[COMMITTEE PRINT]

PROJECT SURVEYOR

REPORT

OF THE

SUBCOMMITTEE ON NASA OVERSIGHT

OF THE

COMMITTEE ON SCIENCE AND ASTRONAUTICS

U.S. HOUSE OF REPRESENTATIVES

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LETTER OF TRANSMITTAL

House of Representatives,
Committee on Science and Astronautics,
Washington, D.C., October 8, 1965.

Hon. George P. Miller,
Chairman, Committee on Science and Astronautics.
Hon. Olin E. Teague,
Chairman, Subcommittee on NASA Oversight.

Gentlemen: I am forwarding to you herewith for committee consideration a report entitled "Project Surveyor." This report is based upon information developed during a 2-day on-site inspection of the Surveyor project at the Jet Propulsion Laboratory, Pasadena, Calif., and the Hughes Aircraft Co. plant, Culver City, Calif., on September 2 and 3, 1965.

Sincerely yours,

Joseph E. Karth,
Chairman, Surveyor Panel,
Subcommittee on NASA Oversight.

CONTENTS

PROJECT SURVEYOR

INTRODUCTION

As Earth's closest celestial neighbor, the Moon has been the subject of much serious study, and at least as much superstitious conjecture, for centuries. In modern times, the scientific knowledge that man has acquired about the Moon is very substantial. Like science in other fields, however, the more that is known and understood, the greater is our appreciation of how much remains a secret, and man's desire for still more knowledge is correspondingly stimulated. The point in history has now been reached when instruments, and soon men themselves, can be sent to the Moon to explore. Many mysteries of the ages soon will yield to newly acquired understanding.

As has been noted in earlier reports by the Committee on Science and Astronautics, the Moon is the object of great interest from a scientific point of view because, since it has no atmosphere, its surface has not been subjected to the erosion of winds and water. Therefore, except for the effects of impacting meteors, its surface, its physical and chemical properties, and its composition and structure have probably remained essentially the same for the billions of years of the Moon's existence. The scientists engaged in NASA's lunar exploration program point out that on the Moon, therefore, there may be preserved the only reasonably accessible natural record of the early history of the solar system, a record long since erased by the atmosphere of the Earth. Defining the characteristics and properties of the Moon should help to unlock the secrets of the formation of the solar system, and throw considerable light on the history of the Earth-Moon relationship.

For these reasons, one of the first formal programs undertaken by the National Aeronautics and Space Administration following its establishment in 1958 was the *unmanned* lunar exploration program. This program consists of three separate projects: Ranger, Surveyor, and Lunar Orbiter.

The recently completed Ranger project successfully returned thousands of high-resolution television pictures of the lunar surface as each of the last three spacecraft approached the Moon; the pictures were transmitted during the final few minutes of the mission, up to the moment of impact. Astronomers have described the results of the Ranger missions as a great scientific achievement, and as the most significant contribution to their field of study in centuries.

Until the last three launches of Ranger spacecraft, the progress of scientific knowledge about the Moon had been quite gradual over the past 3½ centuries. Successive improvements in earthbound telescopes during that period resulted in the disclosure of more and more detail of the Moon's surface. The point had been reached where all features of any size—mountain ranges, craters, and mares—on the side of the Moon which constantly faces the Earth had been mapped and named. Furthermore, many earlier misconceptions had been resolved. For example, the large dark areas assumed by Galileo to be water were now clearly seen to be dry plains, though they'll undoubtedly always be known as "mares." The closeup Ranger pictures also disclosed that the floors of the mares are not nearly as smooth as had been assumed, but are pockmarked with small craters.

The progress of selenographic knowledge took an enormous stride forward with the success of the last three flights in the Ranger project. Ranger 7, launched July 28, 1964, transmitted 4,300 pictures of the Moon's surface back to Earth. Ranger 8, launched February 17, 1965, returned about 7,100 pictures; Ranger 9, launched March 21, 1965, sent back nearly 6,000 pictures.

The best of these pictures of the lunar surface are considered by experts to be about 1,000 times better than any that earthbound telescopes had ever provided. The higher resolution thus available showed details of the lunar surface never before seen by man. In fact, the final pictures transmitted by each Ranger spacecraft revealed relatively tiny features, such as craters only a few feet in diameter and a foot or so in depth.

While the extent of man's knowledge of the lunar surface has been greatly extended by the Ranger pictures, many questions about the nature of that surface continue to be unresolved. In fact, the Ranger pictures have been used by different people to support conflicting theories about the nature of the Moon's surface, and may even have given rise to some additional new theories. Thus, despite the excellence of the Ranger pictures, many controversies remain which are unlikely to be resolved until a successful Surveyor soft landing is accomplished, and data from such a mission is returned to Earth. Some questions about the Moon probably will not be answered until man makes a personal visit.

The program for the unmanned exploration of the Moon assumed a special urgency in March 1961 when President Kennedy announced our national objective of sending men to the Moon within this decade, and returning them safely to Earth. The scientific data expected from Ranger, Surveyor, and Lunar Orbiter is considered essential to a successful manned lunar landing program.

Ideally, design of the Apollo system should have been undertaken after successful missions of the unmanned projects, particularly Surveyor, had provided information regarding the bearing strength of the lunar surface, topographical variations, details on structure, and the size, shape, and uniformity of surface features from particles to large-scale rocklike objects which might be present.

Unfortunately, the early target date for the Apollo mission, together with schedule slippages encountered in the Surveyor project, have resulted in more or less concurrent development of these two projects. Development of the Lunar Excursion Module of the Apollo system is already well advanced. The LEM has been designed to accommodate a wide range of possible variations in the lunar surface; nevertheless, the design is based upon best current estimates of the nature, characteristics, and composition of the surface of the Moon, not upon sufficiently detailed knowledge. Should the information from Surveyor indicate that the LEM configuration might be unsatisfactory in any substantial respect, an expensive redesign would probably be necessary, and the Apollo schedule would almost certainly be delayed.

Still, Surveyor will afford an opportunity to confirm the adequacy of the current LEM design and, in any event, Surveyor is expected to furnish information regarding the lunar surface in advance of the first Apollo launch, without which the Apollo landing could not be undertaken with high confidence.

Thus, while it was originally conceived as a scientific undertaking, the primary objective of Surveyor is now considered to be support of Apollo. Surveyor is also viewed within NASA as complementary to Apollo in the sense that it may assist in site selection for the astronauts, and explore places on the Moon where a manned landing may not be feasible or practicable.

54-203 O—65——2

COMMITTEE INTEREST

The Surveyor project was conceived in 1960; as such, it was one of the earliest approved projects of the then newly established National Aeronautics and Space Administration. The Jet Propulsion Laboratory at Pasadena, Calif., was assigned project management responsibilities, and early in 1961 the Hughes Aircraft Co., Culver City, Calif., was selected as prime contractor for developing the spacecraft and its associated ground equipment.

A NASA press release, dated January 19, 1961, announced that the Surveyor project "is expected to cost upwards of $50 million." As then conceived, the program was to have included seven spacecraft, each of which would weigh approximately 2,500 pounds and be capable of placing over 200 pounds of scientific instruments on the lunar surface. All seven launches were to be accomplished during the 1963–66 period.

From the vantage point of autumn 1965, it is clear that the objectives set forth in the above-quoted NASA press release were overly ambitious to the point of being unattainable even under the most ideal circumstances. In view of the challenging nature of the Surveyor mission, well understood today, but little understood in 1961, it is not surprising that launch schedules have had to be revised, costs have increased, and payload capability has decreased.

In each of these three key areas, however, changes have been dramatic, more far-reaching than the most pessimistic of earlier estimates. The first launch has been delayed about 2½ years. Payload capability has diminished to the point that the first four spacecraft are now called "Engineering Test models," devoid of scientific instruments except for a single scanning television camera. Most remarkable is the increase in costs, which total nearly $350 million through the current fiscal year, exclusive of launch vehicle costs.

During a stormy 4½-year history marked by major design modifications, and reorganizations both at Hughes and JPL, the committee has been asked to authorize substantial increases in funds for Surveyor. Each year, NASA witnesses have explained the severe technical difficulties encountered by Surveyor. There have also been strong indications of serious management deficiencies. Both seem to have contributed to Surveyor's unfortunate record.

Expectations were unrealistically high at the beginning. Technical difficulties inherent in the mission were obviously underestimated. In large measure, this accounts for unanticipated costs and schedule delays. While everybody has been disappointed, those most closely associated with the program now speak with some degree of optimism about the forthcoming flights, the first of which is scheduled for the first quarter of 1966.

Surveyor already represents an investment by the American taxpayer of almost one-half billion dollars for the first 10 spacecraft, plus launch vehicles; the ultimate cost to completion of just this first part of the project is estimated to be approximately $725 million.

Figures are not readily available for the entire 17-flight program which has been planned by NASA.

The Government commitment to the Surveyor project is firm, not only by virtue of the large investment in this relatively mature program, but because of Surveyor's key role as support of Apollo. For these reasons, it was determined that a review of the project by the Subcommittee on NASA Oversight was appropriate at this time.

With the concurrence of Chairman George P. Miller, Congressman Olin E. Teague, chairman of the Subcommittee on NASA Oversight, appointed Congressman Joseph E. Karth to head a panel of Members to conduct an on-site inspection of the Surveyor project at the Jet Propulsion Laboratory and at the Hughes Aircraft Co. plant. One full day was spent with each organization in conference with top management officials and Surveyor project technical directors during the first week of September 1965.

DESCRIPTION OF SURVEYOR SPACECRAFT

The Surveyor spacecraft is a triangle-shaped aluminum structure that carries a variety of highly specialized electronic and mechanical assemblies. Surveyor is to be a "basic bus" capable of soft landing a variety of payloads on the lunar surface.

As for the physical details, the first four Surveyor spacecraft will weigh approximately 2,250 pounds, stand about 10 feet high, and within a circle about 14 feet across. The spacecraft has a triangular frame with a landing leg on each of the three corners. The spaceframe is constructed of aluminum alloy tubular members on which subsystems and scientific instruments are mounted. The tripod landing gear employs airplane-type shock struts. The center of gravity is kept low for landing stability.

A solid-propellant retrorocket engine fits within the center cavity of the frame, and supplies the main thrust for slowdown on approach to the Moon. A planar antenna and solar cell panel are mounted on a vertical mast at the top of the spacecraft. The telecommunications, flight control, and power supply units, as well as the payload items, are mounted in numerous packages around the frame to meet balance and operating requirements (see fig. 1, p. 7).

Two equipment compartments with heaters and superinsulation house the spacecraft electronics. The superinsulation consists of multiple layers of aluminized mylar. Internal temperature is maintained below 125° F., and above zero or 40° F. for the respective compartments. Mechanical thermal switches, actuated with bimetallic elements, control thermal conductivity through the top of each equipment compartment. On all spacecraft surfaces, highly selective finishes are used to maintain acceptable temperatures through proper absorption and emission characteristics.

The data link to Earth is a wideband telecommunications system employing two transmitters and two receivers for redundancy. The high-gain planar array antenna located on the spacecraft central mast is used primarily for television transmission. During transit, the receivers and transmitters can be operated in a coherent transponder mode for tracking. Ground commands for operation of the spacecraft and the scientific payload are implemented through a system of command decoders. Signal processors accept signals from the various sensors and instruments and convert them for modulation in the transmitters and relay to the deep-space stations.

The solar panel mounted on the spacecraft central mast is the primary source of electrical power during transit and the lunar day, supplying up to about 85 watts of power. Silver zinc batteries, rechargeable by the solar panel, are the source of power at night. Battery charging is normally automatic, although it may be ground commanded. A power management system converts, regulates, and switches the power as required by the various instruments and subsystems.

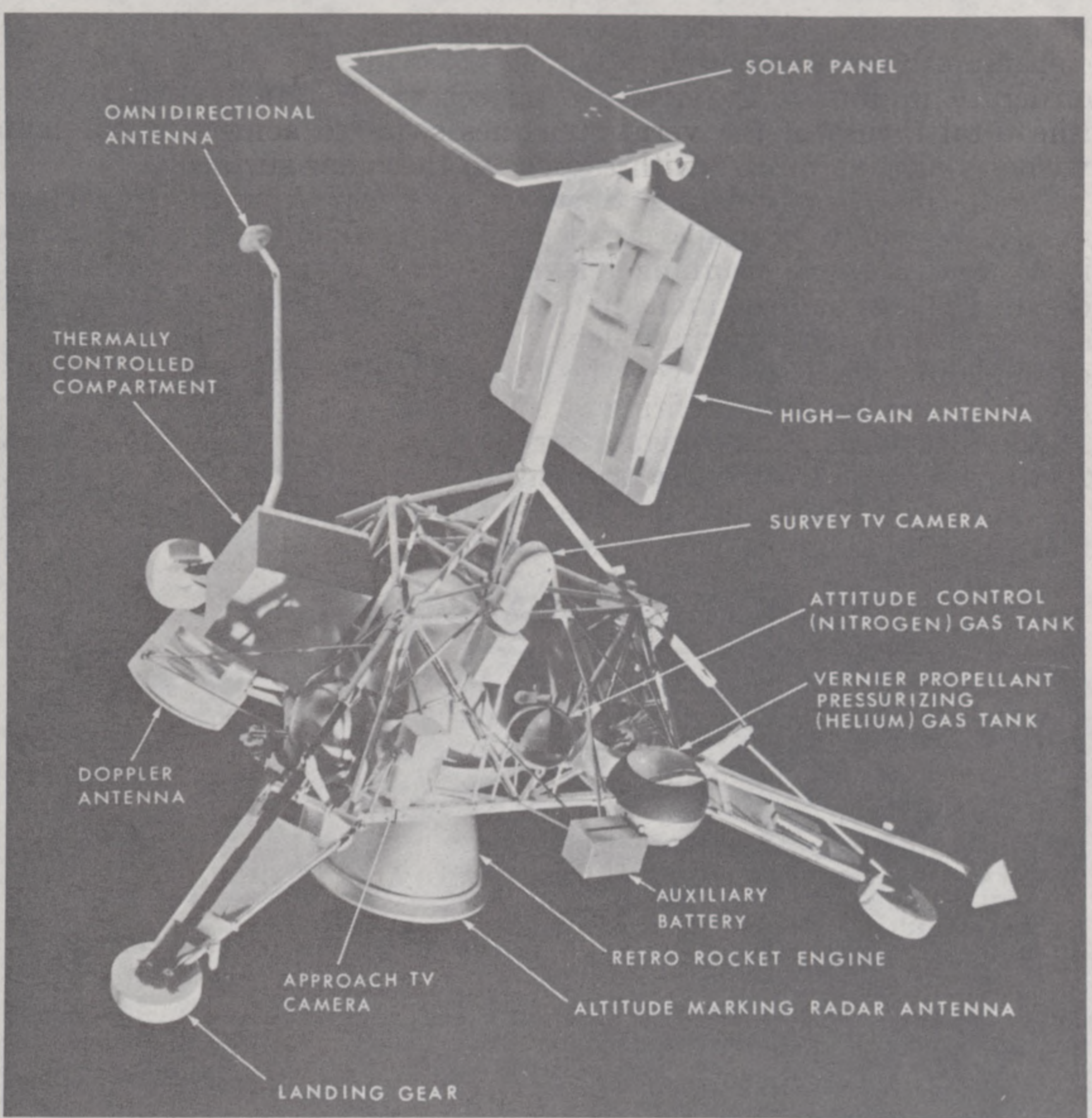

FIGURE 1

Two Sun sensors and a star sensor are used for attitude control of the spacecraft in its coast phases. An inertial reference unit is used in attitude control during retroengine operation.

The main retroengine employs a solid propellant in a spherical steel case. It uses a single submerged nozzle and a pyrogen igniter. The vernier propulsion system uses liquid propellants. Each of the three vernier thrust chambers can supply from 30 to 104 pounds of thrust on command; the system can provide about 50,000 pound-seconds impulse.

In addition to the main retrorocket, and the three controllable-thrust vernier engines, one of which swivels for roll control, the remaining guidance and control elements used to perform the critical landing sequences deserve special mention. These include the altitude-marking radar; the yaw, roll, and pitch gyros of the three-axis autopilot; the analog computer; three beams of doppler velocity radar; and the radar altimeter.

These elements form a highly sophisticated closed-loop automatic landing system which must perform with great precision the following critical functions simultaneously and compatibly: (*a*) It must sense the three components of the spacecraft's velocity relative to the Moon and differentially throttle the three vernier engines so as always to maintain precise alinement of the spacecraft's thrust axis with the continuously changing orientation of the resultant velocity vector, in order to produce a gravity-turn trajectory, and (*b*) it must control the total thrust of the vernier engines so as to achieve a particular velocity-altitude profile with respect to the lunar surface.

In the first four missions, Surveyor will carry engineering instruments to evaluate both spacecraft performance and landing characteristics, and a single scanning television camera which should secure detailed pictures of the immediate area in which it lands. There will also be a downward-looking television camera for in-flight observation of the landing area; however, this camera will be turned off at about 80 miles altitude prior to firing of the retrorocket.

The fifth, sixth, and seventh Surveyor spacecraft will weigh about 2,450 pounds and will carry a scientific instrument payload of about 114 pounds. Six major experiments will be carried by each of these first three Operational Surveyors (see fig. 2).

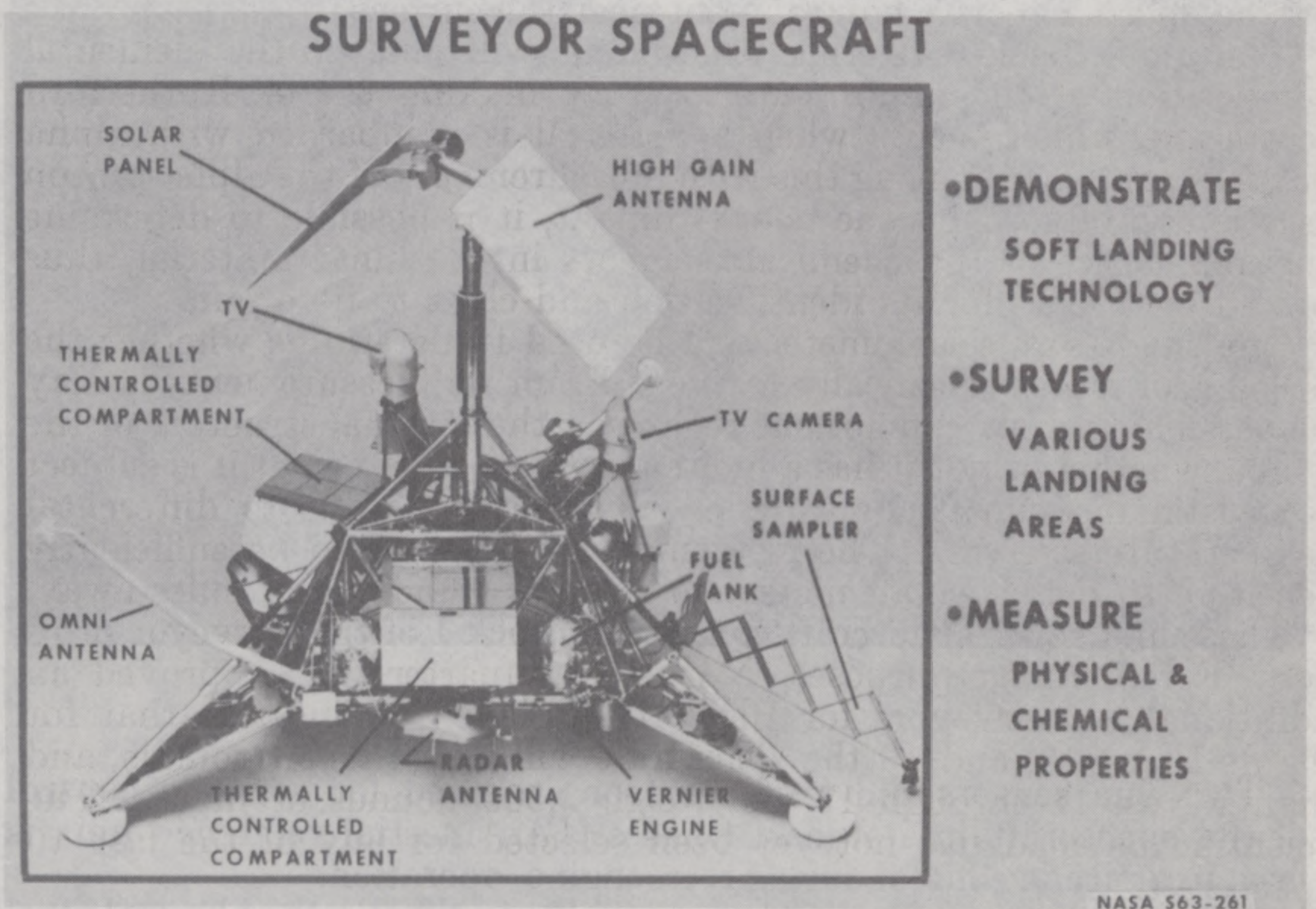

Figure 2

The television experiment contains a downward-looking camera for use during the approach to the Moon and two survey cameras for use on the lunar surface. The survey cameras have zoom lenses, color and polarization filters, and are controllable in elevation and in azimuth. They provide panoramic coverage of the lunar topography from above the horizon to close in to the spacecraft. They permit viewing the complete range of surface features down to the fine texture of the lunar soil.

The touchdown-dynamics experiment consists of strain gages, accelerometers, and rate gyros that are used to determine the motions of the spacecraft during the landing impact and the forces applied to the footpads of the landing gear. This experiment will permit determination of the achieved bearing strength of the lunar surface under dynamic conditions and at a scale directly applicable to Apollo.

The surface sampler is a pantograph mechanism for manipulating the lunar surface and subsurface material. It can dig a trench under the eyes of the television cameras to reveal the compaction, uniformity, texture, structure, angle of repose, and other physical properties of the material down to a depth of about 2 feet. It is instrumented with strain gages to provide quantitative data on the bearing and shear strength of this material. It also has accelerometers to permit its use as an impact penetrometer for dynamic measurements of the bearing strength.

The micrometeorite detector is designed to measure the flux momentum, energy, and mass of primary particles and secondary ejecta. Laboratory experiments have shown that, for each primary hypervelocity impact, up to 10,000 secondary particles may be ejected at speeds up to escape velocity, thus opening the possibility of a virtually continuous duststorm that could abrade optical surfaces or possibly puncture a space suit. This experiment should provide specific data on the micrometeorite environment near the surface.

The alpha back-scattering experiment will analyze the elemental composition of the lunar material. By making use of Rutherford scattering, which occurs when a material is bombarded with alpha particles, and augmenting this with measurements of the alpha-proton reactions produced by the bombardment, it is possible to determine the abundance of the chemical elements in the lunar material, thus providing a basis for its identification and clues to its origin.

The single-axis seismometer will be used to determine whether the Moon is or is not seismically active. From its measurements it may be possible to draw conclusions regarding the internal structure of the Moon, whether or not it has a molten core, whether or not it is subject to crustal movements or experiences dislocations due to differental temperature stresses. The instrument is expected to be sufficiently sensitive to detect small meteorite impacts hundreds of miles away.

These first seven spacecraft constitute Block I of the Surveyor project. For planning purposes, NASA headquarters has approved an additional 10 Surveyors for Block II. Plans now indicate that for flights Nos. 8, 9, and 10 the spacecraft will weigh 2,450 pounds, and flights Nos. 11 through 17 will weigh 2,500 pounds or more. The scientific payload has not yet been selected for any of the last 10 spacecraft.

THE SURVEYOR MISSION

The Surveyor mission is to effect the transit of a complex spacecraft from the Earth to the Moon, perform a soft lunar landing, and transmit back to Earth basic scientific and engineering data relative to the Moon's environment and characteristics. The mission can be divided into four basic functional operations: launching, tracking and midcourse correction, terminal descent and soft landing, and lunar operation.

The mission begins at Cape Kennedy with the launch of tbe newly developed Atlas-Centaur launch vehicle. Folded at launch within the Centaur nose shroud, the Surveyor spacecraft legs and antennas are extended when the shroud is ejected, shortly after launch. The spacecraft is separated after the end of Centaur burning. Some 20 hours after launch, with the spacecraft trajectory accurately determined, a midcourse correction is made to direct the spacecraft to the desired landing spot on the Moon (see fig. 3, p. 11).

Tracking, command, and data reception will be carried out through the three stations of the Deep Space Instrumentation Facility at Goldstone, Calif.; Johannesburg, South Africa; and Canberra, Australia. Central control of the mission is exercised from the Space Flight Operations Facility at the Jet Propulsion Laboratory in Pasadena, Calif. (see fig. 4, p. 12).

Guidance within the Centaur booster assures that upon separation the spacecraft is in a coast trajectory which will take it to the near vicinity of the Moon. Shortly after separation, the Centaur stage will execute a reverse maneuver to increase its distance from the spacecraft so as to avoid the possibility of the spacecraft sensors confusing the booster's shiny surface with the space reference points. Any spacecraft tumbling is damped out so that systematic search for the two space references—the Sun and the star Canopus—can be made. When the spacecraft attitude is fixed by lock-on to the Sun and Canopus, the solar panel is oriented toward the Sun for generation of power. All attitude maneuvers during the coast phase are implemented by thrust from small nitrogen gas jets on the spacecraft legs. The omnidirectional antennas provide coverage for telecommunications in any spacecraft attitude.

The midcourse maneuver is accomplished by adjusting spacecraft attitude in the direction of the required velocity vector and turning on the vernier propulsion system for a short time to supply the required velocity correction. This accomplished, the Sun and Canopus are reacquired to direct the solar panel toward the Sun.

The spacecraft arrives at the Moon after about 66 hours of flight. The first step in the terminal descent phase is to change spacecraft attitude at about 1,000 miles from the Moon to aline the main retro-engine thrust axis with the velocity vector. The planar array antenna is then oriented toward the Earth and television pictures from the downward-looking camera are transmitted. At an altitude of about 50

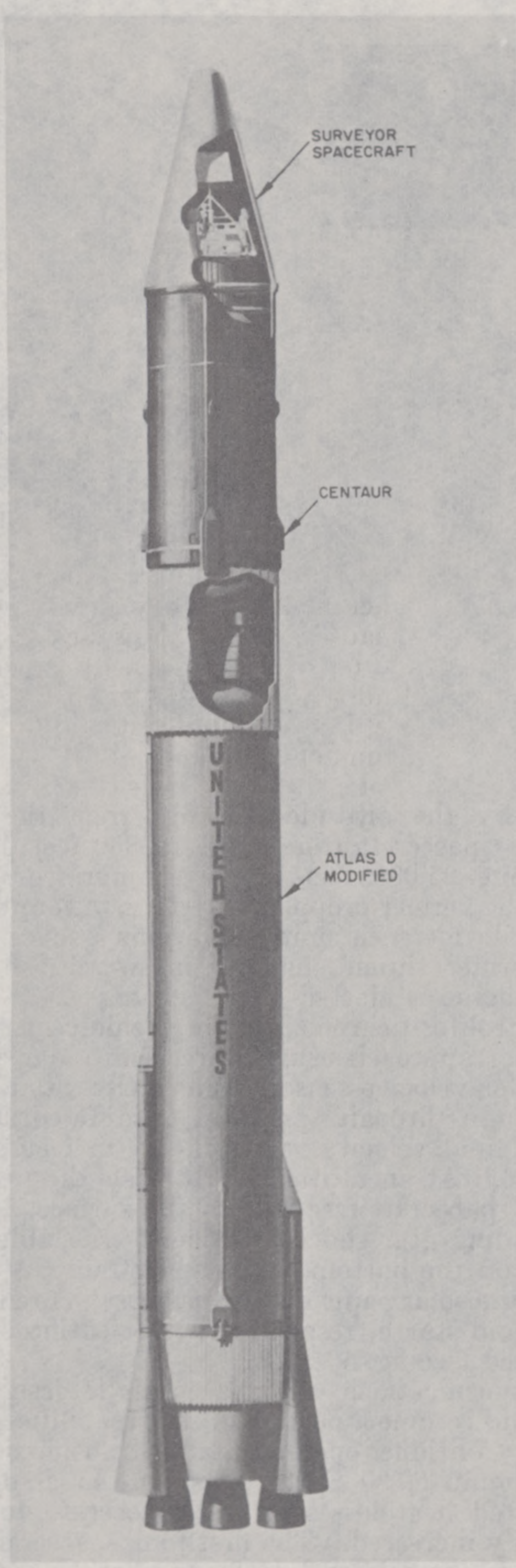

FIGURE 3

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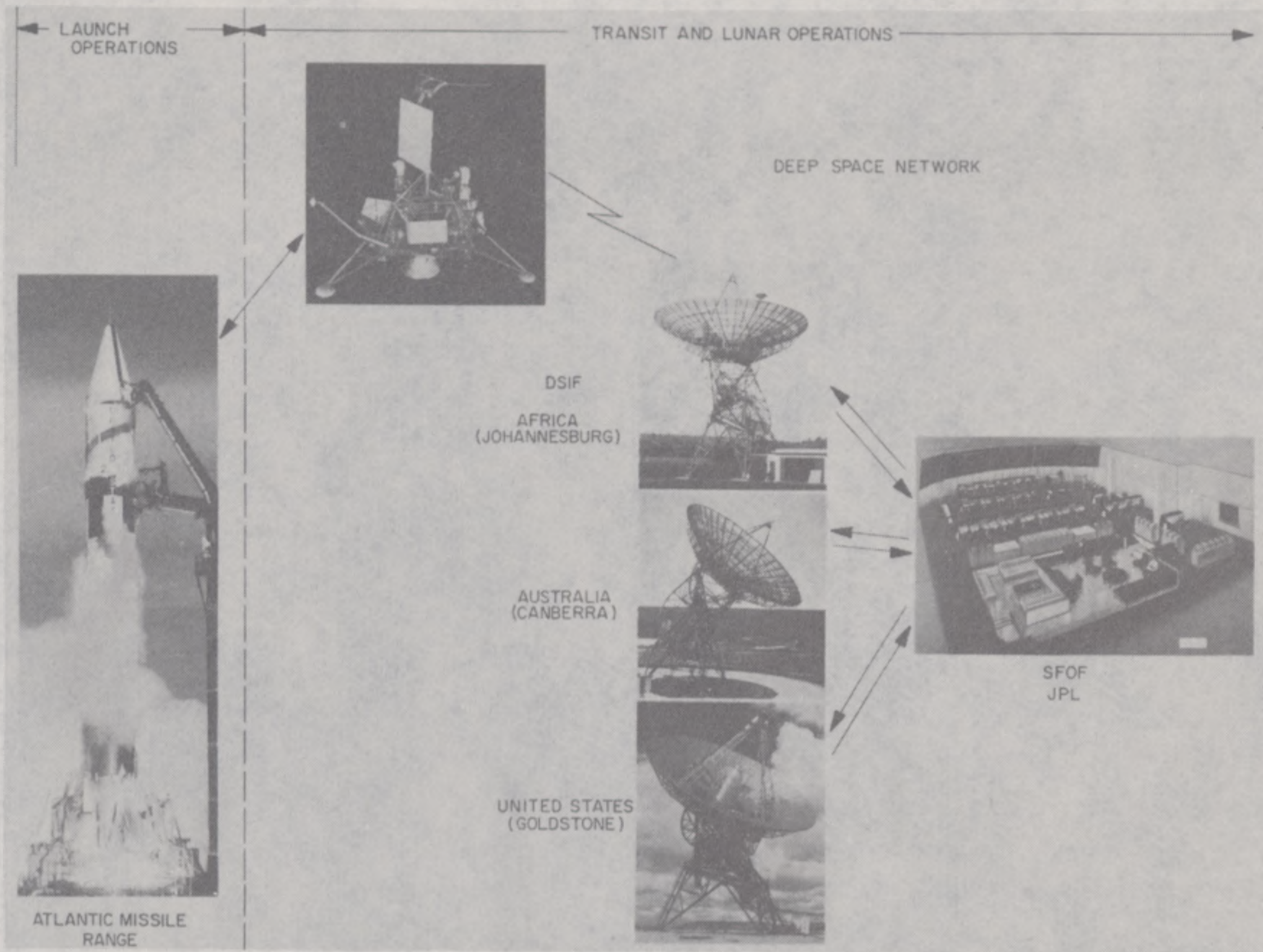

FIGURE 4

miles, triggered by the altitude-marking radar, the retroengine is fired to slow the spacecraft from 9,000 to 350 feet per second as it descends to about 25,000 feet above the surface. During retroengine burning, the vernier propulsion system, in conjunction with the spacecraft inertial reference unit, maintains a constant spacecraft attitude; one vernier thrust chamber is swiveled for roll control. The main retroengine is ejected after burning.

Spacecraft control for the remainder of the descent is automatically referenced to lunar approach using a precision radar altimeter and a three-beam doppler velocity sensor. The three vernier thrust chambers adjust attitude through operation at differential thrust levels and perform the final velocity reduction to 15 feet per second just above the surface. At an altitude of 13 feet, the vernier system is shut off and the spacecraft free-falls to the surface. The landing is cushioned by landing gear shock absorbers, crushable footpads, and crushable blocks on the bottom of the spaceframe.

After landing, the solar panel and planar array antenna are oriented toward the Sun and Earth, respectively. Scientific experimentation can then be started (see fig. 5, p. 13).

According to specifications, the spacecraft is designed to survive the frigid night and resume a portion of its capabilities after the lunar dawn; it should continue operation and transmission of data to Earth for a minimum of 30 Earth days (one lunar day and night). However, estimated heat losses of the spacecraft during the lunar night have steadily increased. The first four spacecraft are therefore expected to survive the cold and darkness of the lunar night for only a few hours; certain equipment may freeze up in a matter of minutes.

On the lunar surface, the spacecraft will survey various landing

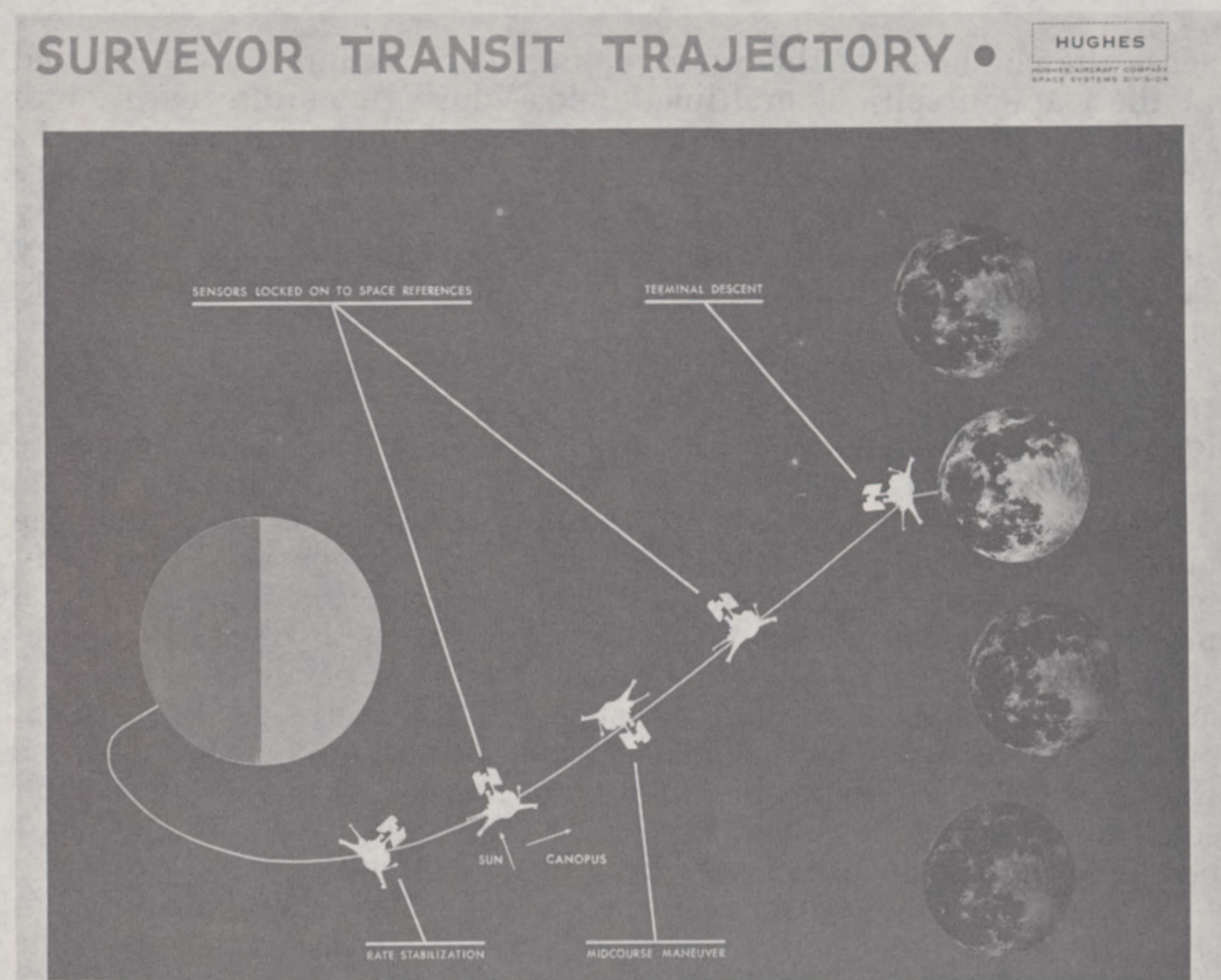

FIGURE 5

areas of interest as possible sites for later manned landings and make measurements to improve our understanding of the nature of the Moon. Landed Surveyors will transmit to Earth a variety of data, such as high-resolution television pictures of the lunar terrain, measurements of the surface texture, hardness, and other physical and chemical properties, lunar seismic activity, and the meteorite environment near the surface.

Except for the fact that Surveyor will be launched with the newly developed Atlas-Centaur launch vehicle, instead of an extensively tested and quite reliable Atlas-Agena, the first half of the Surveyor mission resembles the Ranger mission. The most challenging part, the terminal descent and soft landing, followed by operation of instruments on the lunar surface, requires the development of a technology far more advanced than that employed in the Ranger spacecraft.

Not only must Surveyor navigate through space between the Earth and the Moon, but it must land softly on the Moon, much as a helicopter lands on the Earth—but without the aid of atmosphere and a human pilot. Dr. Homer Newell, Associate Administrator for Space Science and Applications, NASA, has observed that the complexity of the automatic landing maneuver itself can be best appreciated by recognizing that the problem is one of backing down a multistage rocket to a soft landing 240,000 miles and 66 hours removed from the launch site, without human intervention.

This point deserves further elucidation. One need only consider the complex nature of launch vehicles, and the history of difficulties experienced in launching multistage rockets from Cape Kennedy, to sense the challenge of the Surveyor mission. Failures have occurred at the Cape in spite of multiple "holds" during countdowns prior to launch when skilled technicians have been able to make necessary changes, modifications, and other "fixes". Notwithstanding the ready availability of highly trained personnel at the Cape, and virtually unlimited opportunity to make corrections right up to lift-off, many failures have been experienced at the launch site or during the early stages of flight.

By way of contrast, the Surveyor mission requires not only a successful launch into a satisfactory trajectory toward the Moon, followed by a midcourse correction of the trajectory so as to insure a precise collision course with a particular place on the Moon; the Surveyor mission requires much more. At the terminal end of the mission the velocity of the spacecraft must be slowed, essentially by backing down a multistage rocket, all the time maintaining a proper attitude with respect to the Moon, so as to place the spacecraft, undamaged, on the lunar surface. This backing down of a multistage rocket is, in most respects, the reverse of the launch procedure which will have taken place some 66 hours earlier at Cape Kennedy. The difference is that each of hundreds of components and subsystems must perform flawlessly and automatically, without benefit of holds or the services of skilled technicians.

The landing must be made on a surface whose characteristics are still largely unknown but probably ill-suited as a landing field. The spacecraft is then required to operate and perform its experiments in a totally foreign and hostile environment, under extremes of temperature, and in essentially absolute vacuum.

DOCUMENTARY HISTORY OF SURVEYOR

In the spring of 1960, the Surveyor project was formally approved by NASA Headquarters, and the Jet Propulsion Laboratory was selected as project manager. Early in May 1960, JPL distributed a Design Study Requirements document to industry, and later that month a bidders' conference was held.

On July 11, 1960, three companies were awarded study contracts. By letter contract dated March 1, 1961, Hughes Aircraft Co. was awarded the Surveyor spacecraft development work.

Since that time, the history of the Surveyor project has been marked by drastic changes in the weight of the basic spacecraft, in the weight and composition of the experimental payload, and in the launch schedule. These alterations in the program are reflected in the official documents generated by the project since March 1961.

Up to the present time, there have been approximately 46 modifications and 80 change orders executed against the contract. These have been largely of a routine nature. The most significant contract changes have been Modifications 6, 8, 15, Change Order 18 as amended, Modifications 26, 28, 39, and 43. A summary of each of these significant changes is included in subsequent paragraphs. According to JPL, the remaining modifications were, in general, associated with incremental funding to the contract and incorporation of negotiated change orders.

During the period March 1, 1961, through June 15, 1961, the primary effort at Hughes was devoted to developing systems description and program plan for the Surveyor project. On the latter date, JPL issued Basic Functional Specification No. 30240, the controlling technical document for the spacecraft system. This document provided for a basic 2,500-pound configuration, off loadable to 2,300 pounds, so as to provide contingency against possible degradation in launch vehicle performance. First launch was scheduled for August 1963. The payload complement had not yet been defined, but the spacecraft was to be designed to accommodate 345 pounds of scientific instruments.

Within the constraints of available payload weight, power, and packaging, the scientific payload for the 2,500-pound spacecraft was to be selected from the following list of instruments and/or experiments:

(*a*) Television.
(*b*) Subsurface sampler.
(*c*) X-ray diffractometer.[1]
(*d*) X-ray spectograph.[1]
(*e*) Gas chromatograph.[1]
(*f*) Geophysical surface subsystem.
(*g*) Geophysical subsurface probe.
(*h*) Magnetometer.

[1] Requires the sample transport and processor.

(*i*) Plasma probe.
(*j*) Seismometer (required a tape recorder, included in payload weight, but not listed as an experiment).
(*k*) Atmospheric pressure gage.
(*l*) Radiation detector.
(*m*) Surface sampler.

Cost and fee negotiations between JPL and Hughes were completed on August 16, 1961, and a formal cost-plus-fixed-fee contract was executed shortly thereafter.

Modification No. 6, executed on September 25, 1961, definitized the letter contract which had been issued to Hughes on March 1, 1961. Article 1, the Statement of Work, provided a general definition of the spacecraft system contractor's functional areas of effort—i.e., analysis, development, detail design, documentation, fabrication, assembly, test, delivery, operation, data retrieval, and performance evaluation of the Surveyor spacecraft system. In addition, it defined quantities and types of equipment—i.e., spacecraft, spares, system test equipment assemblies, command and data consoles, ground support equipment, and the types of written and film reports to be supplied.

By letter dated January 3, 1962, JPL notified Hughes that the scientific payload for the first two 2,500-pound spacecraft was defined as:

(*a*) Surface geophysical instruments.
(*b*) Subsurface geophysical instruments.
(*c*) Subsurface sampler.
(*d*) Surface sampler.
(*e*) Gas chromatograph.
(*f*) X-ray diffractometer.
(*g*) Sample transport and processor.
(*h*) Radiation detector.
(*i*) Television.
(*j*) Tape recorder (previously included in payload weight, but now listed as an experiment).

There followed a period of reevaluation of the estimated payload capability of the early Centaur launch vehicles, a new high-energy upper stage under development by General Dynamics. Centaur, the first U.S. launch vehicle to use liquid hydrogen fuel, has had a long and troublesome development cycle beginning in 1958. By 1962, it had become apparent that Centaur would not have the capability of injecting a 2,500-pound spacecraft into an escape trajectory to the Moon.

In order to accommodate the anticipated reduced Centaur capability, a decision was made by JPL, with NASA Headquarters concurrence, on March 12, 1962, to redirect all available resources at Hughes to the design of a 2,100-pound spacecraft. This decision was incorporated in Modification No. 8 dated April 5, 1962, which changed the requirement for flight spacecraft from the original eight 2,500-pound spacecraft to five 2,100-pound spacecraft, two 2,500-pound spacecraft, and one flight-spare spacecraft capable of being modified from the 2,100-pound configuration to the 2,500-pound configuration. Under the terms of Modification No. 8, this new 2,100-pound design was to have incorporated a TV-drill experiment.

While Centaur's estimated payload capability was being revised downward, the weight of the basic Surveyor spacecraft structure and associated hardware was increasing. This is important since increased spacecraft hardware weight is normally reflected in a corresponding reduction in scientific payload.

Thus, the weight allowed for the basic spacecraft hardware was increased from 553 to 632 pounds for both the 2,100- and 2,500-pound spacecraft. This, in turn, was reflected in reduced payload. Accordingly, the weight available for the mission payload was decreased from 345 to 266 pounds for the 2,500-pound spacecraft. The weight available for the mission payload for the 2,100-pound spacecraft was specified to be 115 pounds.

In addition, the launch schedule was revised to provide for first launch in November 1963, a 3-month slip.

In July 1962, JPL directed Hughes to discontinue all effort associated with the TV-drill payload, and a new payload definition was to have been provided the following month. This new payload definition was not provided until late in October, however, and a final interface document was not established until December.

By letter dated October 28, 1962, JPL notified Hughes that the scientific payload for the 2,100-pound spacecraft was now defined as:

(*a*) Television.
(*b*) Surface sampler.
(*c*) Sample transport and processor.
(*d*) X-ray diffractometer.
(*e*) Soil mechanics.
(*f*) Micrometeorite detector.
(*g*) Alpha particle scattering device.

Delivery of the first Surveyor spacecraft also slipped an additional 10 months, to September 1964.

Late in January 1963, Modification No. 15 was issued. This modification provided for a single spacecraft configuration weighing 2,100 pounds, to conform with the then current estimated Centaur payload capability. Modification No. 15 eliminated the 2,500-pound spacecraft configuration as an item of deliverable hardware, and also eliminated the requirement for one flight spacecraft which had been planned for use as a spare. Thus, seven identical 2,100-pound spacecraft made up the program at this point in time.

The weight allowed for the basic spacecraft structure and associated hardware was also increased an additional 22 pounds, from 632 to 654 pounds. First launch slipped another month, to November 1964.

In April 1962, JPL issued Change Order No. 18, redirecting the Hughes effort toward four spacecraft with engineering payloads, and three spacecraft with scientific payloads; both payloads to be defined subsequently. An additional proof test model was required, so that one proof test model would be available for the Engineering Test spacecraft configuration, and one would be available for the science spacecraft configuration.

In August 1963, Hughes received amendment No. 1 to Change Order No. 18 defining the payloads for the science missions as:

(*a*) Television.
(*b*) Approach television.
(*c*) Surface sampler.
(*d*) Micrometeorite ejecta detector.
(*e*) Alpha scattering experiment.
(*f*) Single-axis seismometer.

Later that month, the payload requirements were modified as follows: (*a*) the approach television was affirmed to be a part of the basic bus, and not part of the scientific payload; (*b*) the touchdown dynamics experiment was added as a part of the scientific payload.

The engineering payload for the four Engineering Test Flights was defined during the period of August to October 1963. Essentially, the payload was designed to obtain touchdown dynamics, additional engineering telemetry, and to provide for redundancy in part of the power system by the addition of an auxiliary battery.

By letter dated February 3, 1964, JPL provided additional direction to Hughes in connection with Change Order No. 18. This letter stated that the seven spacecraft would be flown on 2 month centers, that Atlas-Centaur direct-ascent trajectories would be flown, that separated weight of the Engineering Test spacecraft would be 2,150 pounds (an increase of 50 pounds) and that the mission was to have an additional midcourse correction capability.

This letter also recognized an additional delay of 4 months in the launch schedule; first launch was thereby slipped to March 1965.

Modification No. 26 was executed on April 21, 1964. This modification definitized both cost and fee which had been negotiated as a result of Modification No. 15. The Hughes cost proposal in response to Modification 15 had been submitted on March 11, 1963. JPL-Hughes cost negotiations were conducted during the period April 18–July 24, 1963. JPL-Hughes fee negotiations were conducted during the period May 10–December 27, 1963. The results of these cost and fee negotiations were definitized in Modification No. 26.

Modification No. 28 was executed on June 10, 1964. The primary purpose of Modification No. 28 was to recapitulate Change Order No. 18, to establish Hughes model descriptions for four Engineering Test Flight and three Operational Flight spacecraft (designated A–21 and A–21A, respectively) as contractual documents, and revise other less significant contractural requirements. Article 1, the Statement of Work, was rewritten for Modification No. 28. The requirement for an up-to-date A–21 proof test model was identified, and the requirement for system test equipment assemblies was changed from four to five; this latter requirement was not specifically defined in Change Order No. 18, but did appear in Modification 28.

Under the terms of Modification No. 28, the separated weight requirement was formally changed from 2,100 to 2,150 pounds for all seven spacecraft, in conformity with earlier directions in the February 3 letter.

The model A–21 engineering instrumentation and auxiliaries were defined to be: Auxiliary engineering signal processor, survey TV camera, auxiliary battery and control, and supplementary engineering instrument.

The model A–21A scientific instruments and auxiliaries were redefined to include: survey television, surface sampler, alpha scattering device, seismometer, micrometeorite ejecta detector, and touchdown dynamics. All other scientific instruments and their descriptions were deleted.

The weight allowed for the basic bus was increased from 654 to 655 pounds, and the payload weight requirement was defined as 62.5 pounds.

By letter dated December 23, 1964, JPL recognized an additional delay in the launch schedule of 8 months. First launch was rescheduled for early in October 1965.

It has been reported that this schedule slip resulted from several vital parts of the project falling behind. For example, problems associated with the testing program had developed. Two drop tests had been attempted during the preceding months; both had been complete failures, and the test vehicles had been destroyed. In addition, testing of the proof test model, and fabrication of the first flight article both had encountered delays. Moreover, the technical problems associated with development of the vernier engines and the radar altimeter and doppler velocity sensor were taking more time to solve than had been anticipated.

Late in January 1965, Deviation Document No. 1 to Modification No. 28 was issued by JPL at Hughes' request. The significant changes were, the separated weight was changed from 2,150 pounds for all seven spacecraft to—

(*a*) 2,250 pounds for the A-21 spacecraft—with not less than 62.5 pounds payload.

(*b*) 2,450 pounds for the A-21A spacecraft—with not less than 114 pounds payload.

Much of this increase in total spacecraft weight apparently represented additional weight of the basic spacecraft structure and associated hardware; for the basic bus has increased from 655 to 695 pounds, its current reported weight.

Modification No. 39 was executed on March 25, 1965. The primary purpose of Modification No. 39 was to formalize program redirection resulting from project reviews conducted during the September–December 1964, period. The elements of such redirection had been established and provided to Hughes on December 23, 1964. The significant program changes were:

(*a*) The requirement for the new A–21 proof test model for the Engineering Test Flight spacecraft was deleted.

(*b*) The spares requirement was redefined to include one set of spares for the Engineering Test Flight spacecraft and one set of spares for the Operational Flight spacecraft.

(*c*) The T–2 test program was expanded and the fabrication of two new class IV test vehicles authorized.

(*d*) A requirement for an A–21 temperature control model was added.

(*e*) An engineering effort was initiated to definitize the A–21A Operational Flight spacecraft design so as to accommodate the complete 114-pound complement of scientific instruments.

(*f*) Recognized that the effort on the Operational Flight spacecraft hardware and associated spares was suspended pending the completion of the engineering effort in (*e*) above.

Modification No. 43 was executed on May 5, 1965. The significant program changes incorporated in Modification 43 were:

(*a*) The work suspension placed on the A–21A Operational Flight spacecraft and spares directed in Modification No. 39 was removed.

(*b*) The requirement to perform a combined system test on SC–1 was deleted.

(*c*) A requirement for an A–21 structural test model was added.

(*d*) A requirement for an A–21A structural test model was added.

(*e*) An upgrade of the vernier propulsion test model S–6 to the A–21A configuration was authorized.

(*f*) A requirement for an A–21A vernier propulsion system test model to replace S–7 was added.

(*g*) A requirement for an A–21A thermal control model was added.

(*h*) Test activity on the new and upgraded test articles was authorized.

(*i*) A requirement for a group test equipment assembly was added.

(*j*) Work on the touchdown dynamics instrument was authorized for the preparation of documentation for long leadtime procurements.

In addition, JPL letter dated March 24, 1965, specified that the trajectory modes to be used for the seven scheduled launches would be as follows:

Engineering Test Flight spacecraft missions A–C: Direct ascent.
Engineering Test Flight spacecraft mission D: Parking orbit.
Operational Flight spacecraft missions E–G: Direct ascent.

In the spring of 1965, when the first flight article was undergoing vibration tests at Hughes, a number of problems were encountered which indicated that additional tests should be conducted prior to subjecting the spacecraft to the solar-thermal-vacuum test.

Hughes suggested several special tests, and JPL prescribed several more. It was determined that approximately a dozen additional special tests were to be run, and this resulted in another delay of about 4 months in the flight schedule. First launch is now expected to occur about February, 1966.

In summary, during the past 4 years, the Surveyor project has been modified in the following major respects:

(*a*) The first launch of an Engineering Test model has slipped over 2½ years, from August 1963 to February 1966; and since the first Operational spacecraft will not be flown until 1967, the schedule slippage might be viewed as approaching 4 years.

(*b*) Total spacecraft weight declined from the original 2,500-pound configuration down to 2,100 pounds; then increased to 2,150 pounds; and currently stands at 2,250 pounds for the first four Engineering Test models and 2,450 pounds for the following three Operational models.

(*c*) The basic spacecraft structure and associated hardware was to have weighed 553 pounds, according to original specifications. This has increased to approximately 695 pounds, according to latest reports. The increase in the weight of the basic spacecraft structure and associated hardware has resulted in a corresponding decrease in scientific payload.

(*d*) Scientific payload has diminished from an original 345 pounds to about 20 pounds represented by the single scanning TV camera on each of the first four Engineering Test models (the remaining 42.5 pounds is engineering instrumentation). The following three Operational models will carry only 114 pounds of scientific instruments.

(*e*) The experimental payload has been through many redefinitions. Beginning with a very ambitious program, the instrument complement has decreased to the point where the first four Engineering Test flights will incorporate nothing more than a single scanning TV camera, while the following three flights, scheduled for 1967, will include only six experiments.

It is clear that Surveyor has undergone a great number of substantial changes. It can be expected, of course, that all complex research and development projects will undergo a certain number of significant changes as the work proceeds. The committee recognizes that such modifications are necessary to success, and when executed in a timely fashion can contribute to cost and schedule objectives.

The above documentary history, however, indicates that the Surveyor project has experienced an excessive number of extraordinary and fundamental modifications; the inevitable result of a poorly defined project.

SUMMARY OF RECENT EVENTS

The year 1964 was a year of trouble for the Surveyor project. A number of major events, not fully reflected by the documentary history set forth in the preceding section, occurred which deserve more detailed treatment.

The vernier engine development contract

In February 1964, Hughes notified JPL that the vernier thrust chamber assembly subsystem had encountered severe technical difficulties. Hughes recommended that its subcontractor, Reaction Motors Division of Thiokol Chemical Co., should be permitted to continue development, but that a second contractor, Rocketdyne, should be brought in as a backup.

The following month, however, in March 1964, JPL directed Hughes to terminate its contract with RMD, and JPL executed a new contract for the vernier engines with TRW/Space Technology Laboratories.

During the next couple of months, in spite of the fact that its contract had been canceled, RMD reportedly undertook an intensive program involving substantial redesign of its vernier thrust chamber assembly; successfully solved some of the technical problems; and reformed its management organization and procedures.

During the same period, it appeared that STL was beginning to encounter difficulties in its effort to produce an engine within the specified weight limitations.

These developments led to a reappraisal by JPL which suggested that RMD might again be the best contender for meeting the launch schedule with a qualified engine, despite earlier disappointment with its performance.

Therefore, in June 1964, a decision was made to reinstate the RMD contract, but this time directly with JPL, rather than with Hughes. It has been explained that JPL has had considerably more experience than Hughes in the development of small liquid rocket engines, and since the vernier propulsion system is a critical subsystem of Surveyor, JPL wished to bring its expertise directly to bear on the RMD work.

In any case, the history of the vernier engine development is noteworthy for two reasons. To begin with, a remarkable sequence of events took place in rapid order. First, JPL ordered the RMD work to be terminated, and STL was placed under contract; then the Laboratory reinstated the RMD contract and canceled the STL contract; all within a period of less than 4 months. It seems fair to assume that this is an expensive way to do business.

On the other hand, termination of the RMD contract seems to have had a salutary effect. Evidently, technical and management problems were solved in rather short order when the contractor realized what was at stake, and that the Government was willing to cancel his contract.

Perhaps more significant is the new arrangement under which RMD, producer of an essential subsystem of the spacecraft, is no longer a subcontractor of Hughes, the developer of the spacecraft, but now works directly for JPL, the project manager.

Other technical difficulties

The problems associated with the vernier engine development represented only one of several areas of concern which came to the attention of JPL in the spring of 1964. A second major subsystem, the main retrorocket engine had also encountered technical difficulties.

The third subsystem essential to a successful terminal descent and soft landing on the lunar surface, the radar altimeter and doppler velocity sensor, was experiencing severe technical problems, as well. The RADVS is considered by the experts to be at the very limits of the state of the art, and there are certain technical problems associated with it which continue to discourage high confidence in the system, even to the present time.

The year 1964 also witnessed two major failures in the Surveyor test program. In order to test the compatible operation of the three major subsystems, referred to above, which are required for a successful terminal descent of Surveyor to the lunar surface, a method was conceived to simulate this phase of the mission. A Surveyor test vehicle was to be suspended from a balloon 1,500 feet above the surface of the desert, and then dropped to Earth. Following release of the test vehicle, the main retroengine and the vernier engines were to be fired, and the descent radars were to be operated, all three in a coordinated fashion, performing as the closed loop system they are intended to provide for an actual mission.

In the first drop test, conducted in April 1964, post operations analysis suggested that an electrostatic discharge caused a failure in the release mechanism, and the test vehicle was dropped prematurely, crashed to earth, and was wrecked. The system apparently was not satisfactorily grounded.

In the second drop test, which occurred in October 1964, five independent component failures occurred, some of which involved spacecraft systems, while others were associated with the test equipment. As an example of the latter-type failure, the test vehicle, during descent, became tangled up with one of the balloon's tethers.

Dr. Newell has testified that these failures were caused by the fact that both test procedures and hardware had been inadequate. In retrospect, the test program appears to have been too austere.

The primary responsibility for testing rests with Hughes, of course; but since these test failures, JPL, in response to strong recommendations from NASA Headquarters, has taken a more active role both in the preparation for, and execution of tests of Surveyor hardware conducted by Hughes.

Two new test vehicles have been fabricated at Hughes. Unlike the earlier test vehicles, flight-quality hardware has been used in their construction. In addition, test procedures have been thoroughly revised, hopefully to avoid the mistakes of the past.

A total of eight drop tests have been scheduled; no attempts have been made, however, since the last failure. It is now hoped that three successful drop tests can be made prior to the first launch in February 1966.

NASA Headquarters project review of March 1964

Dr. Homer E. Newell has stated that, by autumn of 1963, NASA Headquarters had begun to receive indications that the Surveyor spacecraft development work at Hughes was encountering serious difficulties. The succeeding months made it clear that the situation was worsening as hardware development proceeded and the testing program got underway.

Accordingly, in March 1964, a seven-man team from NASA's Office of Space Science and Applications was organized to conduct an intensive review of the Surveyor Project. This investigation took place primarily at JPL and Hughes Aircraft Co. from March 23 through 27, 1964.

The purpose of this review by officials of NASA Headquarters was to evaluate the technical status of the project, the administration of the Hughes contract, and the effectiveness of JPL and Hughes project management.

In April 1964, the NASA review team submitted its findings. The Conclusions and Recommendations Section of the report included 40 separate items. Those considered to be of special significance from the standpoint of the committee's interest in the management and execution of the Surveyor project are summarized as follows:

Regarding JPL organization and management, the NASA report recommended that JPL should establish a much stronger, projectized organization for the Surveyor project.

The NASA report went on to recommend that the Laboratory should carefully review its manpower complement and assign an adequate number of experienced engineers full-time to Surveyor; that these personnel should report directly to the Surveyor Project Office; and that the staff assigned to monitor spacecraft development at Hughes and their subcontractors should be significantly increased.

In addition, the report urged that regular formal reviews be conducted by JPL looking into the technical and financial status of the project, including direct monitoring of Hughes subcontractors by the Laboratory; formal monthly cost reporting by Hughes on each task in greater detail also was recommended.

The NASA report proposed that JPL institute a system for closely monitoring the reliability and quality-assurance effort at Hughes by assigning this responsibility to a senior professional at the Laboratory, and providing him with an adequate staff. The report went on to recommend that the JPL Reliability and Quality-Assurance Office should evaluate and sign off on the reliability of each flight spacecraft before it is allowed to go into system test and, again, before it is allowed to leave the factory.

The NASA review brought to light the fact that JPL's practice had been to monitor, but not sign off on, Hughes test plans and procedures. The NASA report recommended that, in the future, JPL should carefully review in detail and sign off on all Hughes test plans and test procedures, and officially witness and certify such tests; moreover, Hughes test plans should be subjected to detailed Laboratory design review so as to take advantage of the experience of Laboratory personnel who had participated in other JPL flight programs.

Regarding the Surveyor organization and management at Hughes, the NASA report observed that it, too, should be strengthened, and recommended that JPL carefully consider the advantages of a more projectized organization at Hughes.

The NASA report noted that it was not at all clear that Hughes had developed a system to flag incipient technical problems and cost overruns, a so-called "early warning" system, whereby project management could be alerted in sufficient time to take corrective action. The report strongly recommended that such a system be instituted.

In addition, it was noted that the PERT system at Hughes did not adequately tie together the test program with the fabrication of flight hardware, the result being that slippages in the former were not reflected in the latter, in spite of the critical interdependence of the two. Thus, a large and undesirable overlap had developed between them. The report stated that revision of the system was essential.

Finally, the Hughes system for engineering-change control was considered to be unduly cumbersome and time consuming, apparently having been designed for a large mass-production manufacturing program, rather than a research and development program. The report recommended that Hughes and JPL should examine these procedures with a view to streamlining them.

With regard to JPL administration of the Surveyor contract, the NASA report noted that the responsible office was understaffed. The result was a serious lag between the technical program and the contractual status, according to the report. This failure to keep the contractual status of the project up to date resulted in successive negotiations of what were effectively new contracts between JPL and Hughes. Such negotiations occurred after long time lapses subsequent to the implementation of many changes in the project, and the report observed that this could result in a situation approximating a cost-plus-percentage-cost contract.

JPL design review of 1964

Immediately following submission of the NASA Headquarters Surveyor Project Review Report, JPL undertook a complete design review of the spacecraft system in April of 1964. This design review took several weeks and constituted an extraordinary measure by the Project Manager to get to the bottom of the difficulties.

A number of important technical changes were generated by this complete design review; these have been covered generally in the last few paragraphs of the preceding section. More important were the organization and management changes which were adopted.

JPL undertook an internal reorganization of major proportions, starting with a rapid buildup of personnel assigned to Surveyor. Within a few months after the design review of the spring of 1964, the Surveyor staff was increased from fewer than 100 to about 500 people. This buildup of personnel was accomplished largely by reassigning Laboratory employees from the Ranger and Mariner Projects to Surveyor.

In addition, the Surveyor effort at JPL was reorganized along project lines; that is, most assignments to Surveyor were now made on a full-time basis, and personnel were made responsible to the project director. Previously, Surveyor had depended largely upon the support of personnel assigned to functional divisions within the Laboratory. Surveyor had been part-time for many such personnel under the earlier arrangement, and they reported to their division chiefs, rather than to the project office.

As indicated above, it was also the considered opinion of NASA Headquarters that the Hughes Aircraft Co. should undertake an internal reorganization of the Surveyor project so as to provide a sizable staff exclusively to Surveyor. Up to this point, Hughes had also operated under the matrix system, whereby individuals assigned to functional divisions within the organization were made available to the Surveyor project, as needed. Therefore, JPL strongly recommended that Surveyor be "projectized," and Hughes has since adopted this recommendation to some degree, according to Dr. Pickering. Mr. L. A. Hyland, general manager of Hughes Aircraft Co., takes a somewhat different view; he has stated that "the plain fact of the matter is that we haven't really fundamentally changed our management a great deal from the beginning."

In any case, the present situation at Hughes is a sort of hybrid organization providing for approximately 500 personnel specifically, and more or less permanently detailed to Surveyor, but with heavy reliance upon a much larger number, almost 2,000, assigned to the functional divisions.

In December 1964, JPL ordered Hughes to reduce its complement of personnel on Surveyor by over 300, down to about 1,700. It has been explained that "not only was this step necessary to preserve funds which were extremely tight for the remainder of fiscal year 1965, but it was felt that the efficiency of the entire Hughes operation would be improved." Hughes complied with that instruction; however, the Surveyor team at Hughes has grown substantially during the past few months, with the knowledge and concurrence of JPL, and the present level of effort employs approximately 2,400.

These major organizational changes created a strain in the relationship between JPL and Hughes; particularly disturbing to Hughes was the introduction of large numbers of JPL personnel into the development project which, by this time, was more than 3 years old, and the Laboratory's new and intense concern with the technical details of the project.

JPL takes the position that its technical penetration of Surveyor has given the Laboratory a clearer picture of the major problem areas at Hughes, and has resulted in a better basis for understanding between the two organizations. Moreover, it has provided the means whereby JPL has been able to render assistance to Hughes, an organization badly in need of assistance on this most challenging project.

On the other hand, the impression has been received that Hughes has viewed the additional supervision as an exercise primarily designed to educate newly assigned JPL personnel, at least in the beginning.

Hughes reportedly has issued about 400 unescorted badges to JPL engineers working on Surveyor. While not all 400 are present at the Hughes plant at all times, it has been estimated that an average of 200 JPL personnel are on the job at Hughes on any particular day, in addition to approximately 50 JPL engineers "in residence" at Hughes.

There are indications that Hughes has now adjusted to the intensive technical intervention by JPL, but, during the buildup period, Hughes apparently considered this type of supervision quite burdensome.

Many time-consuming meetings resulted because newly assigned JPL scientists and engineers had to be familiarized with the intricacies of the project. While some of the new ideas they brought to the project proved to be worth while, many others were considered by

Hughes to be either unrealistic or not feasible. The situation was compounded by the fact that, as in all such matters, two competent technical people can sometimes look at the same problem but come up with different answers. In any case, a great deal of work and effort on the part of Hughes personnel was required to address these new ideas, thereby diverting constructive effort from the project.

Finally, Hughes has pointed out that there is virtually no such thing as a small change at this stage in the Surveyor program, and all changes are costly. From all appearances, Hughes resented the fact that the JPL team had the advantage of a "second look" late in the project.

Extended cost and fee negotiations

Following last year's complete design review, it is understood that a work statement reflecting JPL's ideas on the content and schedule of Block I of the Surveyor project was furnished to Hughes, and Hughes was requested to submit a cost estimate. The Hughes estimate was in excess of $70 million for fiscal year 1965. Shortly thereafter, Hughes reportedly submitted an unsolicited proposal to JPL providing for a program costing in the neighborhood of $50 million for fiscal year 1965. Evidently, Hughes took this action in the belief that financial constraints would not permit a program as ambitious as the one proposed by JPL.

JPL confirmed that funds available for the Surveyor spacecraft contractor were much closer to $50 million than $70 million for fiscal year 1965, and, accordingly, JPL undertook to provide Hughes with a new statement of work which, in many significant respects, was similar to the Hughes proposal. This work statement provided the basis for negotiation between Hughes and JPL on a work-cost agreement which became known as Modification 28.

This work statement was divided into 16 tasks, and negotiations relating to costs took place during a period of approximately 2 months from early December 1964 through the first week of February 1965. These negotiations were unique in that, according to top management at JPL, they gave the management team at the Laboratory, for the first time, a clear understanding of the details of the Surveyor program, and a good grasp of realistic costs; as General Luedecke, Deputy Director of JPL, has put it, "to give JPL a real handle on the project."

Within JPL, Modification 28 is referred to as "the Base Line program," for it served to pull together and consolidate changes, and thereby provide a redefined program. General Luedecke stated that, while these negotiations were an arduous task for both JPL and Hughes, in his opinion it was the only means available for pulling together the necessary detailed information on a current basis.

Completion of negotiations on Modification 28 by the first week in February 1965 was not the end of cost negotiations between Hughes and JPL on Block I of Surveyor, however. In fact, financial constraints and a more realistic schedule had already made it clear that a program of different content would have to be undertaken. Therefore, late in 1964 it was decided to implement the program now defined by Modification 39.

It is noteworthy that this decision was reached shortly after negotiations on Modification 28 had begun. Nevertheless, it was determined that the best way to arrive at full contractual coverage for this program was to complete negotiation of the Modification 28 program, for which JPL already had a cost proposal from Hughes, and to "delta" from this base.

As indicated above, negotiations on Modification 28 were completed on February 9, 1965. New negotiations were undertaken on February 18, 1965, related to the costs of the currently conceived program incorporated in Modification 39, known as the Hard-core B program. These negotiations were completed on April 9.

During Hughes' preparation of the Modification 39 proposal, it was decided that it would be necessary to issue a subsequent RFP for the additional effort not covered in the Modification 39 proposal, to provide the 114-pound payload capability for the three Operational Flight spacecraft.

This last proposal requirement came about as a result of the increase in the guaranteed Centaur Launch Vehicle capability from 2,250 to 2,450 pounds which occurred in December 1964 during the Modification 39 proposal preparation period. Therefore, the 114-pound payload, which had not been achievable with the lower Centaur capability, taken together with the weight growth of the basic spacecraft structure, was now possible to attain.

Consequently, JPL requested that Hughes prepare and submit a proposal in the form of a "delta" to the Modification 39 proposal, covering the costs of increasing the payload weight for the three science flights from 62 to 114 pounds. This proposal became identified as the Modification No. 43 proposal, and cost negotiations took place from April 30 to May 27, 1965.

These extended cost negotiations absorbed the time and effort of many people from both JPL and Hughes. JPL has furnished the following description of the manner in which the Laboratory organized for the conduct of these cost negotiations.

A finalizing team was appointed, composed of senior JPL representatives from the Surveyor Contracts Office and Surveyor Project Office, with support in attendance from the JPL Cost Analysis Section. This team was charged with the performance of the actual negotiation, providing continuity and consistency to successive negotiation proceedings, and making all final negotiation decisions. This team was assisted in negotiating sessions on any task by the support team assigned to that task.

Sixteen support teams were established, each composed of cognizant JPL personnel (contracts, technical, and cost analysis) and assigned to study the tasks to be performed by Hughes under the terms of the contract. These teams were charged with the highly detailed evaluation of each of the various task areas of the proposals, conducting pertinent discussions thereon with cognizant contractor personnel on a group basis, generation of specific recommendations to the JPL finalizing team, and assistance to the JPL finalizing team in negotiating sessions.

Prior to any given cost negotiating session, a dry-run session attended by the finalizing team and the given support team was held, at which time the support team recommendatious were presented to the finalizing team and discussed in detail, with the JPL posture and approach for the next cost negotiating session then determined. At the formal cost negotiating sessions, the JPL finalizing team and the Hughes finalizing team, together with their respective support personnel, would meet to negotiate the cost proposal at issue on a line-item-by-line-item basis.

During the 6-month period of cost negotiation, a total of 51 formal negotiating sessions were held. In addition, an approximately equal number of dry-run sessions took place, and a number of support team meetings also occurred, either internal to JPL or with contractor counterpart personnel. It has been estimated that between 15 and 30 individuals on each side were engaged during any given formal negotiating session.

According to JPL, the total cost negotiation effort was conducted on the fastest possible schedule, commensurate with thorough negotiating practice, and at a level of detail considered necessary by JPL. Fee negotiations took place from June 14 through July 23, 1965, and a total of nine formal sessions were held during that period.

Evidently, the cost and fee negotiations seemed interminable to the Hughes organization. The procedure absorbed a great deal of time of many key personnel at Hughes, which, in the view of Hughes management, might better have been spent working on the Surveyor project. These extended negotiations obviously created another source of tension between JPL and Hughes.

CONCLUSIONS

Inadequate preparation

It can be inferred from the testimony of Dr. Homer Newell, Associate Administrator of NASA for Space Science and Applications, that a serious mistake was made at the very beginning of the Surveyor project. In essence, insufficient preliminary work was done prior to the decision to go ahead with the project, and the award of a contract for development of the Surveyor spacecraft.

It is now customary in all major NASA projects for the work to be undertaken in phases. Phase I involves conceptual studies, systems definition, and preliminary design. In projects where work on phase I is thoroughly done before hardware development is begun, many of the most serious technical problems can be identified, feasibility judged, alternatives considered, and costs more accurately estimated.

According to Dr. Newell, "In the Surveyor program, we did not do enough of this phase I type of work."

Those more directly associated with the project have expressed the same idea in different words. As Mr. L. A. Hyland, vice president and general manager of the Hughes Aircraft Co., has said, "I think it is fair to say that we pretty much underestimated the magnitude of this job * * *. It is a much bigger job than we originally anticipated." Similar sentiments also have been expressed by Dr. William Pickering, Director of the Jet Propulsion Laboratory.

Referring to the underestimation of the complexity of the Surveyor project, Dr. Newell testified that—

> it is a sort of underestimation that is likely to occur if you simply plunge into a program of this sort. One of the lessons that we have learned, I think, is that an early assessment period in programs of this sort * * * can pay big dividends in doing several things. First of all, to give you an opportunity to develop the total perspective of what you are trying to do; second, to isolate a number of the major areas of difficulty that need early work; and third, to give you an opportunity to breadboard some of the major subsystems that need additional work. All of these can be done before you crank up the total effort leading to the final hardware.

The practical consequences of the failure to do adequate preliminary work in the Surveyor project have been a series of major modifications and program redirections from time to time during the entire history of the project as technical difficulties were encountered. The effects of such drastic changes, made after hardware development was underway, have tended to ripple through the entire system, causing increased costs and delays in the production schedule. The result has been one of the least orderly and most poorly executed of NASA projects.

It is recognized that Surveyor was undertaken almost at the beginning of America's entry into large-scale space activities. The relative lack of understanding regarding the demanding nature of space research and development projects, taken together with the enthusiasm which characterized that early period, largely explains NASA's willingness to plunge into a difficult project like Surveyor.

JPL performance

During the first 3 years of effort on Surveyor at the Hughes plant, the staff at the Jet Propulsion Laboratory was deeply engaged in two major in-house projects—Ranger and Mariner. This fact, together with the manpower ceiling imposed upon JPL by NASA Headquarters, has been cited as the main reason why a very small complement of people was originally assigned to the Surveyor project at JPL. From all appearances, JPL virtually turned Surveyor over to the Hughes Aircraft Co. and didn't get a "handle on the project" until the project was over 3 years old.

Dr. Pickering has estimated that the Surveyor project management group at the Laboratory consisted of about 20 individuals in the earliest days of the project. During the next 3 years there was a gradual increase in the number of JPL technical and management personnel engaged in work on Surveyor. The effort continued to be small, however. The number working on Surveyor is difficult to pin down since, during that period, JPL was organized along functional lines, the so-called matrix system of organization. Therefore, most of the people who worked on the project were not specifically identified with Surveyor. In any case, the total number working primarily on Surveyor at JPL up to about June 1964 is estimated to have been less than 100.

Dr. Pickering has admitted that the staff assigned to Surveyor at JPL was clearly inadequate during the first 3 years and that, as technical director of the project, JPL should have been well aware of the details of Surveyor's difficulties at an earlier date.

As the Ranger and Mariner projects approached their conclusions, JPL had a greater opportunity to check the performance of Hughes Aircraft Co. on Surveyor. By this time, launch schedules had slipped by about 2 years, and costs had rapidly escalated. Hughes was well advanced in the fabrication of hardware, and the testing phase was underway.

By the spring of 1964, it had become apparent that the Surveyor project was encountering severe technical problems at the Hughes plant. Accordingly, JPL undertook a complete design review of Surveyor. This was a more thorough, probing, and comprehensive examination than the periodic reassessment which is considered standard operating procedure in all complex spacecraft development programs. In fact, the review of Surveyor in the spring of 1964 was an extraordinary measure brought about by the fact that Surveyor was in real trouble.

As a result of that design review, JPL, as Project Manager, for the first time became fully cognizant of the extent of the project's technical difficulties, as well as weaknesses in the management organization and practices at Hughes Aircraft Co.

There followed a rapid buildup of personnel working on Surveyor at JPL. As stated previously, the past year and a half has seen the JPL team grow from less than 100 to approximately 500. Other important organizational changes, referred to elsewhere in this report, were also made.

The committee believes that JPL's technical penetration into the program at Hughes should have been more substantial during the first 3 years of the existence of the project, and does not regard JPL's preoccupation with its in-house work as justification for its failure to exercise the degree of technical direction required in Surveyor. The committee is not unaware that the personnel ceiling imposed upon JPL by NASA Headquarters was an important consideration. In any case, the committee concurs with Dr. Newell, who has testified as follows:

> Dr. Newell. Prior to the buildup to 500, we had less than 100 JPL people on the project. We did not have enough JPL people on the program.
>
> Mr. Karth. Was that because we were busy with Ranger and Mariner?
>
> Dr. Newell. Largely, though I don't regard that as an adequate excuse. I think we should have put more people on the project.

When asked whether he considered the complement of 500 personnel assigned to Surveyor at JPL as an unusually high number for the project manager to have, Dr. Newell responded:

> Dr. Newell. I would say yes, but, again, we feel we have a reason for this unusually high number, that we have extremely tight deadlines, and extremely difficult projects to carry out within those deadlines, and we simply want to make certain that the job is done right and on time.
>
> Mr. Karth. Overmanpower is almost as dangerous as undermanpower, isn't that true?
>
> Dr. Newell. Not properly controlled. As we have indicated to you we have a very carefully worked out organization in the application of this manpower * * *. We acknowledge it is a larger staffing than is common; something like 250 to 275 people would be more normal in a project of this sort. But it is our judgment that in order to accomplish this in the time we, in effect, have to do it, we need the additional staffing for the immediate future.

Hughes performance

Dr. Pickering denies any displeasure with the manner in which the Hughes Aircraft Co. has handled the Surveyor project. He has spoken highly of the Hughes organization, pointing to their successes in other projects. He has attributed their difficulties with Surveyor to the fact that the state of the art is being pushed forward on several fronts, and this in turn has given rise to many formidable technical problems.

No doubt this is true, to a large extent. The committee, however, believes Dr. Pickering is overly generous. As a matter of fact, there is strong evidence to suggest that JPL has been disappointed with Hughes' performance on Surveyor.

In the first place, following the complete design review of 1964, JPL brought great pressure upon Hughes to reorganize its internal management of Surveyor along project lines, a reform strongly recommended by NASA Headquarters. NASA has implied that Surveyor previously had not received appropriate attention by Hughes' top management, and that the organization at Hughes had been diffuse.

Both JPL and NASA Headquarters have pointed to management reorganization at Hughes as a significant improvement, though Hughes' responsiveness to these recommendations reportedly has been slow. Moreover it is clear that Hughes has complied only partially with this recommendation. In fact, the general manager of Hughes, Mr. L. A. Hyland, has denied that there has been any substantial change in his organization.

However much Hughes may have complied with JPL's suggestions to reform the management of the Surveyor project, the mere fact that such strong suggestions were made is revealing.

Secondly, JPL has penetrated into the technical aspects of the project to great depth with its own personnel, most of whom, according to Dr. Pickering, have had valuable experience on Ranger and Mariner. Dr. Pickering has explained that Hughes simply needed assistance in solving some of its technical problems, and JPL, having responsibility for technical direction of Surveyor, determined to render that assistance. It is also interesting to note that, late in 1964, JPL instructed Hughes to reduce substantially its complement of personnel working on Surveyor at the very same time the Surveyor staff at JPL was increasing very rapidly.

Finally, JPL has taken over management of a major subsystem, the vernier engine development, from Hughes. Originally, the Reaction Motors Division of Thiokol Chemical Co. was given a subcontract by Hughes to develop the vernier thrust chamber assembly. Hughes canceled that contract on orders from JPL in February 1964. Subsequently, in June 1964 the RMD contract was reinstated, but this time with JPL, not Hughes. Dr. Fred P. Adler, vice president, Hughes Aircraft Co., has explained: "I am sure JPL felt that the many difficulties that RMD was experiencing were in a large part, or less than a large part, due to insufficiently good management on the part of Hughes, and I think we should and could have managed them somewhat better."

The Hughes testing program has also come in for some criticism. The two drop test failures in 1964 have contributed to delays in the launch schedule, and resulted in additional costs to the project. Losses associated with these two failures have been estimated to be at least $2 million, which the Government has had to absorb.

The following colloquy points up the manner in which the tests were carried out:

> Mr. MOSHER. When you were talking about these Surveyor drop tests, it seemed to me there was an implied criticism when you said you found that they were not using flight quality hardware. Now, who were you criticizing at that point? Whose fault was this?
>
> Dr. NEWELL. I think the Hughes contractor agrees that these tests weren't prepared for or conducted properly. The criticism was directed toward those who were carrying out the tests where both the hardware and procedures were inadequate. The contractor has now devised new procedures, and has introduced flight-type hardware into the program.

Mr. Mosher. Is there any penalty here? In our contract with Hughes, is there any comeback that the Government has with Hughes in this respect?

Dr. Newell. We didn't have an incentive contract at that time; no.

Mr. Mosher. This was a cost-plus arrangement?

Dr. Newell. Yes; cost plus fixed fee.

Mr. Conable. But you are moving more toward incentive contracts, aren't you?

Dr. Newell. We are moving toward incentive contracts. In fact, the Office of Space Science and Applications has the largest number of such contracts in the agency, as just a means for trying to avoid this sort of problem, for getting the attention of the contractor to these things, since it affects him in the pocketbook.

Mr. Mosher. The mistake on Hughes' part is something you necessarily write off as experience from which we can benefit next time; is that right?

Dr. Newell. Yes.

Mr. Karth. Now, I assume that some of the JPL management team was also working on the problems of the drop test, or was this an exclusive thing on the part of Hughes? I am trying to pinpoint some responsibility.

Dr. Newell. Well, it is a responsibility we all have to share, because if we had penetrated properly into the testing program we should have spotted this, too.

NASA Headquarters performance

The committee is well aware of the fact that Surveyor is one of NASA's more difficult projects. The challenging aspects of the undertaking to soft-land instruments on the Moon have been recounted during committee hearings on several occasions. The committee accepts the notion that the difficulties inherent in the project account for some of the increased costs and launch schedule delays that have occurred.

By the same token, a project as troublesome as Surveyor demands vigorous centralized management and effective control at the top. From all appearances, these important elements have been largely missing right from the beginning of the project. Their effects on costs and schedule cannot be assessed with certainty, but the committee is convinced that such management weaknesses have contributed significantly. As indicated above, the first deficiency was NASA's failure to require sufficient preliminary design work before hardware development.

Secondly, it should have been apparent to NASA Headquarters prior to the spring of 1964 that JPL was not carrying out, or was not able to carry out, its responsibilities as technical director of the Surveyor Project because of preoccupation with other projects and a ceiling on manpower imposed by NASA. The danger signs were present in the form of increased costs and schedule slippages. Some affirmative action should have been taken by NASA Headquarters to stimulate JPL's attention to Surveyor, and achieve adequate performance on the part of the Laboratory. If manpower was a critical factor at JPL, then consideration should have been given to removing the manpower ceiling imposed by NASA Headquarters.

Perhaps the project should have been reassigned. While JPL is recognized as NASA's technical team for unmanned lunar and planetary exploration programs, other NASA centers have demonstrated capabilities in this field. It is noteworthy that Lunar Orbiter, a project within JPL's special competence, and assumed to be destined for management by the Laboratory, was assigned instead to NASA's Langley Research Center.

In any case, a timely decision followed by firm direction on the part of NASA Headquarters might well have produced better results. Instead of some sort of positive action, however, Surveyor was virtually ignored by JPL and NASA Headquarters until Ranger and Mariner were almost concluded, and personnel at the Laboratory were thereby released for work on Surveyor. By that time, Surveyor was 3 years old and in deep trouble.

The committee also believes that NASA's presence should have been felt more directly by the contractor. With the exception of the March 1964 project review and a followup conference with Hughes' top management, NASA Headquarters seems to have been remote from the project, and evidently depended too heavily upon JPL to develop and carry out policy in connection with Surveyor. In fact, three-way meetings of officials from NASA Headquarters, JPL, and Hughes were first instituted in the summer of 1965; an innovation described by Hughes' top management as "a very, very healthy thing." In the case of Surveyor, the committee agrees.

It is the view of the committee that the March 1964 NASA project review, while somewhat overdue, was an effective contribution to improving Surveyor's situation. Unfortunately, that review was exceptional, and communications between NASA Headquarters and Hughes seem to have been virtually nonexistent during the first 4 years of the project, up until quite recently.

Not all projects require such close monitoring by NASA Headquarters. In any project as difficult and trouble-plagued as Surveyor, however, NASA Headquarters might be expected to take a direct, continuing, and active interest in developments. Perhaps Hughes' responsiveness to NASA's direction, reportedly slow and somewhat reluctant, would have been better if communications between the two had been more substantial. Inevitably, NASA's management performance in the Surveyor project must be judged in the light of a history of too little direction and supervision until just recently.

The committee is convinced that Surveyor is extremely important to the success of the Manned Lunar Landing Project. This investigation of Surveyor has brought to light a most troublesome history, and revealed that all problems are not yet satisfactorily solved. For these reasons, it is considered highly desirable that NASA management continue their present high level of attention to the Surveyor project. Depending upon progress during the coming months, it is conceivable that even greater attention may be required. Such a determination is being left to the NASA organization, which has demonstrated excellent managerial and technical competence in many other space programs—both manned and unmanned.

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