JET PROPULSION LABORATORY

1967 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, 1967, to December 31, 1967.

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JET PROPULSION LABORATORY

CALIFORNIA INSTITUTE OF TECHNOLOGY

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During 1967, the Laboratory achieved a new high in its commitment to support the nation’s unmanned lunar and planetary flight missions. In addition to its continuing efforts in supporting research and advanced development, fourteen flights were involved, representing the heaviest load ever placed on our operational, tracking, and data recovery facilities.

With Surveyors III, V, and VI, JPL essentially completed its program of on-site surveillance and inspection of potential landing locations for the Apollo manned lunar program. These missions produced over 50,000 close-up photographs of prime Apollo candidate landing areas. The soil sampler and alpha scattering experiments yielded a wealth of new data about the mechanical properties of the lunar surface and its chemical composition.

The success of Mariner V concluded several years of effort by many segments of the Laboratory when its 4-month flight to Venus returned valuable new information about that planet’s atmosphere and physical environment. The Mariner IV mission was tracked to its termination in December of last year, culminating a 1 1/2 billion-mile mission involving over 1100 days and 26,000 operating hours without catastrophic failure of on-board components or systems.

In its broadening program of application of space technologies to other scientific fields, the Laboratory made significant progress in extending the techniques of computer enhancement of photographs to the improvement of medical x-rays. Another example is the mini-recording of microscopic magnetic data on film using pulsed laser beams. The research program at JPL continued to encompass a wide variety of fields ranging from micro-organic tests of Antarctic soil as a possible clue to life on Mars to studies in general relativity.

The Laboratory looks forward to a continuing program of science-oriented research on the moon and the planets, with an expanding complementary effort relating to our terrestrial environment in which we can apply the technologies developed during our first full decade of exploration beyond earth’s atmosphere.

W. H. Pickering
Director
Surveyor

Four Surveyor missions were flown in 1967. Three of these missions were highly successful and provided all of the essential information regarding lunar surface characteristics required in preparation for the manned Apollo flights. The one remaining probe in the Surveyor series has been scheduled for launch in early 1968.

Surveyor III

Surveyor III lifted off from Cape Kennedy on April 17, 1967. The launch vehicle was an Atlas/Centaur combination. The flight was uneventful until, a few seconds before touchdown on April 20, the radars lost lock, preventing vernier-engine cutoff at 14 feet above the surface as had been planned. As a result, Surveyor touched down with the engines still firing, lifted off, touched down a second time, lifted off again, and then touched down for the third time after engine cutoff was commanded from the earth. Nevertheless, the spacecraft came to rest in an upright position, at an angle of about 14 degrees.

Surveyor's landing site was the inner wall of a medium-sized crater in Oceanus Procellarum, about 390 miles east of the area in which Surveyor I had landed in June 1966. The angle of the spacecraft and its position within a lunar crater permitted valuable observations to be made that would not otherwise have been possible. In addition to being able to examine the interior of a sizable crater, Surveyor III's camera took advantage of the spacecraft's tilt by obtaining color photographs of an eclipse of the sun by the earth as well as of the earth itself, and of the planet Venus. These views would have been beyond camera range if the spacecraft had landed on a level surface. Among the 6315 pictures taken on the first lunar day (1 lunar day = 14 earth days) were television observations made with color filters which indicate that the lunar surface is varying shades of gray even in disturbed areas.

In addition to the survey television camera and instrumentation for obtaining in-flight and post-landing engineering data that were included in all of the missions, Surveyor III was the first to carry a soil-mechanics surface-sampling device, which provided valuable new information on the physical properties of the lunar soil. The sampler consisted of a scoop, about 5 inches long and 2 inches wide, mounted on a pantograph arm that could be extended up to 5 feet from the spacecraft. The arm could be pivoted in a horizontal arc, lifted about 39 inches
above the surface, or dropped onto the lunar surface by means of a spring. The scoop also contained a controllable door, which allowed the device to manipulate the soil in various ways while the results were being observed by the television camera. The sampler picked up objects as small as 1 inch in diameter, furrowed four trenches to confirm that the surface material has definite cohesiveness, and made eight bearing-strength tests and fourteen impact tests which indicated that the lunar surface has a bearing strength of 3 to 9 pounds per square inch. By May 3, the end of the first lunar day, the surface sampler had operated for a total of more than 18 hours.

Surveyor IV

Surveyor IV was launched on July 14, 1967. The Atlas/Centaur launch vehicle provided satisfactory injection into a lunar transfer trajectory, and a close-to-nominal mission was achieved through the coast phases. The midcourse correction was successful, and the automatic terminal descent sequence was initiated approximately 62 hours after launch. The retro descent appeared satisfactory until the spacecraft radio signal abruptly ceased 41 seconds after main retro motor ignition and about 1.4 seconds before predicted motor burnout. At the time, the spacecraft was 49,000 feet above the moon's surface and was traveling at 1070 feet per second. Attempts were made to no avail to re-establish radio contact with the spacecraft using every feasible operational technique, including that of commanding the spacecraft to operate in all possible modes. An intensive investigation made subsequently of available data did not reveal a cause for the failure that could be substantiated.

Surveyor V

The landing, on September 11, 1967, of Surveyor V is a vivid example of the ability of a skilled project team of engineers and scientists to respond to an emergency situation, making the kind of decisions and judgments that can convert a potential failure into a success.

After a satisfactory launch on September 8, Surveyor V was injected into an earth parking orbit, and the flight proceeded normally for about 18 hours. At that time, a midcourse maneuver was initiated and successfully executed. Following the maneuver, however, the helium regulator in the vernier propulsion system failed to reseat properly, permitting helium to escape that would be needed to slow the spacecraft's descent prior to the landing. After careful analysis, the decision was made to alter the standard terminal descent maneuver so as to make possible a soft landing despite the loss of critical helium pressure. Three additional vernier engine firings were made to reduce the spacecraft weight and to increase the helium ullage, thus ensuring a minimum helium pressure
During the terminal maneuver, ignition of the main retro engine was delayed from the originally planned 30,000 feet to 4400 feet above the lunar surface. This permitted Surveyor to descend within the reprogrammed descent contour at a velocity of 400 to 500 feet per second, which resulted in a completely successful soft landing.

Surveyor V touched down just below the rim of a small crater some 18 miles northwest of its original target site in Mare Tranquillitatis on the eastern side of the moon. It was the first lunar spacecraft to carry an alpha scattering instrument, a device designed to make chemical soil analyses by radioactivity. The instrument bombards the lunar surface with alpha particles, which, upon striking the atomic nuclei of the elements present in the lunar soil, are scattered in numbers and at energy levels unique to each element. Measurement of the reflected particles thus makes possible the identification of the elements exposed to the bombardment. The results of the experiment showed that the chemical composition of the lunar crust at the site sampled resembles that of terrestrial basalt.

Surveyor also performed an experiment to determine the possible existence of iron on the moon, using a magnet attached to its landing gear. The test demonstrated the presence of ferromagnetic material in quantities similar to those found in earth-type basalt samples.

At the request of the Apollo Project, Surveyor's vernier engines were fired by radio command for approximately six tenths of a second after the landing to enable the cameras to observe any erosion effects that might occur. The test disclosed no problems associated with the effects of the rocket exhaust.

In the course of its lunar operations, Surveyor V sent back to earth 18,006 pictures on the first lunar day and over 1000 on the second. Conclusions drawn on the basis of the pictures and the data from the various experiments indicate that the moon's maria were formed as a result of partial melting of the lunar material caused either by internal volcanic action or by external bodies impacting the surface. The crater in which the spacecraft rests has a rimless contour perhaps caused by erosive drainage into a subsurface fissure.
Surveyor VI

The Surveyor VI mission was the most successful accomplished to date in terms of achieving a near-perfect launch, midcourse maneuver, terminal descent, and post-landing operations. The performance of the Atlas/Centaur launch vehicle and the spacecraft were well within nominal expectations, and the initial trajectory following injection from the parking orbit provided for a landing within 3 degrees of the target. A minor midcourse correction resulted in a soft landing approximately 2.5 miles west of the aiming point.

Launched from Cape Kennedy on November 7, 1967, Surveyor VI touched down 3 days later in Sinus Medii, just a few miles from the impact point of Surveyor IV. Like Surveyor V, the spacecraft carried an alpha scattering instrument for examining the chemical content of the lunar soil. Unlike any of its predecessors, however, Surveyor VI actually lifted off the surface about a week after its initial landing. On signal from earth, it fired its three vernier engines, rose 10 feet, and then landed again 8 feet from its original site. It was the first rocket-powered takeoff from the face of the moon. The spacecraft then transmitted a series of pictures encompassing a 360-degree panorama which clearly disclosed two of the three footpad imprints at the original touchdown point as well as the blast effects of the vernier engines. By the end of its first lunar day, Surveyor VI had transmitted a total of about 30,000 television pictures, which included stereo coverage resulting from photographs taken before and after its shift in position. The outstanding quality of all the pictures was at least partly due to two new features incorporated in Surveyor's camera: the camera mirror was carefully shielded from dust and particles that might otherwise have accumulated on it during touchdown, and polarizing filters were used for the first time.

Summary of Surveyor Results

The four Surveyor spacecraft that have successfully soft-landed on the moon have provided over 66,000 photographs ranging from coverage of an eclipse of the sun by the earth and views of the solar corona to high-quality closeups of the lunar surface that show objects as small as a fraction of an inch in diameter. The last three missions have yielded the first direct analysis of the chemical composition and physical structure of the surface, and their composite findings indicate that

The chemical composition of the crust resembles earth-type basaltic silicate.

The surface consists of fine, granular material having a wide range of grain sizes. The lunar soil is weakly cohesive and behaves like fine, damp soil on earth. Rocks and clod-like clumps of soil are strewn over the surface.

Ferromagnetic material exists on the surface in quantities consistent with measurements made on earth-type basaltic samples.
The lunar material was probably differentiated by melting and solidification and, accordingly, the moon’s core was, and probably still is, hot with volcanic activity.

The bearing strength and erosion properties of the surface at the sites sampled are such that no problems are anticipated that would adversely affect Apollo landing operations.

Surveyor III’s surface sampler deepening a furrow dug in the lunar surface by three earlier passes with the scoop

Mariner

Although Mariner V was the only Mariner-class spacecraft launched during the year, tracking activities for Mariner IV, whose flight began in 1964, were continued. Coverage was intensified in August and September so that the relative spatial positions of Mariners IV and V could be used to provide information about interplanetary space never before available to man. Another Mariner mission, scheduled for 1969, is designed to perform further investigations of Mars in preparation for future scientific and technological experiments.

Mariner IV

Mariner IV, which flew within 6200 miles of Mars on July 14, 1965, and took the first photographs of the Martian surface, has now logged over 1000 days in space, with more than 24,000 hours of normal performance of its subsystems. During the 17 months following mission termination on October 1, 1965, the Deep Space Network used the spacecraft as a radio beacon to facilitate the development of telecommunications elements and techniques.

March 1, 1967, marked the resumption of regular operational activities in the retrieval of telemetry data from the spacecraft, and full-time tracking commenced in mid-July. Coverage was intensified in September to take advantage of the unique relative spatial positions of the Mariner IV and Mariner V spacecraft to gain additional knowledge of the characteristics of the interplanetary medium. Mariner IV came within approximately 29,000,000 miles of earth on September 8, and on September 15 encountered a small cloud of meteoritic particles, with the cosmic

Color calibration chart mounted on one of Surveyor VI’s antenna booms (left) before and (right) after spacecraft’s liftoff from the moon
FLIGHT PROJECTS

detector registering 17 hits in 17 minutes. Some particles were of sufficient size and velocity to perturb the sun orientation of the spacecraft, but no apparent damage was sustained by any of the exposed components.

On October 5, Mariner IV was subjected to a series of commands that resulted in the first reacquisition of the star Canopus since early 1966. On the following day, the spacecraft was transferred to the inertial control mode and reoriented so that the high-gain antenna was once again positioned toward earth; when the spacecraft transmitter was switched to the high-gain antenna, the received signal strength increased by 22.5 decibels. Simultaneous tracking coverage of Mariner IV and V ended at this time to permit a concentration of effort on the imminent Venus encounter of Mariner V.

In late October, a second propulsion system burn was successfully performed to determine whether the system had survived almost 3 years in space, an operation that involved the reactivation of components which had been essentially dormant since December 1964. The information obtained will verify the applicability of similar propulsion system designs for future missions and significantly raised the level of confidence in the use of the same system in the Mariner V and Mariner Mars 1969 missions. On October 26, over 2 years after the photographs of Mars were taken, the video storage subsystem was commanded to retransmit one of the pictures stored on tape back to earth; the subsystem responded and replayed the last half of picture 16 and the first half of picture 17. Since very little was known about the long-term effects of non-operating precision mechanical devices stored in space, the successful accomplishment of the test greatly enhanced technical knowledge in this area. Other command sequences, including Canopus acquisition, were transmitted to the spacecraft, and in all cases, responses were normal. Analyses of the subsystems indicate that responses to command sequences were as precise as they had been during the pre-launch tests performed in 1964 and that no appreciable degradation has occurred in the intervening 3 years.

Mariner V

The Mariner mission to Venus in 1967 was launched from Cape Kennedy on June 14. The spacecraft passed within 2344 miles of the surface of Venus on October 19, 1967. All launch-phase events occurred as planned, with all systems of the Atlas/Agena vehicle performing properly, and injection was accomplished as programmed.

Immediately after initial sun acquisition, the spacecraft was rolled for magnetometer calibration purposes, and the science instruments made measurements of the environment in three distinct regions:
(1) inside the magnetosphere, where the trapped radiation detector monitored the Van Allen radiation belts, the helium magnetometer measured the geomagnetic field, and the plasma probe detected no plasma; (2) during passage through the magnetopause (outer boundary of the magnetosphere), where the first detection of plasma was made and changes were noted in the solar plasma as modified by the passage through the shock wave that precedes the earth; and (3) during passage through the plasma shock wave, which was indicated by a sudden decrease in the magnetic field and a change in the energy spectrum of the solar plasma to one typical of the interplanetary solar wind. Observations of disturbances in the magnetic field, which indicated some solar activity when the geiger counter pointed toward the sun, resulted in the detection of at least one burst of solar x-rays.

Throughout the period when the spacecraft was rolling, the ultraviolet photometer periodically observed the hydrogen in the earth's geocorona. In addition, new data were obtained that, tentatively interpreted, indicate a higher temperature in the exosphere than had been expected. Atomic hydrogen was also observed in another direction, which later proved to be in the galactic plane (Milky Way).

A successful midcourse maneuver was performed 5 days after launch that required a motor burn of 17.66 seconds and added 14.7 hours to the predicted time of flight. Following this maneuver, final Canopus acquisition was delayed for 3 hours to allow the spacecraft to revolve on its roll axis three times for the purpose of sweeping the celestial sphere with the ultraviolet photometer.

On completion of the midcourse maneuver, doppler measurements were made and ranging was accomplished for the first time with a Mariner spacecraft to facilitate redetermination of the trajectory. The accuracy of the data obtained far exceeded that required to determine the trajectory and the planet flyby distance of the spacecraft; however, the data will be of considerable value in post-mission analysis to determine the subtle effects that cannot be measured with existing analytical tools.

Forty days after launch, the telemetry data rate was automatically switched from 39/3 to 81/3 bits per second; all subsystems continued to operate normally. An intense stream of solar particles was encountered on September 19 which was associated with a small solar flare (or series of subflares) that occurred near the west limb of the sun. The high intensity of the stream indicated that the spiral interplanetary magnetic field lines existing in the vicinity of Mariner V at the time connected directly with the source of the flare on the solar surface. Extremely high proton, x-ray, and alpha-particle intensities were also detected by both Mariner IV and V at the time.

Encounter preparations proceeded smoothly, and the command to start the encounter sequence was transmitted to the spacecraft on October 18. Closest approach occurred on the following day at a distance of 2544 miles above the assumed surface of the planet. Occultation and loss of radio signal were observed at 17:39:08 GMT, and exit occultation (signal reacquisition) occurred at 17:59:59 GMT. Preliminary observations showed many positive and interesting readings on all scientific instruments, with the possible exception of the trapped-radiation detector. As a result of
the close approach to the planet, the magnetometer and the plasma probe observed phenomena not noted during previous planetary encounters. Operations at the Space Flight Operations Facility were normal, and the spacecraft performed flawlessly.

Preliminary results based on data from the Mariner V flight have already yielded considerable information concerning Venus and its environment.

Tracking of Mariner V is continuing, and additional scientific information is being obtained. On November 7, the spacecraft had reached a point in space 180 degrees from its location at the time of the midcourse maneuver, after which Mariner was rolled three times. This operation was repeated at the new point in space to allow the ultraviolet photometer to observe and map the same region of the celestial sphere. Playback of the science data was completed on November 9, and all subsystems responded to the commands for this operation. The data obtained are of great interest for instrument calibration purposes.

Mariner V will continue in a solar orbit that will carry it closer to the sun than any previous spacecraft has flown and thus will probe another hitherto unknown region of space.

Mariner Mars 1969

The Mariner Mars 1969 Project, now in the development and fabrication phases, is the next step in the exploration of Mars. Two launches are planned between February and April of 1969, and the spacecraft are scheduled to pass within about 2000 miles of the planet in early August 1969. At the present time, this project represents the last formally approved undertaking included in NASA's funding for planetary missions. The project, authorized in 1965, has as its objectives the carrying out of exploratory investigations of Mars to set the basis for experiments relevant to the search for life, and the development of the technology required for future planetary exploration missions.

Two identical 850-pound spacecraft will be launched by Atlas/Centaur vehicles. They will differ from the Mariner IV spacecraft design in that all the scientific instruments will be planet-oriented and mounted on the scan platform, and in the communications, control, data-handling, and storage features, which have been modified to enhance the recovery of planetary data.

The scientific instrument payload will be mounted on a platform which both slew and elevates to permit programmed instrument pointing during the encounter. Wide-angle and narrow-angle television cameras, providing a format of 16 times as many picture elements as did the Mariner IV camera, will take a series of pictures of the whole planet during the approach and alternating wide- and narrow-angle pictures near the time of closest passage. An infrared radiometer will provide surface temperature measurements for correlation with visible features, an infrared spectrometer will examine the atmospheric and surface composition and properties, and an ultraviolet spectrometer will assist in the identification of atmospheric constituents. Two investigations requiring no special spacecraft instrumentation, S-band radio occultation and celestial mechanics, will provide information on the physical properties of the atmosphere and furnish data on certain fundamental solar system parameters to extend similar data recovered from previous Mariner missions.

Broad industrial and scientific participation characterizes the Mariner Mars 1969 Project. Eleven industrial firms, under contract to the Laboratory, are involved in the manufacture of major flight equipment elements, and members of eight universities or research establishments are concerned in the scientific investigations. JPL is responsible for the overall project management, spacecraft system design, integration, and assembly. During the past year, systems designs were completed, spacecraft subsystem design verification testing was undertaken, and flight hardware fabrication was in progress.

Voyager

The Laboratory's involvement in the Voyager Project during the past year consisted of providing support to NASA's Interim Voyager Project Office in the area of mission analysis and engineering. JPL carried out assignments relating to the planning of the tracking and data-acquisition system, the mission operations system, and the surface laboratory system, and managed the landing capsule system contracts.

The recent Congressional decision not to appropriate funding for the Voyager Project this fiscal year, together with the uncertainty as to when the project might be re-instituted along the lines of its original concept, resulted in the suspension of all Voyager Project activities at the Laboratory in November.

Planetary Extension Program

With the termination of the Voyager Project activities, the Laboratory was requested by NASA to establish an Advanced Planetary Missions Technology program to encompass supporting research and technology relating to planetary missions during the period 1970 through 1975. This effort is to include engineering studies, technological development, and scientific instrumentation definition directly applicable to flyby/orbiter and lander-type missions. These contemplated missions would involve flights to the planets Venus, Mars, Mercury, and Jupiter and would be based on the utilization of the Atlas/Centaur, Titan III, or Saturn V classes of launch vehicles. Studies and advanced engineering efforts designed to capitalize on the technological and scientific advances that have resulted from the Ranger, Surveyor, and Mariner Projects have been initiated.
Operations

The Deep Space Network (DSN) provided tracking and data acquisition support during 1967 for the Surveyor III, IV, V, and VI missions; the Lunar Orbiter III, IV, and V missions; and the Pioneer VIII, Mariner V, and Apollo IV missions. In addition, the Lunar Orbiter II and Mariner IV extended mission support was concluded, and Pioneer VI and VII were supported throughout the year. During the calendar year, the DSN experienced the heaviest loading in its history, and most of the network was in operation 24 hours a day, 7 days a week.

Special support was provided to the flight projects, as typified by the following accomplishments: (1) polarization diversity reception for Mariner V and Pioneer, (2) planetary ranging for Mariner V celestial mechanics, (3) waveform measurements for Mariner V occultation, (4) precision doppler and ranging for Lunar Orbiter selenodesy, (5) simultaneous Surveyor and Mariner telemetry processing through a single computer string, (6) evaluation of nongravitational forces on Mariner and Pioneer spacecraft, and (7) standardization of telemetry using software demodulator techniques for Mariner IV and V.

A recapitulation of the DSN elements at year's end provided a new profile for the Deep Space Instrumentation Facility (DSIF) and updated capabilities for the Space Flight Operations and Ground Communications Facilities (SFOF and GCF). The DSIF profile now includes seven 85-foot antenna stations, one 210-foot station, one 30-foot station, one launch support station, and one development station. Four of the 85-foot stations are "DSN-only" and three are combined DSN-Manned Space Flight Network (MSFN) stations (including a new MSFN wing at each of the three stations). Capabilities of the SFOF were augmented by the installation of a fourth computer string for data processing, and by the addition of multiprocessing in the 7044 computer. A significant addition to the GCF was a teletype message-switching processor; major events in 1967 were use of high-speed data links and the first DSN use of a Comsat satellite to relay communications from Ascension Island to Cape Kennedy for Surveyor.

The Advanced Antenna System (210-foot-diameter Mars Station antenna at Goldstone, California) was utilized to support extended missions requiring greater communications capability than is available in the network of 85-foot antenna stations. During most of the year, both Pioneer VI and Mariner IV were far beyond the limits of normal 85-foot antenna communication, and the extra performance capability of the 210 was used to provide over 1500 hours of unexpected data from these spacecraft. Since the dedication of the 210-foot antenna at Goldstone on April 29, 1966, operating performance and engineering test evaluation have continually demonstrated that the antenna meets, and in many cases exceeds, all engineering specifications. The methods and analysis used in the engineering design of the antenna have been verified in field operations. The S-band gain of the Advanced Antenna System (obtained by using Surveyor I on the moon) was measured at 61.6 ±0.3 decibels, and provides a tracking and pointing accuracy capability considerably better than the smaller 85-foot antennas. Degradation due to weather has not affected operations, and winds up to 50 miles per hour have produced no noticeable effect on S-band gain or pointing accuracy.

A program for improvement of the operation of the hydrostatic thrust bearing used in the 210-foot antenna, involving the installation of machine-ground contour shims and precision measurement instrumentation, resulted in greater operational reliability and increased ease of maintenance. Bearing instrumentation has been developed that enables measurement of the operating height of the oil film between the bearing runner and pad, on which the 6-million-pound structure rotates, to within 0.001 inch, and measurement of the bearing runner profile, with respect to gravity level, to within approximately 0.002 inch.

The accuracy of the master equatorial precision angle-sensing instrument installed at the intersection of the elevation and azimuth axes of the 210-foot antenna was verified in a series of angle-mounting tests. The instrument provides a precise and stable positional reference for the antenna.

Special Support for the Pioneer Project

Special equipment for the 85-foot deep space stations was developed which significantly improved the telemetry reception from Pioneer spacecraft. The equipment includes (1) a waveguide configuration that reduces transmission line losses by bypassing the diplexer and two waveguide transfer switches, (2) a reduction in the receiver carrier loop bandwidth from 12 to 3 hertz, and (3) a metal lens grating for the Cassegrain feed that converts incoming linearly polarized signals from the spacecraft to circular polarization, and outgoing circularly polarized command signals to linear polarization signals for transmission to the spacecraft. Performance improvements associated with these modifications have effectively doubled the communications range for Pioneer VII. The
waveguide and receiver bandwidth modifications improved the signal-to-noise ratio by approximately 3 decibels; the lens grating eliminated the 3-decibel polarization loss, which has been associated with the Pioneer-type spacecraft, for both uplink and downlink communication.

A polarization diversity receiver, originally installed at the 210-foot station for the Mariner V bistatic radar experiment, was modified to accommodate linear polarization signals from Pioneer spacecraft. A combiner was added to measure the orientation of the linearly polarized signal as well as to increase the signal level by 3 decibels. With the addition of this feature, Pioneer spacecraft are no longer limited by communications range; telemetry data may be acquired throughout their entire lifetimes.

Tracking and data acquisition overall support for Pioneer was enhanced by the above improvements and by extending the tracking periods through the use of standard microwave communication links between stations. All of these techniques were employed to provide additional coverage of special events such as solar flares.

Support of Scientific Experiments for Mariner V

The Mariner V mission to Venus provided the opportunity for the DSN to prepare special instrumentation in support of three scientific experiments: the celestial mechanics, the S-band occultation, and the bistatic radar astronomy experiments.

The celestial mechanics experiment was designed to reduce the uncertainties in interplanetary distances and to provide measurements of the masses of celestial bodies, using DSIF-generated tracking data. The major element of the earth-based radio tracking instrument was a newly developed planetary ranging system, which successfully ranged the Mariner V spacecraft to a distance of 98 million kilometers with an accuracy of 10 meters or less. The spacecraft ranging module was simple, with the complexities designed into the computer-based experimental ground system.

The S-band occultation experiment was conducted to determine the characteristics of the Venusian atmosphere as a function of altitude. Special instrumenta-
tion was developed, including a low-noise cone at the Goldstone Venus antenna, to accomplish this experiment. Measurements were successfully made of the perturbations produced on the phase and amplitude of the S-band radiofrequency carrier as the signal passed through the atmosphere of the planet. To maximize the signal-to-noise ratio, the 210-foot antenna station at Goldstone was utilized and specially configured.

The objective of the bistatic radar astronomy experiment was to study the surface of Venus by analysis of the Mariner V signal reflected from the planet. Simultaneous recording of four signals (right- and left-circular polarization from both the open- and closed-loop receivers) necessitated the addition of a second maser and other modifications to the receiving equipment. During the critical hour of the encounter period, all four signals were recorded on magnetic tape for further analysis.

Radio Science Support

The high performance of the network is making it increasingly attractive to that part of the scientific community doing research in radio astronomy. During the past year, experiments were undertaken with Harvard University, the California Institute of Technology, and the Weapons Research Establishment of the Department of Supply in Australia. The Harvard experiments were conducted to observe, via an antenna at Goldstone, two radio stars during occultation by the moon to refine the angular size and shape of each star. The Weapons Research Establishment, Australia, and the California Institute of Technology performed interferometry experiments to resolve several quasar sources, using the long baseline between the Goldstone and Woomera stations. The California Institute of Technology also employed Goldstone facilities for measurements of radio source diameter, using scintillation phenomena as the radio signals passed through the solar corona.

Radar studies of Mars, Mercury, and Venus were performed during 1967. Most of the data were collected by monostatic operation from the Venus Station at Goldstone, but some data were obtained through the use of the 210-foot Mars Station in a bistatic mode. The strongest echoes from Mars were usually found in the border area between the bright and dark visual markings. The edge of Trivium Chrontis was again, as in 1965, a remarkably strong and smooth radar reflector. The “mountains” of Venus also returned to radar view, having first been tracked during the conjunction of 1964. These permanent topographic features will make possible the most accurate measurement yet of the rotation period of Venus. The ranging capability of the planetary radar has been improved to an accuracy of 3 microseconds using Venus as a reflector.

Advanced Development

Two new techniques were investigated for precision time calibration and synchronization of station clocks. One utilized quasar 3C 273 as a radio signal source, and the other used the moon to reflect a coded X-band signal originating from a master station located at Goldstone. When time was transferred from one station to another via the moon, the ephemeris-derived distance to the front cap of the moon was verified by measurement prior to each transmission period. Then time was transmitted with microsecond precision to a remote station in Australia after compensating for the known delay in time of flight of the radio wave. The accuracy of the lunar radar technique was verified by transmitting time through a Lunar Orbiter spacecraft in orbit around the moon and by utilizing portable cesium time standards. The transfer accuracy using the moon as a reflector was better than 5 microseconds. The principal advantages of the lunar reflection method are instantaneous detection of clock errors, which facilitates resetting the clock; no requirement for active satellites or spacecraft; and low operating system costs.

A 450-kilowatt S-band klystron amplifier tube was developed and tested at the manufacturer’s facility.
The tube was delivered to JPL for installation at the high-power test facility at Goldstone in preparation for integrated tests of the transmitter, antenna, and microwave subsystems. In response to a NASA request, the unified S-band radiofrequency equipment used in both the DSN and MSFN was redesigned to enable reception over a wider tuning range. The purpose of the change is to make it possible for the DSN to provide tracking and data acquisition support to the MSFN, and vice versa.

A telemetry demodulator was designed and constructed entirely of computer software. Its performance was compared experimentally to the special-purpose telemetry equipment previously deployed at the deep space stations and was found to be equivalent or better. As a result of experimental verification and a body of theory to support the development, a commitment was made to supply computer-based telemetry demodulators at all DSN stations for use on a variety of missions, including Mariner Mars 1969. In addition, an advanced coding concept was incorporated in a demonstration telemetry link, and predicted performance improvements were achieved. A decision was made to implement this capability at the 210-foot-antenna station when the improvement in link performance appeared to be of value to the Mariner Mars 1969 telecommunication system.

Studies were continued to determine the inherent tracking accuracy of the DSN. The change in range of the Lunar Orbiter spacecraft was measured using accumulated doppler and compared to the change in range obtained from differencing two range measurements over the same period of time. The purpose of the test was to verify experimentally the predicted effects of radio wave propagation through ionized media. Analyses of tracking data were continued for the purpose of reducing the uncertainty of the physical location of the tracking stations, since station location errors now represent one of the major factors limiting the accuracy of spacecraft position determination. Confidence in the knowledge of station locations was increased as a result of these analyses, and errors were reduced by an order of magnitude to below 20 meters. The precision of the DSN tracking data has been useful in determining spurious non-gravitational forces acting on a spacecraft. Analyses were performed which showed that these forces can be determined to better than $10^{-12}$ km/sec$^2$ over several hours of observation time.

An unanticipated result became apparent when tracking data from the Lunar Orbiter and Surveyor spacecraft were evaluated by differencing the tracking data observables with the spacecraft position as determined from the orbit computation process. Surprisingly large anomalies became visible when Lunar Orbiter was in orbit around the moon and Surveyor was on the lunar surface. After verifying that the tracking instrument provided by the DSN was functioning properly, the lunar gravitational theory and ephemerides were re-examined in the search for an explanation. A significantly improved lunar ephemeris was produced, and the anomalies were greatly reduced. The Apollo Project became interested in the explanation of the remaining anomalies because of their need for precise navigation associated with orbiting and landing men on the moon.

*Tense moment at Space Flight Operations Facility during landing of Surveyor V*
Research

Continuing research is performed in a number of scientific and technological areas for the purpose of acquiring knowledge and understanding of the physical phenomena associated with all phases of space exploration, present and future.

Electron Impact Spectroscopy

The recently constructed low-energy, high-resolution electron impact spectrometer was used to study molecular energy levels of He, H₂, N₂, and C₂H₂. The study of photon transitions provides only limited information about the energy levels because the observable spectral region is restricted and many transitions are spin or symmetry forbidden. The electron scattering technique not only extends the range of observable transitions but provides additional information through angular distribution and energy dependence studies.

Ion Cyclotron Resonance Studies

An ion cyclotron resonance spectrometer was constructed which can be operated in a dual-frequency mode. In this manner, reactions involving a particular ion can be initiated, and the subsequent secondary ion yields can be measured. The reactions between C₂F₆ and its principal ions were studied, resulting in a clearer picture of which mechanisms occur. In addition, charge transfer reactions between CH₄, Xe, and their principal ions were investigated. This technique promises to be a powerful method for studying ion-molecule reactions.

Relativity and Gravitation

The dyadic formalism for treating general relativistic problems was applied to the general problem of gravitating systems. A variety of new exact solutions were found for the dynamic processes stimulating gravitational collapse and, in particular, an exact solution of the Einstein theory for a rotating self-gravitating perfect fluid. Such solutions are being sought extensively at present because of the interest in gravitational collapse and quasars.

Applied Mathematics

Considerable effort was expended in attempting to derive suitable models for the random nongravitational forces acting on a planetary spacecraft, based on the data from Mariner IV. The results remain ambiguous. Complementary studies involved the difficult subject of navigation and (optimal) control of such stochastic dynamic systems. A related set of studies was concerned with the problems of optimal estimation of the state vector of a spacecraft, nonlinear estimation techniques, data compression techniques, and the stability of continuous estimation methods. Advances were made in each of these areas.

Various aspects of general relativity were considered, and new tests of the theory appear tentatively feasible because of the inherent accuracy of the Deep Space Network, using suitably designed spacecraft trajectories.

The study of interval arithmetic, a procedure by which absolute error bounds are computed, was a noteworthy development in this period.

High-Density Magnetic Information Storage

Recent JPL research has shown that thin films of ferromagnetic manganese bismuthide (MnBi) are capable of magnetic information storage densities of 10⁷ to 10⁸ bits/cm²; the information now contained in a 10-cubic-foot computer memory unit could be condensed onto 1 square inch of MnBi film. To produce a bit, a small beam of light from a ruby laser is focused momentarily onto a 1-micron region of the film at an intensity sufficient to heat it just above its Curie temperature, where its magnetization disappears. As the spot cools, it acquires a magnetization opposite in direction to that of the surrounding regions from their demagnetizing field. The same laser beam, at reduced intensity, is used to view the switched regions through crossed polarizers. Studies are now being made of the switching process itself, with the goal of demonstrating rapid and repeated switching of single bits in an applied external magnetic field, as would be required in a practical high-density computer memory.

Thin-Film Thermal Detector

In the course of investigations made with thin dielectric films, it was discovered that an abnormally large variation of capacitance with temperature can be obtained in thin-film capacitors when a fixed ionic space charge is present in sufficient density in the dielectric film. This effect was made the basis for a new kind of thin-film thermal detector, whose performance at room temperature equals or exceeds that of comparable devices at much lower temperatures.
The new thermal detector offers significant advantages as a temperature sensor in systems that use digital means for data handling and control. Present investigations are directed toward methods of optimizing the structure of the device and forming arrays that could be used in infrared imaging systems.

**Plasma Production by a Giant Pulsed Laser**

Spectroscopic measurements in a laser discharge utilizing an image-converter camera were made using vaporized liquid mercury drops. This technique makes it possible to examine the early stages of the laser discharge in a gas where the absorption process is dominated by inverse bremsstrahlung electron heating followed by ionization due to inelastic electron-atom collisions.

**Plasma Heat Transfer**

One of the factors that influence the structure of the boundary layer in a thermally ionized gas flow subjected to severe cooling at the walls of a channel is the effect of variable transport properties. An investigation of this effect on a laminar boundary layer shows that the normalized velocity and enthalpy distributions become steeper near the wall as the free-stream-to-wall temperature ratio is increased. Experimental measurements obtained with a water-cooled probe in the boundary layer of an argon flow at a free-stream temperature of 14,300°F tend to substantiate the theoretical predictions. For the test conditions, the viscosity varied by about a factor of 11 across the boundary layer, and the density by a factor of 25. These studies reflect but one of the effects that can occur near the surfaces of cooled electrodes used in electrical propulsion concepts such as magnetoplasmadynamic arcs.

**Electronic Transport in Organic Polymers**

In order to obtain a better understanding of the conduction mechanism in organic materials, a new series of polyelectrolytes was synthesized. These were given the generic name of "ionenes," since the structural units of the polymers consist of ionic amines. Detailed investigations of the rates of formation of a variety of ionenes revealed that the mechanism of the reaction requires an ionization step, followed by propagation.

The elucidation of the mechanism of ionene formation makes it possible to tailor-make a new class of positive polyelectrolytes in which the nitrogen atoms are separated by known distances. The new aliphatic or aromatic ionenes exhibit high bactericidal activity and combine with negative polyelectrolytes such as polystyrene sulfonic acids, polyacrylic acids, heparin, etc., to form membranes whose characteristics depend on the structure of the ionene.

Apart from their biological activity and the high electrical conductivity of TCNQ complexes, the new polyelectrolytes show promise in such areas as water desalination, body implants, permeable membranes, and plasticization of commercial polymers.

**Functionality Determination of Elastomer Prepolymers**

The feasibility of a new method of functionality determination of castable elastomers, based on the measurement of critical network parameters, has now been demonstrated. The method consists of determining which of an array of polymer formulations having a slightly varying composition marks the composition of incipient gelation at complete reaction, and calculating the functionality from equations derived from the work of Flory. Flory's relations were extended to include monofunctionality in the two situations theoretically possible, and both relationships were found to agree with Stockmayer's equation, which is more general.

Future work on this method will be directed toward reducing the time of reaction, increasing the potential for complete reaction, and extending its capability to provide reactive end-group assay as well as determination of functionality itself.

**Physical Space Science**

Planetary observations, both ground- and spacecraft-based, constitute the broad area of research toward which the physical space science program is directed. The principal activities involve the development of techniques and technologies for determining planetary surface and atmospheric properties.

**Optical Astronomy**

The JPL Connes-type interferometric spectrometer was installed in the Coudé room of the 24-inch Cassegrain/Coudé telescope at Table Mountain Observatory in 1966. Formal observations using the instrument began in September 1967. Spectra of Venus have been obtained at resolutions of 5 cm⁻¹ in the spectral range 2600 to 3500 cm⁻¹ [2.9 to 3.8 microns]. Solar comparison spectra were also obtained, at resolutions of 0.5 cm⁻¹, over the same spectral interval.

A high-dispersion spectroscopic investigation of Mars in the 7000–9000 Angstrom spectral range was carried out with the improved Coudé spectrograph of the 82-inch reflector at McDonald Observatory (University of Texas). Observed band strengths indicated an abundance of CO₂ of 100 meter-atmospheres; from the observed strengths of doppler-shifted H₂O lines, it was estimated that there were 10–15 microns precipitable water on Mars during the 1967 opposition, although the amount was found to be significantly variable. A similar spectroscopic investigation
of Venus was carried out, but at generally higher dispersions and covering the 7000–13,000 Angstrom spectral range. No water was detected, indicating an upper limit of 10 microns precipitable water on Venus.

Radio Astronomy
A new 18-foot Cassegrain antenna was installed at the Table Mountain facility, and observations of Venus have begun using a new, tunable 30–37 gigahertz narrowband radiometer. This antenna should be operational to a wavelength of 1.3 millimeters.

A redesign of the Cassegrain cone of the DSN 30-foot antenna now permits an extensive (18–26 gigahertz) observational program to be carried out on a noninterference basis. A long-term Venus observation program began in September using a tunable, narrowband radiometer. In December, this radiometer was replaced by one having 26 fixed tuned channels.

Mars Radar Observations
Mars was observed by ground-based radar during May 1967. The experiment employed an 85-foot antenna at the DSN Venus for transmission and the 210 for reception. The use of this bistatic configuration resulted in a factor-of-6 improvement in signal-to-noise ratio compared with previous JPL Mars radar experiments. The experiment yielded about 250 CW spectra of the reflected signal from Mars. These spectra have been combined into approximately 60 composite spectra, representing the average spectrum of Mars for every 5 degrees of longitude of the planet. Mars' mean reflectivity is 6.2%—very close to that of about 7% found for the moon. The reflectivity is quite variable as a function of longitude, however, ranging between 1.7 and 12.3%. This suggests a large variation in the degree of compaction of the Martian surface. There is a tendency for the broad regions around Mare Acidalia, Trivium Charontis, and Laocoontis-Nepenthes to have the highest reflectivities, although these appear to be local minima in the reflectivity when the major dark regions are on the Martian central meridian. The mean bandwidth of all the spectra is 575 hertz, which is 7.5% of the full limb-to-limb bandwidth. This suggests that the average slope of surface facets larger than a few wavelengths must be less than 4 degrees. There are large variations around this mean, however. The narrowest bandwidth is again found near Trivium Charontis.

Optical Properties of the Moon
The reflectance properties of mineral and rock powders in the wavelength interval 0.4 to 2.6 microns were studied in the laboratory, and the results were used to estimate rock compositions on the moon and Mars. Variations in particle size were found to have significant effect on rock colors as well as on integral reflectance. It was concluded that differences in

Field camp for life detection studies in McKelvey Valley, Antarctica
mean particle size may govern many of the albedo and color contrasts on the moon.

Absorption bands in the near-infrared reflectance spectra of rock powders were found to be caused entirely by iron in the constituent minerals. Variations in the positions of the bands are a means of identifying iron-bearing minerals, which, in turn, can be used to characterize rock type. A basaltic composition predicted for the lunar surface on this basis was verified by the subsequent Surveyor alpha-scattering results. Evidence was found for extensive basaltic rock on Mars also; basalt oxidized in the laboratory duplicated the Martian reflectance curve.

**Solar Wind Effects on the Moon**

For some years it has been assumed that the moon's low reflectivity is the result of bombardment by the ions of the solar wind. Experimental studies of the darkening effect of proton bombardment on rock powders have now shown that protons with typical solar wind energies and fluxes cannot account for the low reflectivity of the lunar surface or for the apparent darkening with age of crater rays. Darkening of basalt powder by prolonged bombardment with 2-16 kilo-electron-volt protons was found to be slight except when the incident proton flux was sufficient to heat the sample above 150°C. Darkening then increased with incident flux for a given proton dose; thus, the darkening is bombardment-rate-dependent. The solar wind, which blows at a flux 6 orders of magnitude less than the minimum laboratory proton flux that produces detectable darkening, could not significantly darken the lunar surface even in 10^9 years.

**Bioscience**

The search for life on other planets is the mission of the bioscience program. Toward this end, experiments are performed in simulated planetary environments and terrestrial microorganisms existing under extreme climatic conditions are studied.

**Mass Spectrometry**

In preparation for the exploration of the terrestrial planets, a breadboard of a small mass spectrometer was completed. It is intended for analyzing atmospheric constituents with unit resolution over the mass range of 10–90. On the basis of this laboratory development, the physics of the instrument and its functional performance have been studied for an atmosphere entry experiment. The most probable major atmospheric constituents as well as trace constituents are within the range of the experiment.

An electronic recording high-resolution mass spectrometer has been routinely operated in a fast scan mode for the analysis of organic compounds containing oxygen, nitrogen, and sulfur heteroatoms. This unique accomplishment makes it possible to analyze organic compounds which have a short lifetime in the ion source. For the first time, an instrument of this type can be applied to the analysis of delicate organic compounds or to the effluent of a gas chromatograph.

**Deep Space Effects on Microbial Organisms**

The effects of a simulated deep space environment on the survival of bacterial spores were investigated in the molecular sink (MOLSINK) vacuum chambers. Mariner IV cruise temperature data were utilized in the study to simulate conditions on board a spacecraft. Bacterial spores were exposed to test conditions for 7-day periods on simulated space hardware. The results indicate that a significant percentage of the organisms are killed at temperatures ranging from 100 to 140°F in the simulated deep space vacuum.

A quantitative determination of the time rate of change in mass of the exposed spores is being conducted using a quartz crystal microbalance technique with a mass sensitivity of 10^-10 g/cm². In addition, very sensitive mass spectrographic techniques are being incorporated to determine qualitatively the molecules which are released from the spores. These data will provide a better understanding of the death of microorganisms in the outer space environment and will be utilized in future planetary quarantine analyses.

**Flight Science Experiments**

The development of experiments to be flown on vehicles other than JPL spacecraft is an important segment of the work performed by the Laboratory. Such experiments have been carried on a variety of flights, from terrestrial weather satellites to moon-orbiting spacecraft.

**OGO Series Magnetometers**

To date, there have been four flights in the OGO series of earth-orbiting missions, and two more missions are scheduled for 1968. JPL has magnetometer experiments on each of the six spacecraft, with the objective of investigating low-frequency magnetic variations in the magnetosphere, magnetosheath, and interplanetary space. The resulting data are used to study the spatial distribution and temporal changes of the naturally occurring signals, and have provided increased knowledge about the boundaries of the magnetosphere and the magnetosheath as well as a better understanding of the properties of these bands.

**Lunar Orbiter Selenodesy Experiment**

During the past year, the last of the five Lunar Orbiter spacecraft was successfully launched. A first
estimate of the lunar gravity field harmonics based solely on Lunar Orbiter tracking data shows satisfactory compatibility with the second-degree harmonics based on lunar libration data. In terms of the moon's mass distribution, the results suggest a more or less uniformly dense moon, slightly pear-shaped, and somewhat "rounder" in terms of the size of the higher-degree harmonics than was anticipated.

The orbit of the moon, revised on the basis of new information obtained during the last year, was checked against Orbiter range tracking data. Results show remarkable agreement (on the order of less than 100 meters in range) between theory and observation.

**Temperature Sounding Experiment**

The infrared multidetector radiometer developed last year to obtain atmospheric temperature information was flown on a high-altitude balloon in February 1967. Experimental data from the flight were used to verify the soundness of the analytical approach. The technique for inverting the radiation equation was checked and the results compared to temperature soundings made with standard radiosondes and independent temperature sensors on the balloon gondola. This showed that the inversion technique produced satisfactory temperature profiles but that the desired accuracy could not be achieved because of errors introduced through lack of accurate transmission information. An additional balloon experiment is being planned for January 1968 to make an independent check of the newly derived atmospheric transmission data.

**Electronics**

Telecommunications, guidance and attitude control, and data handling are some of the areas dependent on the contributions made by electronics research. Work performed in this field is relevant to many technological phases of space exploration.

**Biomedical Image Enhancement**

The computerized television image processing techniques originally devised to enhance lunar and planetary photographs are finding increasing application in other fields. In particular, the procedures which remove blemishes from pictures and increase contrast so as to clarify certain details and bring out others not visible in the unenhanced picture are being investigated in terms of their contribution to biomedical imagery. Thus far, particularly encouraging results have been obtained from enhancement of photographs of the retina and of x-ray films of the chest and skull, bringing out latent detail that can be used in earlier diagnosis of disease symptoms. The potential use of the computer process in the detection of incipient abnormalities in various parts of the body is being studied by several universities and medical institutions in cooperation with the JPL Image Processing Laboratory.
Telecommunications

A number of specialized systems are being developed for communicating with planetary entry and landing capsules.

A high-impact, sterilizable, S-band 3-5 watt transmitter for planetary landing capsules is under development. A high-power amplifier-multiplier module survived indirect impact shocks of 10,000 g and three sterilization heat treatments at 145°C for 14 hours with no observable performance degradation.

Two major 2300-megahertz tube developments are being sponsored by JPL. A 20-100 watt electrostatically focused amplifier and a 100-watt traveling wave tube are in the experimental stage. High efficiency and long life are the primary goals of both programs. The electrostatic focusing and radiation cooling features of the amplifier are especially valuable for advanced spacecraft designs.

A similarity principle was derived for multipacting breakdown. As a result, the physics of multipacting breakdown is better understood, and prediction for multipacting breakdown can be made for geometries where the fields are nonuniform. These scaling relations were demonstrated in the coaxial geometry over a frequency span of 10-800 megahertz. Ionization breakdown data were obtained for the coaxial geometry over a frequency range of 10-2400 megahertz. It was shown that if the multipacting and ionization breakdown scaling parameters are suitably grouped and displayed, an invaluable breakdown nomograph results. A voltage breakdown facility that has a 6-foot-diameter plexiglass vacuum chamber was completed. It is the largest facility of this type in the United States and will permit the testing of full-size antennas under deep space conditions.

Significant progress was made in a number of communication theory topics. These include self-synchronizing telemetry codes, efficient convolutional telemetry codes, telemetry-modulation design techniques, data-compression techniques, and automatic phase-control acquisition. The application of part of these results to the Mariner Mars 1969 telecommunication system design has resulted in an equivalent ten-fold increase in the data-rate capability over that of the Mariner IV/V system.

A solid-state device, called a photon-actuated isolation switch, was developed which converts electrical energy into infrared radiation (photons) and back into electrical energy. This device makes it possible to transmit electrical signals across an interface without electrical connection, thus eliminating electrical interference (noise) due to current flow between subsystems.

Guidance and Attitude Control

Emphasis in the area of spacecraft control was on the development of attitude-control components, advanced system concepts utilizing these components, and analytical tools in the form of control laws and computer programs necessary for the study of advanced system requirements.

Progress was made in the development of single-axis gyroscopes and miniature precision accelerometers. Tests of gaseous thruster nozzles that were conducted on a series of nozzle designs of varying sizes, exit angles, and expansion ratios have confirmed computer studies of the relation between nozzle design, thrust, and impulse.

Accomplishments in advanced system concepts include a successful program to thermally sterilize control-system electronic circuits, and completion of an advanced scan platform electronic breadboard. A prototype optical approach-guidance subsystem was designed and fabricated which will provide the technical base for the use of approach guidance on future planetary missions, making possible on-board optical measurement of a planet's position relative to other spacecraft references. A joint JPL/USAF effort to develop and prove the feasibility of an inertial navigation system using electrically suspended gyroscopes concentrated on integrating the various subsystems and providing the necessary component and system analysis.

In the development of control system design tools, a flexible-body computer program was completed which simulates the dynamics of multibody spacecraft. Significant progress was made on computer techniques for the automatic design of optical systems.

Control and Data Handling

The organization of the self-testing and repair (STAR) computer, designed to achieve reliability through self-testing logic and hardware redundancy, has evolved into a form in which the repairing is accomplished by automatic switching of unit modules. Error detection is based upon a scheme whereby each number or data-word is represented in the machine by its product with another number called the checking modulus. The arithmetic unit of a computer using such a product-coded number representation requires special algorithms.

In the area of advanced spacecraft science data subsystems—the control and data-handling "heart" of a scientific instrument payload—progress was made in on-board data-processing ("compression") techniques designed to make more efficient use of the limited communication bandwidth at planetary distances. The development of a stored-program (computer-like) science data subsystem was begun. This "next-generation" approach is required in order to satisfy the functional requirements of advanced orbiter and lander missions. Furthermore, it affords a degree of inter-mission commonality which should reduce the cost and development time required on subsequent missions.
Spacecraft and Capsule Aerothermomechanical Engineering

The survival and unimpaired functioning of spacecraft hardware throughout all phases of a mission is an essential requirement. This involves not only the development of special materials and components but also the testing of the spacecraft and its systems in simulated space environments.

Solar Spectrum Measurement

Because of the complexity of interplanetary spacecraft and the need for accurate thermal control, such vehicles are tested extensively in thermal vacuum chambers equipped with high-fidelity solar simulation systems. It is important in these tests to know the relation between the simulated and the true solar spectrum and irradiance. A basic limitation here is that the two most widely accepted estimates of the solar spectrum differ by as much as 50% in some
spectral regions. In an effort to resolve these differences, a device was developed which can measure the solar spectrum and irradiance above the sensible atmosphere. This device uses fast-response thermopiles and narrow-bandpass filters. To date, solar observations have been made from jet aircraft at altitudes up to 45,000 feet and from the X-15 III aircraft at 240,000 feet; the results are now being analyzed.

**Planetary Entry Research**

To obtain a better definition of the expected plasma heating of a planetary atmospheric probe, heating rates on physical models were measured in plasma flow generated by shock tubes. The measured model convective and radiative heating rates are extrapolated to flight conditions by means of theoretical computer models of the plasma flow field preceding the flight vehicle. Recently, it has become possible to measure shock-tube plasma time-resolved spectral radiation at far-ultraviolet wavelengths by use of a JPL-developed spectrometer. Since the bulk of the expected plasma radiation occurs at these short wavelengths, the recent measurements, coupled with visible wavelength measurements, have reduced the uncertainty in entry probe heat-shield requirements. Work has been initiated to study radiation encountered by Jupiter atmospheric entry probes.

**Dynamic Stability of Blunt Entry Shapes**

A blunt, high-drag vehicle entering a planet's atmosphere must maintain a reasonable attitude with respect to the flight path in order to perform properly during entry. The most effective method of damping attitude oscillations is to ensure that the vehicle possesses inherent dynamic stability. Dynamic stability tests of blunt, 120-degree-included angle cone shapes were performed in both JPL and Ames Research Center wind tunnels using JPL-developed free-flight testing techniques. Favorable dynamic stability results were measured for sharp-trailing-edged cones from transonic through supersonic speeds. However, in the transonic regime, particularly for bodies with rounded trailing edges, this favorable condition becomes marginal.

**Thermal Control and Analysis**

A conical-cavity absolute radiometer was developed with a dynamic range of two solar constants. Its performance is expected to be within 0.25% for all radiation levels from ultraviolet to infrared. A miniaturized model has been incorporated in the temperature-control flux monitor to be flown on Mariner Mars 1969. Continuous measurements of the total solar flux, to be made for the first time, are expected to be of great interest to both solar-cell and temperature-control specialists.

**Chemical Propulsion**

Chemical propulsion research combines the study and development of liquid and solid propellants with the development of propulsion equipment and the investigation of the various physical and chemical phenomena associated with rocket propulsion.

**Liquid Propulsion Motor Development**

Improvements in the "state-of-the-art" in liquid technology are demonstrated in the trajectory-correction propulsion subsystem to be used on the Mariner Mars spacecraft in 1969. This unit is similar to the subsystems used on earlier Ranger and Mariner missions but has been modified to incorporate the new Shell 405 spontaneous catalyst for startup of the monopropellant hydrazine engine. The development of a spontaneous catalyst for hydrazine decomposition has opened a wide variety of new uses for this propellant in the fields of propulsion and remote power generation. In the case of the trajectory-correction unit, the use of the new catalyst eliminates the oxidizer start assembly (used on the earlier missions), which in turn permits a 30% reduction in the number of components and a 45% reduction in the total number of potential leak paths.

**Liquid Propulsion Heat Sterilization**

Heat sterilization has become a firm requirement for spacecraft elements intended for landing on the near planets. Several mileposts have been passed in developing liquid propulsion systems that can be sterilized at 275°F in a loaded and sealed condition. A complete monopropellant propulsion unit was held at sterilization temperatures for 360 hours and subsequently test-fired. A loaded tank of the oxidizer nitrogen tetroxide was successfully carried through a similar treatment, thus demonstrating the most critical techniques and materials needed for sterilization of higher-energy bipropellant systems.

**Propellant Leak Detection**

An important factor in long-duration space missions to the planets is the assurance of very low leakage of fluids stored aboard spacecraft. A technique recently developed for sensing extremely small propellant leakage will permit seal verification in short-duration tests: A carrier gas is convected around the test article and ducted into the sensor. In the sensor, a charged cloud of electrons is generated by a radioactive source. Propellant molecules passing through the cloud capture electrons and reduce the static charge. The change in charge is detected by an electrometer. Concentrations of less than one part per million of propellant in the carrier gas can be detected.
Advanced bipropellant injector element showing fluid spray formed by impinging liquid sheets

A step toward solving the problem of leakage past valve seats was taken by impregnating the metal surfaces of the seats with ultrafine diamond powder. The resulting elimination of galling, corrosion, and erosion greatly increases the leak-free lifetime of valves.

Injector Development

A liquid bipropellant injector concept based on impinging sheets is evolving as a major advance in this technology. Sheet elements are formed in a precise, reproducible manner by directing a circular jet tangentially onto a curved surface. A multiple-element 2000-lb-thrust injector has produced consistently high performance with a variety of earth-storable propellants. This technology is now being applied to the space-storable combination oxygen difluoride-diborane. The corrosive, high-temperature combustion environment produced by this combination presents a great challenge, but the potential performance gains are significant.

Opposed Flow Burner Combustion Studies

The laminar flame theory developed for the opposed parallel-plate burner is unique in that it can be applied with equal ease to either premixed flames or diffusion flames. Experiments are currently under way using ethylene and oxygen to compare the heat-release rates measured in the opposed flow burner in these two modes. In later experiments, highly reactive propellants which cannot be premixed will be used in the diffusion flame mode in order to determine heat-release rates and ignition data.

Solid Propellant Nonsteady Burning

The burning of solid propellants under nonsteady-state conditions, such as occurs during rocket motor combustion instabilities or rapid depressurization to accomplish extinguishment, is not well understood, and no theoretical or experimentally derived relation exists for predicting or analyzing burning under these conditions.

A technique has been developed which makes it possible to measure rates up to the 20,000 psi/s pressure decrease range. A microwave signal is reflected from the burning surface of a propellant strand, and the doppler shift of the signal is measured. This extremely small frequency change (1 out of 10⁸) is measured continuously, which could not be done using earlier techniques. By means of this microwave method, transient burning rate data can be obtained that may be used to better analyze and predict solid rocket motor instability and extinguishment without expensive trial-and-error motor tests.

New Polymeric Binders for Solid Propellants

It has been predicted for many years that two important improvements in solid propellant technology could be obtained by the development of binders consisting essentially of saturated hydrocarbons. First, high-temperature stability of conventional propellants, based on ammonium perchlorate, would be improved. Second, higher performance could be obtained by application of any one of several more energetic oxidizers known to be incompatible with conventional binders.

Three distinct chemical approaches are being investigated for synthesis of the saturated hydrocarbon prepolymer from which the propellant binder is created: (1) free-radical polymerization of ethylene and neohexene, (2) cationic polymerization of isobutylene, and (3) anionic polymerization of 1,3-dienes followed by hydrogenation. Progress has been made with all three approaches.

These new materials can be expected to find use not only as propellant binders but in other applications for castable elastomers where chemical and thermal ruggedness are required. Continuing effort
is being directed toward improvement in control over desired characteristics, optimization of qualities such as molecular weight and microstructure with regard to end-item requirements, and scale-up. Considerable variety of possible microstructures is afforded by the multiplicity of synthetic approaches.

**Mechanical Properties of Filled Rubbers**

The properties of a filled, rubbery system are governed by the viscoelastic nature of the rubber binder, by the amount of filler present, and by the extent of interaction between the binder and filler. These attributes have now been combined to give rise to a theory for the mechanical properties of such systems that is couched in terms of the molecular parameters characteristic of the rubber and the degree to which the rubber can be loaded by the filler in question.

The results have immediate applications for rubbery, filled polymers, such as rubber tires and solid composite propellants, and indicate a desirable area of research on hard polymers containing fillers, such as the glass-reinforced plastics.

**Space Power and Electric Propulsion**

Future missions that will fly enormous distances from the sun will require far greater amounts of power than present-day flights. This means that using the sun as the principal power source will no longer be feasible. The conversion of other kinds of energy into the electrical power needed to propel spacecraft of the future is the primary concern of studies being made in this field.

**Sterilizable Batteries**

The development of a heat-sterilizable silver-zinc battery has progressed to the point at which cells have been sealed and heat-sterilized without leakage. In continuing studies, a slow charging method was devised which minimizes gas pressure and increases cell capacity. Efforts to design for high impact provided cells capable of withstanding peak impacts of 3000 g. A program to develop a heat-sterilizable nickel-cadmium battery has been started as a backup to the silver-zinc battery development.
High-Temperature Heat Transfer

The development of a heat-transfer device known as a heat pipe is expected to be very useful for the transmission of heat from solar or nuclear power sources to the power-conversion equipment, and from there to the heat sinks. The device makes use of the heat of vaporization of a working fluid to absorb heat from a source and to deliver it to a load upon condensation of the vapor. The fluid is then returned to the source by capillary action.

A 1-inch-diameter molybdenum heat pipe using lithium as a working fluid has been operating for nearly 10,000 hours at a temperature of about 1500°C. The operation of this pipe demonstrates the capability of transmitting over 10 thermal kilowatts for a distance of about 2 feet with a temperature drop of less than 10°C. The effective thermal conductivity of the pipe is nearly 10,000 times that of a solid copper rod of the same diameter and length.

Photovoltaic Sources

Extremely large-area, light-weight solar arrays are required to meet further needs for spacecraft power sources. Arrays with deployed areas in excess of 4800 square feet which weigh less than 0.4 pounds per square foot are being developed. Results to date are encouraging, and it is anticipated that the feasibility of fabricating a 50-kilowatt solar array with a specific power capability of 25 watts per pound will be demonstrated by next year.

Lithium-Boiling Potassium Rankine-Cycle Test Loop

Test loop operations during the last year included performance of a series of tests which indicated the transient and steady-state behavior of the loop when subjected to a series of planned perturbations.

Full-power operation, at 200°F lithium and 1900°F potassium temperatures, was readily achieved. These full-power boiling runs were very stable as contrasted to the severely oscillatory flow behavior experienced during startup and low-power operations. Step-change transients resulted in smooth transitions to new stable operating points. Approximately 1000 hours of loop operations were accumulated during this phase.

Thermionic Reactor Dynamics, Stability, and Control

Studies of thermionic reactor dynamics and stability resulted in a substantially increased understanding of the dynamic characteristics of such reactors. The analytical work indicates that the system as applied in a space nuclear powerplant is generally stable. Engineering redesign of a marginally stable system can readily be achieved. The small temperature coefficients of reactivity lead, however, to relatively large changes in the operating point in the open-loop plant even for small perturbations; i.e., the uncontrolled system is self-regulating, but the regulation is unsatisfactory. Therefore, active control is desirable.

The control system studies have investigated the implications of maintaining constant voltage output at the reactor terminals under all electric load conditions. This appears feasible in the range between 10 and 100% of rated power output. Also, it does not seem necessary to employ sophisticated mechanisms to achieve the control objective.

Liquid-Metal Magnetohydrodynamic Power Conversion

The feasibility of generating alternating-current electric power in liquid-metal MHD powerplants was demonstrated with the production of 1000 watts of three-phase ac power at 700 hertz from a stream of sodium-potassium eutectic (NaK). A 50-kilowatt MHD system for testing with NaK and nitrogen at room temperature is in preparation. In flow tests with water and nitrogen, the system provided 90 kilowatts of fluid power to the generator channel. The possibility of 10,000-hour lifetimes at the temperatures required for a space system was enhanced when lithium was circulated through a niobium-1% zirconium channel at 1100°C and 49 meters per second for 500 hours with only 8 microns material loss. A cobalt-iron alloy that would be easier to fabricate and would not require oxygen-free containment was tested with 900°C lithium at 64 meters per second and found to be sufficiently resistant to permit useful laboratory testing of a 100-200 kilowatt MHD system at 900°C.

Electric Propulsion Applications

Recent progress in the development of large solar arrays and the development of integrated propulsion systems, combined with results from mission analysis and spacecraft design efforts, make the prospects for solar-powered electric propulsion spacecraft missions in the 1970's quite promising. As the first phase of the program, an array of four electrically decoupled mercury ion engines, with a common propellant manifold and zero-gravity propellant tanks, was fabricated and tested. The primary objective of the test was achieved in several hundred hours of operation with no failures in the electrically decoupled feed system. The zero-gravity tankage concept was also fully demonstrated. Engine performance was improved from an initial value of 52 to 60% total efficiency at a specific impulse of 3500 seconds, but it is felt that further performance improvements can be achieved, and tests are continuing with such improvements as their primary objective.
Advanced Studies

During 1967, two studies were completed, and preliminary results from a third are available. The two completed studies are a Venus survivable lander mission and a Venus-Mercury gravity-assist mission. The third, and on-going, study concerns a mission to Jupiter utilizing solar-powered electric propulsion.

A major conclusion of the first study is that the step from a nonsurvivable Venus atmospheric probe to a survivable Venus lander is much smaller than the initial step from a flyby to the entry probe. The hardware technology required to survive to the surface of Venus is also adequate for survival on the planet’s surface for a limited time, provided significant additional measurement capability is not required of the lander.

The Venus-Mercury mission study, in which the gravitational field of Venus is used to assist in deflecting the spacecraft trajectory toward Mercury, showed that present spacecraft technology is adequate for such a venture, and that the Atlas/Centaur launch vehicle has more than enough capability to perform this mission during the 1970 and 1973 opportunities. The study also confirmed that little complexity need be added to a Venus flyby spacecraft to enable it to perform significant and valuable flyby experiments at Mercury as well.

Preliminary results from the Jupiter solar-electric study indicate that at least a Mariner-class flyby mission can be performed at Jupiter using the Atlas/Centaur launch vehicle with a solar-electric third-stage spacecraft. Integration of the spacecraft functions with the continuous low-thrust propulsion system poses unique but solvable problems, and the solar array furnishes large amounts of power for spacecraft/science use when the propulsion system is not in operation—most significantly, at planet encounter. The very encouraging results to date provide the option of using existing small launch vehicles in conjunction with solar-electric-powered spacecraft, instead of much larger boost vehicles and conventional spacecraft, to deliver significant payloads to Jupiter.
Office of Plans and Programs

A new staff office, headed by the Assistant Laboratory Director for Plans and Programs, was established early in November 1967 to serve as a focal point for the functions of planning and program development at the Laboratory. The Office of Plans and Programs is responsible for (1) the formulation of candidate overall Laboratory plans for the achievement of Laboratory objectives; (2) developing and analyzing information relevant to the establishment of Laboratory goals and objectives; (3) assessment of potential areas for the application of future effort and the coordination of actions, including proposals, leading to preparation for and assignment of corresponding programs and projects; (4) conducting studies to establish the scientific rationale upon which to base proposals for the exploration of the solar system; (5) conducting technical studies to evaluate the feasibility of potential missions and to define the characteristics of candidate systems consistent with JPL objectives; (6) coordination of the Laboratory operational planning effort, and assembly and review of overall operational plans; and (7) recommending to the Laboratory Director/Deputy Director the resources to be allocated to operational elements of the Laboratory at the division level and by program or project, consistent with approved plans.

Financial Management and Procurement

An automated requisition control system was implemented during the year, which provides visibility for determining the location and status of requisitions in the Procurement Division and greater accuracy in measuring the workload of individual buyers/negotiators and in evaluating individual and organizational performance. This is the initial step in the development of an improved procurement information system.

The use of incentive-type contracts continued to increase. Of the fifteen major subcontracts issued for the Phase I (Design and Development) effort under the Mariner Mars 1969 Program, ten contained an incentive arrangement.

The Laboratory's first stockless purchase plan contract was issued for electrical supplies. This type of contract is unique in that the supplier has the responsibility of maintaining a sufficient inventory to provide 24-hour delivery service. Because of this contract, the Laboratory will realize substantial savings in operating costs due to drastic reductions in the inventory of, and the number of purchase orders issued annually for, electrical supplies. More contracts of this type are being planned for other supply-type items.
A system was established to screen procurement requisitions for supplies and equipment against excess Government property listings. This screening activity resulted in the acquisition during 1967 of excess property from Government sources valued at $761,700 without expenditure of the NASA contract funds.

The Automatic Data Processing Office, a control organization and central information source for the Laboratory's more than 90 leased and Government-owned computer systems, is engaged in an effort designed to reduce the cost of leased computer equipment by transferring more work to owned computers, and by consolidating smaller computer activities wherever possible. Long-range plans to achieve more "data bits per dollar" are based on the concept of replacing small- to medium-sized computers with a computer service characterized by local terminals which access multipurpose centralized computers.
The FY '67 Cost Reduction goal was $7 million. At the close of the fiscal year, the Laboratory had reported approximately $10 million of validated cost reductions. The FY '68 Cost Reduction goal is again $7 million, and present indications are that it will be attained. NASA evaluated and rated the overall Cost Reduction Program for FY '67 as “excellent.”

Personnel

Early in the year, the manpower ceiling was increased from 4400 to 4650, and intensive recruiting efforts resulted in manpower goals being reached in late summer. However, later program changes required that reduction-in-force procedures be exercised to limit personnel levels to a ceiling of 4150.

Significant improvements in the group life insurance program resulted from the elimination of the age-reduction factor, inclusion of coverage for eligible retirees, and utilization of dividend credits to increase the benefit schedule. Other changes in the insurance program resulted in a small increase in premiums for disability income coverage and an improved schedule for surgical benefits under the health insurance coverage.

The management development program was expanded to include all levels, from group supervisors to members of the executive council.

A United States Savings Bond program was started, making it possible for employees to purchase bonds through payroll deduction.

The Office of Public Educational Services continued as a source of information about the space program for the educational community and the general public. In the program to update and upgrade space-related material available to schools, booklets, factsheets, photos, and illustrated leaflets were furnished to schools within Los Angeles County. In 1967, 6662 individual written inquiries from teachers, students, and the general public throughout the world were answered, an increase of 43% over last year.

A Speakers’ Bureau, consisting of some 50 engineers, scientists, and staff members, filled a total of 180 requested appearances before civic groups, service clubs, and other organizations. In addition, tours of JPL facilities were conducted as part of school or professional society educational programs. 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.

Patents and New Technology

Largely as a result of a multifaceted program to make Laboratory employees more aware of the Caltech and NASA programs for patents and new technology, the number of inventions and innovations acquired by the Office of Patents and New Technology increased significantly, reaching a total of 346. Of this number, 259 were formally reported to NASA. Of further interest is the receipt by two JPL inventors of NASA monetary awards, each in the amount of $1000, and the issuance of 41 patents in the names of JPL inventors. The patent issuances were noteworthy, especially in view of the fact that only 43 patents were issued to JPL inventors during the preceding 7 years of the JPL-NASA relationship.

Facilities

A milestone in the development of the Laboratory reached during the year was the accomplishment of the first phase of the landscaping master plan. This work included the construction of a central mall and the completion of walks and plantings throughout the southwest portion of the Laboratory.

Master planning has continued with the publication of 10-year plans for the Edwards Test Station and Table Mountain sites. The landscaping plan for the entire JPL (Pasadena) site was also published.

The acute shortages in space for personnel housing were relieved to a small degree by several building additions and modifications. Approximately 17,000 square feet of office and laboratory space were gained by the addition of second and third floors to the Spacecraft Development Building. A second floor was constructed in the Materials Research Laboratory to provide some 8000 square feet for use as engineering offices and a drafting room, and an additional 18,000 square feet of office space were obtained by conversion of a warehouse floor in the Materiel Services Building. The Spacecraft Assembly Facility was modified by the addition of 6000 square feet of laboratory space for operations support equipment.

Extensive modifications to the main cafeteria were undertaken during the year, and an addition providing seating for approximately 400 persons was completed during December.

A source of water for emergency use was obtained by the construction of a 1-million-gallon storage tank in the northwest portion of the Laboratory. Construction of a road which will provide direct access to the antenna range and other Mesa-top facilities was also begun.

Two new technical facilities became operational during the year—the modified 25-foot space simulator and the Sterilization Assembly Development Laboratory (SADL). Demonstrations of the vacuum and cryogenic systems of the modified simulator were carried out, the 23-foot-diameter collimator mirror was installed and aluminized, and reflectors, lamps, and other elements of the solar simulation system were installed. Operation of the completed facility began in August. The construction work on SADL was completed and the facility became fully operational in October.
# JET PROPULSION LABORATORY EXECUTIVE COUNCIL

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