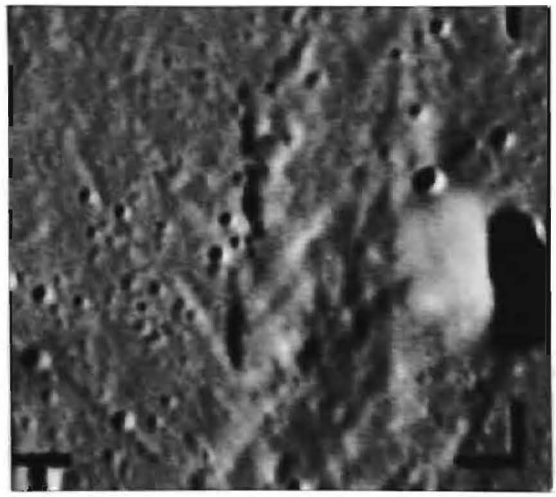
Jet Propulsion Laboratory 1965 Annual Report



JET PROPULSION LABORATORY 1965 ANNUAL REPORT FOR THE FISCAL YEAR ENDING JUNE 30, 1965

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THE COVER: *Two historic investigators of the Moon share this year's cover — Galileo Galilei, 17th century father of modern astronomy, and JPL's Ranger VII, first spacecraft to take close-up pictures of the lunar surface.*

OPPOSITE: *Photograph taken by Ranger IX at an altitude of 140 miles above the Moon's surface, 1 minute 35 seconds before impact in the crater Alphonsus on March 24, 1965.*

Jet Propulsion Laboratory 1965 Annual Report

1965 was a year of major advances in space exploration for the Jet Propulsion Laboratory. It saw the culmination of man's effort to extend his knowledge beyond the Earth by examining selected portions of the Moon's surface, and the continuation of an even more ambitious undertaking – the investigation of deep space and the near planets.

It was the year of *Ranger* and *Mariner*. *Rangers VII, VIII,* and *IX* took more than 17,000 close-up photographs of the lunar surface, and *Mariner IV* successfully completed its 325-million-mile journey to Mars and returned the first pictures of that planet.

The Laboratory confidently looks ahead to the continued exploration of the Moon and the planets by *Surveyor* and *Voyager,* the growth and improvement of the Deep Space Network, and the broadening of its dynamic research and development program.

W. H. PICKERING
Director

Lunar Projects

A series of cislunar and deep-space probes, the *Pioneer* Project, marked the beginning of the Lunar Program in 1958–59. JPL developed two of the early missions in this Project, *Pioneers III* and *IV*.

The next phase of lunar exploration was the *Ranger* Project, which developed improved spacecraft technology and conducted a number of lunar missions. This Project, whose first mission was conducted in 1961, was successfully concluded during the last fiscal year.

Developing and demonstrating the technology of lunar soft landing is the initial task of the *Surveyor* Project; the first *Surveyor* missions will be conducted within the next fiscal year.

Ranger

During FY '65, the *Ranger* Project culminated in three successive near-perfect photographic missions to the Moon. *Ranger VII*, launched July 28, 1964, returned more than 4300 television pictures of the lunar surface before crashing into a region between Oceanus Procellarum and Mare Nubium, subsequently named Mare Cognitum in honor of the achievement of *Ranger VII*. Early in 1965, the last two missions of the Project were flown. *Ranger VIII* surveyed a broad swath of lunar highlands and of Mare Tranquillitatis, returning more than 7100 pictures before its impact on February 20, 1965. *Ranger IX* landed within 2¾ miles of its aiming point within the crater Alphonsus on March 24, after taking a series of some 5800 television pictures, the last of which showed lunar detail with a photographic resolution of about 1 foot.

PROJECT HISTORY

The Project was initiated in 1959 as a development vehicle in several pioneering aspects of spacecraft technology and as the first substantial U.S. lunar project. The two initial flight missions, conducted in 1961, were intended as test flights rather than lunar missions; the next three, carried out in 1962, were designed to roughland a seismometer capsule on the lunar surface after obtaining some gamma-ray data in space and television and radar data on the surface. None of these missions was successful, although at the conclusion of the second block of flights, the design verification objectives of Block I had been accomplished.

During 1963, *Ranger* Block III, a series of four missions built around a multicamera television payload, was thoroughly reviewed and redesigned on the basis of the experience gained in the early flights. Risks were reduced by design simplification, functional redundancy, and the removal of elements such as the secondary scientific instruments. The six-camera television subsystem was redesigned and made nearly independent of the spacecraft. The first mission of the new block, *Ranger VI*, was a successful spacecraft flight marred only by catastrophic damage to the television subsystem during the launch phase which prevented television operation and picture recovery. The succeeding three missions were completely successful

The objective assigned to *Ranger* Block III was to obtain television pictures of the lunar surface at least an order of magnitude better in resolution than any available Earth-based photography in preparation for the U.S. manned lunar program and to enhance scientific knowledge in general. *Rangers VII, VIII,* and *IX* surpassed their assigned objective.

MISSION SUMMARY

All of the *Ranger* missions were launched from the Air Force Eastern Test Range, Cape Kennedy, Florida, by *Atlas/Agena B* vehicles. The *Atlas* employs three rocket engines, all ignited at launch. Kerosene-like RP-1 and liquid oxygen are the propellants. Guidance is accomplished by radio command. The *Agena* second-stage vehicle uses a single restartable hydrazine/nitric acid engine in a parking-orbit mode. The space vehicle is first placed in a low Earth-satellite orbit, and then, after a brief coast, a second thrust period from the same engine accelerates *Agena* and spacecraft into a lunar flight path. The *Agena* is subsequently maneuvered away from the path of the spacecraft.

During the launch phase, *Ranger* was tracked and its telemetry received via an *Agena* link by downrange elements of the Eastern Test Range. Shortly after

Ranger VII press conference: Experimenter Gerard B. Kuiper explains first pictures.

spacecraft/*Agena* separation, the spacecraft signal was acquired by the Johannesburg station of the Deep Space Network; thereafter, throughout the mission, it nominally remained in two-way lock with one or another station of the Network.

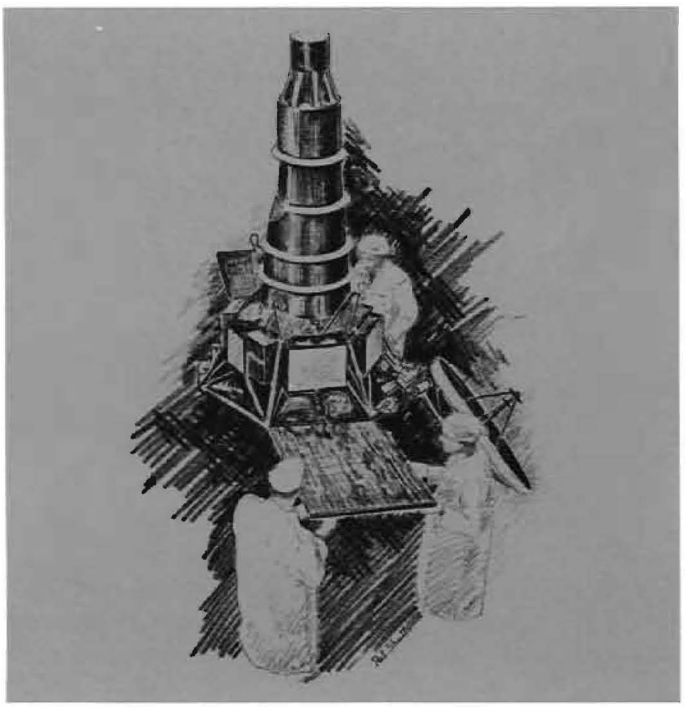
Four Deep Space Stations were committed in support of *Ranger*: Johannesburg, South Africa; Woomera, Australia; and Echo Station at Goldstone, California, with Goldstone Pioneer used in redundant support, receiving only during the terminal lunar television phase of the mission. The Space Flight Operations group for *Ranger* consisted of a Flight Path Analysis and Command team, a Spacecraft Data Analysis team, and a Space Science Analysis and Command team.

The 66-hour trajectory for each flight was chosen to place the terminal portion of the mission in view of the two Deep Space Stations at Goldstone, where ground recording equipment for television data was installed. The launch opportunity was timed so that lunar-surface lighting conditions, the position of Earth and Sun for spacecraft attitude stabilization, and the motion of Earth, spacecraft, and Moon were all most favorable for the mission conditions, which is the case for about 7 days per month. The daily launch period of a few hours was determined by the passage of the lunar-trajectory injection through the range of safe firing angles of the Eastern Test Range.

Each mission had only a few minutes of powered flight. After separation of the *Agena,* the spacecraft proceeded to deploy solar panels and high-gain antenna and to acquire Sun and Earth in the appropriate photoelectric sensors, permitting the use of solar power and high-gain communications with Earth.

Ranger had the capability of performing two maneuvers during the flight. The first, used to refine the flight trajectory and bring the lunar impact location and time closer to the desired target than launch-vehicle precision would permit, entailed pointing and firing the on-board propulsion system. This is done nominally about 16 hours after launch, but in the case of *Ranger IX,* the maneuver was delayed to 40 hours after launch. The data obtained

President Johnson presents NASA Medal for Exceptional Scientific Achievement to Harris M. Schurmeier, JPL Ranger Project Manager.



in the additional day of tracking were used to increase the accuracy of the impact even further. The maneuver has the capability of altering spacecraft velocity by as much as 60 meters per second.

The second spacecraft maneuver, which provided spacecraft reorientation without thrust, was intended to align the television cameras toward their desired target along the direction of approach to the lunar surface. In the case of *Rangers VI, VII,* and *VIII,* the camera-axis alignment was such that no terminal maneuver was required. On the *Ranger IX* mission, a terminal maneuver, consisting of pitch and roll turns, was employed to align the axis of the full-scan A-camera along the flight vector.

The television subsystem consisted of six cameras, two operating in a full-scan mode and feeding one radio channel, and four operating in a partial-scan mode and feeding another radio channel. The two chains of cameras, power supplies, control-electronics systems, and radio transmitters were packaged independently in the subsystem.

TV data from the two channels were received and recorded at Goldstone Pioneer and Echo Stations. During the *Ranger IX* mission, data from the two full-scan cameras were transmitted to the Space Flight Operations Facility (SFOF) by the microwave link and there converted for real-time presentation to the public via commercial-type television equipment.

MISSION RESULTS

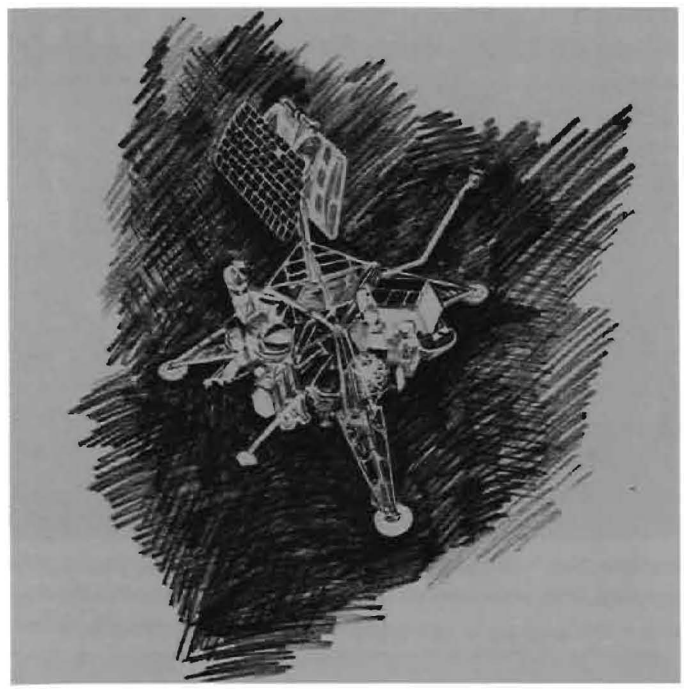
A wealth of new visual data about the Moon has been provided by the *Ranger* program. The combined total from *Rangers VII, VIII,* and *IX* was 17,259 photographs. The data thus obtained indicate that there are no serious topographical hazards for the unmanned and manned landing missions. The question of lunar surface hardness cannot be answered by photographs alone. The unmanned landing missions will have to supply further information before a manned landing is attempted.

On the basis of the new data obtained by *Ranger,* Earth-based lunar studies such as crater size–frequency dis-

Ranger VII press conference: W. H. Pickering announces mission success.

tributions have been extended. The excellent photographs of certain features of the crater Alphonsus, such as the central peak, the crater walls, the rilles, and the dark-haloed craters, have answered some questions and raised others. The complete interpretation of the *Ranger* photographs will take years and require additional data.

Among the scientists who participated in the *Ranger* Block III lunar investigations were astronomers Gerard B. Kuiper, principal investigator, and Ewen A. Whitaker, Director and Research Associate, respectively, of the University of Arizona's Lunar and Planetary Laboratory; Eugene M. Shoemaker, geologist and Director of the Astrogeology Branch, United States Geological Survey; Harold C. Urey, Nobel Laureate in Chemistry and Professor at the University of California at San Diego; and Raymond L. Heacock, Chief, Lunar and Planetary Instruments Section, Jet Propulsion Laboratory. Atlases of the photographs obtained in the missions and the experimenters' evaluations have been and are being published by the Laboratory, and NASA is preparing the photographs in book form.



Surveyor spacecraft

Surveyor

Calculated to span the gap between the *Ranger* and *Apollo* Projects, the *Surveyor* Project is designed to take the next step in advancing lunar technology by making soft landings on the Moon with unmanned spacecraft which will perform various engineering and scientific experiments during and after touchdown. Through its Office of Space Sciences and Applications, whose Lunar and Planetary Programs Office has the responsibility for the overall direction and performance evaluation of the *Surveyor* Project, NASA assigned the Jet Propulsion Laboratory the management responsibility for the Project.

The *Surveyor* Project is divided into two phases: Block I and Block II. Seven *Surveyor* missions, scheduled for 1965 through 1967 launchings, currently make up Block I. Hughes Aircraft Company, Space Systems Division, is under contract for the development, fabrication, testing, and launch operations of the first seven spacecraft. The first four missions, A through D, will be engineering test missions to demonstrate system capability for touchdown and limited postlanding operations. The engineering payload includes elements of redundancy, diagnostic telemetry, touchdown instrumentation, and survey TV. An approach TV camera will also be carried.

Missions E through G will carry science payloads designed to extend our knowledge of lunar surface characteristics and to provide information in support of subsequent manned exploration. The payload presently consists of six scientific experiments (described in more detail later).

Ten missions are planned for Block II.* The objectives of the first three, Missions H through J, are identical to those of Block I Missions E through G. The remaining seven missions, K through Q, are designed for more extensive scientific exploration of the lunar surface. The proposed payload will consist of advanced scientific instruments that can be integrated into the spacecraft design without necessitating major changes to the basic spacecraft configuration.

*Subsequent to the end of FY '65, authorization has been limited to Missions H, I, and J.

PROJECT HISTORY

In February 1960, at NASA's request, JPL initiated a study of the application of the *Centaur* stage to lunar and planetary missions. The study concluded that the soft landing of a significant payload on the lunar surface could be accomplished within the NASA schedule with an *Atlas/Centaur* launch vehicle.

Spacecraft system development was formally initiated in March 1961, with the contract being awarded to Hughes Aircraft Company, Space Systems Division, of Culver City, California. The first Project plan, reflecting the NASA schedule and Hughes' proposals, specified seven 2500-pound separated-weight spacecraft, all of which were to carry a full complement of scientific experiments.

Subsequent events necessitated reducing the spacecraft weight to approximately 2100 pounds to be compatible with the expected launch-vehicle performance, and a decision was reached to designate the first four spacecraft as engineering test flights, carrying an engineering payload, and the later missions as operational flights, carrying scientific payloads.

Surveyor prototype spacecraft in environmental test chamber

SYSTEM DESCRIPTION

The launch vehicle is a two-stage configuration consisting of an *Atlas* first stage and a *Centaur* second stage, both developed by General Dynamics/Convair under the direction of the NASA Lewis Research Center. The *Atlas* stage, a modified *Atlas D*, consists of a two-engine jettisonable booster section and a sustainer engine. Utilizing liquid oxygen and RP-1 (kerosene) fuel, a take-off thrust of approximately 400,000 pounds is available.

The *Centaur* has two 15,000-pound-thrust engines which burn a liquid hydrogen and liquid oxygen mixture and are gimballed for space-vehicle directional control.

Two basic units make up the spacecraft: the bus and the payload. The bus comprises those spacecraft elements of structure, telecommunications, power generation, propulsion, and flight control which provide the capability to perform the Earth–Moon transit and make a soft lunar landing while maintaining two-way communications. It is composed of aluminum-alloy tubular members (8 feet high), with three landing legs equipped with crushable pads, and a solar panel and high-gain planar antenna mounted on top. Solar and star (Canopus) sensors, a radar doppler velocity sensor, gyros, three nitrogen gas-jet assemblies, altitude-marking radar, three liquid-propellant vernier engines, and a solid-propellant retrorocket are included for use during the midcourse maneuver and terminal descent.

Missions A through D will carry the following engineering payload:

1. Survey TV to provide pictures of selected portions of the lunar surface and of the spacecraft after landing.
2. An auxiliary battery and associated circuitry to provide backup for emergency power and peak power loads on the main battery during transit.
3. Engineering sensors to provide data on the performance of the spacecraft and its response to the environment.

Missions E through G presently have a scientific payload of six experiments:

1. The television experiment will provide a panoramic view of the lunar surface and pictures of the spacecraft after landing.

2. The soil-mechanics experiment will qualitatively determine the mechanical properties of the lunar surface.
3. The alpha-scattering experiment will gather information on the composition of the lunar surface.
4. The micrometeorite-ejecta experiment will measure ejecta resulting from micrometeorites impacting the lunar surface.
5. The seismograph experiment will measure physical disturbances on the Moon.
6. The touchdown-dynamics experiment will provide data on the forces between the spacecraft and the lunar surface during touchdown, thus yielding information regarding the bearing strength of the lunar surface.

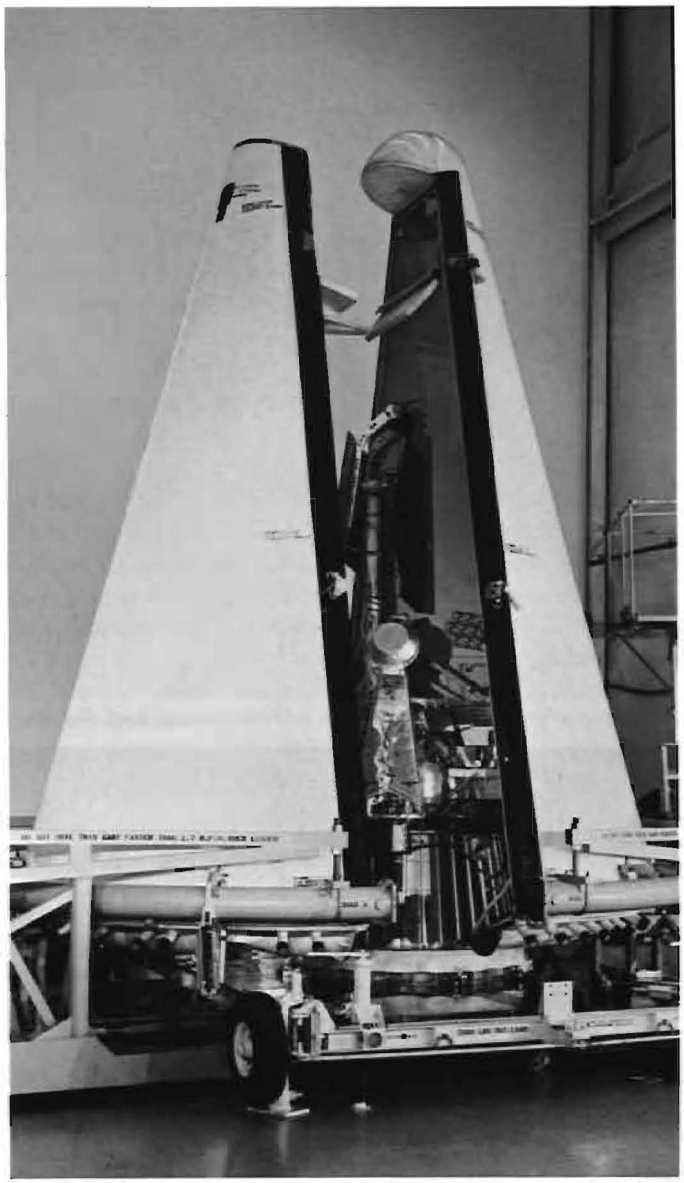
Surveyor differs from all earlier spacecraft in that (1) it requires a fully self-contained automatic landing system and (2) it relies basically on remote control rather than preprogramming (only during final descent will the vehicle be under programmed inertial and radar control; at all other times, it will be controlled by the JPL Space Flight Operations Facility).

Control of spacecraft operation is achieved through a loop that is closed through Earth-based equipment and decision-making processes. The only operations not subject to this control are those associated with attitude stabilization, the terminal-descent phase, and portions of the solar-panel deployment.

FLIGHT OPERATIONS

After its launch from the Eastern Test Range, the vehicle will be tracked at S-band (about 2300 megacycles) from the Spacecraft Monitoring Station, Cape Kennedy, Florida. After the aerodynamic nose fairing covering the spacecraft has been ejected, and prior to separation of the spacecraft from the *Centaur*, its omni-antennas and landing gear will be extended. After acquisition of the spacecraft by the Johannesburg tracking station, *Surveyor* will be commanded to acquire the Sun and the star Canopus.

During the initial attitude alignment and throughout most of the Earth–Moon trajectory, three sets of small nitrogen-powered gas jets on the ends of the landing-gear legs will be used to adjust and maintain spacecraft attitude.



Encapsulation of prototype Surveyor spacecraft in nose fairing
OPPOSITE: *Surveyor test launch*

After 16 to 20 hours of tracking, the midcourse correction maneuver to rotate the spacecraft to the proper inertial attitude and to begin the motor burn will be commanded. The correction will be executed by the firing of three small vernier engines, after which *Surveyor* will reacquire Canopus and the Sun.

Approximately 1 hour before the landing, the spacecraft will be commanded to orient its thrust axis along the velocity vector expected for the time of retro-ignition. A large solid-propellant retrorocket will reduce the spacecraft velocity from nearly 9000 to 450 feet per second, and the three vernier engines used for the midcourse correction will further reduce the descent speed to approximately 10 feet per second.

Touchdown impact will be absorbed by a tripod landing gear and crushable metal pads under the spacecraft frame. After the landing, the solar panel and the high-gain antenna will be raised so that they will not shadow the experiments. Then, the solar panel will be positioned to face the Sun, the high-gain antenna will be realigned with the Earth, and *Surveyor* will begin its experiments.

TRACKING AND DATA ANALYSIS

The results of the flight experiments will be telemetered to Earth by the spacecraft and recovered and recorded by the Deep Space Instrumentation Facility (DSIF). Portions of the flight data required for mission control will be transmitted to the SFOF at JPL. Preliminary real-time reduction and analysis of the experiment data will be performed as rapidly as possible in order to enable the experimenters to maximize the value of the remaining lunar operations of the spacecraft.

A group of investigators has been selected by NASA. The principal investigators, working through and with the JPL Project scientist, will be given support by the Space Sciences Division.

When the operational phase of each mission is completed, primary attention will be devoted to the reduction and analysis of the flight data. The scientific data will be reduced, processed, and prepared by computer techniques for analysis by the principal investigators and supporting personnel.

Planetary and Interplanetary Projects

Missions utilizing spacecraft in orbit in the near vicinity of planets and the landing of instrumented capsules on their surfaces constitute the Planetary–Interplanetary Program. These missions, initiated in 1962 and planned through the 1970's, are expected to reveal new scientific information on the planetary and interplanetary environments, as well as on the surface conditions of the planets. Emphasis of the future missions will be on the exploration of the nearby planets.

The initial probing of Venus was successfully accomplished by *Mariner II* in December 1962, and a mission to Mars is now in progress, with the flyby of Mars by the *Mariner IV* spacecraft to take place in mid-July. Preliminary steps, in the form of mission planning and design concepts for the *Voyager* Project, are currently underway, with the detailed exploration of the environment and surface of Mars to start in 1971.

Mariner Mars 1964

The *Mariner Mars* 1964 mission was authorized in November 1962. The JPL responsibilities, which included all phases of the mission except the launch-vehicle system, were handled by a Project Manager, who determined the policies and evolved the requirements necessary for the success of the mission, on the basis of information from such areas as overall system design, spacecraft weight limitations, launch-period constraints, and launch-vehicle performance requirements. Responsibility for the launch-vehicle system was assigned to NASA Lewis Research Center.

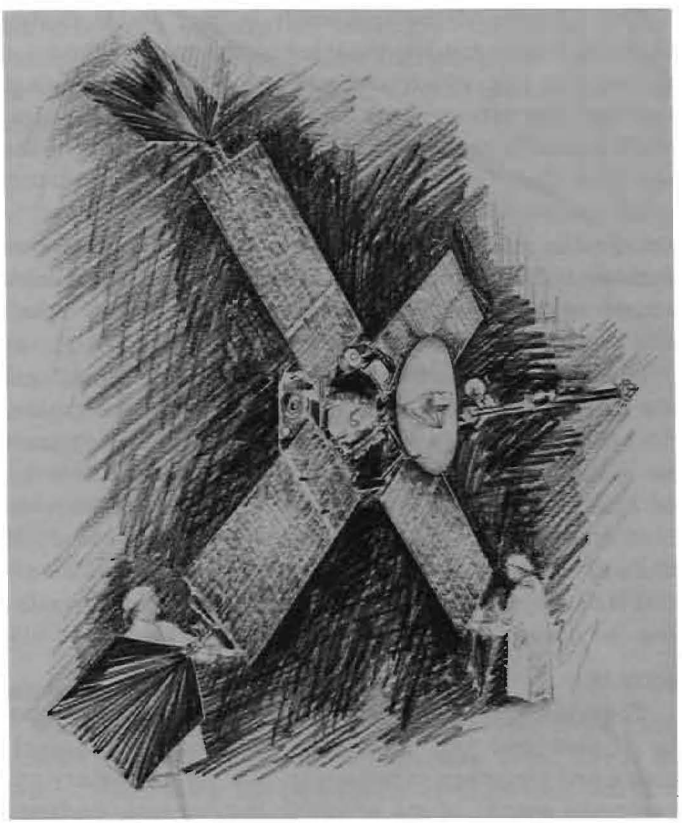
An improved *Atlas D* first stage and an improved *Agena D* second stage were used as the *Mariner Mars* 1964 launch vehicle.

SPACECRAFT SYSTEM DESCRIPTION

The *Mariner* spacecraft is basically an octagon structure. Four solar panels extend from the structure to form a cross, and at the end of each solar panel is a wing-like solar vane. Above the octagon are the radio antennas, and below are the lenses for tracking the star Canopus and for locating and taking television pictures of the illuminated face of Mars. The dimensions of the spacecraft are approximately 9½ by 22½ feet.

The solar panels present 70 square feet of surface area to the Sun and contain over 28,000 photovoltaic solar cells. The amount of power available from these cells decreases as the spacecraft recedes from the Sun. In addition to the solar panels, the spacecraft carries a rechargeable battery, which is used as a power source whenever the solar panels are not pointed at the Sun. The battery is also available as an auxiliary power source for peak loads.

Communications are maintained with the spacecraft 24 hours a day. The communications equipment consists of a radio receiver, two radio transmitters, and two antennas. The spacecraft continually transmits a radio signal to Earth, and this signal is used to obtain telemetry informa-



Mariner Mars 1964 launch vehicle poised for flight

tion and to measure the spacecraft's velocity and position in space. Periodically, radio signals are transmitted to the spacecraft from Earth. These signals are received by the spacecraft receiver and are retransmitted to Earth by the spacecraft transmitter.

Both a low-gain antenna and a high-gain antenna are carried on the spacecraft. The low-gain antenna is an omnidirectional device and does not have to be pointed directly at the Earth in order to receive a signal. Because of its directional characteristics, the high-gain antenna can be used only when it is pointing at the Earth, that is, during the latter half of the trajectory.

All of the instruments on board the spacecraft are timed by the central computer and sequencer. This device is an extremely accurate electronic clock, which initiates various events on the spacecraft.

The attitude of the spacecraft is kept stable during flight by twelve gas jets mounted at the ends of the solar panels. The jets, which comprise two separate, redundant systems, fire nitrogen gas into space to keep the spacecraft correctly oriented with respect to the Sun and the star Canopus.

Mariner carries a small rocket motor which is used to change the velocity and direction during the midcourse maneuver. The *Mariner* propulsion motor is the first midcourse motor capable of being re-ignited if more than one maneuver becomes necessary.

In order to ensure operation of the mechanical and electronic equipment in the severe environment of space, the temperatures of various parts of the spacecraft must be controlled. Temperature control is accomplished by both heat-absorbing and heat-radiating materials, louvered heat shields, and temperature-shielding blankets made of aluminized mylar. During the construction phase, a special temperature-control model was made to aid in verifying the design of the temperature-control system.

SCIENCE

The science experiments carried aboard *Mariner IV* may be divided into two categories: interplanetary experiments and planetary experiments. The interplanetary experiments consist of six scientific instruments, designed to operate throughout the mission: a trapped-radiation detector, a cosmic-ray telescope, a cosmic-dust detector, a helium magnetometer, a solar-plasma probe, and an ionization chamber. The planetary experiments consist of the television experiment and the occultation experiment.

Results from the interplanetary scientific experiments are expected to be of particular interest because the *Mariner IV* flight is taking place during the quiet phase of the Sun, which occurs approximately every 11 years.

Interplanetary Experiments

The purpose of the *trapped-radiation detector* is to monitor and study solar cosmic rays and energetic electrons in interplanetary space, search for magnetically trapped particles in the vicinity of Mars, and provide further information about the Van Allen radiation belt around the Earth.

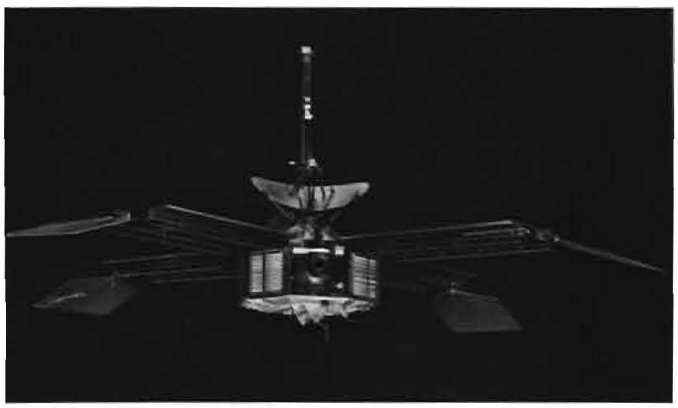
The *cosmic-ray telescope,* consisting of a columnar array of three solid-state detectors and two absorbers, detects and measures solar and galactic cosmic rays.

The *cosmic-dust detector* measures the distribution and velocity of micrometeorite dust particles. It consists of a plate in the center of which is mounted an acoustical microphone. Particles striking the plate (or the microphone) set up an acoustical vibration, which is then converted to an electrical signal.

The purpose of the *helium magnetometer* is to determine the magnetic field of Mars. In addition, it takes measurements of the interplanetary magnetic field and provides information about the boundary between the interplanetary and planetary fields.

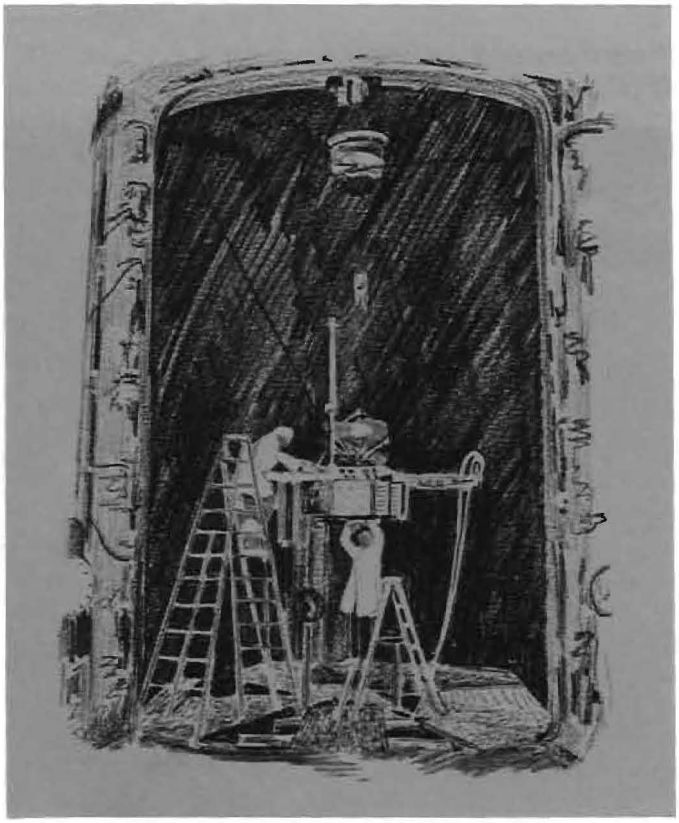
The *solar-plasma probe* measures the intensity of low-energy protons which are ejected from the Sun. A similar scientific experiment aboard *Mariner II* provided significant information about the solar plasma, and the *Mariner IV* experiment is expected to increase our knowledge of the solar wind even further.

The *ionization chamber* measures the intensity of ionizing radiation in interplanetary space, correlates this information with the solar-plasma probe and helium magnetometer information, and measures the intensity and extent of any magnetically trapped radiation in the vicinity of Mars.



Mariner Mars 1964 spacecraft

Mariner spacecraft in 25-foot space simulator



Planetary Experiments

The *television* experiment consists of a television camera, a wide-angle acquisition sensor, a narrow-angle acquisition sensor, a tape recorder, and associated electronic circuitry. The wide-angle acquisition sensor searches for the sunlit disc of Mars. When the disc comes into the field of view of the lens, the scan platform on which the sensor is mounted ceases its searching motion and keeps the camera pointed toward the target area. When the disc comes within the 1-degree field of view of the narrow-angle acquisition sensor, the tape recorder begins recording pictures of the Martian surface.

The *occultation* experiment does not involve any specialized equipment aboard the spacecraft. When the spacecraft appears to move behind the planet, its radio signal passes obliquely through the Martian atmosphere and is diffracted; the propagation velocity of the signal is also changed. Measurement of these changes to the radio signal can yield significant information about the Martian atmosphere.

TESTING

There were four *Mariner Mars* 1964 spacecraft built in addition to selected spares: a proof-test model and three flight models. Temperature-control and structural test models were also constructed to help define the design parameters required for the mission. The proof-test and flight models were put through rigorous tests at the Laboratory using the 25-foot space simulator and other environmental facilities. The spacecraft were tested and retested many times, both in Pasadena and at Cape Kennedy, before they were accepted as ready for a flight to Mars. In addition to qualifying the *Mariner* spacecraft for flight, the test program provided valuable information concerning spacecraft system testing in general, which will be useful to future space programs.

MISSION PLANNING

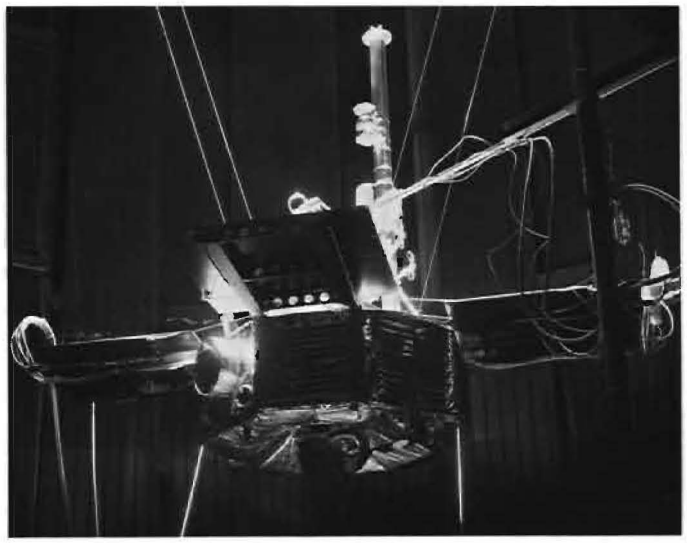
Mission planning activities of the *Mariner Mars* 1964 Project included designing a trajectory from Earth to Mars, determining the probability of impacting Mars or otherwise contaminating the planet, and evaluating the

numerous considerations which would affect the success of the mission.

Among the many factors which had to be considered in the design of an accurate trajectory were the 28-day launch period resulting from the positions of the two planets, the gravitational pull of various planets in the solar system, the position of Mars and Earth at encounter, and the TV scanning requirements of the mission. Because the Sun would be used both as a power source and as a reference body for the attitude-control system, the spacecraft had to be able to "see" the Sun at all times, even when passing Mars. It was necessary to consider the positions of Mars and its moons so that the Canopus-tracker field of view would not be blocked. The spacecraft had to pass within 25,000 miles of the surface of Mars in order to obtain the maximum scientific results and to achieve the desired picture resolution from the television system. And finally, the spacecraft had to pass behind the planet (as seen from the Earth) in order to meet the requirements of the occultation experiment. After the spacecraft was launched, position and velocity measurements were used to determine the amount of correction required by the midcourse maneuver. After the midcourse maneuver was performed, information telemetered from the spacecraft was used to continuously refine the calculations of the flight path and to determine more accurately the point in space where *Mariner* would achieve its closest approach to the planet.

Since the *Mariner* spacecraft would not be sterilized, the chance that it would hit the planet had to be kept to less than 1 in 10,000. A target point was chosen sufficiently far away from the planet to meet this requirement.

During the 8½-month flight to Mars, it would be necessary to send commands to the spacecraft and receive telemetry information in order to control and evaluate the flight. Tracking and telemetry data are relayed to the Space Flight Operations Facility in Pasadena, where the mission control center is located. Here the incoming data are fed to computers, which translate the digital information into familiar and readily usable form. The data received from the spacecraft contain information



Mariner spacecraft undergoes system test.
BELOW: *Close-up of camera*

concerning the performance of the various subsystems on board; the orientation, velocity, and position of the spacecraft; and the reactions of the scientific instruments to the environment of interplanetary space.

MISSION SUMMARY

It was originally intended to send two *Mariner* spacecraft to Mars. *Mariner III* was launched on November 5, 1964. Shortly after injection, it was determined that the aerodynamic fiberglass shroud had not separated from the spacecraft and that the spacecraft could not extend its solar panels to acquire the Sun. With no solar power available, the spacecraft battery finally ran down after 8 hours and 43 minutes, and communication was lost. Work was immediately started on the design, fabrication, and testing of a new, all-metal shroud, and 23 days later, on November 28, 1964, *Mariner IV* was successfully launched.*

On December 5, the spacecraft performed a midcourse maneuver, changing its velocity and direction so that it would pass approximately 5600 miles from Mars.

During the encounter phase, a number of sequential operations must be performed. First, the central computer and sequencer commands the scan platform to start rotating, initiating the search for the planet. Then, the wide-angle acquisition sensor must sense the presence of the planet and cause the scanning platform containing the television camera to track at the proper position. Next, the narrow-angle acquisition sensor must pick up the planet in order to trigger the start of picture recording for the camera. The television camera then takes approximately 20 pictures of the sunlit Martian surface through an alternating sequence of red and green filters. The picture-taking sequence lasts approximately 25 minutes. Picture information is stored on the magnetic tape in the form of "bits" representing various shades of black and gray. The spacecraft subsequently passes behind the planet. About 55 minutes later, it re-emerges and, assuming nearly immediate radiofrequency lockup, again provides atmospheric data. Approximately 10 hours later, the spacecraft begins transmitting the television picture data recorded on its magnetic tape. Because of the low bit rate (8⅓ bits per second), it takes approximately 8½ hours to transmit one complete picture. It is expected that the pictures will be "played back" twice, in order to make sure that all of the information was received correctly. After picture playback, the spacecraft is sent a command to return to its normal cruise mode of operation and remains in that mode until communications are lost as a result of the increasing distance.

MISSION RESULTS

Mariner IV is the first spacecraft to explore the region of interplanetary space beyond the Earth's orbit and maintain intelligible communications. It is the first spacecraft to use a star tracking system. It will achieve a record in communications distance—more than 134 million miles at encounter. At the time of encounter, the spacecraft will be farther from the Earth than the Sun is, and it will take approximately 12½ minutes for a radio signal to travel between the Earth and *Mariner*. The mission proves the feasibility of many of the engineering techniques used on this spacecraft in terms of their application to future spacecraft design.

Mariner II, in its flight to Venus, was one of the first interplanetary space probes. It provided significant new scientific information about interplanetary space, about the regions around Earth and Venus, and about the effects of solar phenomena. *Mariner IV*, in its flight to Mars, is adding to and refining our knowledge of interplanetary space. For instance, the amount of galactic cosmic rays measured in the solar system by *Mariner IV* is about 40% higher than the amount measured by *Mariner II*; the reason is probably attributable to the quiet period of the Sun during the *Mariner IV* flight. For the first time, low-energy electrons have been detected as far out as 23 Earth radii. *Mariner IV* has detected significantly larger amounts of cosmic dust than did *Mariner II*, particularly during the later portions of the flight. And finally, much additional information has been obtained

**Mariner IV* encountered Mars on July 14, 1965, and has provided a wealth of scientific data from its on-board experiments, including 22 pictures of the planet's surface. The occultation-experiment data have resulted in a new estimate of the atmosphere of Mars.

concerning the shock wave which is produced at the Earth by the solar wind. Unfortunately, the solar-plasma probe was partially inoperative after the 9th day of flight, and the ionization chamber became completely inoperative shortly after a solar flare was seen on February 5, 1965.

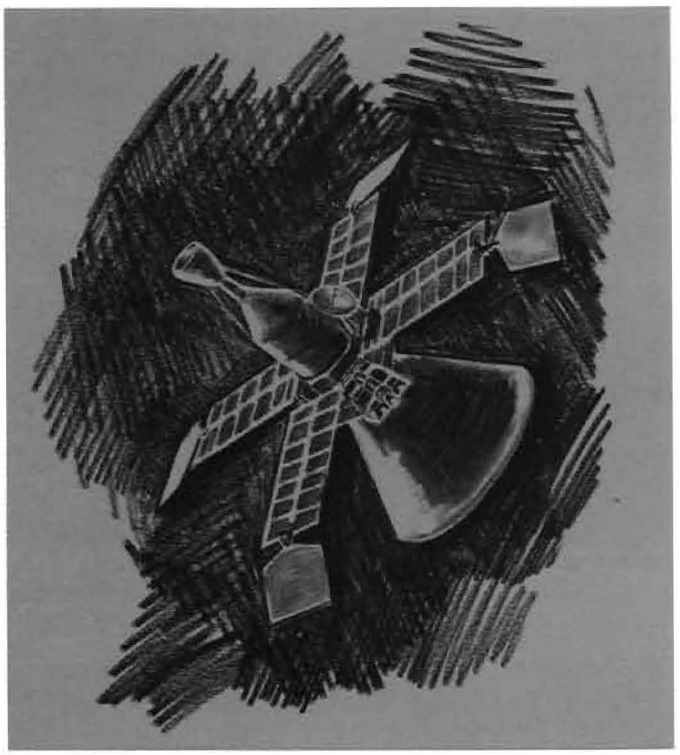
It will take years to evaluate all of the data received during the flight of *Mariner IV*; more than 12 million engineering measurements and 18 million scientific measurements will be made during the mission. However, preliminary analyses have already indicated that a great deal of valuable scientific and engineering information is being obtained.

Voyager

The *Voyager* Project will continue and extend the unmanned scientific exploration of the solar system begun by the *Mariner*, *Ranger*, and *Pioneer* programs. Present planning is for the conduct of both orbiter and lander missions to the planet Mars during the 1970's. Inherent in the *Voyager* design will be the capability of carrying significant scientific payloads to the planet, telemetering large amounts of data back to Earth, and having a long operating life.

Voyager's primary objective will be to perform experiments on the surface of and in orbit about the planet Mars during the 1971, 1973, and subsequent opportunities in order to obtain information about the existence and nature of extraterrestrial life; atmospheric, surface, and body characteristics of the planet; and the planetary environment. A secondary objective is to perform certain field and particle measurements in interplanetary space between the orbits of Earth and Mars.

As a result of the many potential requirements for experiments, the *Voyager* Project is concerned with both orbital and landing missions. The missions will be designed to place significant scientific payloads in orbit about Mars for extended periods of time and transmit the observations back to Earth; to enter the atmosphere of Mars and obtain data on the atmospheric characteristics; to land the capsule on the planetary surface so as to conduct operations there and return capsule observations to Earth; to provide confirmation of the technologies used; to supply experience with the flight and ground systems required to deliver and operate an orbiter and its payload; and to ferry, separate, land, and operate the capsule and its payload.



Voyager spacecraft — artist's conception

A major requirement placed on the *Voyager* Project is the maintenance of Mars quarantine to prevent contamination of the planet by live organisms transported from Earth. This requirement necessitates development of a sterilization technology for all landed equipment, including heat sterilization and assembly under clean, and possibly bio-clean, conditions.

Overall direction and evaluation of the *Voyager* program is the responsibility of the Office of Space Science and Applications of the National Aeronautics and Space Administration. Management of the *Voyager* Project and implementation of selected systems is the responsibility of the Jet Propulsion Laboratory.

Advanced Studies for Possible Future Interplanetary Missions

The Advanced Technical Studies Office acts as a central management point within the Laboratory to sponsor and direct studies of the feasibility and desirability of future missions in the lunar and planetary area, both from the standpoint of missions which might be assigned to the Laboratory for implementation, and from the standpoint of providing technical and management information for the use of NASA Headquarters in determining the national program needs. Over the past several years, the principal theme of these mission studies has been the exploration of Mars. More specifically, a major portion of the effort has been directed toward defining the *Voyager* concept and its application to the exploration of Mars and to the investigation of the existence of life on that planet. During the past year, this activity passed a critical milestone when NASA approved a first phase of the *Voyager* program. The Laboratory has set up a *Voyager* Office and is proceeding on a phased basis toward this extensive program of planetary exploration. Approximately half of the activities of the Advanced Technical Studies group for the past year were carried out in cooperation with the *Voyager* Project Office.

These studies were of substantial significance in that they brought out the important role that the planetary quarantine policy plays in defining orbiting missions. It was found that our present understanding of the Mars exosphere is so poor that very substantial degradation in the information that could be obtained from an orbiter might be required in order to meet the quarantine objectives.* More specifically, if the most conservative estimate of the Martian exosphere is used, if the orbiting spacecraft is unsterilized, and if it is assumed that the quarantine objectives in these circumstances would be met by requiring that the spacecraft have a lifetime of 50 years in orbit, then the minimum periapsis altitude for the spacecraft would have to be approximately 4000 kilometers. Under this condition, it is apparent that it would be very difficult to obtain high-resolution photographs of the Martian surface. The results of the studies show the need for a more detailed examination of sterilization policy and for scientific means of determining more accurately the Martian exospheric and surface chacteristics, as well as the interrelation of these problems.

A Mars lander external study indicated that such a mission could be carried out but that our lack of detailed knowledge of the Martian environment severely penalizes the design efficiency. The *Mariner* studies directed toward the evaluation of such environmental factors as the Martian surface pressure and wind velocities should contribute considerably to the determination of appropriate design conditions for future Mars missions.

In addition to the studies of the exploration of Mars, some initial steps were taken toward other potentially interesting targets in the solar system. The possibilities of investigating the asteroid belts and comets were investigated. Whether or not exploration missions to these more exotic members of the solar system should be carried out depends primarily upon the resolution of two quite different questions: first, the question of scientific interest and second, the question of technological difficulty. These preliminary studies have dealt primarily with the technological problems of carrying out such missions. In general, the results look favorable. The studies will be continued over the next years in order to develop the background information needed to initiate specific programs to implement these objectives.

**Mariner IV* data from the occultation experiment have considerably improved our knowledge of the Mars atmosphere.

The Deep Space Network

The Deep Space Network (DSN) is composed of three main elements: the Deep Space Instrumentation Facility (DSIF), with space communication and tracking stations encircling the globe; the Space Flight Operations Facility (SFOF) at JPL, the Pasadena command and control center; and the Ground Communication System, which uses facilities of the worldwide NASA Communications System to connect all parts of the DSN by telephone and radioteletype.

The Jet Propulsion Laboratory pioneered the development of many of the critical elements of communications systems designed for cislunar and interplanetary missions, and in 1958 established the first three-station network of receiving stations to gather data from the first U.S. Earth-orbiter, *Explorer I*.

Mission Support

Since its inception in late 1958, the DSN has participated in a number of technological firsts. Among these were *Pioneer IV*, the first U.S. probe to reach Earth-escape velocity and the first to be successfully tracked beyond the Moon; Project *Echo*, the first experiment in using passive communication satellites; and the *Mariner II* 1962 mission to Venus. Prior to the Venus mission, the DSIF development station at Goldstone, operating in a radar mode, made the first successful radar detection of the planets Venus and Mars, making possible accurate determinations of their distance for spacecraft guidance.

In the past year, the DSN supported the *Ranger* reconnaissance missions to the Moon, receiving and recording the TV photographs of the lunar surface radioed back to Earth. Since November 1964, the DSN has been engaged around the clock in tracking *Mariner IV* on its 8-month, 325-million-mile journey to encounter at Mars, setting new telecommunications records in long-distance, long-term control of a spacecraft.

This year, the DSN successfully tracked *Ranger VIII* in February and *Ranger IX* in March, while at the same time continuing tracking coverage of *Mariner IV*. Other projects supported this year were the *IMP-C* (Interplanetary Monitoring Probe) spacecraft and the *Atlas/Centaur 5* missile.

In the second half of this decade, the DSN is scheduled to support the *Surveyor* and *Voyager* programs, for which JPL has been given management responsibility, as well as *Lunar Orbiter*, a photographic exploration mission to record pictures of the lunar surface from a satellite, under the direction of NASA Langley Research Center; *Pioneer*, a series of interplanetary probes designed to investigate the nature of solar flares and other deep-space phenomena, for which NASA Ames Research Center has management responsibility; and *Apollo*, the manned spacecraft mission that will put men on the Moon, under the direction of the NASA Manned Spacecraft Center.

Components of the Deep Space Network

Three of the basic functions performed by the Deep Space Network in a space-flight project are tracking, telemetry data acquisition, and command. These functions are performed as a team effort by the Deep Space Instrumentation Facility and the Space Flight Operations Facility, supported by the DSN Ground Communication System.

THE DEEP SPACE INSTRUMENTATION FACILITY

The DSIF stations are situated approximately 120 degrees apart in longitude, so that the spacecraft is always within the field of view of at least one of the ground stations. The DSIF ground transmitters operate at power levels of 10 kilowatts; one of the Goldstone, California, stations also has an advanced capability of transmitting at 100 kilowatts.

One of the major improvements made in FY '65 was the installation of new tracking and telecommunications equipment designed to operate at the S-band frequencies of 2100 and 2300 megacycles recently allocated to the DSIF.

Goldstone Space Communication Stations

Goldstone consists of three operating stations—Pioneer, Echo, and Venus—all using 85-foot-diameter antennas. Pioneer was the first DSIF station to be built. One of its main uses has been as an advanced testing site for DSIF operations and for new techniques and equipment. The Echo station, in addition to its tracking activities, serves

Massive 85-foot-diameter DSIF antenna

as the Goldstone administrative center and operations headquarters. The Venus site is primarily a research facility, used to develop high-power radiofrequency transmitters and advanced receiving systems for the DSIF and to conduct related research and development activities. A fourth station, Mars, is currently under construction and is due to be operational in March 1966. It will be the site of the first 210-foot-diameter antenna system to be completed in the DSIF.

Cape Kennedy Spacecraft Monitoring Station

The JPL-operated Cape Kennedy station was moved to a new, permanent facility in FY '65. This station, using a 10-foot-diameter antenna, monitors the spacecraft during checkout operations and tracks it during the launch phase and for a short time thereafter.

Overseas DSIF Stations

Construction is proceeding on the Ascension Island station in the South Atlantic Ocean, with completion scheduled for early 1966. The station is of a gap-filler type, and uses a 30-foot-diameter antenna for data acquisition during the early part of flights launched from Cape Kennedy.

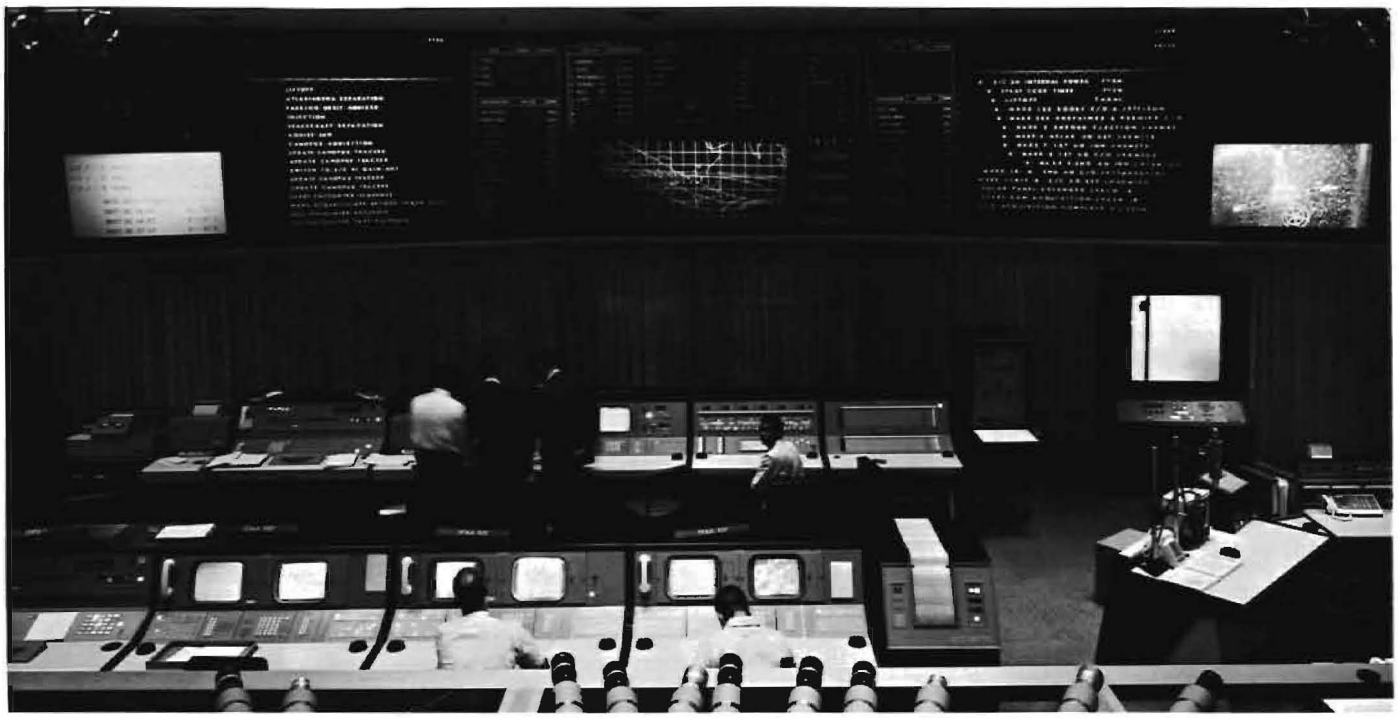
All other overseas stations are operated by the governments of the countries in which they are located. All of the stations are currently equipped with the basic DSIF 85-foot-diameter antenna system.

One of the two Australian stations, Woomera, situated in South Australia, participated in tracking *Mariner IV* and *Ranger*, and will take part in tracking the *Lunar Orbiter* next year. The second station, located near the city of Canberra, was completed in early 1965. *Surveyor* tracking will be its primary task in the coming year.

Because of its geographic location, the Johannesburg station in South Africa is the first DSIF station to acquire the spacecraft in most launching trajectories. It has been tracking *Mariner IV* regularly for 10 hours a day, except for short switchovers to the *Ranger* flights early this year.

Two new stations will be located at Robledo, near Madrid, Spain. One of the stations was completed in time to participate in tracking *Mariner IV* during the encounter phase; construction of the other will begin soon.

DSIF station at Tidbinbilla, near Canberra, Australia



Operations area in the JPL space flight operations facility

THE SPACE FLIGHT OPERATIONS FACILITY

The central control and data-processing facility of the Deep Space Network is the Space Flight Operations Facility, located at the Jet Propulsion Laboratory in Pasadena. The SFOF is the center for spacecraft command operations, performance evaluation, and data analysis. It is the control center for all tracking and data-acquisition activities of the DSIF, trajectory determination, generation and execution of commands to the spacecraft, and analysis and interpretation of data received. The SFOF contains mission support areas for flight-project mission control activities, and is the JPL terminal for the DSN Ground Communication System. The facility is equipped to support and control activities for two missions simultaneously, with monitoring capability over a third mission.

The SFOF was first used during the *Ranger VII* lunar photography mission in July 1964. Early in 1965, it had its first test in multiple-mission control when it was used for flight-operations control of *Ranger VIII* and *Ranger IX* while continuing tracking coverage of *Mariner IV*. In the coming year, the SFOF will be the control center for *Surveyor, Pioneer,* and *Lunar Orbiter* missions.

DSN GROUND COMMUNICATION SYSTEM

Voice and teletype communications among the overseas DSIF stations, Goldstone, the SFOF, and Cape Kennedy are provided by the DSN Ground Communication System. A special microwave link is used between the SFOF and Goldstone to transmit critical and wide-bandwidth data.

Teletype is the primary means for transmitting tracking and telemetry data from the DSIF stations to the SFOF, and for sending predictions and other data to the stations. Voice circuits are used for transmission of high-priority communications other than data. Communications-processing equipment separates information received for dispersal throughout the SFOF.

Research and Development

TELECOMMUNICATIONS

In addition to the telecommunications developments applied to the *Ranger* and *Mariner* missions (discussed in connection with these Projects), several advanced engineering projects were completed during the past year which are expected to provide technical improvements in the DSIF. These included ultrahigh-power continuous-wave transmitters in the 100- to 400-kilowatt region, precision ephemeris control for antenna steering and receiver and exciter tuning, and computer control of selected equipments in the DSIF. The experimental field work for these investigations was accomplished at the Venus site at Goldstone in connection with the lunar and planetary radar experiments.

The advanced 210-foot-diameter antenna being constructed at Goldstone is nearing completion, and will be put into operation for spacecraft tracking and other scientific and engineering uses during the coming year. When this antenna is commissioned into service, it will be the highest-capability device of its type in the world, providing more than six and one-half times the transmitting and receiving capacity of the 85-foot antennas. Plans are being developed for the installation of 210-foot antennas at two overseas locations—Madrid and Canberra—which, together with the Goldstone "210," will provide a high-capability continuous-coverage network for deep-space missions in the 1970 decade.

JPL SUPPORT TO THE APOLLO PROGRAM

Development of the unified S-band receiver-exciter ranging system for the Manned Space Flight Network (MSFN) was completed in FY '65. Forty-three S-band receiver-exciter ranging systems are required for the MSFN; six of these systems have been delivered to Goddard Space Flight Center by JPL, and the remaining 37 are scheduled for delivery during the next year.

Using the unified S-band concept, all of the required tracking and communications functions are consolidated by combining them into one radio link. In the past, these functions were supplied by three or more special-purpose subsystems utilizing different radiofrequency (RF) carriers. The unified S-band system provides coherent measurement of the RF-carrier doppler cycles, thus permitting measurement of changes in vehicle range to better than 1 RF doppler cycle (about 12½ centimeters). Telemetry, voice communications, commands, and ranging data in the form of phase modulation at low modulation indices are superimposed upon the RF carrier without disturbing the integrity of the phase-coherent RF link which provides the precision RF doppler.

210-foot-diameter DSIF antenna under construction

The JPL ranging subsystem employs a pseudorandom code to determine the range of the spacecraft from the ground station without the need for *a priori* knowledge of approximate range or for continuous tracking from launch. This technique of ranging utilizes a cross-correlation process with a pseudorandom binary code of sufficient length to obtain unambiguous range information to approximately twice the Earth–Moon distance. Rapid and automatic range acquisition is made possible by cross-correlating separately each of five independent code components, which are then combined to form the range code. Using RF doppler cycles, continuous updating of range in accordance with spacecraft motion is accomplished to a precision of the order of ±1 meter. Overall ranging accuracy is ±15 meters.

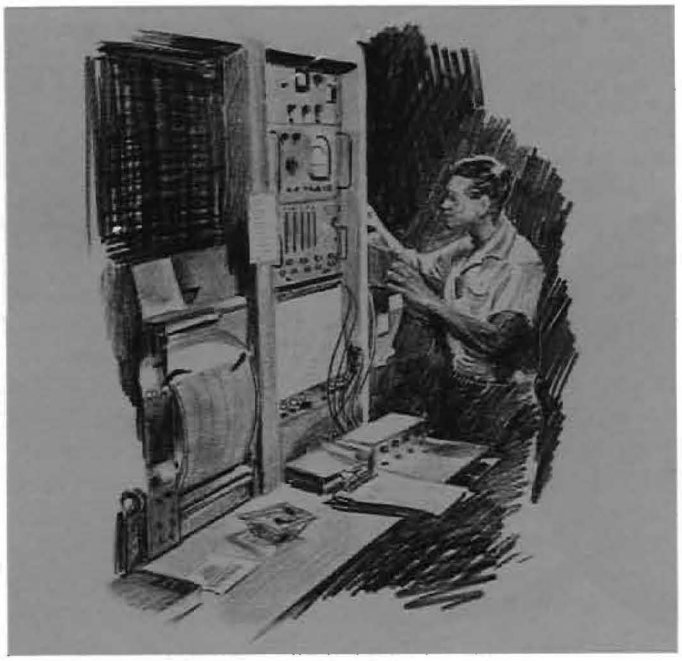
RADAR ASTRONOMY

Radar contact with Venus was first made on March 10, 1961, at the Goldstone Venus station by JPL personnel investigating new techniques for deep-space communications. That first series of experiments yielded interesting new data, the most surprising of which was a new value for the astronomical unit that refined the previous accuracy by more than two orders of magnitude.

A second series of radar experiments, carried out during the inferior conjunction of Venus in the Fall of 1962, resulted in new information concerning the rotation of Venus.

In June 1964, Venus was again close enough to Earth for a third series of radar observations. Analysis of the 1964 data has refined the accuracy of the earlier measurements.

Several strong topographic features were identified on Venus during the 1964 experiment. These were seen to move across the disc as the planet rotated. A Venus-centered coordinate system was established, and the features were located in that system.



Radar observations of Mars were carried out during the 1965 opposition of the planet. Relatively strong echoes were detected from the regions of Nodus Laocoontis and Nubis Lacus. Even stronger and very narrowband echoes were received from Trivium Charontis. That area, therefore, appears to be a good radar reflector and very smooth. It is hoped that *Mariner IV* photographs will help determine the true nature of this region.

ADVANCED DEVELOPMENT

A transmitter power supply and heat exchanger capable of supplying 1 megawatt was designed, installed, and evaluated at the Goldstone Venus station. During the past year, it was used with klystron RF power amplifiers having efficiencies of 40% at power output levels up to 100 kilowatts. The transmitting system will ultimately be capable of delivering powers of 400 to 500 kilowatts to the transmitting antenna. Preliminary engineering for a 400-kilowatt amplifier was completed.

A new S-band radio ranging system was developed which is capable of operating at planetary ranges. This system will employ a phase-coherent carrier. However, a coherent carrier is not required even if the signal level is too weak for satisfactory automatic phase control of the receiver local oscillator. Because of the lack of a suitable transponder in deep space, the planet Venus was used as a substitute. Venus was successfully ranged to an accuracy of ± 20 microseconds in a total signal travel time of 300 million microseconds.

A technique was developed for automatic angle tracking of radio star sources and was applied to Hercules A, the Crab Nebula, and Virgo.

An analytical technique was developed which utilizes a boundary-value solution to Maxwell's equations to synthesize optimum nonoptical subreflectors for two-reflector antenna systems.

In the area of antenna-feed design, multimode-horn research has continued toward the goal of physically realizing the ideal synthesized radiation patterns. A study is in progress on the properties of conical feed horns with apertures excited by three or more cylindrical waveguide modes.

Supporting Research and Technology

Systems

Research activities of the Systems Division this year were centered in the celestial-mechanics and numerical-analysis fields. Two projects of interest will be described.

The first was directed toward obtaining more accurate knowledge of forces acting on lunar and interplanetary spacecraft. Extremely precise radio tracking information from the *Mariner* and *Ranger* spacecraft made possible considerable refinement in our knowledge of the masses of Venus, Mars, the Earth, the Sun, and the Moon as well as correlated improvement in dependent constants such as the astronomical unit and the mean Earth–Moon distance. A further by-product of such tracking data was the precise measurement of tracking-station coordinates.

As a result of studies carried out during FY '65, a joint JPL–Langley Research Center proposal for analysis of lunar-orbiter tracking data to determine the Moon's gravity field was formally accepted by NASA. Future work will be influenced considerably by the theoretical problems arising in this undertaking.

Development of planetary and lunar ephemerides was the purpose of the second project. These ephemerides are tables giving the position and velocity of each planet and the Moon and the nutations in longitude and latitude, with their time derivatives, as a function of Ephemeris Time.

During FY '65, improvements were made in the efficiency of computer programs used in ephemeris development. Systematic studies were conducted on the accuracy of the numerical integration subroutine used in the computation of the planetary trajectories.

Improvements were made in the mathematical model of ground-based lunar and planetary radar experiments. This model was incorporated into a new double-precision computer program (RADAR 1) which was used to provide the range and doppler predictions needed for the execution of these experiments.

These projects aided materially in achieving a high guidance accuracy for the *Ranger* and *Mariner* spacecraft. Further improvements in accuracy are anticipated, as well as additional basic knowledge concerning the size, shape, and motion of the Moon and planets.

Space Sciences

In order to develop the capability of flying meaningful experiments on interplanetary satellites and probes, the Space Sciences Division performs research in physical chemistry, biological sciences, interplanetary physics, solar physics, magneto-fluid dynamics, plasma physics, physics of planetary atmospheres, planetology, optical and radio astronomy, low-temperature physics, geophysics, and related fields. Some of the significant accomplishments of the Division during FY '65 are listed below.

The Sinanoglu many-electron theory was examined from the standpoint of symmetry considerations. Rules were established for forcing the correlation correction to the Hartree–Fock function for closed-shell systems to be an eigenfunction of spin. The implications of these rules on the pair-correlation functions were investigated. The many-electron theory was applied to the Be atom, and the intershell correlation energies were calculated. The total correlation energy obtained agrees to within 1% of the experimental value. The iso-electronic series Be, B^{+}, C^{+2}, ... was investigated.

The use of the Fourier convolution theorem for evaluating the integrals arising in molecular quantum mechanics was extended, and a theory for calculating the energies of negative-ion resonant elastic scattering states to which the usual variation principle is not applicable was proposed and applied to the H_2^- and H^- resonances. The theory is based on a quasi-variation principle and has given excellent results in the cases considered thus far.

In the continuous investigation of surface forces, a new electrostatic theory was developed which has wide application in surface chemistry. The theory was devised to explain the chromatographic separation of ortho- and parahydrogen on an alumina column at low temperatures and makes possible a very sensitive measure of the effect of radiation damage in solids by exploring the surfaces with the ortho- and parahydrogen separation.

New techniques for the concentration of metal ions at high dilution were developed using chelating agents coupled to cellulose. This work has important implications in the disciplines of biochemistry, geochemistry, oceanography, and the chemistry of extraterrestrial bodies.

Solar simulator virtual light source and optic in the 25-foot space simulator

Processes by which ozone in the atmosphere is decomposed by sunlight were studied in detail using several different wavelengths of ultraviolet light. Whereas the efficiency of this decomposition is not dependent on the wavelengths over a wide range in the ultraviolet, the products formed are a function of the wavelength. As one goes to longer wavelengths and approaches the near-ultraviolet, the products are ground-state, or "ordinary," atomic oxygen and molecular oxygen. At shorter wavelengths, the ground-state atomic oxygen gives way to an excited atomic oxygen, which plays a particularly important role in the upper atmosphere.

Analytical techniques were developed and continuous-flow instruments devised for measuring the concentration of urea, creatine, creatinine, and calcium in primate urine. The instruments are miniaturized and lightweight and are suitable for flight use on such programs as the *Biosatellite* mission.

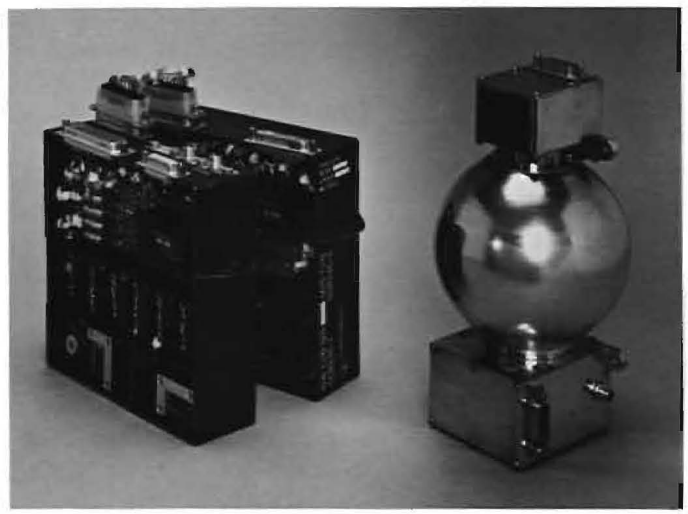
A high-resolution interferometric spectrometer was developed and used for Mars observations in the 1- to 3-micron region at Haute Provence Observatory during March–April, 1965. Preliminary results showed indications of producing accurate CO_2 pressure-broadening information which will be used to compute a new value for the Martian surface pressure.

Ultraviolet dayglow was measured on an Aerobee rocket flight and a second positive band of molecular nitrogen recorded. These bands resulted from bombardment by fast photoelectrons, and their intensity provided a means of measuring the flux of photoelectrons in the upper atmosphere.

Studies of the dynamics and thermodynamics of a superconductor rotating in a magnetic field were conducted within the framework of both the London equations and the equations governing the motion of an inviscid incompressible electron fluid.

A new formulation of general relativity in terms of operationally defined vectors and dyadics was developed; it was successfully applied to the problem of relativistic rigid motion, and appears to be very useful in formulating and solving a number of other basic questions of gravitation theory.*

*J. Math. Phys., Vol. 5, 1964, pp. 1629–44.



Mariner helium magnetometer

Mariner IV's cosmic-ray experiment was designed for the purpose of studying galactic cosmic rays and solar energetic particles in interplanetary space, and trapped radiation near Earth and Mars. The helium magnetometer used in this experiment was designed to measure fields near the boundary of the Earth's magnetosphere, in interplanetary space, and in the vicinity of Mars.

The existence of new modes of instability for a hypersonic boundary layer was demonstrated theoretically. The properties of these new modes change differently with changes of heat-transfer rate through the boundary layer than do the properties of the previously known mode, so that the new theory might explain some features of the confusing experimental picture of hypersonic boundary-layer stability.

An electrostatic vibrating-diaphragm capacitor modulator was developed which has 1/13 the weight and 1/10 the volume of a comparable *Mariner II* unit. The unit survived sterilization and is expected to withstand 10,000-*g* shock testing.

An aerosol sampling system was developed for biological sample collection under Martian atmospheric pressure conditions. Mechanical sampling techniques were studied, and work was begun on the development of tech-

niques for physical and chemical analysis of soil samples both in lunar vacuum and Mars atmospheric conditions.

In the area of scientific instrument development, there were three major efforts outside of specific Project support: the Mars atmosphere gas chromatograph, the fluorometric urinalysis instrument for the *Biosatellite* program, and the x-ray diffractometer for the manned lunar mission.

The gas-chromatograph effort is of particular interest because of the technology being demonstrated. All of the critical instrument components survived 10,000-*g* shock testing. The unit was also designed and fabricated to survive sterilization. The specific instrument does not functionally meet all the requirements for a Mars experiment, but the demonstration of the high-*g* technology is necessary to permit consideration of this general class of instrument.

A breadboard of the urinalysis instrument was completed, and the engineering design of the prototype configuration was well underway by the end of FY '65. This experiment has extreme engineering interest because it provides an opportunity to demonstrate in actual practice a wide range of wet chemistry processes and components which can be invaluable in life-detection experiments on Mars.

Development work was begun on an *Apollo* x-ray diffractometer for use by astronauts on the lunar surface, as a follow-on to the earlier *Surveyor* x-ray diffractometer effort. In addition to designing a lightweight, rugged, and compact unit, an attempt will be made to integrate the x-ray tube and its associated high-voltage power supply.

Telecommunications

Improvements and developments in the area of deep-space communications made by the Telecommunications Division are discussed elsewhere in this Report. In addition, research was carried out in a number of other areas.

Design of a novel type of far-infrared maser was completed during the past year which will be the first to operate on a molecular transition in the pure rotation spectrum.

Millimeter-wave techniques were investigated for possible future deep-space communications. A modified 60-inch searchlight and associated radiometric equipment were used to observe the December 18, 1964, lunar eclipse. Results indicated that, to an accuracy of $\pm 6°K$, there was no observable variation in lunar temperature.

A low-data-rate telemetry system was designed for extremely long-range missions, in which the data rate must be reduced to compensate for the increased range. It operates on the principle of multiple-frequency shift keying and maximum-likelihood detection. The system features self-synchronization for both frequency and word timing.

Additional development work was done on a block-coded telemetry system that utilizes word detection instead of bit detection for the purpose of providing higher information rates over the same channel. The block-coded telemetry system is self-synchronizing, uses a comma-free code, and has a maximum data rate of 750 bits per second. It provides a theoretical improvement of 4½ decibels over the *Mariner IV* pulse-code-modulated telemetry system.

A very promising method of data compression for spacecraft application is offered by the use of quantiles. Quantiles are easily computable characteristics of any given probability distribution. For example, if 25% of a population are 5 feet tall or less, then 5 feet is the quantile of order ¼ (or quartile). In an experiment involving statistical data, it is often possible to transmit the appropriate quantiles instead of the data and achieve data-compression factors of 10^2 or 10^3. A small special-purpose machine for the computation of quantiles was built and demonstrated.

Theoretical work in the field of error-correcting codes resulted in a new development called the punctured cyclic coder. A demonstration model was designed which is applicable to the correction of bit errors that may occur over a wide assortment of transmission channels. Worldwide standard teletype channels such as those which tie the stations of the DSIF to the Pasadena control center were studied experimentally and found to have peculiar characteristics which did not fit any of the usual theoreti-

cal models. Therefore, a special-purpose error-correcting scheme was designed to improve communications over these channels.

Guidance and Control

The Guidance and Control Division is responsible for research and advanced development in the areas of spacecraft control, navigation, on-board guidance computation, and spacecraft power.

RESEARCH

Research in solid-state and physical electronics was increased during FY '65 to include work in the areas of semiconductors, thermoelectric films, photoconductive films, and nuclear magnetic resonance. In the past, existing materials were investigated and processed for various applications. It is now becoming possible to make materials with properties proscribed in advance, to understand why materials fail, and to predict the ultimate performance of materials for various applications. Investigations will be conducted in this area.

An experimental study was made of the electro-optical effect in barium titanate, in which the piezo-optic contribution was found to play a predominant part. Low-frequency oscillations of spontaneous origin occurring in cesium diodes were characterized experimentally and explained in terms of space-charge fluctuations. Laboratory tests of the cryogenic gyroscope demonstrated drift rates in the 1- to 15-degree-per-day range. Construction of a He^3 cryostat was completed, and experiments on the velocity and attenuation of sound waves in He^4 were initiated in the temperature range between 0.3 and 1°K.

SPACECRAFT CONTROL

The design concepts of a lunar and planetary horizon scanner (an instrument which can be used for sensing the local vertical of the Moon or a planet) were verified by testing performed in late 1964. In contrast to current horizon scanners, the new instrument is completely static and has no moving parts; hence, it is useful for long-life missions. The local vertical is obtained by establishing the horizon position at several points and processing this information. The horizon is determined by sensing the discontinuity of the self-emitted long-wavelength infrared energy (15 to 50 microns) between the planet and the space background.

Checking simulated earthlight intensities — Ranger Project

An effort culminated in FY '65 which increased the shock load-carrying capability of a single-axis gyroscope with a gas bearing spin motor. The ability of such gyros to survive shocks without damage to the motor and without drift performance degradation outside the specifications was increased from approximately 30 to 200 *g*. The approach taken on this development effort was to fabricate a very precise yet rugged holding fixture where variations of the gas bearing motor could be evaluated outside an actual gyroscope. This was an important development, considering the time and expense involved in

having to disassemble and reassemble gyroscopes each time a bearing modification was to be tested. The shock and vibration testing accomplished with the various test models pointed out the design areas that could be tailored for increased load-carrying capability. The gas bearing gyro can now be considered for use in spacecraft control systems.

COMPUTER DEVELOPMENT

Magnetic Logic Computer

A small general-purpose digital computer using magnetic elements for logic as well as for memory was designed, and a breadboard version put into operation. The computer is intended to perform guidance computations and the sequencing function on board a spacecraft.

An effort was made to minimize the use of semiconductors in the computer and to employ magnetics wherever possible in order to enhance reliability, reduce power consumption during the cruise mode, and minimize vulnerability to temporary power failure.

It should be noted that the extensive use of magnetics also permits this machine to serve as a sound basis for the development of a radiation-resistant computer. Future plans for this development include the consideration of flight packaging for the computer, the completion of an input/output system for interfacing with typical spacecraft systems, and the preparation of specific guidance programs to be used with it.

Guidance Computer Organization

An effort was made to improve reliability of spacecraft computers and sequencers for extended missions through use of special computer logical organization. Two of the major problems in the development of self-repairing machines are (1) the possibility of introducing so much extra equipment to perform diagnosis, switching, etc., that the probability of a large number of failures (more than the self-repair technique is capable of overcoming) becomes significant and (2) using a machine which may itself be in a partially failed state for diagnosis of failure.

Two techniques were under active study in this program. The first is the so-called triple-modular redundancy, wherein logical blocks in the computer are built in triplicate and their outputs voted. The result will be correct if no more than one of the three channels has failed. It was deemed that this technique was well enough understood in theory to justify building a test vehicle. A logical design was made of a sequencer functionally identical to that in the *Mariner IV* spacecraft, and a subset of this design will be constructed.

The second technique is more of a long-range effort aimed at the development of a self-repairing computer. In this technique, failures will be diagnosed both by use of a special error-detecting code and with limited special circuitry. The defective equipment will then be removed from the system and a new unit inserted by automatic switching. The switch itself must be fail-safe so that its own failure cannot prevent operation of the computer. It is also necessary to develop an error-proof control system in order to sequence the diagnosis and switching. Triple redundancy will be used to a limited extent in this part of the system. The fact that most of the computer is not triply redundant permits a large saving in power consumption, and fewer spares will be required. Not only may spares be shared by units to some extent, but it is also not necessary for two units to be working at all times in order to obtain a voted result.

Previous work on this program led to the development of a suitable special code for the diagnosis of and to the logical design of an arithmetic unit which will permit detection of a maximum number of errors. The error pattern produced in the output by a given failed component is of great importance in this detection procedure. The continuation of construction of the arithmetic unit, the design of a magnetic switch, and development of the control are planned for FY '66.

SPACECRAFT POWER

A solder-bond technique applicable to the fabrication of solar arrays was developed which eliminates the use of an adhesive for mounting the cells to their substrate. Material investigation produced a tungsten interconnecting piece that has many of the advantages of kovar, which was used on *Mariner Mars,* but has the added

Solar test of thermionic generator for space power

advantage of being nonmagnetic. These mounting techniques, combined with the use of other new elements, including 8-mil-thick solar cells and H-film substrate material, were utilized in a sample array of approximately 1 square foot and were evaluated for performance and environmental strength. Contract work was supported covering the structural, deployment, and fabrication aspects of very lightweight arrays.

Thermionic diode performance was improved during the past year from a current density of 17 to 22 watts per square centimeter and increased in efficiency from 9 to 12½%. Development work included the continued life testing of thermionic diodes; three diodes had lifetimes in excess of 6000 hours. Environmental testing of cold thermionic diodes to simulate launch conditions showed the diodes to be capable of withstanding 20-*g* vibration (sinusoidal) and 100-*g* shock (½-millisecond duration). Sunlight testing of thermionic generators confirmed these improvements.

Study of other elements of the thermionic system also continued, including the environmental tests of a 5-foot mirror and generator-supporting structure utilizing a dummy generator.

FUTURE ACTIVITIES

The present research and advanced development tasks of the Division will be continued during the next fiscal year, and two additional tasks will be initiated – a guidance and navigation system based on an electrostatically suspended gyroscope and a formal and intensified program of roving-vehicle motion control.

Engineering Mechanics

It is the responsibility of the Engineering Mechanics Division to develop and maintain proficiency in the professional discipline areas relating to materials, structures and dynamics, mechanisms, fluid mechanics, aerothermodynamics, temperature control, electronic packaging, and other environmental survival factors.

MATERIALS RESEARCH

The mechanical properties of single crystals of various materials have been studied by many investigators because of their simple structural and behavioral characteristics. Preliminary results of a study conducted at JPL indicated that macroscopic as-grown crystal rods of sodium chloride have more uniform, reproducible, and comprehensible mechanical properties than annealed, water-polished cleavages of the type usually studied. In addition, these crystal rods do not show the atmospheric embrittlement common to cleavage crystals, and they are not sensitive to the deformation rate. Until further data are available and a more complete analysis can be made, it is postulated that these unusual characteristics are due to the absence of artifacts, such as surface cracks, cleavage steps, dislocation loops, and localized areas of extensive deformation which result from the cleavage operation and which are not removed by annealing or careful polishing.

Measurements of thermoelectric power have been used as a means of characterizing the structure of materials. However, the relationship between thermoelectric power measurements and the defect structure is not clearly understood, and the presently available theory does not explain the experimental results. During the past year, the thermoelectric power of Cu–Al and Cu–Si alloys was determined from room temperature down to within a few degrees of absolute zero. Analysis of these data resulted in the separation of thermoelectric power into its two components, i.e., phonon drag and diffusion.

Investigations of the kinetics of the process by which carbons change into graphite when heated to high temperatures and of the correlation between structure and properties were continued. It was clearly established that for pyrolytic carbons and for conventional pitch-coke carbons, graphitization is a time-dependent process, not just a temperature-dependent process as had been assumed.

Techniques for producing ultra-high-purity MgO powder in a very small particle size were developed to the point where usable quantities of the material can be produced in the laboratory. Hot-pressing parameters were determined which will allow this material to be fabricated into high-density solid bodies of extremely fine grain size. It was found that these solid bodies do not show the sudden increase in thermal expansion, or bloating, that occurs in nearly all commercial grades of oxides when heated above 1800°C. The extremely high purity of the new material is proposed as the reason for this behavior.

TEMPERATURE CONTROL

An experimental technique of thermal scale modeling at steady state was demonstrated using a 0.43-scale model of the *Mariner IV* spacecraft. The so-called temperature-preservation approach was used in that the model was designed so that temperatures at homologous locations in model and prototype were identical. The model was tested under solar simulation, and tests which corresponded to *Mariner IV* in Earth-cruise, Mars-cruise, and TV-picture-playback (post-Mars-flyby) modes were conducted.

The absorptivity standard, an instrument which measures the absorptance of solar radiation and determines property degradation with time, is being flown on *Mariner IV*. The spacecraft surface is treated with an ultraviolet-resistant white paint, a black paint, an aluminum silicon paint, and polished aluminum. The most unexpected result of the experiment is that the degradation of the white paint is proceeding almost ten times as rapidly as predicted by laboratory UV testing. This is believed to be due to solar-wind proton bombardment.

AEROTHERMODYNAMICS

Recent investigations of Mars have indicated the possibility of the presence of significant amounts of argon in the Martian atmosphere. Previously, the atmosphere had been assumed to be principally carbon dioxide and nitrogen. Detection of the pressure of a monatomic gas, which would increase the temperature and ionization level encountered during planetary aerodynamic entry, stimulated the investigation of the effect of argon on heat transfer.

High-temperature thermionic converter test

A theoretical study of high-temperature radiative heat transfer in mixtures of carbon dioxide, nitrogen, and argon was performed. The results of this study indicated that the increase in temperature resulting from the presence of argon shifts the dominant radiation region to lower entry velocities but does not strongly affect the magnitude of the radiation.

To determine the influence of argon upon stagnation-point convective heat transfer, a series of experiments were conducted in the JPL Hypersonic Shock Tube Facility. Data from these experiments indicated that higher convective heating rates occur in atmospheres containing a sizable concentration of argon.

STRUCTURES AND DYNAMICS

During the past year, the structural-analysis-system computer program was developed into an operational program suitable for analysis of frame, truss, plate, and shell structures. Structural idealization is automated in the program and is based upon the direct stiffness method. In order to apply this method accurately to shell elements, a rational force-averaging technique for stress prediction was developed.

An extensive experimental program was initiated to evaluate the crushing strength of balsa wood under conditions of high vacuum, heat (300°F), cold (−100°F), and relative humidity (0 to 14%). According to the limited test data obtained to date, balsa wood of one density shows degradation in energy-dissipating capacity when tested in a vacuum environment at ambient temperature. This experimental program directly supports capsule designs using balsa wood for impact protection.

HIGH-IMPACT TECHNOLOGY

It is the intent of the high-impact technology program to develop the technology necessary to produce spacecraft-type equipment capable of surviving high impacts (10,000 *g* for a few milliseconds). The following is a summary of some of the past year's accomplishments in the high-impact technology program.

An average of 40 tests per month were performed in conjunction with the high-impact technology program. In the majority of cases, the test specimen was accelerated to the impact speed and then decelerated by penetration of a crushable material. The three test facilities in use are a 40-foot drop tower, a bungee-powered catapult, and a 6-inch-diameter compressed-air gun, capable of accelerating specimens to 50, 200, and 500 feet per second, respectively. The catapult is the most widely used of the facilities, since it provides impacts of the desired magnitude with reasonable energy content. A 10,000-*g* average impact from 200 feet per second will last approximately 0.6 milliseconds. The air gun provides longer shock pulses and is used to represent the most severe case likely to be encountered during a Mars impact. The terminal speed of a typical aerodynamic entry body in free fall would be approximately 500 feet per second. A 22-inch-diameter compressed-air gun under development will provide the capability of accelerating several hundred pounds of weight to a velocity of 500 feet per second.

10,000-g impact testing of an S-band transmitter designed to survive planetary impact

A breadboard of a Mars atmospheric gas chromatograph completed in FY '65 underwent further development to make it into an impact-resistant instrument. The completed unit will occupy a volume of $4 \times 4 \times 7$ inches, weigh approximately 8 pounds, and be capable of surviving a 10,000-*g* impact.

A ruggedized 3-watt solid-state S-band transmitter was designed in cooperation with the Telecommunications Division. The completed transmitter will consist of three units of approximately $1 \times 2 \times 4$ inches and will weigh about 2 pounds. Development work was begun on a high-impact crystal which is mechanically restrained so as to be free to vibrate but not break under impact deflections. This crystal will be sterilizable and capable of surviving 10,000 *g*.

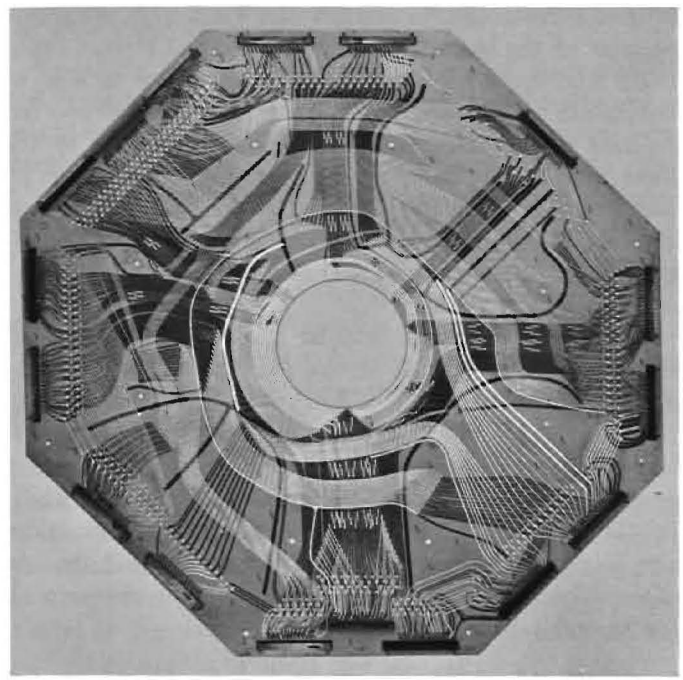
An investigation of the behavior of batteries under impact was carried on in conjunction with the Guidance and Control Division. Both silver–zinc and silver–cadmium cells were investigated for adequacy of internal structure. Cells in both the charged and uncharged stage were potted into a rigid aluminum fixture which supported the cell wall. The cells were of the size range usable in a spacecraft and utilized conventional parallel plates. The investigation will be continued in FY '66.

The behavior of mechanical components under high impact was investigated. Various bearings, gears, and mechanical devices were subjected to the high-impact environment and ruggedized.

LOW-STRESS ENCAPSULATION TECHNIQUE

Accepted procedures of encapsulating electronic components with rigid resin systems have, in many cases, exposed such components to compressive stresses of several thousand pounds per square inch. Diodes encased in glass can be crushed by such pressure generated in the encapsulating system at very low temperatures.

Advanced measurement systems were designed to monitor the pressures applied to glass components by various resin systems. These stress measurement techniques support the development of improved encapsulation systems which reduce the stresses on components, thereby increasing the reliability potential for future spacecraft.



Mariner printed conductor board

PRINTED CONDUCTOR SUBSTITUTION FOR A COMPLEX CABLE HARNESS

Replacement of the complex wire cable ring harness used in the *Mariner* by an etched printed conductor board appeared to have promising possibilities. A board, together with suitable jumper cables, was fabricated and mounted on top of the trough of the proof-test model for evaluation and comparison of the two types of harnesses.

In 95% of the circuits, it was found that the noise level was less for the printed board than for the conventional harness with its shielded and twisted wire. In the remaining 5%, the noise level was somewhat higher but still well within the specification limit for that particular circuit. From an electrical performance standpoint, the printed board is considered a flight-quality item.

INTEGRATED-CIRCUIT PACKAGING

Integrated-circuit devices, which were developed as products of microminiaturization programs, are being

utilized increasingly in satellite and spacecraft programs because of the potential gain in individual circuit reliability and in system reliability. The latter is due to redundant subsystem functions made possible by the reduced power, volume, and weight requirements of the integrated-circuit devices. However, the development of packing techniques has not kept pace. As a result, few existing packaging schemes suitable for spacecraft systems take full advantage of the integrated-circuit size and inherent reliability.

An integrated-circuit modular assembly was developed in FY '65 which satisfies all electronic packaging requirements for spacecraft to a marked degree. Some of its features are (1) the use of film-insulated wire for multilayer interconnections at the discrete module level; (2) nonmagnetic weldable and solderable terminals for high-reliability repairable interconnections; (3) minimum design and fabrication time requirements; and (4) the use of one-dimensional coplanar conductors (no crossovers) for assembly-level interconnections.

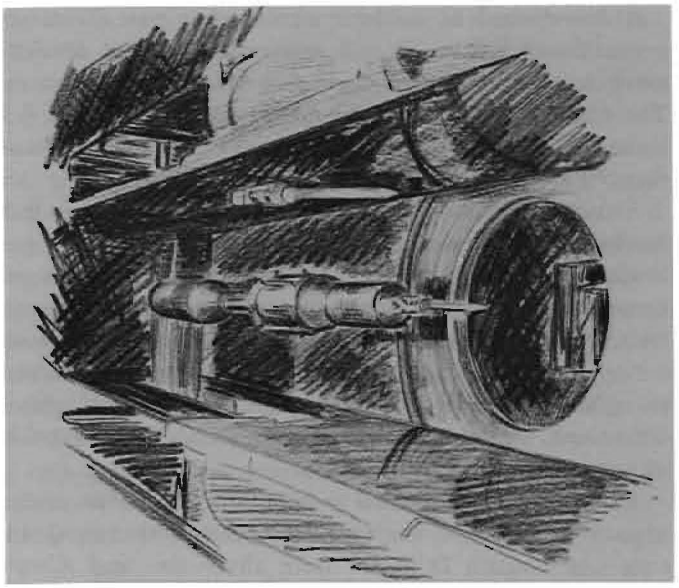
Engineering Facilities

The Engineering Facilities Division provides support to the Laboratory's programs through the development, operation, and management of environmental test laboratories, space-simulator facilities, aerodynamic facilities, and ground instrumentation and data-recording systems.

Two areas which received particular emphasis during the past year were the development of new aerothermodynamic testing techniques for high-speed wind tunnels and the development of a large, high-quality solar-simulation system for space-environment or surface simulation facilities.

AERODYNAMIC TESTING

Aerodynamic facility development was concerned primarily with the establishment of the hypervelocity laboratory and the subsequent instrumentation for obtaining gas properties, along with convective and radiative heating at enthalpy levels equivalent to expected planetary entry velocities. In order to extend the investigations of heating problems into the lower-density regions, work was done on the development of a large shock tube operated by a clean-gas free-piston driver. This low-density shock tube was in the final stages of shakedown operation by the end of FY '65.



Sting-mounted model of missile configuration in 21-inch hypersonic wind tunnel

Another important area under investigation was the distribution of heat transfer over the entire vehicle during planetary entry. Preliminary studies were made in the hypersonic wind tunnel at low flow enthalpies, and included the effects of various gas mixtures on heat-transfer distribution.

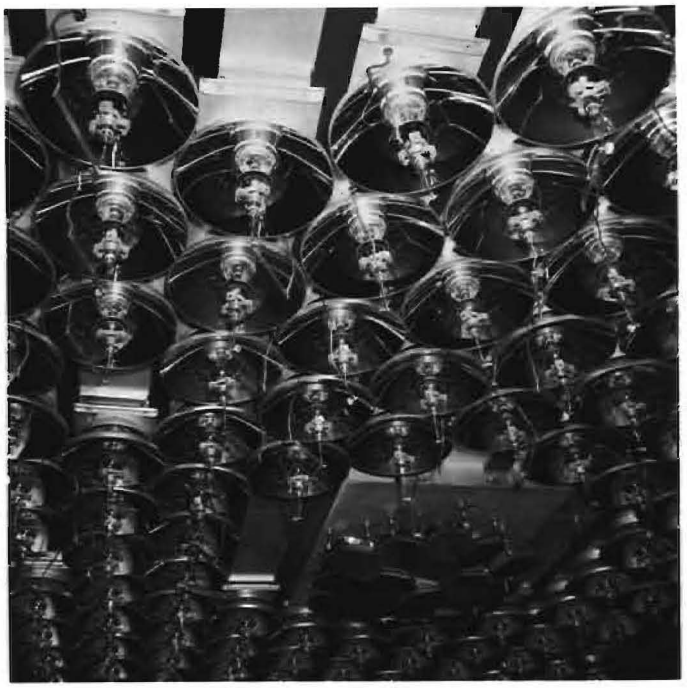
In order to accommodate the interference-free testing required for certain drag and stability studies in connection with investigations of model base (pressure and heating) and wake properties, a conventional wind tunnel was used for free-flight testing. Models were launched into their trajectories either by releasing them from a notched wire, or by propelling them against the airstream using a pneumatic piston arrangement. This testing method permits dynamic damping in pitch measurements at high angles of oscillation (up to 180 degrees) of blunt shapes having very low damping characteristics.

Studies of the effect of roll rate on pitch damping were initiated. As a complement to damping measurements of models using the free-flight technique, models mounted on a near-frictionless sting-supported gas bearing were used to obtain more extensive data and evaluate the effects, if any, of the support interference.

ENVIRONMENTAL SIMULATION

Solar simulation has been the subject of an intensive research and development project. The solar simulator constructed as a result of this effort provided either large beam-size or Venus-intensity (twice Earth) capability; collimation (±1 degree), producing high-fidelity shadows and low nonrealistic side lighting; and uniformity (±3%), giving the proper level of illumination to all parts of the spacecraft. The system employs a number of integrated sources of light, each contributing illumination to every point in the final beam. Therefore, different kinds, or colors, of light can be used to provide a mixture whose spectral characteristics are more "Sun-like" than those of a single source.

Xenon lamp array in solar dome of 25-foot space simulator



To verify the thermal characteristics of spacecraft in the space environment, testing under high-fidelity simulation conditions is mandatory. A new facility for conducting such tests was completed in April 1965. The 10-foot space simulator, which has an 8-foot-diameter solar simulator, will be used to test the *Surveyor* spacecraft in FY '66.

A modification to the existing 25-foot space simulator was designed which will provide the increased capability necessary for testing the *Surveyor* science lander under both flight and post-landing thermal conditions in the Fall of 1966.

PREVIEW

Among the new developments planned for the future is the construction of multi-shaker mechanic and acoustic vibration-testing capabilities to provide better controlled environments and to accommodate large vehicles. Another future project is the development of a lunar-surface thermal simulator to provide a post-landing-condition thermal testing capability in the 25-foot space simulator.

In addition, the construction of a number of new technical facilities is planned, including a launch-environment simulator; a Mars surface simulator; an assembly, test, and sterilization facility; a 20-foot solar simulator and albedo simulator systems for the 25-foot space simulator; and a post-injection test facility.

Propulsion

The Propulsion Division carries on a continuing broad-based research and advanced development program in solid-propellant, liquid-propellant, nuclear-electric, and solar-electric propulsion, ranging from basic studies in fluid physics and polymer chemistry to feasibility demonstrations and preflight development of prototype spacecraft propulsion systems. Summaries of some of the more significant accomplishments of the past year follow.

POLYMER RESEARCH

One of the major achievements in the field of polymer research was the development of a theory of tensile

strength which successfully describes the breaking properties over wide ranges in temperature of all unfilled amorphous rubbers studied to date at JPL or reported in the literature. Only two parameters are required, one characteristic of the polymer and determined by its chemical structures, and the second determined by the amount of curing agent added.

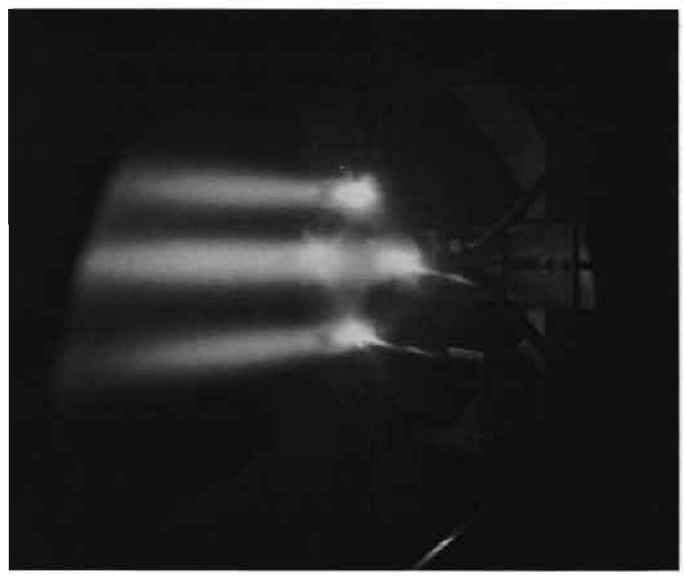
Studies made at small deformations proved that the simple theories heretofore applied to describe rubber-like elasticity are invalid. We do not yet have a molecular explanation for this experimental fact.

As part of the Laboratory program on sterilization, more than 160 materials were subjected to type-approval tests and more than 75 to the full three-cycle, 36-hour-per-cycle thermal sterilization. The accompanying changes in mechanical properties were measured, a unique computerized data logging and retrieval system was set up, and an extensive report was published on progress to date.

Semiconductor behavior in organic solids was investigated, with the ultimate goal of wedding the electrical properties of transistors with the fabricability of plastics. In one study, a high-molecular-weight material was compared to a low-molecular-weight analog which was a poor semiconductor. The simple act of joining the small molecule segments together into a large molecule enhanced the conductivity by a factor of roughly 1000. Even though the resistance of the best material was still too high, this type of structural variation is impossible with conventional semiconductors but very straightforward for polymers.

FLUID PHYSICS RESEARCH

The plasma-flow research program of FY '65 concentrated on the measurement of electron diffusion rates and electron–ion recombination rates at moderate pressures with argon. These rate processes are vital to plasma containment in devices such as MHD power generators and accelerators, both of which are of potential significance to nuclear-powered spacecraft. In addition, the effects of injecting heavy-molecular gases into the boundary layers and wakes of bodies under re-entry flight conditions were investigated as a means of preventing communications blackout upon re-entry. Several promising injectants were found. Other plasma investigations included the plasma physics and fluid dynamic details of the flow field in the free jet of an extremely high-enthalpy self-accelerated arc, and the heat transfer from partially ionized argon to cooled electrodes, nozzles, and diffusers.



Array of four plasma accelerators discharging free jets of ionized argon at temperatures in excess of 20,000°K and velocities of over 20,000 meters per second

Continuing research on the heat transfer from high-temperature, rapidly accelerating turbulent boundary layers in nozzles showed experimental results to be in substantial agreement with theory, based on solutions of the integral momentum and energy equations. An exception to this agreement, however, was encountered in a low-Reynolds-number region, where fully turbulent boundary layers under severe acceleration and cooling tended to undergo a transition back toward a laminar state.

LIQUID-METAL POWER CONVERSION

Progress was made in the direction of experimentally demonstrating the feasibility of the liquid-metal magnetohydrodynamic power-generation concept. All of the

critical components of this two-phase, two-component Rankine cycle system have now been demonstrated in nitrogen–water tests to perform acceptably close to theoretical prediction. Several of the components were also tested with a cold liquid metal, the sodium-potassium eutectic, and again were found to perform as anticipated. Construction of a hot test facility in which 2000°F lithium and cesium vapor will be used was initiated; the facility will be in operation in FY '66.

A liquid-metal test loop for 2000°F lithium and boiling potassium was nearly completed. The loop will be used to investigate the system dynamics of a turbo-alternator, boiler, radiating condenser system and the stability of boiling potassium. Other efforts directed toward the analysis of thermionic reactors uncovered a potentially serious stability problem, which will be the subject of future investigations.

ADVANCED PROPULSION STUDIES

A detailed study was made of the feasibility of a solar-powered electrically propelled spacecraft for mid-1970 missions to Mars. Preliminary results of the study indicated that current state-of-the-art technology in each of the relevant areas is sufficient to permit the development of a solar-powered electrically propelled spacecraft which would offer modest payload improvement over comparably sized chemically propelled spacecraft. For missions more energetic than the 1970 Mars flight, the payload improvement is anticipated to become quite substantial.

LIQUID-PROPELLANT COMBUSTION RESEARCH

The liquid-propellant combustion research effort was directed toward attaining predictable control of chemical energy release, of heat rejection to combustion-chamber boundaries, and of resonant oscillatory combustion.

A technique was devised for making quantitative measurements of the separation of streams of hypergolic liquids. The separation is due to rapid initial reactions, possibly in the liquid phase, that occur when the fuel and oxidizer first come into contact. It was found that a critical liquid-filament dimension exists, above which the separation is so complete that adequate mixing of the propellants and subsequent complete reaction are prevented. The effect of pressure level on this phenomenon will be investigated next. This work is yielding important parameters for the design of injectors for the hypergolic propellants, which include as a class most of the storable propellants of interest for long-duration Mars missions.

Insight was gained into the geometrical configuration and the physical characteristics of detonation-like waves that occur in resonant combustion through the use of very high-response pressure gages which are mounted on the boundaries of large (11- and 18-inch-diameter) reaction chambers. It was found that a single, nearly radial wave front sweeps around the chamber at several thousand revolutions per second. The intensity of the wave, which travels at a speed in excess of the speed of sound, decreases toward the center of the chamber and downstream in the chamber as one moves away from the vicinity of the initial reaction zone. Immense increases in heat transfer and erosion occur at the intersection of such waves with chamber boundaries, and it is this phenomenon that is believed to cause the sudden destruction, by resonant combustion, of large rocket engines.

It is hoped that the study of the critical physical and chemical reactions leading to the observed detonation-like waves will yield design parameters which will predictably preclude the occurrence of resonant combustion.

LIQUID/GAS REGULATOR

A simple one-stage, spring-loaded, pressure-balanced regulator was developed whose unique features include a ball and circular-seat regulating port, an all-metal sensing diaphragm supported by a metal flexure ring, and a Belleville spring assembly. All-metal construction makes the design amenable to use in heat-sterilizable propulsion systems and resistant to a wide variety of corrosive liquids or gases.

Successful applications of the concept were in the form of gas-pressure regulators in the *Ranger* Block III and *Mariner IV* midcourse propulsion systems. In FY '65, a regulator of this design was used to control the flow of liquid hydrazine to a monopropellant rocket motor. Hydrazine was supplied from a tank which contained both the propellant and the high-pressure pumping gas, separated

by a flexible impermeable bag. During operation, the gas expanded, supplying propellant to the regulator with progressively lower supply pressures. Advantages in design reliability and operational simplicity are expected to accrue from the reduction in the number of valves and seals of the liquid-regulation system, as compared with the separate gas supply and gas regulation used in the *Mariner* propulsion system.

PYROLYTIC-GRAPHITE ROCKET CHAMBERS

Pyrolytic graphite and various pyrolytic alloys offer the possibility of containing the highest-energy chemical reactions for sustained operation at temperatures approaching equilibrium flame temperatures. JPL provided pioneering support to the development of pyrolytic-graphite chamber technology, and fired the first one-piece rocket chamber made of this material in 1961. During 1965, long-duration (of the order of several minutes) firings of the smaller chambers tested earlier were conducted, and the first test of a 2000-pound-thrust chamber – the largest piece of free-standing pyrolytic graphite ever formed for this purpose – was successfully performed. During the tests, equilibrium temperatures in excess of 4000°F were sustained.

STERILIZABLE SOLID PROPELLANTS

Significant strides were made in the technology of solid propellants that will withstand sterilizing conditions. A technique was developed for bubbling a bactericidal gas such as ethylene oxide through the solid propellant during mixing. This technique will reduce, if not eliminate, the internal bacterial load of the cured propellant.

The problem of final sterilization of the complete rocket motor by heat was investigated, and two presently available propellant systems were identified that will withstand the sterilization temperature cycling: an ammonium perchlorate oxidizer/polybutadiene acrylic acid fuel system and an ammonium perchlorate oxidizer/polyesterstyrene fuel system.

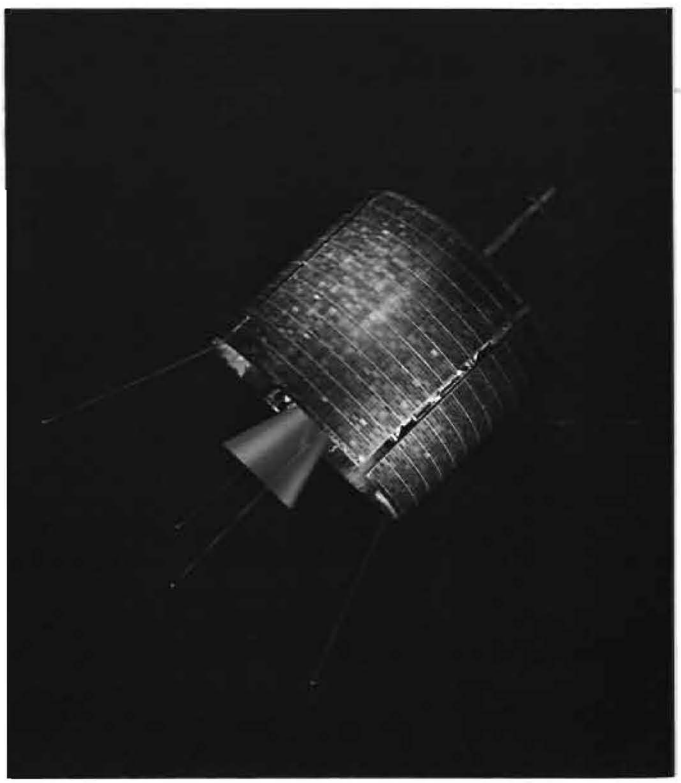
BERYLLIUM MOTOR TECHNOLOGY

The use of beryllium instead of aluminum as a fuel additive to solid propellant appreciably increases the specific impulse of the rocket motor and consequently permits a significant increase in useful payload for spacecraft. However, the effects of the high temperatures, erosiveness, and corrosiveness of the combustion products of berylliumized propellant on the rocket-motor chamber and nozzle present a serious problem. Early in 1965, three large rocket motors engineered to withstand these damaging effects were successfully test-fired.

SATELLITE KICK MOTORS

A solid-propellant "kick" motor fired at apogee, designed and developed by the Propulsion Division, was used in the successful orbiting of two communications satellites. *Syncom III* was placed into stationary orbit in August 1964, and the *Comsat* "Early Bird," a commercial version of *Syncom,* in April 1965.

Comsat "Early Bird" commercial communications satellite with JPL apogee motor



PREVIEW

The future program of the Division will continue to concentrate on the development of more efficient and reliable spacecraft propulsion systems. Work on nonchemical systems (nuclear-electric and solar-electric) will continue at a level consistent with the rate of growth of interest in extremely high-energy missions such as out-of-the-ecliptic shots and Mercury, Jupiter, or Saturn probes or orbiters.

Quality Assurance and Reliability

During FY '65, particularly strong efforts were made by the Parts Reliability Staff to ensure the readiness of standards for electronic piece parts to be used in planetary exploration during the next decade. Since electronic piece parts are essentially proprietary items standardized in the details of material, processing, and assembly by their manufacturers, emphasis was placed on the suitability of such parts for thermal sterilization after manufacture. The tendency of elevated temperatures to cause material migration and, particularly, the embrittlement of plastic materials, raises serious questions as to the reliability of electronic piece parts which have been thermally sterilized. Progress was made during the year toward the establishment of a list of electronic piece parts apparently capable of reliable performance after thermal sterilization.

Incipient failure is the most difficult physical condition to evaluate by test. Therefore, JPL parts-reliability technology is based on exhaustive failure-analysis methods. During FY '65, an x-ray and TV radiographic system was acquired for the purpose of detecting failures without the need for dissection of the parts to be examined.

Other Activities

Support of the Laboratory in terms of maintaining sound relationships with various government agencies, private industry, local political entities, and the general public, and the implementation of California Institute of Technology policies and procedures is the function of the supporting services. In addition, the supporting groups serve in an advisory capacity to the senior management of the Laboratory, recommending and assisting in the formulation and administration of plans, policies, and procedures.

Information Programs

The major activities of the news service staff of the Office of Public Education and Information in FY '65 were concerned with the flight missions of *Rangers VII, VIII*, and *IX* and *Mariners III* and *IV*. During each of these missions, the news service staff handled arrangements for coverage of the events by the news media.

For each of the flight missions, a detailed kit was prepared for use by the press. News releases were generated during the missions and at the end of each flight, including photographs in the case of *Ranger*. In addition, news releases were prepared for the subcontractors and assisting subcontractors for each mission, providing pertinent information for their use.

Throughout the past year, programs of an educational nature continued in support of three traditional areas: the Laboratory's general efforts in public information, the series of educational programs sponsored by NASA's Western Operations Office, and the programs promoted by NASA Headquarters' Division of Educational Programs and Division of Special Activities. Educational information in the form of booklets, brochures, photographs, slides, and other material was furnished directly to over 500 junior and senior high school libraries within Los Angeles County.

A Speakers' Bureau, consisting of some 40 to 50 engineers, scientists, and staff members who speak before civic groups, school classes, service clubs, and other organizations, filled a total of 304 requested engagements during FY '65. Seventy-six tours were conducted, giving 3310 persons a first-hand view of the Laboratory, a significant increase over the previous year's total of 41 tours and 1955 visitors.

Patents and New Technology

The Office of Patents and New Technology was established near the end of the fiscal year to represent the California Institute of Technology and discharge its contractual obligations to NASA in the fields of new technology, patents, copyrights, and other matters involving proprietary rights in technical data. This new Office, which includes the former Patent Group, reports to the Deputy Director of the Laboratory and is managed by the JPL Patent Counsel (a newly created staff function). During FY '65, 173 items of new technology were submitted to NASA, and assistance was rendered to NASA in the preparation of 48 patent applications and 37 amendments to the 113 pending JPL-originated applications already on file in the Patent Office. Forty-eight abstracts on patentable items of new technology were prepared for presentation to the Inventions and Contributions Board, and three awards were made by NASA to JPL employee-inventors. In addition, 288 subcontracts of JPL were reviewed for compliance with requirements of their respective new technology clauses, and 567 requests from industry and laymen for additional data on publicized items of new technology were answered.

Arms Control Study Group

The Arms Control Study Group (ACSG) was established at the Laboratory in May 1962, in response to a request from the U.S. Arms Control and Disarmament Agency (ACDA) for assistance of primarily a technical nature. The ACSG is responsible for providing information to the Laboratory, to NASA, and to ACDA on matters affecting the relationship between space technology and plans for arms control and disarmament. The ACSG contact at NASA Headquarters is the Office of Policy Planning.

To fulfill its responsibility during the fiscal year, the ACSG undertook appropriate studies of arms control and disarmament problems, analyzed those aspects of space technology likely to interact with arms control and dis-

armament plans, consulted with other groups and individuals at the Laboratory for support, acted as a consultative group to ACDA, and provided a technical link between ACDA and NASA.

Procurement

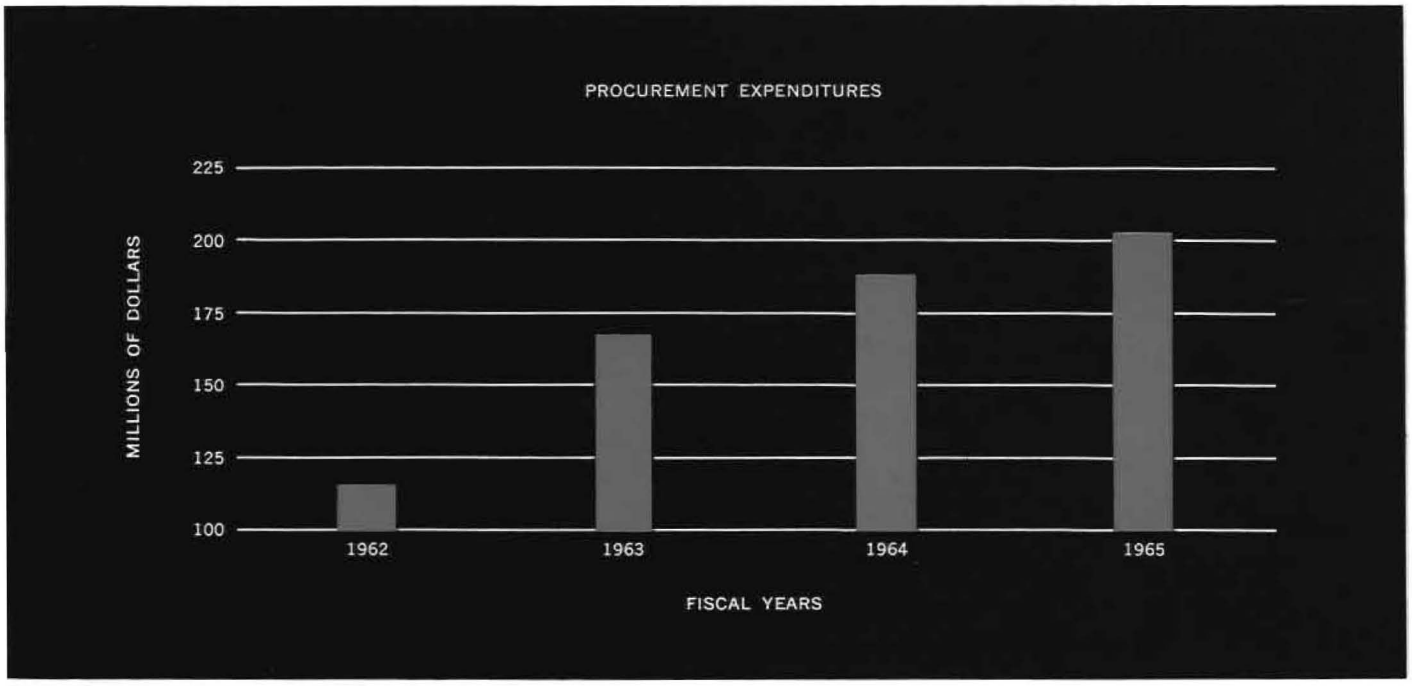
Among the procurement activities carried out during FY '65, the following are worthy of specific mention. The *Surveyor* contract with Hughes Aircraft Company was the subject of practically continuous negotiations. Phase 1A of the *Voyager* contract was activated, and effort was expended in the development of new procurement material leading to follow-on *Voyager* Project phases. A program was instituted to upgrade Deep Space Network antennas and to provide additional antennas in Australia and Spain.

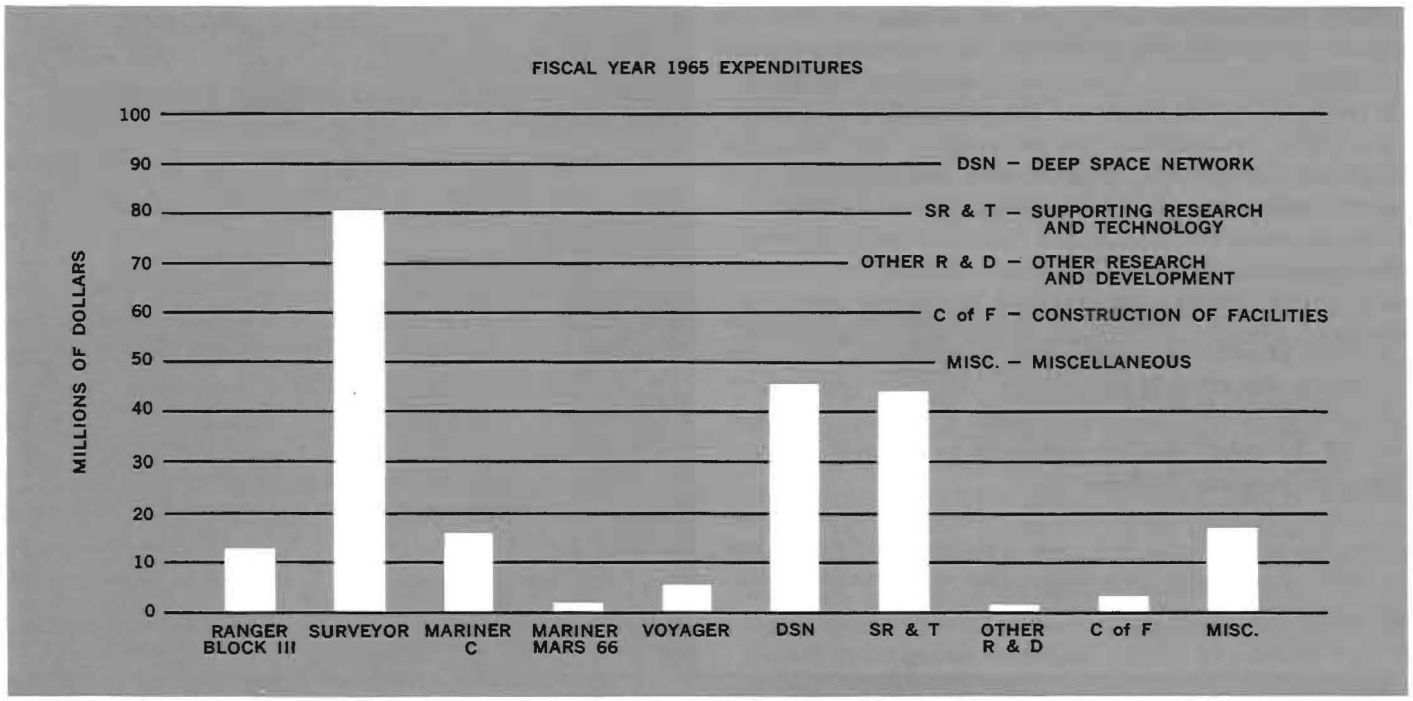
Following an intensive study, new procedures and policies were developed during the year describing the procurement operations of the Laboratory. To familiarize the personnel concerned with the new policies, a procurement information session, followed by a procurement management seminar, was offered to all group supervisors and cognizant engineers in the technical divisions and project offices.

Financial Management

The Financial Management Division consists of four Sections: Accounting, Financial Planning, Business Services, and Cost and Price Analysis. They accumulate and coordinate the Laboratory Financial Operating Plan, exercise funds control, audit costs, prepare and analyze the Laboratory Financial Reports, operate the business computer, provide business systems and procedures, review supplier proposals for possible price reduction, and handle travel reservations.

During FY '65, a number of major systems improvements were accomplished. A cost-accounting system was developed for supporting services; accounting controls were established over property and stores; a subsidiary accounting system for asset and liability statements was





installed; a system for timekeeping and labor accounting for subcontract employees was developed; the Financial Activity Report was automated and improved; and a capability for forecasting administrative operations costs was developed.

Cost Reduction Program

The CIT/JPL Cost Reduction Program was formally initiated in 1964 in response to a letter from President Johnson, in which he called for an affirmative program of cost reduction in the performance of space programs.

To implement the Cost Reduction Program at the Laboratory, a Cost Reduction Office was organized, headed by a Special Assistant for Cost Reduction reporting directly to the Deputy Director. By the second quarter of FY '65, formulation of the Program and communication of its requirements to the JPL management organization were essentially completed, and a cost reduction goal of $3,500,000 was established for the fiscal year. The Program, which, contrary to general practice, proposed to report only savings that had been achieved and verified, was formally approved by the NASA Cost Reduction Board in June, 1965.

For the six-month period ending June 30, 1965, 79 instances of cost reductions and cost avoidances were reported. The major areas included were salaries and wages; materials and supplies; equipment, tools, and furniture; construction of facilities; rental and services; travel and moving; and communication and utilities. The total savings achieved (less the costs incurred in administering the Program) were $4,207,817 for the six-month period reported. Savings for the entire fiscal year of 1965 were $6,595,943, exceeding the goal set for the year of $3,500,000 by 88%.

The Cost Reduction Office is planning to continue to implement and broaden the scope of the JPL Cost Reduction Program. Among other activities directed toward this end, the Office will make an investigation of em-

ployee motivational factors in an attempt to increase participation and will undertake an extensive publicity program within the Laboratory, including recognition given to individual employees for outstanding cost reduction ideas. In addition, the exchange of cost reduction methods among JPL, other NASA organizations, and contractors will be encouraged.

Personnel

In FY '65, the Personnel Section emphasized reduction-in-force procedures rather than recruitment. Increased attention was given to employee development, particularly in the field of technical management. Programs were also set up for indoctrinating employees to the new procurement policies and procedures.

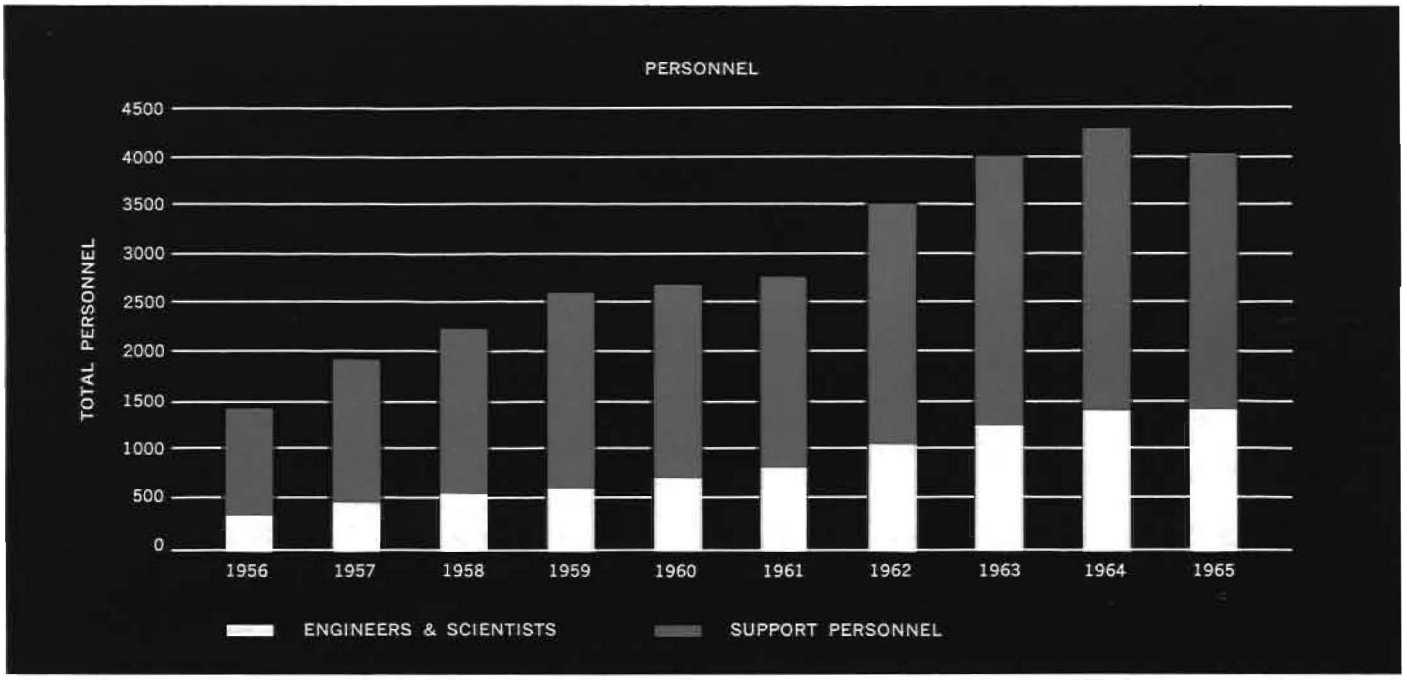
A new disability insurance (income continuation) plan was put into effect, and the Teachers Insurance and Annuity Association retirement plan was broadened during the year.

CUCOSS

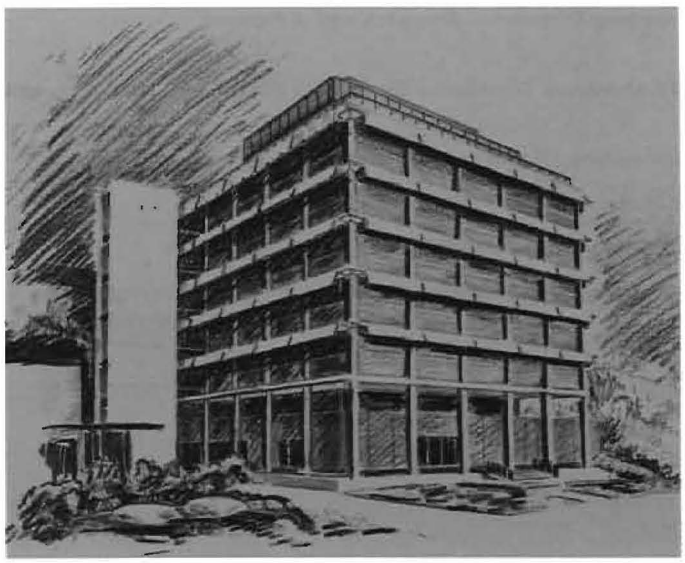
The California Universities Council on the Space Sciences (CUCOSS) was established in December 1961 to foster cooperation among its member institutions: University of California at Berkeley, University of California at Los Angeles, University of California at San Diego, University of Southern California, Stanford University, and the California Institute of Technology.

During the first several years of its existence, CUCOSS was of considerable value to the member organizations, as they were just beginning to develop their own programs in the space sciences and needed guidance in selecting courses appropriate to the very rapidly changing technical environment.

However, all of the university members now have well established space programs, and there is no further need for the formal organization of the Council. After discussion with the members and with NASA, it was unanimously agreed that CUCOSS should disband.



Newly completed 10-foot space simulator
BELOW: *New Telecommunications Building*



In order to provide a focal point for questions concerning JPL–university relationships, a University Liaison Office has been established.

Facilities

During the past year, several new facilities were added to the JPL physical plant. These structures include two new office and laboratory buildings, a new space simulator, several specialized laboratory buildings, modifications to existing structures, and general utilities. Negotiations were completed to retain Albert C. Martin and Associates as master planners for JPL.

Among the new support facilities is Building 169, a 40,000-square-foot office and laboratory building, completed in February 1965, housing the major elements of the *Surveyor* Project office. Building 238 is the new 76,000 square-foot facility in which the majority of the offices and laboratories of the Telecommunications Division are located. A 21,000-square-foot addition to the Space Flight Operation Facility was completed which will permit development of a four-mission capability. Significant additions were also made to the antenna laboratory, materials research processing laboratory, and environmental laboratory. An inertial test laboratory facility, a spectroscopy laboratory, and a materials research laboratory will be completed shortly.

A new 10-foot space simulator was constructed this year, and extensive modifications were begun on the 25-foot space simulator. Conceptual plans have been developed for the facilities required by the *Voyager* Project. An experimental assembly and sterilization laboratory was completed which provides an exceptionally clean area for exploring further the problems related to sterilization of spacecraft.

Several large utility projects were completed in FY '65, including a 600,000-gallon water-storage tank, a new hillside parking lot which accommodates 275 cars, and additions to two existing parking areas. Plans were completed and approved for the relocation of the heliport to provide a more adequate and safer airport facility. Construction work on the heliport will be completed before the end of 1965.

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PHOTO CREDITS: *General Dynamics/Astronautics, p. 12; Hughes Aircraft Company, pp. 9, 10, 11.*

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