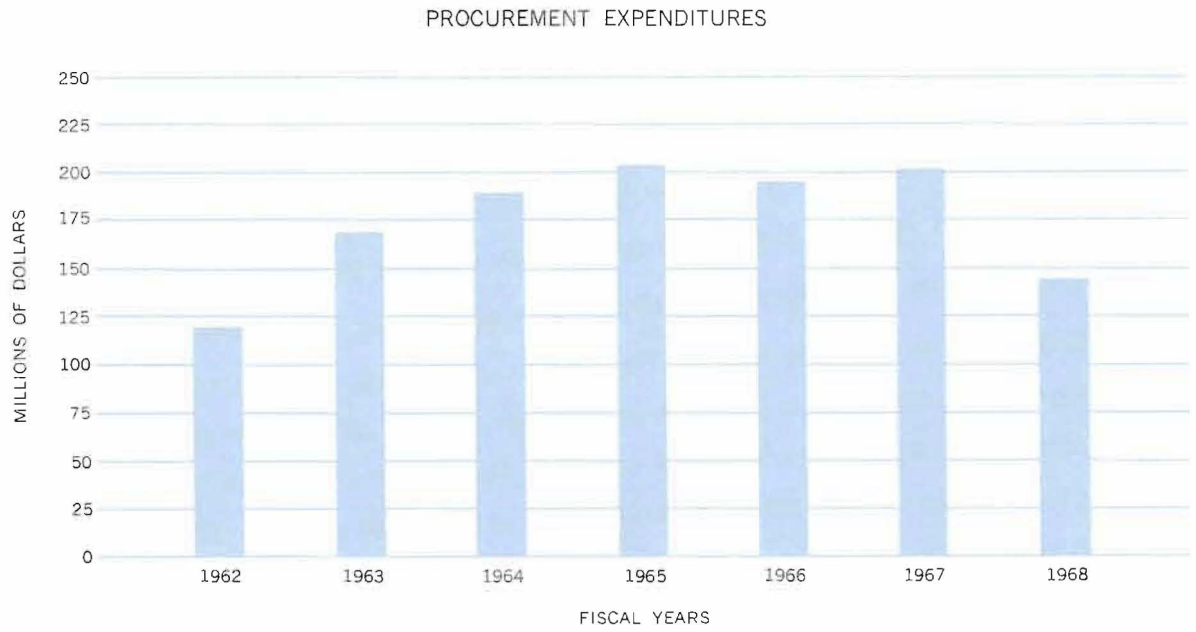
FINANCIAL MANAGEMENT AND PROCUREMENT

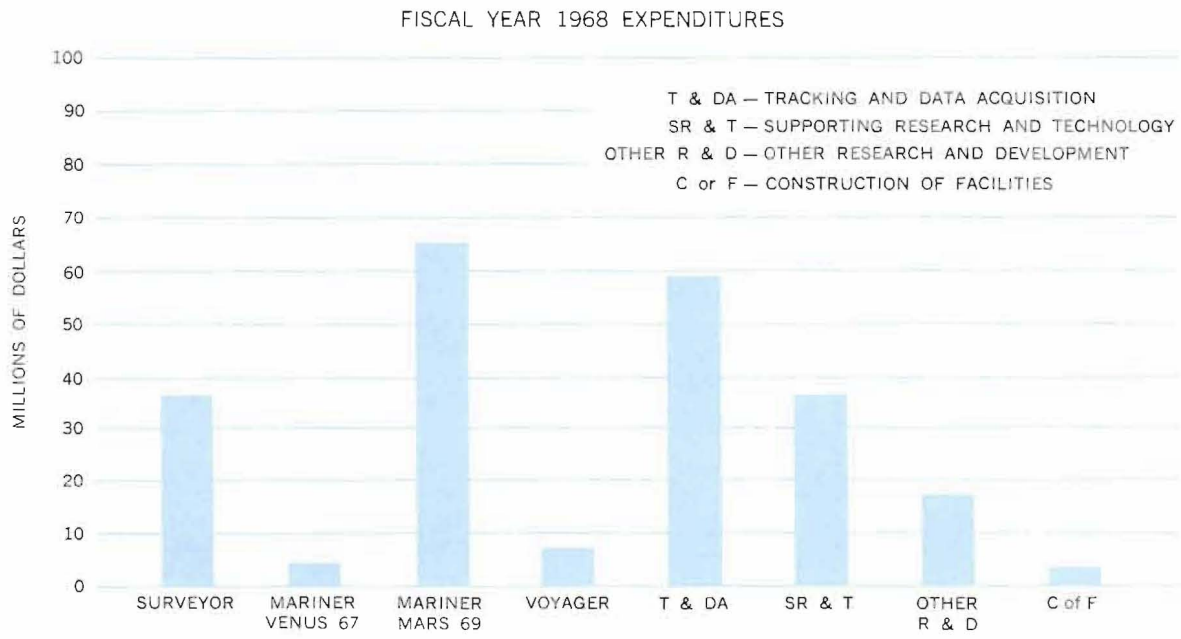
The fabrication effort under the contracts for the Mariner Mars 1969 Project was successfully completed with the delivery of subsystems and related documentation. Work was started in the development of procurement plans and requests for proposals for the forthcoming Mariner Mars 1971 Project contracts and the contract for the 210-foot antenna project.

A new concept, Blanket Order Charge Account Agreements, was employed to facilitate placement and obtain timely delivery of supply-type procurements not exceeding $250. Under these agreements, verbal orders are placed within 24 hours after the Procurement Division receives the procurement requisition and delivery is made within 2 working days.

The Automatic Data Processing Requirements Office, a control and central information office for the Laboratory's electronic computer systems, is in the process of implementing a semiautomated data collection and computerized data bank system for preparing inventory, cost, and usage reports for JPL's 94 computer systems consisting of more than 1300 separate components.

The FY '68 cost reduction goal of $7 million was exceeded, and, in addition, over $1 million in savings was realized by the re-use of surplus and salvageable items. Greater emphasis was placed on recognition of the employee's contribution by expanding the individual awards for cost reduction submissions. The overall program for FY '68 was rated as "excellent" by NASA.




FISCAL YEAR 1968 EXPENDITURES
T & DA — TRACKING AND DATA ACQUISITION
SR & T — SUPPORTING RESEARCH AND TECHNOLOGY
OTHER R & D — OTHER RESEARCH AND DEVELOPMENT
C or F — CONSTRUCTION OF FACILITIES
MILLIONS OF DOLLARS
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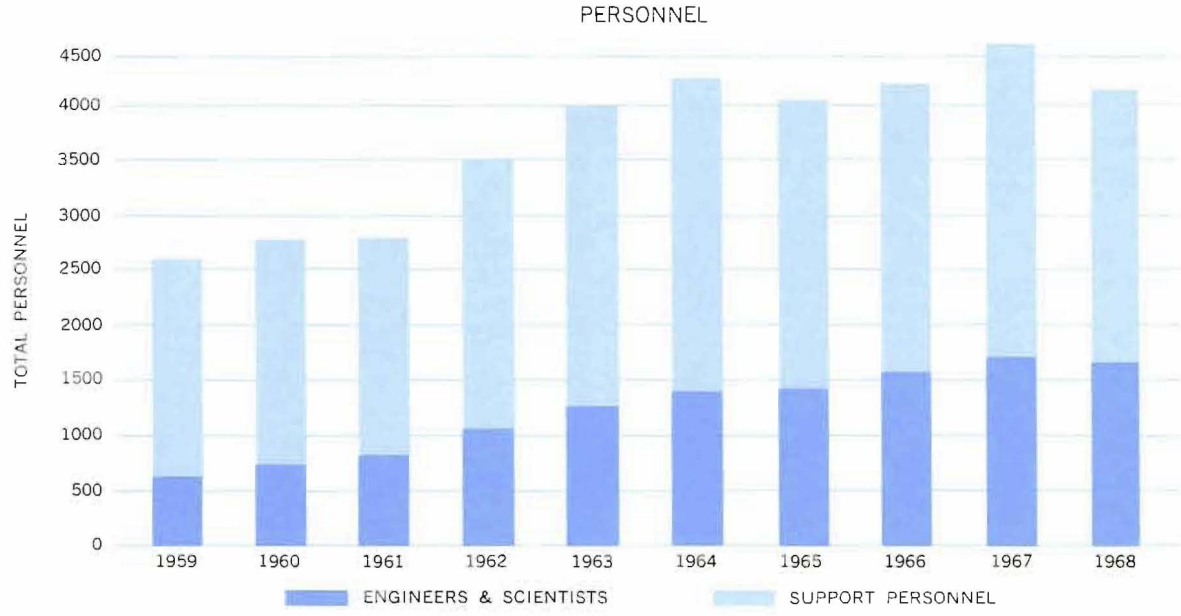
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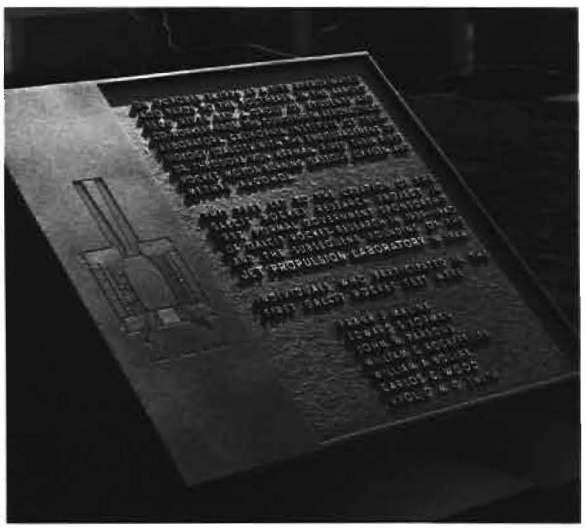
ENGINEERS & SCIENTISTS
SUPPORT PERSONNEL

PERSONNEL

The critical talent drain created by voluntary terminations, which increased because of Voyager cancellation and other reduced project funding, coupled with scheduled layoffs, had a significant effect on the staffing activities. Total utilization of engineering talent for ongoing programs through reassignment and transfer, placement assistance for employees affected by layoffs, and replacements of personnel vital to the Mariner 1969 effort were the primary responsibilities of Employment.

The Employee Development program was continued, concentrating on the area of management development. New programs included courses on the role of the technical group supervisor and the introduction of seminars in wage and salary administration. In conjunction with UCLA, a Summer Faculty Fellowship Program was inaugurated, with 12 university professors participating. The Resident Research Associate Program reached a peak of 20 participants.

The Public Educational Services Office continued its service to the general public and the educational community. More than 21,000 persons in civic organizations were reached through the Speakers' Bureau, which filled 287 requests in 1968. Tour activity increased. Over 9600 visitors, mostly school-age youth, saw various facilities and heard presentations during special tour programs. An additional 4500 school children and their teachers who wrote for information were furnished booklets, fact sheets, photos, and illustrated leaflets prepared or collected by the Office. Los Angeles area junior and senior high school libraries were provided with new issues of updated space-related material. Over 511 exhibit items, including models, slides, and graphics were loaned during the year for various educational purposes. In support of NASA programs directed toward teacher education, the Office staff made presentations, provided consultation, and furnished material assistance at summer workshops and teacher conferences.



Plaque commemorating first test of a rocket motor by Caltech students and associates on October 31, 1936

FACILITIES

Additional landscaping was completed during the year in a number of areas in accordance with the long-range plan. The JPL master plan was revised to reflect the 1968–78 period, and a new master plan report was published.

An internal road connecting the Mesa antenna range area to the main portion of the Laboratory was completed, as was an enlarged museum area in von Kármán Auditorium, making available permanent display space for various spacecraft and models. Construction was begun on an addition to the fabrication shop building to house the sheet-metal and welding activities. The energy-conversion research laboratory space was more than doubled by remodeling and an addition to the north side of the building.

Modifications to the main cafeteria were completed, and the old cafeteria in Building 114 was closed providing space for additional offices and for a vending machine center.

Work was started on a partially underground addition to the SFOF building to provide for a standby power plant, including three 1380-kilowatt gas-fired diesel generator sets and an uninterruptible power supply system which will greatly increase the reliability of the space flight center and its associated equipment.

Personnel housing requirements have been reduced by the decrease in manpower during the year. As a result, and with the conversion of 6500 square feet of warehouse to office space, it was possible to eliminate 18,000 square feet of off-Laboratory leased office space and to dispose of 33 trailers.

Off-Laboratory work included the remodeling of the cafeteria at Echo Station and the completion of a new Operations Support Building at the Mars Station to house the operations control functions for the 210-foot antenna at Goldstone.

SPECIAL RECOGNITION

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

Honorary Awards

F. H. Felberg, NASA Exceptional Service Medal for outstanding and sustained technical and management leadership

R. M. Goldstein, NASA Exceptional Scientific Achievement Medal for outstanding engineering and scientific leadership in development and exploitation of advance techniques for deep space communication

L. D. Kaplan, NASA Exceptional Scientific Achievement Medal for outstanding research leading to better understanding of the atmosphere of Venus

Mariner Occultation Experiment Team, NASA Group Achievement Citation for outstanding performance, resulting in definitive fundamental information regarding the temperature and pressure profiles of Venus' upper atmosphere as well as new information about its chemical composition

W. H. Pickering, Arthur Noble Award of City of Pasadena; Louis W. Hill Space Transportation Award of the American Institute of Aeronautics and Astronautics

A. Rembaum, NASA Exceptional Scientific Achievement Medal for outstanding contributions in the fields of physical organic chemistry and polymer synthesis

C. W. Snyder, NASA Exceptional Scientific Achievement Medal for significant contributions to the success of the Mariner V flight to Venus

Surveyor Project Team, NASA Group Achievement Citation for outstanding technical achievement and dedication in the development and operation of the Surveyor spacecraft system

Faculty Appointments

R. M. Goldstein, Lecturer in Radar Astronomy, Department of Planetary Science, California Institute of Technology

L. D. Kaplan, Visiting Professor, Department of Geology and Geophysics and of Meteorology, Massachusetts Institute of Technology

A. Rembaum, Lecturer, Department of Chemical Engineering, California Institute of Technology

M. M. Saffren, Member, Visiting Faculty, Department of Chemistry, University of Southern California

C. Solloway, Lecturer, Summer Institute of Dynamical Astronomy, Massachusetts Institute of Technology

D. I. Tchernev, Associate Visiting Professor, Department of Engineering, University of Texas

C. S. Wu, Visiting Professor, Physics Department, National Taiwan University

Academic Recognition

A. C. Ludwig, NDEA Fellowship, University of Southern California

C. W. Snyder, Honorary D.Sc., University of Redlands

W. Stavro, Murray Scholar, California Institute of Technology

G. D. Thompson, Jr., NDEA Fellowship, University of Southern California

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Note Dr DuBridge retired on January 15, 1969 He was succeeded by Dr H Brown

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