50 Copies

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Report 32-1223

Surveyor Surface Sampler Instrument

E. R. Rouze

M. C. Clary

D. H. Le Croissette

C. D. Porter

J. W. Fortenberry

JET PROPULSION LABORATORY

CALIFORNIA INSTITUTE OF TECHNOLOGY

PASADENA, CALIFORNIA

February 1, 1968

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Report 32-1223

Surveyor Surface Sampler Instrument

E. R. Rouze
M. C. Clary
D. H. Le Croissette
C. D. Porter
J. W. Fortenberry

Approved by:

D. H. Le Croissette

D. H. Le Croissette, *Manager*
Instrument Development Section
Surveyor Project

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

February 1, 1968

TECHNICAL REPORT 32-1223

Prepared Under Contract No. NAS 7-100
National Aeronautics & Space Administration

Contents

Contents (contd)

Tables

Figures

Contents (contd)

Figures (contd)

Abstract

On August 1, 1966, arrangements were completed for Hughes Aircraft Company to design, fabricate, and deliver a flight model of a surface sampler instrument to the Air Force Eastern Test Range in December 1966 for attachment to *Surveyor III*.

This report presents the objectives planned for the surface sampler lunar experiment, as well as details of design of the flight hardware, mounting techniques, and thermal control. Operational capabilities, methods of deployment command and control, and areas of lunar operation and television viewability are discussed. The report concludes with a description of the surface sampler mission operation and a summary of surface sampler activities during the first lunar day of the *Surveyor III* mission.

Surveyor Surface Sampler Instrument

I. Introduction

On June 1, 1966, the *Surveyor I* spacecraft made a successful landing on the lunar surface. As a result of this landing, television observations of the lunar surface at a range of a few feet were conducted and preliminary estimates of the lunar-surface bearing properties were made by viewing the impressions of the footpad in the surface. These estimates were of great use both for their scientific value and for the assistance they provided in preparation for a later manned landing on the moon.

The television pictures of the footpad interaction with the lunar surface were limited to observations of the landed spacecraft. It was not possible to disturb the lunar surface in any way and to take a picture before, during, and after the motion. Several scientific instruments were planned to be carried aboard later spacecraft, one of which was to be capable of performing an elementary lunar soil-mechanics experiment. This soil-mechanics device was not expected to be available until the fifth spacecraft in the series. With the spectacular success of the first *Surveyor* spacecraft, a brief study was initiated by the Surveyor Instrument Development Section at the Jet Propulsion Laboratory to determine how soon a soil-manipulative device could be developed and integrated into the spacecraft design. The instrument developed as a result of that study was later mounted on the *Surveyor III* and *IV* spacecraft. On the *Surveyor III* mission, the surface sampler instrument was operated with great success, and the experiment provided valuable new data on lunar-surface properties. *Surveyor IV* spacecraft did not achieve a soft landing and all communication with the spacecraft was lost in the last few seconds of the terminal descent. The seventh *Surveyor* spacecraft, launched in January 1968, also carried a surface-sampling device.

The surface sampler as originally conceived for the *Surveyor* program in 1961 was a manipulative device that could pick up rocks and pebbles on the lunar surface and place them into a small hopper, which fed a grinding mechanism carried on the spacecraft. The finely divided powder produced from this grinding operation was then to be transported to two scientific instruments for analysis. The grinding apparatus was found to be unreliable, however, and this method of lunar material preparation was abandoned. The surface sampler was retained as a possible surface-manipulating device and after some changes and simplifications in design was ultimately carried on the *Surveyor III* spacecraft, which successfully landed on the moon on April 19, 1967.

The surface sampler described in this report was an instrument attached to the spacecraft (Figs. 1 and 2) and designed to operate in three coordinate planes, *X*, *Y*, and *Z*. The surface sampler was made up of two units. One unit was the electronic compartment or auxiliary, which housed the electronic system for the operation and control of the mechanism. The mechanism was a separate unit, which comprised the lazy tongs, the scoop, and the motors that moved the lazy tongs and the scoop door. Three motors at the base of the mechanism controlled the motion of the lazy tongs in azimuth, extension and retraction, and elevation. A fourth motor, at the end of the lazy tongs, controlled the opening and closing of the scoop door. The lazy tongs mechanism could elevate and lower, extend and retract, and move to the left and to the right a forward-mounted scoop. The scoop was similar to a small excavating shovel and it had a door that could be controlled to open or shut. The scoop position may readily be described in polar coordinates. The instrument allowed the operator to dig, scratch, push, pull, grasp at, and trench the lunar surface (Fig. 3). All of these operations were carried out on *Surveyor III* and were observed by the television camera on the spacecraft. Still-television pictures at a maximum rate of approximately one every four seconds were taken of the lunar-surface soil manipulation and much useful soil-mechanics information has been obtained from these pictures.

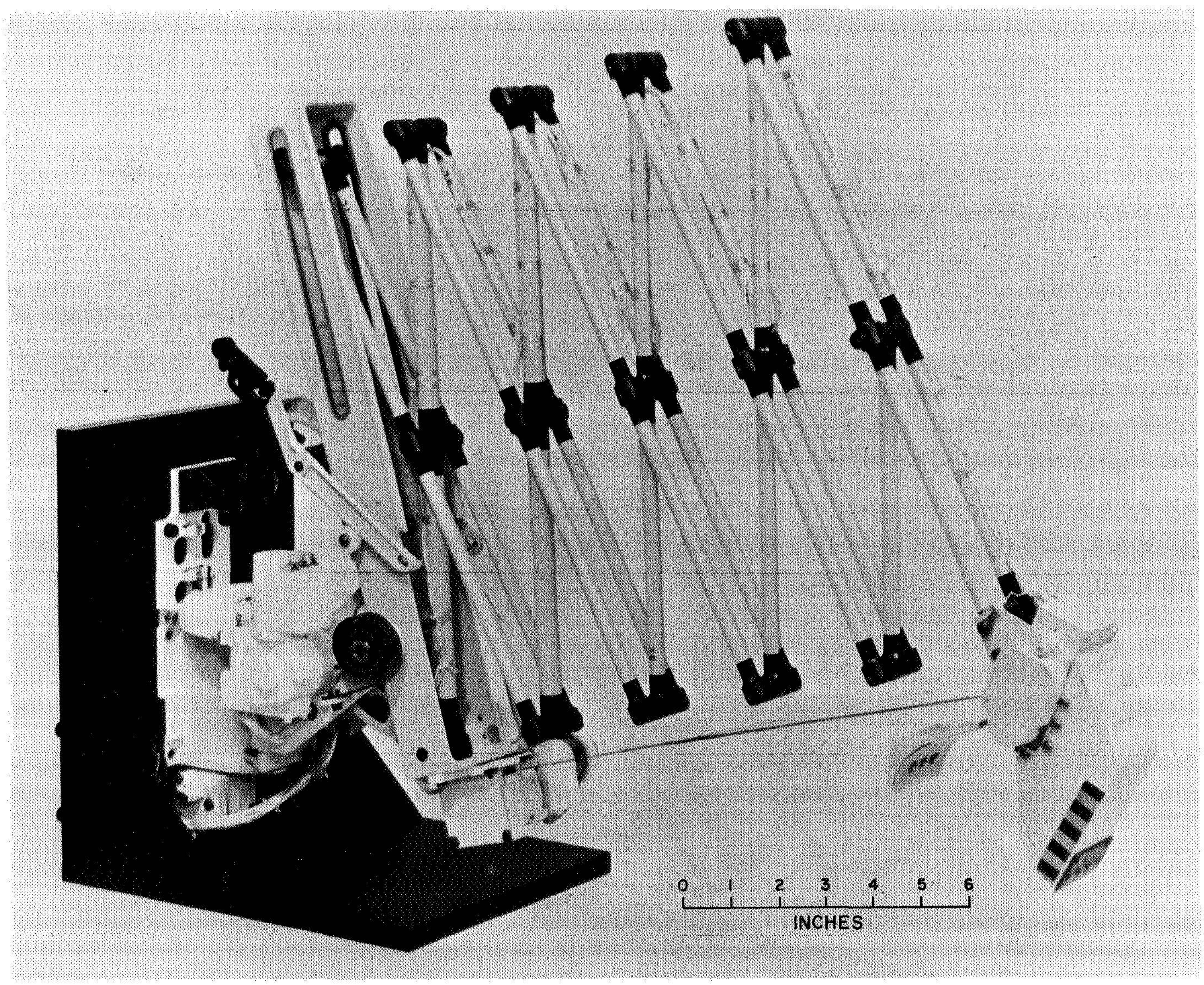


Fig. 1. Surface sampler

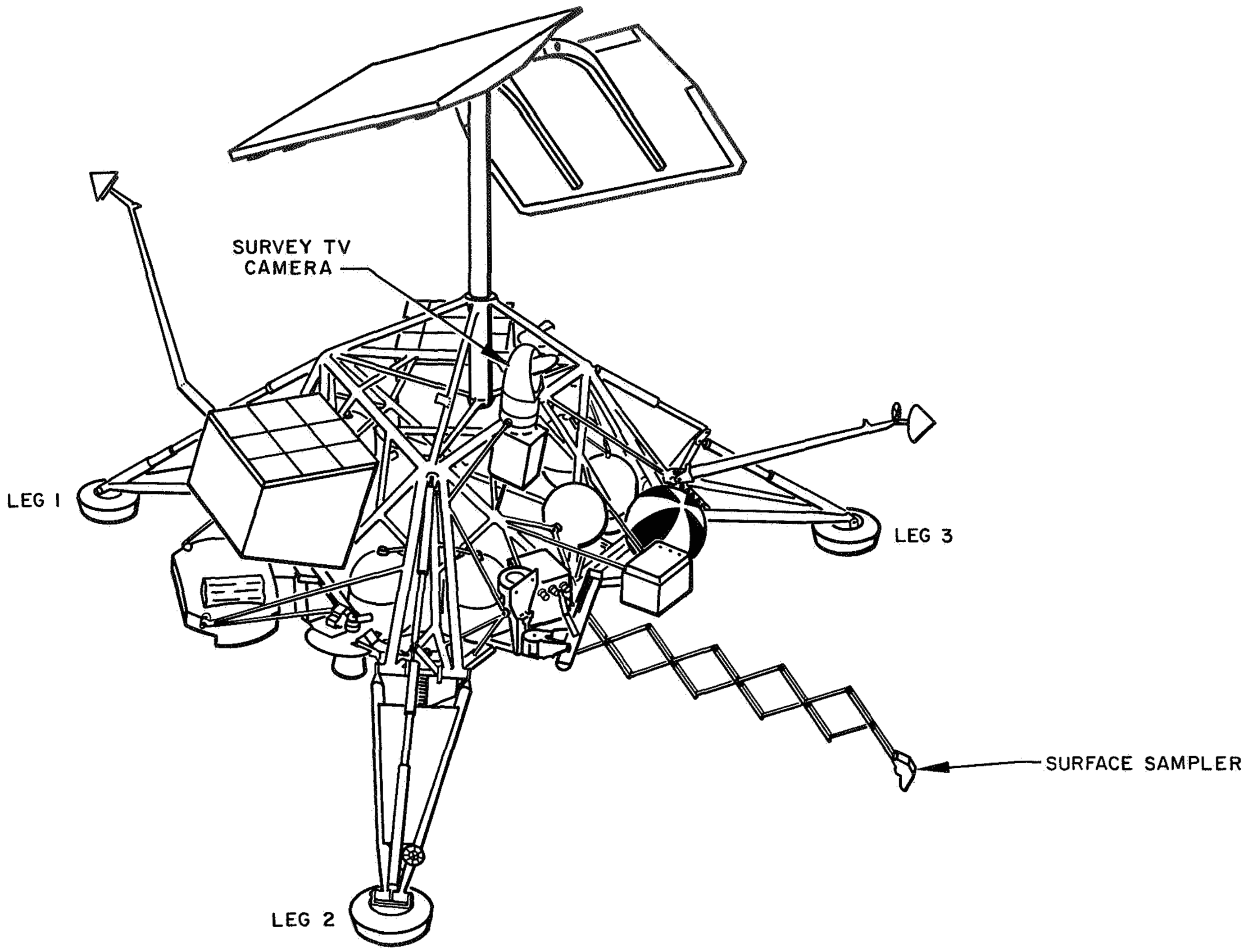


Fig. 2. Surveyor spacecraft (with surface sampler)

The soil-mechanics experiment as originally conceived for the later *Surveyor* spacecraft was designed around a soil-mechanics surface sampler of essentially similar design to the device described here. There are two significant differences between the two concepts, however. The experiment (which will now not be flown) planned for *Surveyors V, VI,* and *VII* was designed to use data obtained from strain gages mounted on the device and from an accelerometer or load cell on the scoop. Readings from these force- and acceleration-measuring instruments would have allowed quantitative results to be obtained during the manipulative sequences. No strain gage, accelerometer, or load cell was mounted on the instrument described in this report. In the original surface sampler, position potentiometers were mounted to give three readouts that would allow the position of the device to be determined. Because of lack of time and the absence of data channels, these potentiometers were omitted in the final instrument and its position was estimated by television pictures.

The development and fabrication of the surface sampler was carried out by the Hughes Aircraft Company (HAC) at El Segundo, California, for the Jet Propulsion Laboratory (JPL). The contractual arrangement to build and integrate the surface sampler into *Surveyor III* was completed on August 1, 1966, and the first completed instrument was delivered to the Air Force Eastern Test Range (AFETR) at Cape Kennedy for attachment to the spacecraft on December 19, 1966. Because of the short time available for the development of the instrument it was decided to utilize the existing instrument design, to

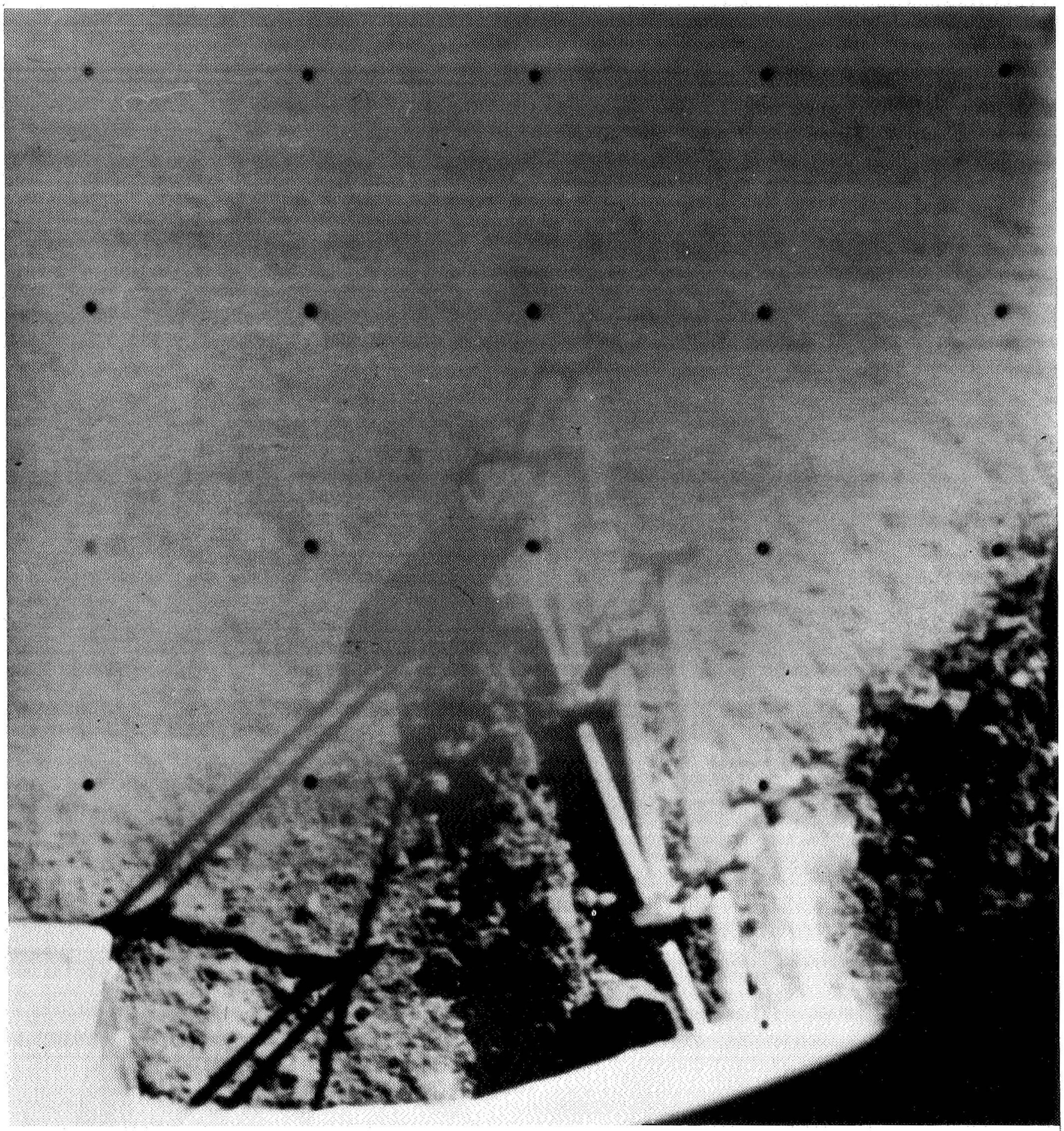


Fig. 3. A trench dug by the surface sampler

simplify it by removing the strain gages, the accelerometers, and the potentiometers, and to redesign it only where considered necessary. In order to avoid an electrical harness change on the spacecraft, the surface sampler was made to replace the approach television camera. Thus, the electronic auxiliary for the instrument was redesigned to be compatible with the existing approach-television electrical interface. Provision was made to return via telemetry channels a reading of the current drawn by any of the four surface-sampler motors once every 250 ms. Because of telemetry problems that developed on *Surveyor III,* which were unconnected with the instrument, this measurement proved to be of little use.

The principal investigator for the soil-mechanics experiment associated with the surface sampler on the moon was Ronald F. Scott of the California Institute of Technology. The cognizant scientist at JPL was Floyd I. Roberson. The development of the instrument at the Hughes Aircraft Company was under the direction of project engineer Edward R. Zinn. The cognizant engineer at JPL was Eugene Rouze.

II. Flight Hardware

A. Description

The final version of the surface sampler is shown in Fig. 1, and its location on the spacecraft is shown in Fig. 2. Initially it was intended that an approach television camera be mounted at this position; the camera was removed and an adapter plate was fabricated to permit attachment of the surface sampler to the spacecraft approach-television mounting bracket. The adapter plate is shown in Fig. 4. The location of the SS mechanism relative to the television camera and relative to footpad 2 is shown diagrammatically in Fig. 5. The mechanism was mounted just above the main lower spaceframe between footpads 1 and 2. Also shown in Fig. 5 is the location of the SS auxiliary, an internally insulated metal box that housed the surface sampler electronic system.

The surface sampler mount consisted of a support bracket (painted white) that served as an azimuth hinge for the mechanism, a mount and clevis for the squib stowage-release mechanism, and as a lock for the stowage yoke.

The open channel at the rear of the mechanism served as a structural basis; the "lazy tongs" or "scissors" provided the operable mechanism and also supported the scoop. Utilizing respective pivots, dc motors provided the surface sampler motion.

The lazy tongs device was retracted into the open channel and locked into this position by means of a spring-loaded yoke. This yoke was restrained in the mechanism locking position by means of a clevis and pin. To disengage the yoke for unstowing the lazy tongs, the squib of the squib pin puller was fired, thus moving the pin out of its locking position in the clevis. Released, the spring-loaded yoke rotated, thus releasing the lazy tongs. The tongs, though now released, were restrained by a steel retraction tape.

In the operation of the lazy tongs, a double-coiled spring wrapped about each exposed joint provides a continual application of an extension force. A motor-operated spool, mounted to the base of the channel, unwinds the steel restraining tape, thus permitting the lazy tongs to extend as shown in Fig. 6. Rotated in the opposite direction, the spool rewinds the tape, causing retraction of the lazy tongs and applying a maximum of approximately 20 lb pull on the scoop.

One motor and gearing provide azimuth motion; the elevation motor and elevation gear provide angular motion in the vertical plane. Each motor is operated by timed pulses. The scoop encases its own motor for operation of the scoop door.

The scoop consists of a hydroformed case, a scoop door operated by a motor through a coiled flat spring, and a hardened-steel chopping plate mounted to the scoop edge. The scoop door is strengthened by the addition of a laminated plastic base, which also provides a pressure plate for soil bearing tests.

The surface sampler is a completely noninstrumented system. There are no position potentiometers, strain gages, or accelerometers on the equipment to indicate forces or action of the mechanism. Except for the portion painted white (Fig. 1), and the joints, which were black, the surface sampler was light blue in color.

B. Project Management

Cooperating teams were set up at Hughes Aircraft Company and at the Jet Propulsion Laboratory. The primary responsibility of the Hughes organization was to provide the design and to develop, test, and deliver

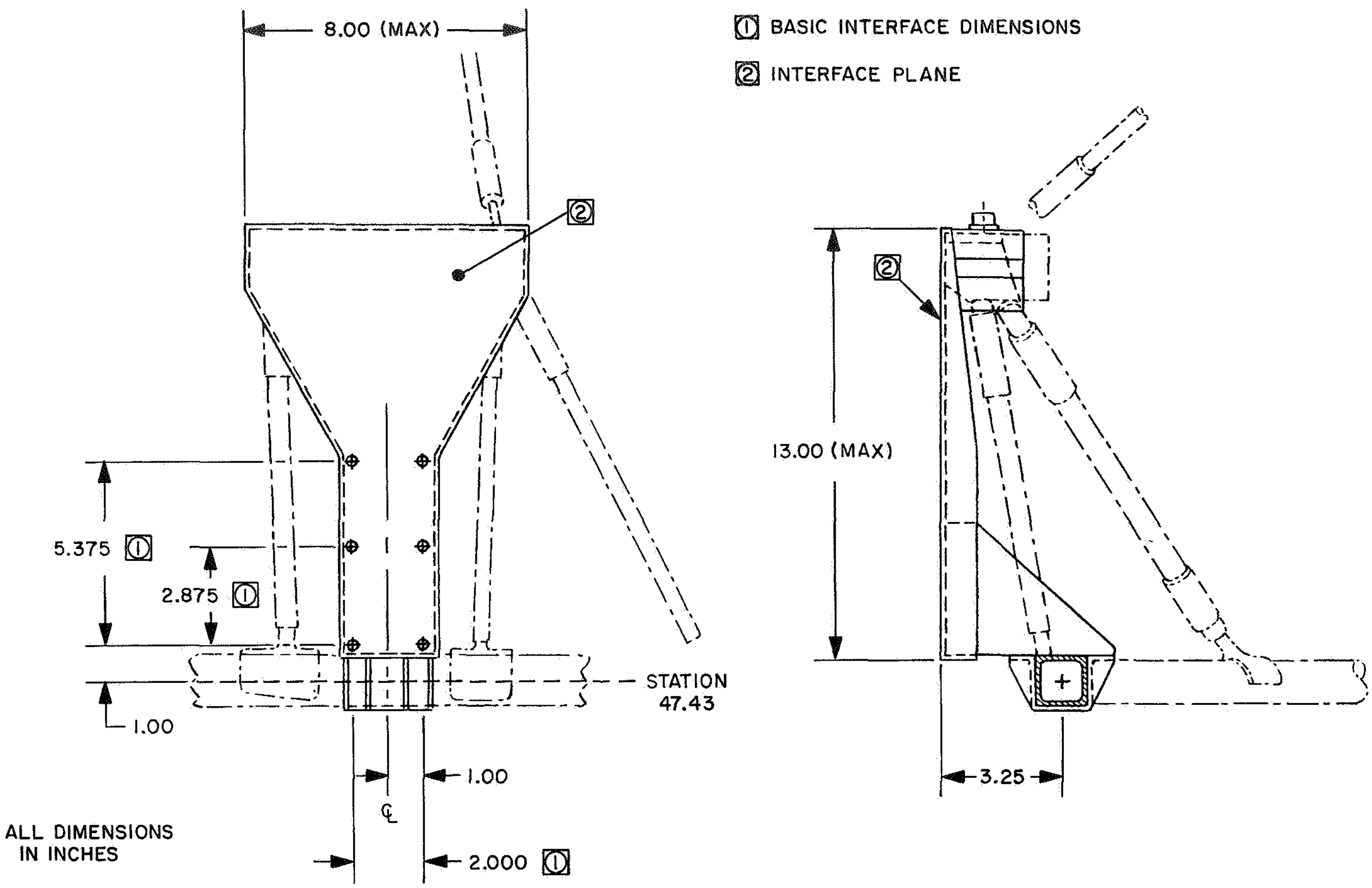


Fig. 4. Substructure of surface sampler mechanism

the hardware in accordance with the requirements of of the Jet Propulsion Laboratory. The chief responsibilities of the surface sampler organization at the Jet Propulsion Laboratory were to assure that the desires of NASA and of JPL were accomplished by HAC.

C. Schedule

The milestone chart in the Appendix gives the surface sampler schedule, which includes both scheduled dates and actual completion dates. It is obvious that there were slippages, and some of these caused considerable concern. As shown in the chart, the first major delay, or slippage, occurred for the completion of the final layout drawings. This, of course, was a major item, because finalizing of the design was necessary prior to fabrication. The surface sampler electronics auxiliary for *Surveyor III* was designed and fabricated without a slip in schedule.

Some of the early problems that required resolution were JPL-HAC agreement on the surface sampler specification; also agreement on the electronics design. Considerable effort was devoted to the wording and release of a Surveyor Quality Assurance Directive for the surface sampler. A great deal of study was given to the matter of an explosive squib and the dangers involved in an inadvertent firing. The squib circuit was designed with an attempt to avoid the possibility of accidental squib firing very much in mind.

The chart in the Appendix itemizes the milestone dates in detail; a few of the more pertinent were Project Go-Ahead, August 1, 1966; Auxiliary Circuit Design Complete, September 7, 1966; Mechanism Final Layout Complete, September 28, 1966; Motor Delivery, November 5, 1966; Mechanism Assembly Complete, November 17, 1966; and Auxiliary Complete, November 5, 1966. These milestones could be simplified further by quoting four milestones: the contractural "go-ahead" of August 1, completion of the auxiliary on November 5, completion of assembly of the mechanism on November 17, with the unit being available one month later. The original

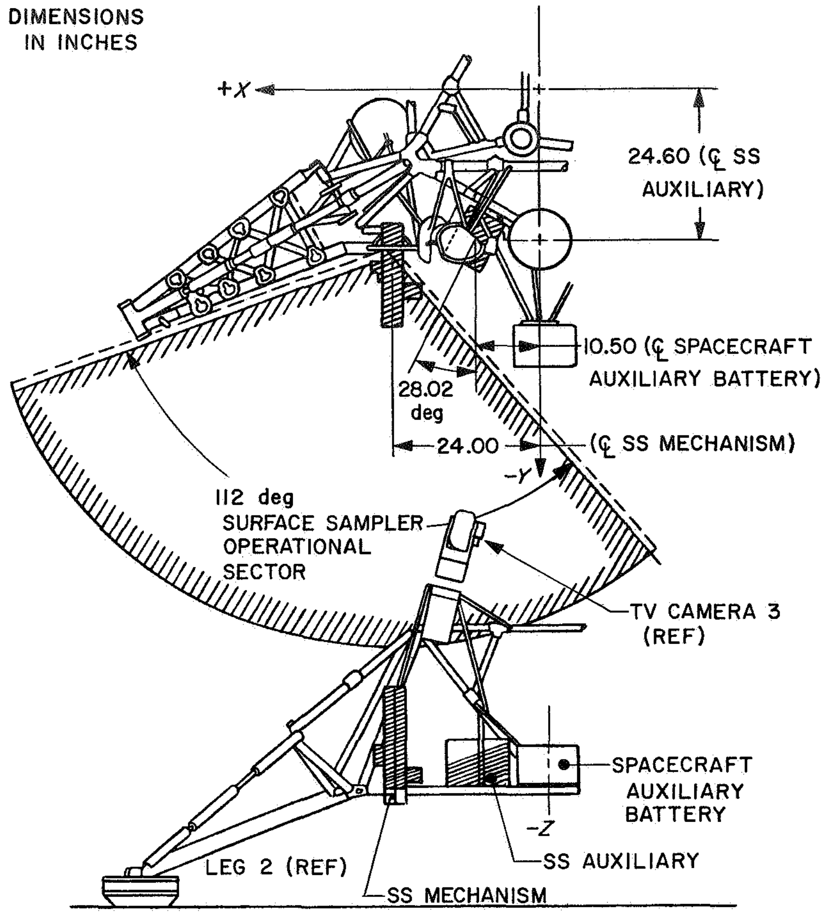


Fig. 5. Surface sampler physical arrangement

December 3 goal for delivery could have been met, but circumstances at the AFETR made it possible to take additional time for surface sampler testing.

D. Design

1. Mechanism. The basic concept of the surface sampler derived from a need for a device to acquire a portion of lunar soil and to transport it to, and deposit it in, an analyzing mechanism. Early prototypes of the surface sampler utilized a basic mount, an open channel, a lazy tongs, and a scoop with an operable door.

The redesign retained the basic idea, but with considerable modification. First, the lazy tongs members were strengthened. Secondly, the two extension springs that exerted force to "squeeze" the lazy tongs into an extended position were eliminated and replaced by individual coiled springs at each exposed lazy tongs joint. Acting collectively, the total extension force equals approximately 1.5 lb. A third major modification from the earlier design was the mode of elevation action. Early designs utilized a tape winding and unwinding simultaneously onto a double-ended spool. This caused difficulties inasmuch as the tape either had to be loose (causing sloppy motion) or would break when wound from one extreme to the other. The modified design utilized internal gearing.

A fourth redesign was in the scoop door operation. Previously, the scoop door was rigidly attached to a motor shaft, and limit switches were utilized in an attempt to stop the door motor at the appropriate time. This design created several difficulties; for example, either the motor coasted to a point beyond closing the door, causing the shaft to break loose and continue to rotate while the door remained stationary, or the motor stopped prior to the complete closing of the door. Another problem was that if the door was closed on a rigid object or on loose sand, there was no way to exert continuous pressure on the grasped object. In the redesigned scoop shaft, these problems were solved by not

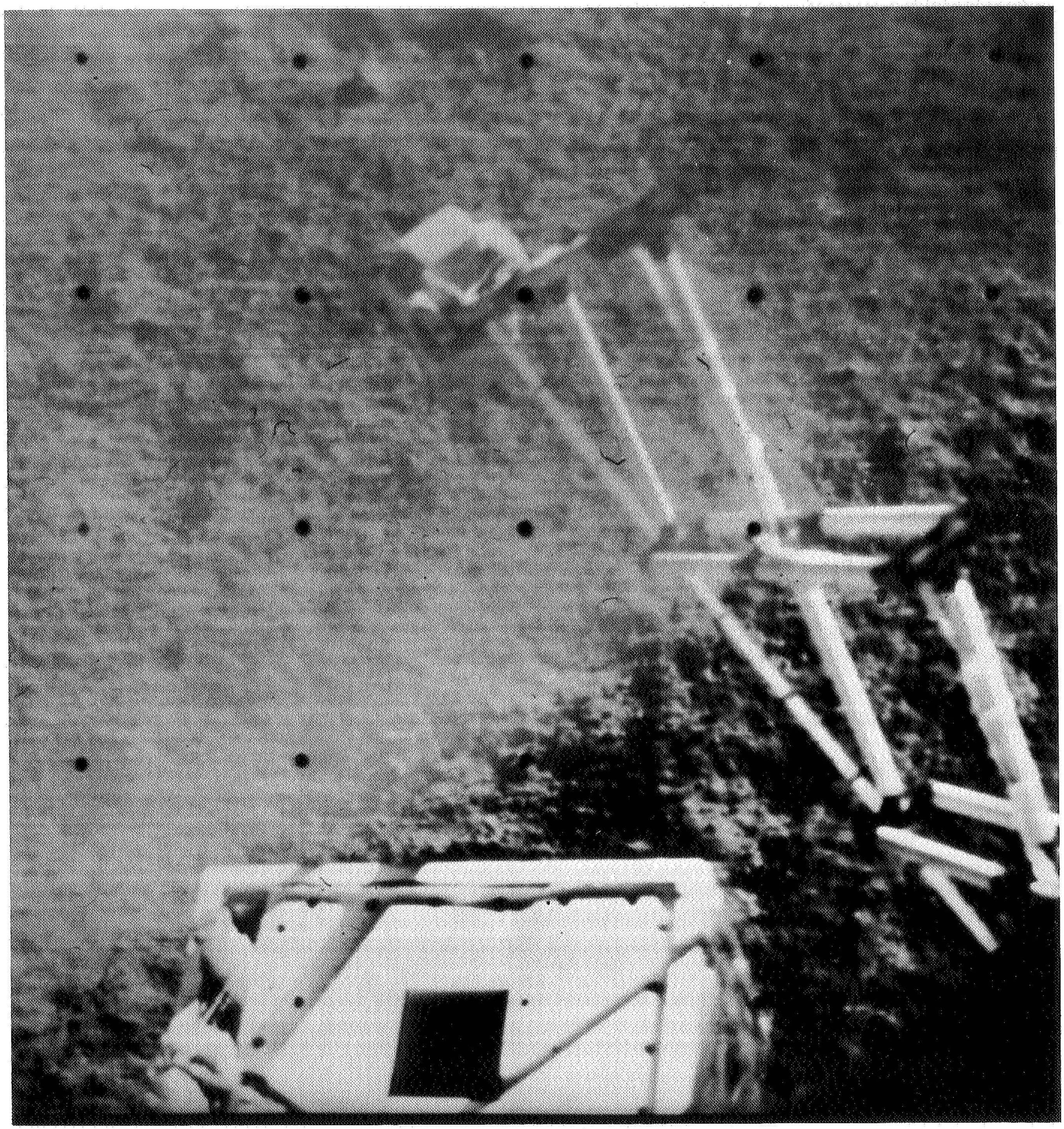


Fig. 6. Surface sampler, partially extended above lunar surface

connecting the motor shaft directly to the door. Instead, the scoop door was attached to a shaft that was connected to the motor shaft through a flat clock-type spring. This spring permitted 108-deg rotation before tightening around the shaft to the point where the two shafts acted as a direct drive on the door. A 108-deg rotation of the motor shaft relative to the scoop-door shaft placed a 2.3-in.-lb torque loading onto the scoop door. Therefore, if sand or a rigid object were grasped between the scoop and the scoop door, even though the motor was stationary, the scoop door, by means of the shaft spring, continued to press on the object grasped.

The surface sampler included a "chopping" or "picking" spring. The design also incorporated a solenoid-operated elevation clutch. By elevating the surface sampler scoop above the lunar surface, and by instantaneously disengaging the elevation gear from the lazy tongs assembly, and assisted downward by torque exerted by the picking spring, the knife-edge of the scoop (with the scoop door opened), or the laminated plastic pressure plate attached to the door (the scoop door closed), would sharply impact whatever existed at the time below the scoop. Experiments at Hughes Aircraft indicated that the surface sampler used in this manner had the capability of chopping, or splitting, a common building brick in two. A preloading of 16.2-in.-lb existed on the surface sampler when it was extended in a plane horizontal to the *X-Y* plane of the *Surveyor* spacecraft.

The surface sampler served as an operable "hand" of the *Surveyor* spacecraft. Powered by small dc motors, the mechanism could extend and retract, move left azimuth and right azimuth, move up and down in elevation, and the scoop door could open and close. Each plane of operation was actuated by a motor. The motors were continuous but were operated by timed pulses, thereby permitting the operator to position the scoop at a desired location. Pictures of the surface sampler could not be taken while the sampler was operating, so the mechanism was moved, photographed, and moved again until accurately positioned. Figure 7 shows the surface sampler at the far end of a trench dug in the lunar surface.

2. Joint Test Program. Almost at the inception of the surface sampler program, about August 10, 1966, a Joint Testing Program was initiated. Because the lazy tongs joint had undergone redesign, it was desired to test both the original bearing design, which used a glass-reinforced Teflon bushing, and the new bearing design, which used Lubeco 905 instead of Teflon at all bearing points, and to compare results. The test was performed in a high-vacuum chamber at Arthur D. Little, Inc., Cambridge, Mass., and required about five weeks. The test was conducted by R. E. Imus of JPL and V. A. Peckham, Jr., of HAC. A complete report of the test, including data, was written and published by V. A. Peckham, Jr.[1] Figures 8 through 11 show the two bearing designs and the schedule of tests for each. Table 1 summarizes the design and performance characteristics of the Lubeco 905 bearing. The following excerpts from the Peckham report summarize the main findings of the tests:

> A journal bearing utilizing Lubeco 905 (molydisulfide) was successfully operated in a vacuum of 10^{-11} to 10^{-12} torr for a period of 12 days. Bearing friction dropped throughout the test but had apparently reached its lower limit at the conclusion of the test. After it was run for nine days in a vacuum, the difference between its static and its running friction almost disappeared. This reduction in friction could not be attributed to burnishing because the friction rose immediately to its original value when the bearing was re-exposed to the air.
>
> A bearing with a glass-reinforced Teflon bushing was similarly tested. Unexpectedly, this bearing did not perform as well below 0°F as did the one using Lubeco 905. It was tested in high vacuum for seven days. It appears that temperature had more effect on its friction than vacuum did.
>
> The surface-sampler lazy-tongs mechanism is being redesigned to use Lubeco 905 instead of Teflon at all bearing points. Since Teflon has the lower coefficient of friction in air and no stick-slip characteristic, it was necessary to know how much the change to Lubeco 905 would affect bearing performance, particularly in high vacuum. A special test fixture was designed to test the Lubeco journal bearing at 240 psi. The Teflon bearing was checked at 115 psi. Arrangements were made with Arthur D. Little, Inc., to use their high-vacuum chamber for the test that covered a range of temperatures from +300°F to −195°F.

3. Motor rework. One area of difficulty experienced with the protoype surface sampler was the action of the motors and the motor gear trains. The problem was due primarily to the lubrication used by the manufacturer and the environment to which the motors were to be subjected. Also involved was the material used by the manufacturer in the fabrication of the brushes. The brush material initially used would arc and rapidly show excessive wear at high vacuum.

The grease lubricant originally used by AiResearch Manufacturing (manufacturer of the motors) would become stiff at low temperatures; the coefficient of friction became so great in the motor bearings and in the gear trains that the motors would not function properly.

[1]*Thermal Ultra-High Vacuum Test of SMSS Journal Bearing—Surveyor,* Report 2774.2/3, Hughes Aircraft Co., El Segundo, Calif., Oct. 17, 1966.

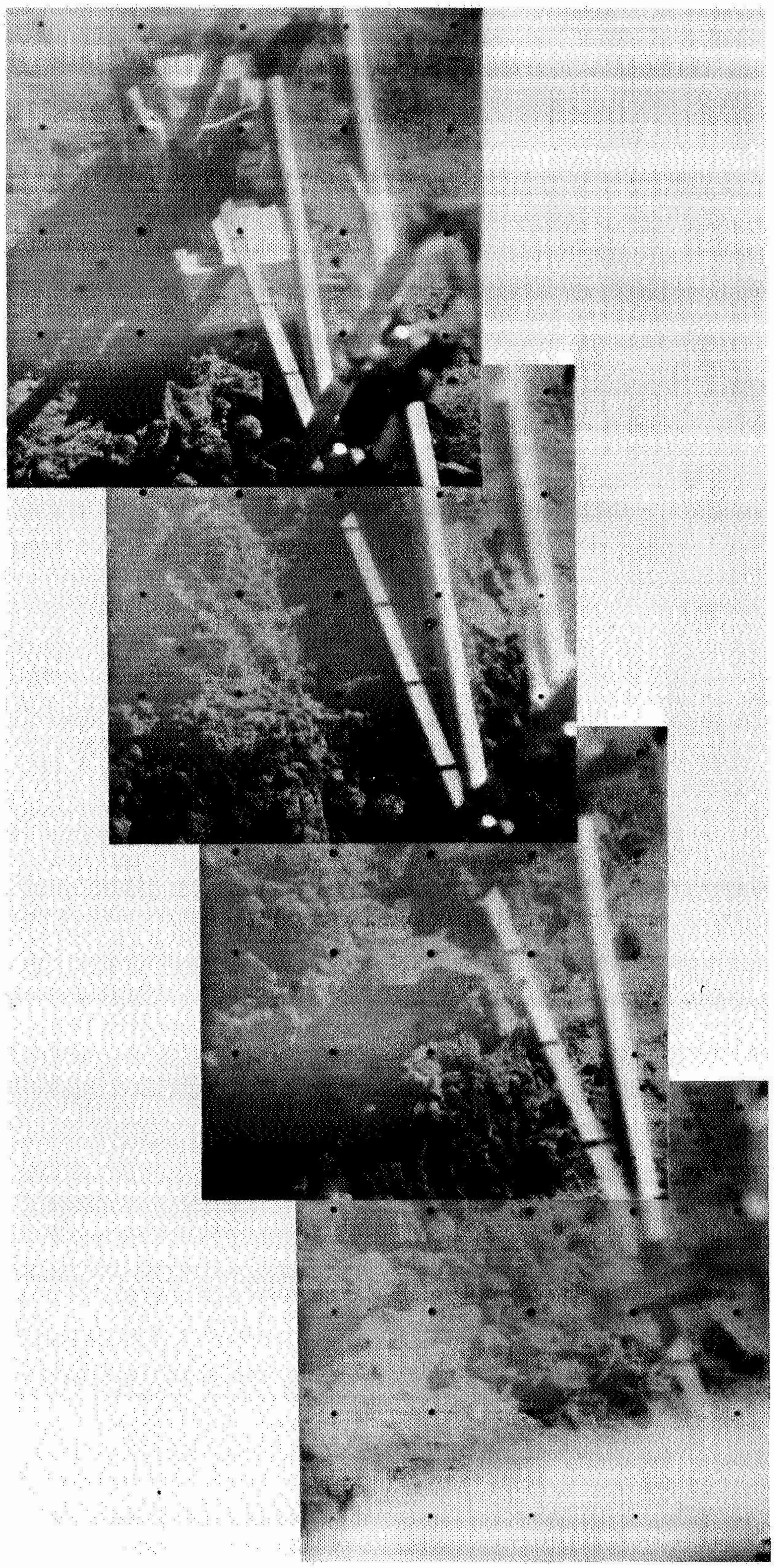


Fig. 7. Narrow-angle view mosaic showing surface sampler at far end of trench 15 in. long and 2 in. wide. Scoop door is open; position markings show on drag tape

Table 1. Lubeco 905 bearing and its performance (taken from HAC Report 2774.2/3)

Environment	Ultra-high vacuum at various temperatures
Chamber	12 in. in diameter x 18 in. long; evacuated with an ion pump and a liquid-helium cryopump
Temperature range	+300 to −190°F
Shaft material	Stainless steel coated with Lubeco 905 (molydisulfide)
Material of journal bearing	Aluminum coated with hard anodize and Lubeco 905
Angular movement	30 deg
Bearing loading	240 psi
Approximate bore	0.243 in. in diameter
Diametral clearance	0.0004 in. inboard; 0.0005 in. outboard
End play	0.005 in.
Test Results	
Cycles	3500+
Bearing wear	0.0002 to 0.0003 in.
Time at 5 x 10^{-11} torr or lower	12 days
Coefficient of friction:	Temperature, °F:
0.330	Ambient air
0.190	300
0.140	260
0.145	200
0.105	100
0.090	0
0.100	−65

Furthermore, the excessive outgassing from the petroleum lubricant was entirely unacceptable. These difficulties forced Hughes Aircraft to have the motors reworked to remove the petroleum lubricant and to replace it with a dry lubricant.

The time allowed by the schedule for delivery of a surface sampler was tight. AiResearch Manufacturing, who designed the motors and held the original design drawings, was given a contract to rework the motors so that their life and operating characteristics in vacuum were improved. In addition, a parallel effort was initiated at Hughes Aircraft to rework some of the existing motors. As the work progressed it became apparent that one of the more critical items was the dry lubricant used in the motor to provide smooth operation in the space environment. Hughes Aircraft chose to use Lubeco 905, a molybdenum disulphide dry lubricant, in the motor bearings and gearing. This lubricant was already qualified for *Surveyor* use with

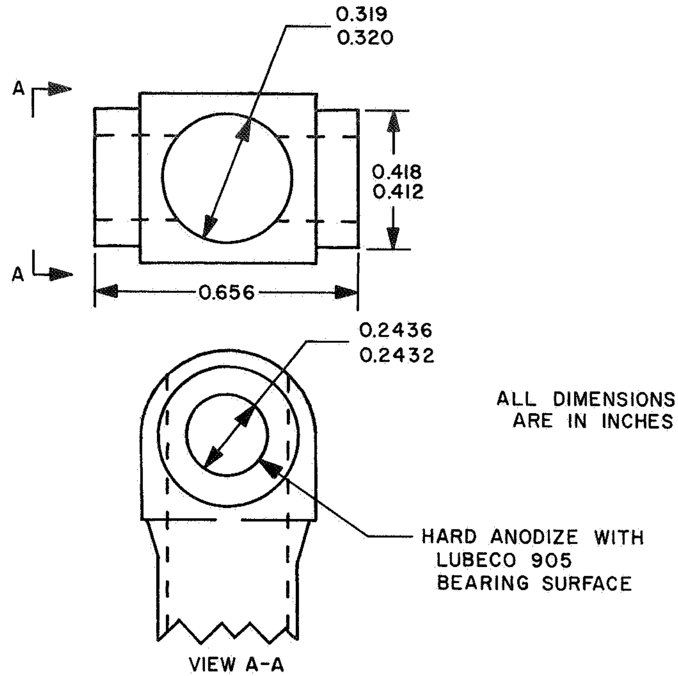


Fig. 8. Surface drawing of Lubeco 905 journal bearing (taken from HAC Report 2774.2/3)

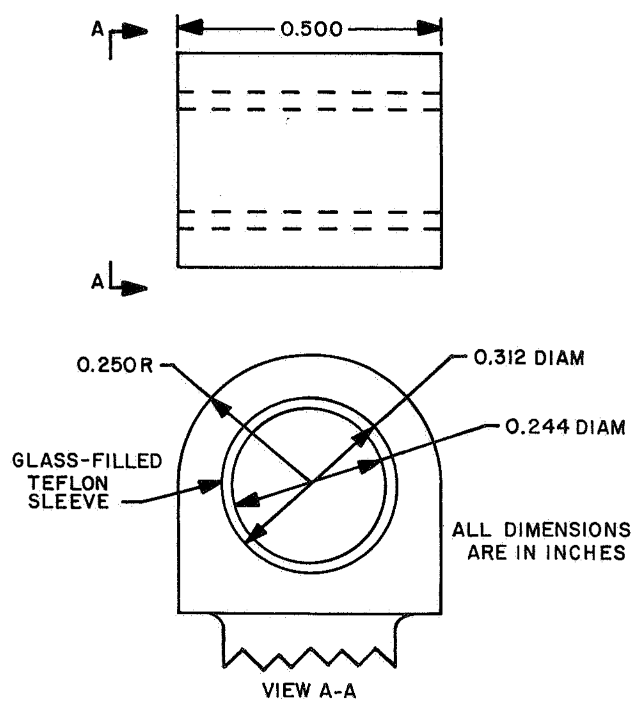


Fig. 9. Surface drawing of Teflon bearing (taken from HAC Report 2774.2/3)

the television camera system. Boeing 046-45 compact brush material was used for the brushes. Hughes' work on the motors was successful and it was therefore decided to use the Hughes reworked motors on the surface sampler, with the AiResearch motors serving as a second source. Delivery of the motors reworked by Hughes Aircraft was compatible with the schedule established for the surface sampler.

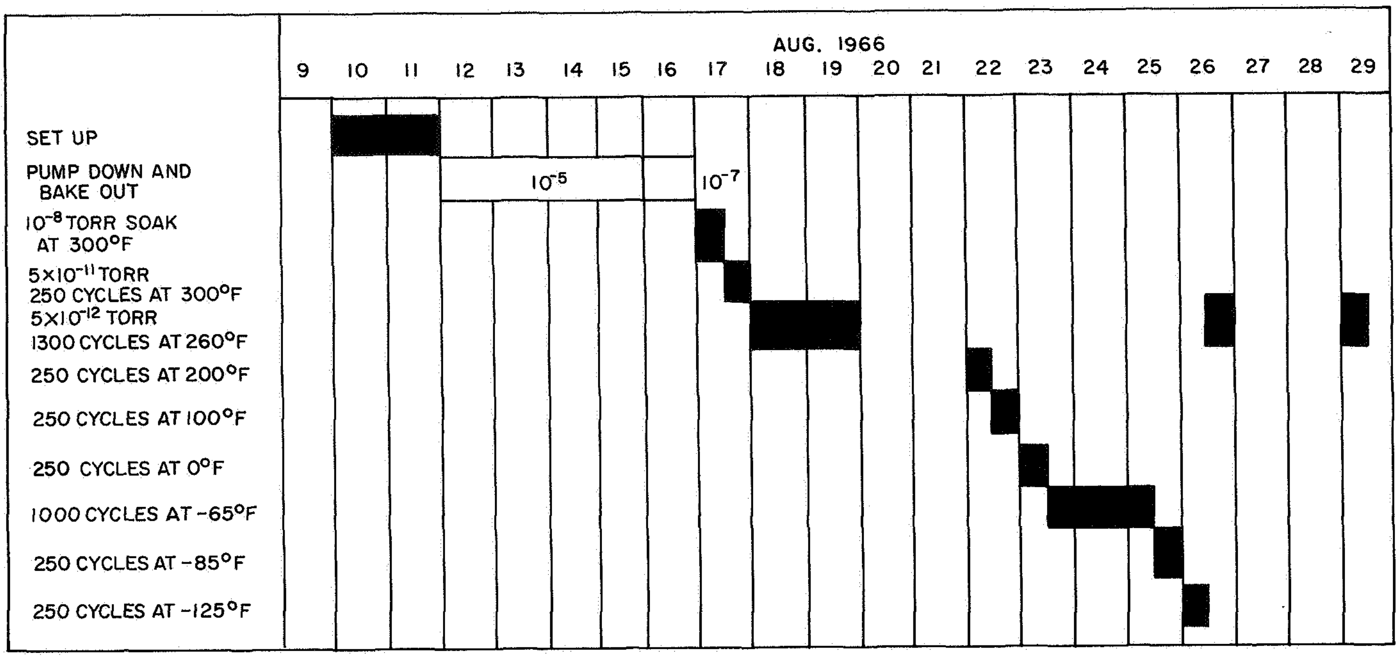


Fig. 10. Schedule for tests of Lubeco 905 bearing (taken from HAC Report 2774.2/3)

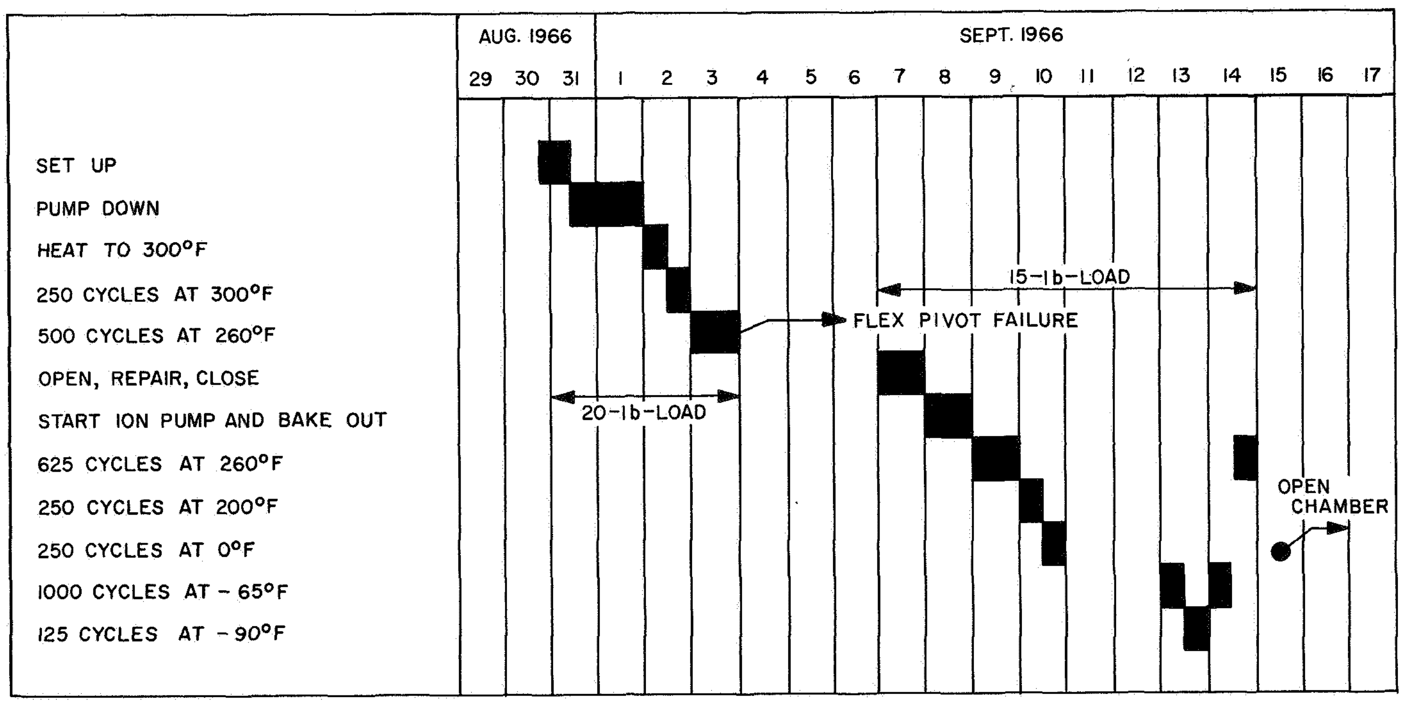


Fig. 11. Schedule for tests of Teflon bearing (taken from HAC Report 2774.2/3)

A complete report of the motor rework program was prepared by A. L. Vodopia and approved by N. R. Kramer,[2] both of Hughes Aircraft Company. A summary of that report is given in the following excerpt:

Drive Motors Summary

The reversible drive motor assemblies for positioning the scoop in extension-retraction, azimuth, and elevation, and for operating the scoop door, consist of a direct current motor, an integral gear train, and a radio noise filter. The elevation drive motor assembly in addition includes a positive latching clutch which can be disengaged from the gear train by actuation of a solenoid. The motors are designed to withstand stall without damage, and a reasonable margin is provided between the upper limit of stall current and the rating of the fuse in the Auxiliary.

Improvements which were incorporated in the motors have been determined as a result of testing of existing motors received from the supplier (AiResearch), and experience gained from testing other components since the original motor development effort was initiated. Procurement and schedule problems dictated that a parallel effort by HAC and AiResearch be followed to assure the availability of motors. Thus, one group of motors were reworked at HAC and the other group of motors were reworked at AiResearch. Barden "Bartemp" bearings were used where the sizes were available. The further rework of all motors incorporated "Lubeco 905" dry film lubricant on the gears and other bearings and rubbing surfaces, Boeing 046-45 compact brush material to minimize the generation of RFI and to extend brush life, and the strengthening of the output shafts where necessary to withstand expected forces.

4. Operation. The operational capabilities of the surface sampler described in this section are further discussed with respect to mission operation in Section VI. The electronic controls and command-operation techniques are detailed in Section III. Suffice it to mention here that a wiring harness provided the electrical connection between the spacecraft and the surface sampler (SS) auxiliary, which housed the electronic system for operation and control of the SS mechanism. The mechanism, which was mounted on the spacecraft so as to permit azimuth and elevation motion, was designed for digging, scratching, and scooping the lunar surface under the photographic "eye" of the television camera. Other than motor current, no data were to be telemetered back to earth.

The SS mechanism was designed to operate within a specified space envelope, which is illustrated in Fig. 12. As shown in this diagram, the SS mechanism was capable of moving 112 deg in azimuth and 54 deg in elevation. This motion permitted the scoop to move to a possible penetration depth of about 18 in. (assuming a level lunar surface), and to extend over spacecraft footpad 2 to a distance of about 2 in. This extension permitted the scoop to be positioned over the attitude-control gas jet. Extreme azimuth motion away from footpad 2 was limited by the spacecraft auxiliary battery. Extreme upward vertical motion was 18 deg above horizontal, or a total height above the lunar surface of slightly more than 30 in.

Extension of the scoop was empowered by coiled springs at the joints of the lazy tongs and, therefore, the pushing force was low—approximately 2 lb. Retraction caused by rewinding of a steel tape—which was attached to the scoop—by means of a retraction motor, exerted approximately 20 lb of pulling force. The downward force equaled about 8 lb, and the lateral (azimuth) force was fractional.

A solenoid-actuated device permitted instant release of the elevation clutch. This action permitted the scoop to be dropped, with the dropping velocity accelerated by a clock-type spring mounted for this purpose.

Figure 13 diagrams the area that is blind to the television camera; also shown is the area of surface sampler scoop operation. The relatively small, scimitar-shaped overlapping area indicates the region in which the surface sampler is capable of operation, but where it is not viewable by television.

Thermal restrictions were established on both the SS mechanism and the SS auxiliary for both operation and nonoperation periods. Temperature restrictions on the SS auxiliary are discussed in Section IV. Temperature restrictions of the SS mechanism were determined primarily by the motors. Temperature limits for the mechanism in a nonoperating phase without danger of functional degradation are +300 and −300°F. The upper temperature limit of the nonoperational mode has never been precisely determined, but a safe high-temperature limit is considered to be at least +300 to a probable +500°F. The operational temperature restrictions are specified as −40 and +257°F. The surface sampler has been operated at these temperatures with no degrading effect evident.

Because of weight and power-availability limitations, the strength margins of safety were designed to a minimum. The design loading margins of safety were 10% for yield and 25% for ultimate for the SS mechanism and the SS auxiliary; they were zero for yield and 10% for ultimate for the substructure.

[2]SMSS Drive Motors Report, Dec. 9, 1966.

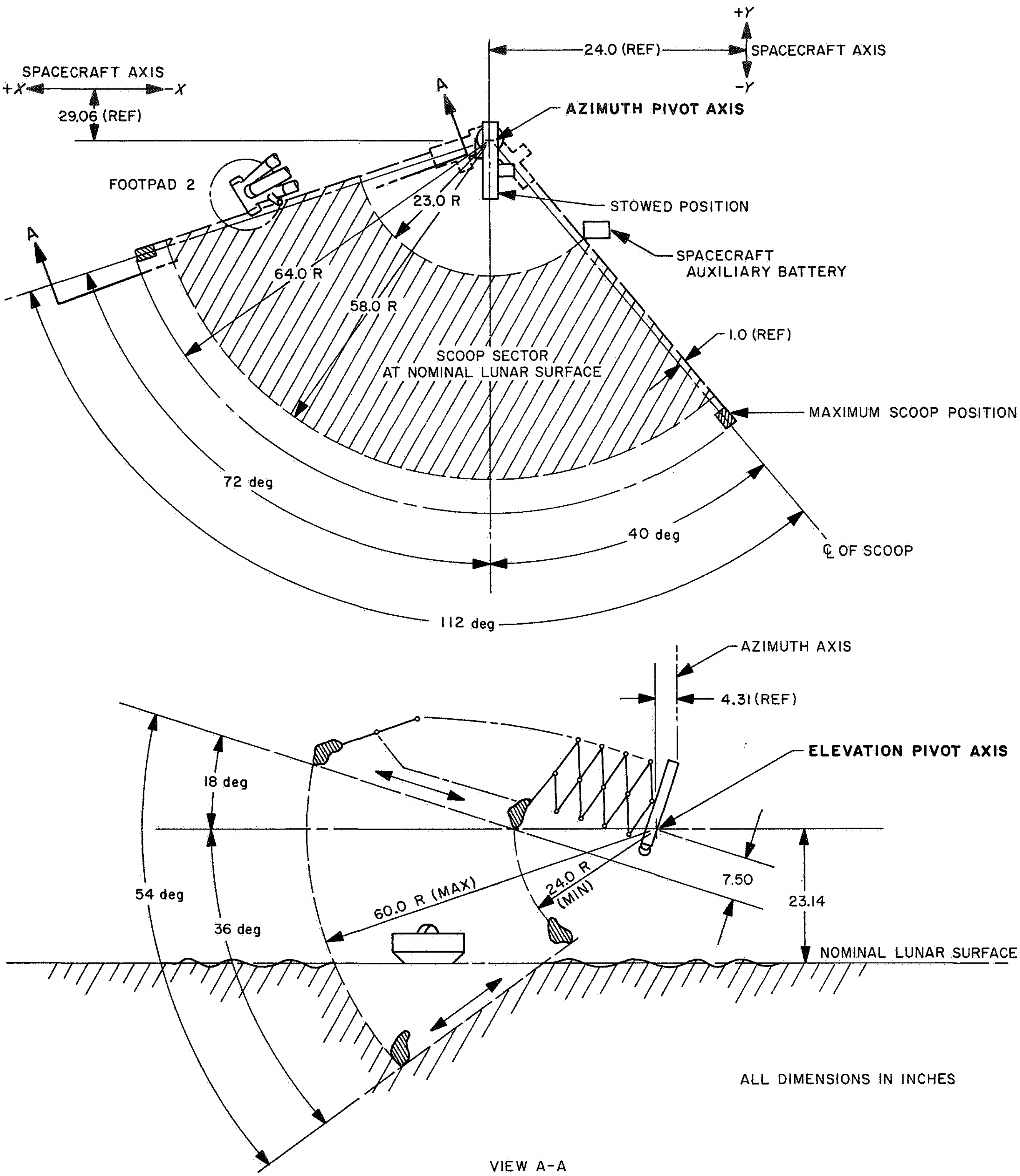


Fig. 12. Space envelope of operation, surface sampler mechanism

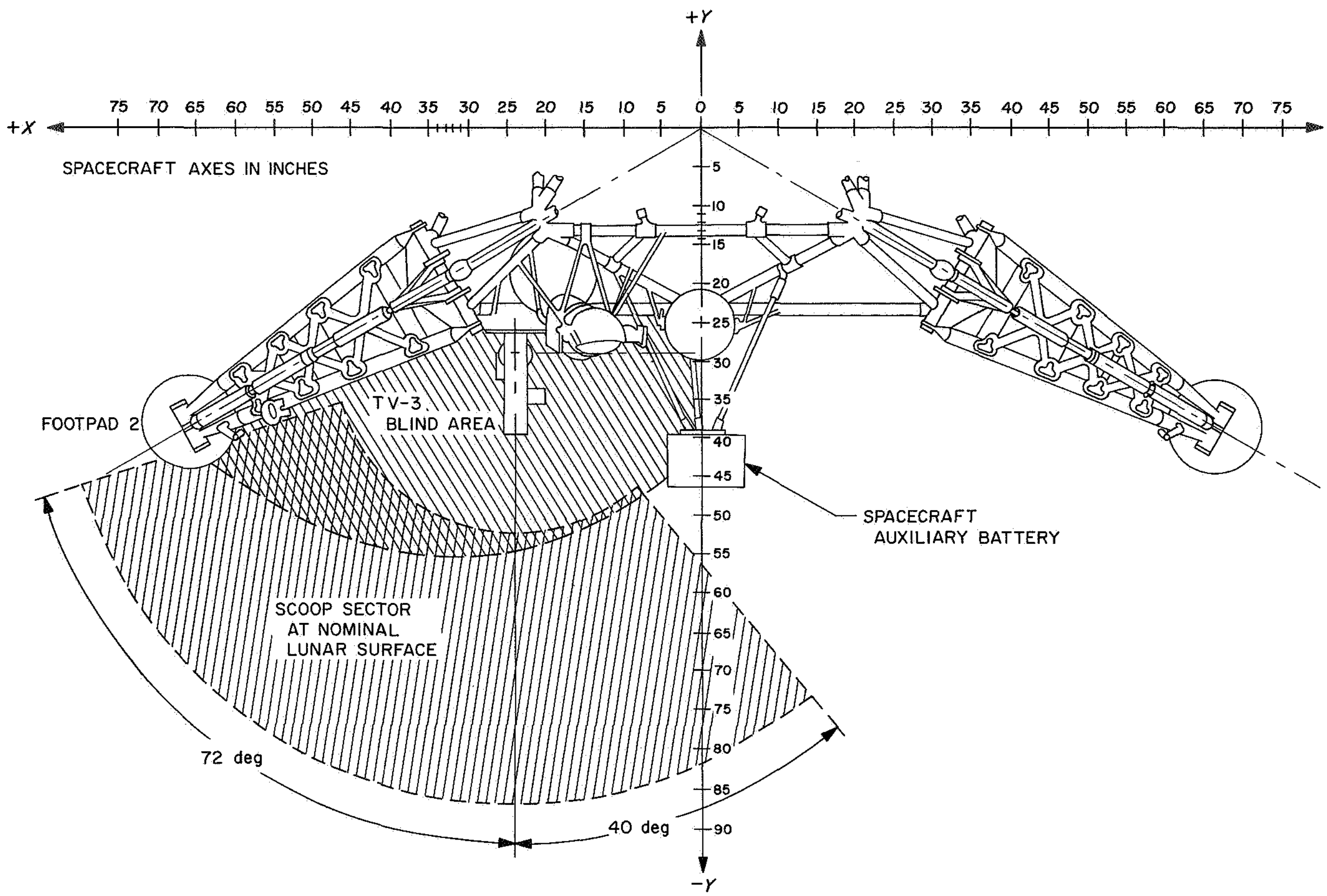


Fig. 13. Area of television viewability

Early in the program the surface sampler finish became an object for study by both the temperature groups and those interested in television picture quality.

A white color was considered for thermal properties, but was eliminated because of the probability of TV flare. Black was discarded because of little anticipated contrast with the lunar surface. A light-gray color was acceptable by both television and thermal interests. However, inasmuch as there was a color wheel utilizing a clear filter plus three different color filters, and since a pastel color offered the same thermal values as gray, it was decided to paint the surface sampler a light blue. This would permit the operators to vary the contrast of the surface sampler relative to the lunar surface by simply varying the color filters during lunar operation.

The original schedule did not permit time for extensive surface sampler tests, nor for much on-spacecraft testing. However, because of delays encountered during spacecraft checkout and testing at AFETR (Fig. 14), more time became available for surface sampler testing. At the request of the cognizant scientist, the prelaunch testing was greatly expanded to include many tests on the surface sampler that were not originally planned. Hughes Aircraft prepared an all-inclusive master test procedure,[3] which was documented in such a manner that a test director could set up any desired tests, or combination of tests, simply by specifying the section numbers from the master test procedure. Unit, subsystem, and system thermal-vacuum testing was performed. The only major design change that resulted from the testing was increasing the thickness of the locking cams because there were some indications that they might become unhooked from the stowing yoke during vibration.

5. Weight. Weight is of utmost importance to any part of a spacecraft payload. Extreme effort was expended to design the surface sampler hardware as light in weight

[3]Special Test No. 176, SMSS A-21 Spacecraft Compatibility

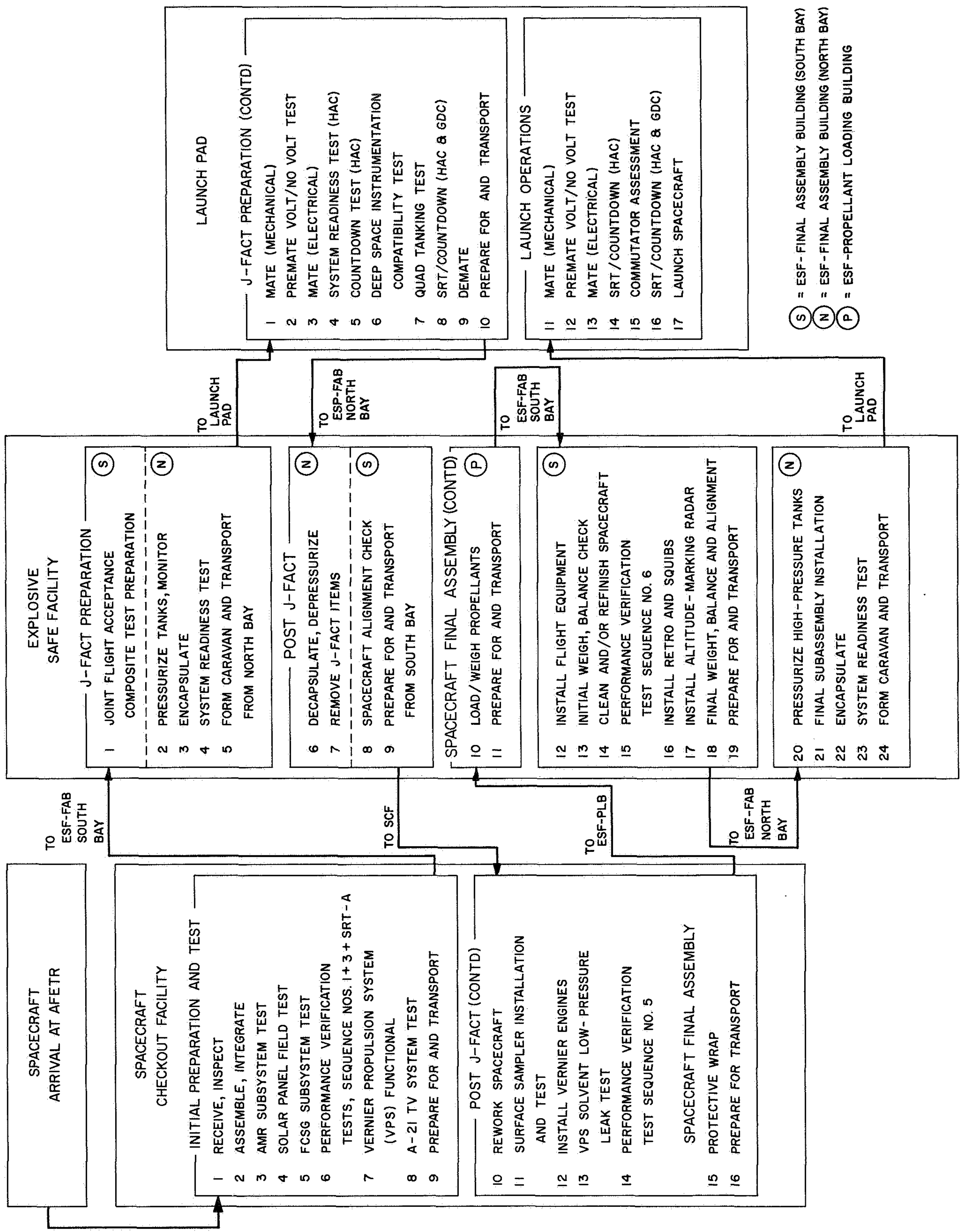


Fig. 14. AFETR operational flow

as possible and still permit a required margin of safety in strength. A more extensive discussion of the system stress analysis is given in Section V.

A protoype of the surface sampler was designed and built early in its history. With actual hardware available, accurate weight estimates could therefore be made. The total weight of the original protoype was 13.68 lb. Since the flight model replaced the approach television camera, a design change was required in the electronic auxiliary and in the mounting hardware, thus causing about a 5-lb increase in weight.

A breakdown of surface sampler subsystem weights appears in Table 2.

Table 2. Surface sampler subsystem weights

Subsystem element	Weight, lb
Mechanism	8.40
Auxiliary	6.40
Substructure and mounting hardware	2.60
Wiring harnesses	.70
Subsystem total	18.10

III. Surface Sampler Electronic System

The surface sampler auxiliary is the electronic system that provides the required command decoding, data buffering, power management, squib firing, and control of the SS mechanism motors and clutch. Because the surface sampler was to replace the approach television camera, the development of the SS auxiliary was governed by a spacecraft interface constraint, and only those electrical interfaces that had been established for the approach camera could be employed.

A. Command Generation

The approach TV electrical interface had only six command leads, two of which were directly related to temperature control. In addition, there was no squib-firing interface with the spacecraft engineering mechanisms auxiliary. Since a minimum of 15 commands were required for deployment and control of the SS mechanism and only four usable commands existed in the approach TV electrical interface, a unique approach was employed in the generation of surface sampler commands.

In the standard *Surveyor* command structure a series of digital bits is transmitted to the spacecraft. The logical levels and sequence of the series of bits determine the routing of the command signal through the spacecraft electrical interfaces. As an end result a single on-off pulse of nominally 20-ms duration appears on a specific command lead. Now if two such command leads are available, it is possible to construct an N-element shift register that is capable of generating $2N$ unique logical combinations. When this is accomplished, all that remains is to provide a decoding matrix, a signal that initiates execution of the coded command, and a means of clearing the shift register for use in generating subsequent coded commands.

The foregoing philosophy was implemented by designing the SS auxiliary to provide a clock pulse conditioner, four-element command register, count register, command enable latch, command pulse amplifier, a 16-command decoding matrix, and a reset buffer one-shot. A functional block diagram of the SS auxiliary along with its electrical interfaces is presented in Fig. 15. The four usable command signals from the approach TV interface along with their octal command numbers were reassigned as follows:

(1) 0131 Surface sampler power on/execute

(2) 0132 Surface sampler digital one

(3) 0133 Surface sampler digital zero/reset

(4) 0134 Surface sampler power off

B. Interface Command Functional Description

0131 Surface sampler power on/execute

Transmission of this interface command when the SS auxiliary is off applies 29 V regulated nonessential power to the auxiliary electronic system and automatically generates a reset pulse to clear the command register. Transmission of this interface command after a combination of four digital *ones* and *zeros* have been transmitted to the turned-on SS auxiliary results in execution of the command, which has been coded into the command register. Transmission of this interface command when the SS auxiliary is on and four digital bits have not been transmitted has no effect.

0132 Surface sampler digital one

Transmission of this interface command when the SS auxiliary is on results in generation of a clock pulse that gates a digital *one* into the command register. Transmission of this interface command when the SS auxiliary is off or after four digital bits have been entered in the command register has no effect.

0133 Surface sampler digital zero/reset

Transmission of this interface command when the SS auxiliary is on and four digital bits have not been entered in the command register results in generation of a clock pulse that gates a digital *zero* into the command register. Transmission of this interface command after four digital bits have been entered in the command register results in generation of a reset pulse that clears the command register. Transmission of this interface signal to the SS auxiliary when it is off has no effect.

0134 Surface sampler power off

Transmission of this interface command after the SS auxiliary has been commanded on removes 29 V regulated nonessential power from all elements of the auxiliary except the *on/off* low-power latch. Transmission of this interface command when the SS auxiliary is off has no effect.

The functional description of the four interface commands is summarized in Table 3. Table 4 lists the logical

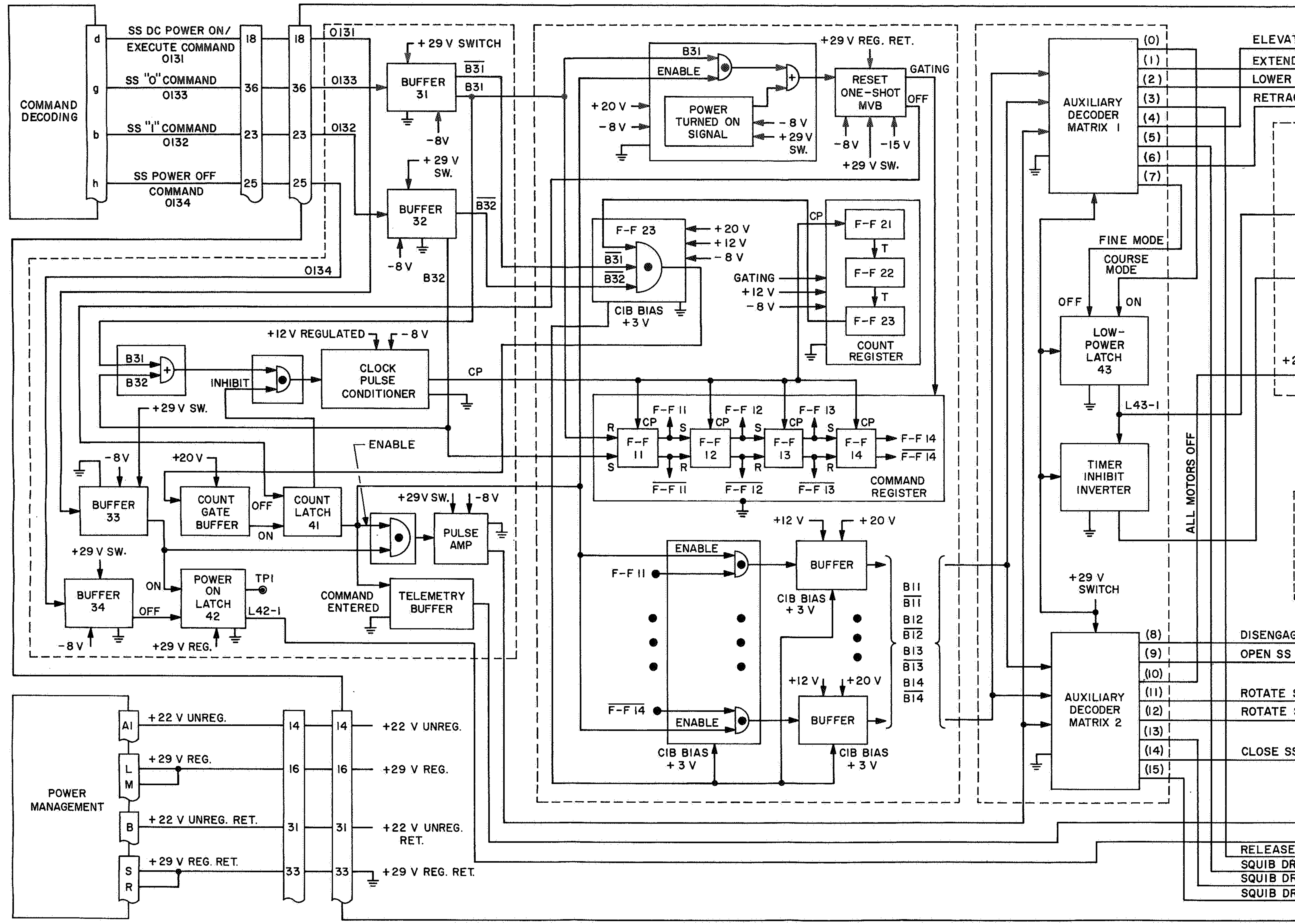
Table 3. Command assignment to SS auxiliary decoder

Octal command number	Command	Function
0131	SS decoder power on/execute	Applies +29 V power to SS auxiliary or executes a command when four bits are in the command register.
0132	"1" level input	Enters a "1" into the command shift register.
0133	"0" level input	Enters a "0" into the command shift register. Clears command register if transmitted after four bits are in register.
0134	Power off	Removes +29 V power from the SS auxiliary.

Table 4. Command assignment from SS auxiliary decoder

Digital word[a]	Command number	Command	Function initiated
0000	0	Coarse timing mode	Sets 2-s timing mode for motors and solenoid.
0001	1	Extend	Power applied to extension motor to move sampler out.
0010	2	Lower	Power applied to elevation motor to lower sampler.
0011	3	Release SS	Energizes squib-actuated pin-puller to release mechanism from stowed position.
0100	4	Elevate	Power applied to elevation motor to raise sampler.
0101	5	Squib enable on	Enables squib-firing circuit.
0110	6	Retract	Power applied to extension motor to move sampler in.
0111	7	Fine-timing mode	Switches timer from coarse to fine mode. Inhibits disengage clutch command.
1000	8	Disengage clutch	Power applied to clutch to permit pick-action operation. In 2-s mode only.
1001	9	Open scoop	Power applied to scoop motor to open scoop.
1010	10	All motors off	Removes all power from motor and clutch.
1011	11	Rotate left	Power applied to azimuth motor to move sampler left.
1100	12	Rotate right	Power applied to azimuth motor to move sampler right.
1101	13	Squib enable on	Enables squib-firing circuit.
1110	14	Close scoop	Power applied to scoop motor to close scoop.
1111	15	Squib enable off	Disables squib-firing circuit.

[a]The digital word sequence is in the order of transmission.



COMMAND DECODING
SS DC POWER ON/ EXECUTE COMMAND 0131
SS "0" COMMAND 0133
SS "1" COMMAND 0132
SS POWER OFF COMMAND 0134
BUFFER 31
BUFFER 32
+29 V SWITCH
+29 V SW.
B31
B32
CLOCK PULSE CONDITIONER
+12 V REGULATED
INHIBIT
CP
ENABLE
BUFFER 33
BUFFER 34
COUNT GATE BUFFER
COUNT LATCH 41
POWER ON LATCH 42
TP1
L42-1
PULSE AMP
COMMAND ENTERED
TELEMETRY BUFFER
POWER TURNED ON SIGNAL
RESET ONE-SHOT MVB
+29 V REG. RET.
GATING
F-F 23
CIB BIAS +3 V
F-F 21
F-F 22
COUNT REGISTER
F-F 11
F-F 12
F-F 13
F-F 14
COMMAND REGISTER
BUFFER
B11
B12
B13
B14
AUXILIARY DECODER MATRIX 1
AUXILIARY DECODER MATRIX 2
FINE MODE
COURSE MODE
LOW-POWER LATCH 43
L43-1
TIMER INHIBIT INVERTER
ALL MOTORS OFF
+29 V SWITCH
ELEVATE
EXTEND S
LOWER S
RETRACT
DISENGAGE
OPEN SS S
ROTATE SS
ROTATE SS
CLOSE SS
RELEASE S
SQUIB DRIV
SQUIB DRIV
SQUIB DRIV
POWER MANAGEMENT
+22 V UNREG.
+29 V REG.
+22 V UNREG. RET.
+29 V REG. RET.

19-A

19-B

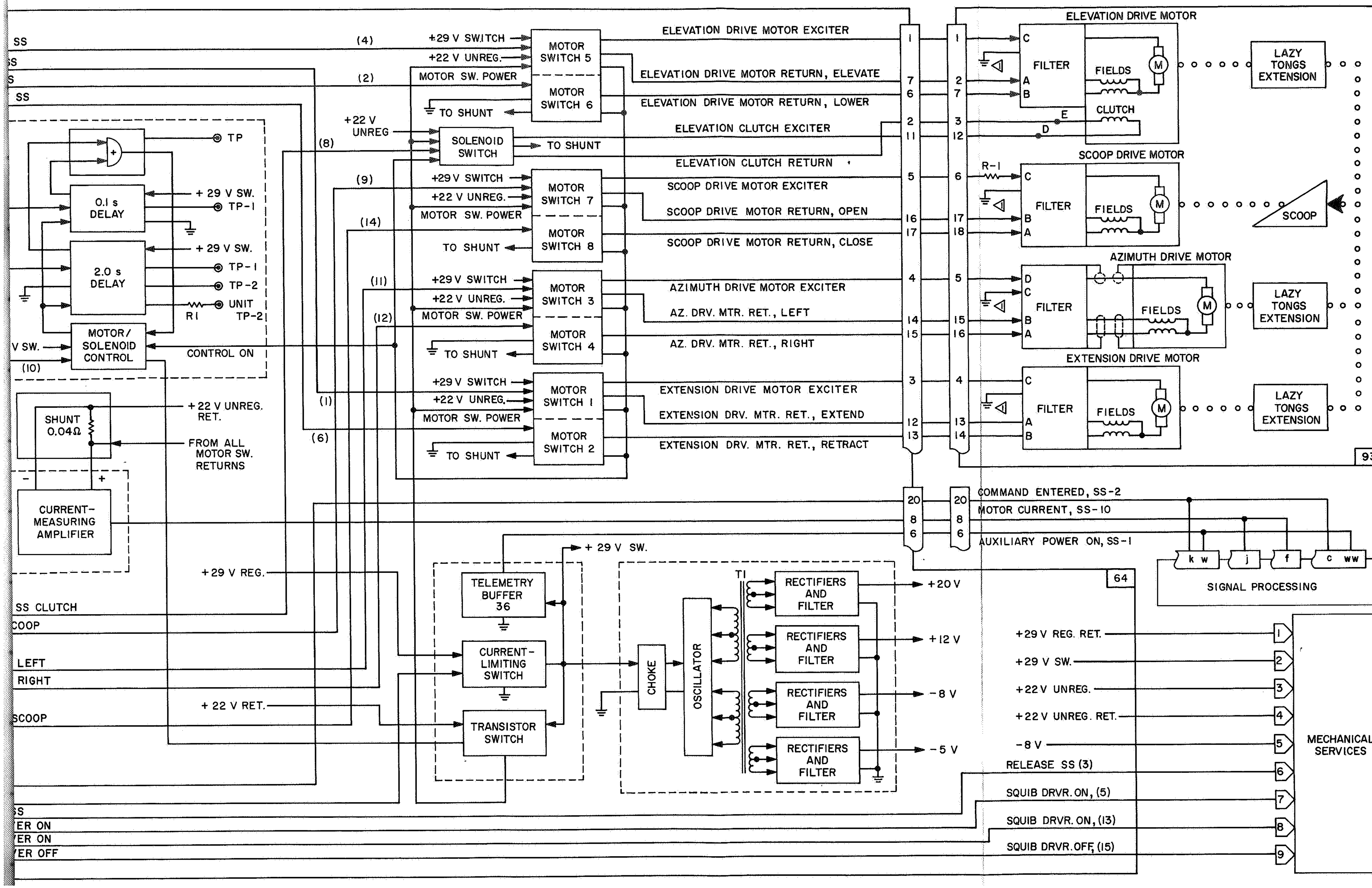


Fig. 15. Block diagram of surface sampler auxiliary

19-C

form of surface sampler functional commands that are generated from a sequence of interface commands in the SS auxiliary.

C. Surface Sampler Mechanism Deployment (Squib-Firing Circuitry)

Deployment of the SS mechanism is accomplished by electrical activation of an explosive pin-puller device that allows a spring-loaded yoke to disengage from the SS mechanism. The normal *Surveyor* method of activating explosive devices is to first execute an interlock command and during the short dwell time of the interlock signal transmit a second command that selects and activates the desired device. This sequence enables a semiconductor switch that is wired to the squib bridge and simultaneously activates an electronic conversion unit in the spacecraft engineering mechanisms auxiliary that supplies current to the squib. The current source is activated only during the dwell time of the second command, nominally 20 ms.

Since the *Surveyor III* and *IV* surface sampler subsystem was required to mate directly, without modification, to the existing approach television electrical interface, no interface with the spacecraft engineering mechanism auxiliary was available. This resulted in divergence from the normal *Surveyor* method of controlling detonation of explosive devices. Since inadvertent deployment of the SS mechanism during mission-critical times, such as during launch phase, could have catastrophic results on the mission, design of the surface sampler squib-firing circuitry was approached very cautiously. To safeguard the *Surveyor* spacecraft and ensure success of the surface sampler's mission, the following design conditions were established. The squib-firing circuitry was designed to:

(1) Guard against inadvertent squib-firing by providing interlock provisions.

(2) Protect the spacecraft electrical system in the event the squib bridge failed in the shorted mode.

(3) Provide sufficient firing current when the open-circuit battery voltage is above 19 V dc.

The final squib-firing circuit met all these requirements by providing:

(1) A low-power switch that must be commanded on before the squib-firing circuitry is enabled.

(2) A high-power switch that controls squib-firing current and whose dwell time is approximately 20 ms.

(3) Series-fusing resistors to protect the spacecraft electrical system in the event the squib should fail in the shorted mode.

Exploding the SS mechanism deployment squib requires that a total of 12 spacecraft commands be transmitted from earth. The required sequence of octal spacecraft commands and their functions are as follows:

(1) 0131 Surface sampler power on

(2) 0132 Surface sampler digital one

(3) 0132 Surface sampler digital one

(4) 0133 Surface sampler digital zero

(5) 0132 Surface sampler digital one

(6) 0131 Execute command in surface sampler register

(7) 0133 Clear surface sampler command register

(8) 0133 Surface sampler digital zero

(9) 0133 Surface sampler digital zero

(10) 0132 Surface sampler digital one

(11) 0132 Surface sampler digital one

(12) 0131 Execute command in surface sampler register

Commands 2–5 enter the digital word "squib enable on" in the surface sampler command register. Commands 8–11 enter the digital word "release mechanism" in the surface sampler command register. Command 12 finally activates the high-power switch that supplies current to the squib for approximately 20 ms.

D. Surface Sampler Mechanism Control

After initial deployment of the SS mechanism from its stowed (boost and transit phase) position by activation of an explosive pin-puller device, control of the SS mechanism is provided by transmitting mechanical energy to the mechanism from four reversible electric motors. Bidirectional motor operation is possible because each of the four motors has two oppositely wound field windings. Excitation is applied to the armature (rotor) and rotational direction is selected by completing the circuit through the appropriate field winding.

E. Control of the Surface Sampler Motors

Two timing cycles are provided for the control of the SS mechanism motors. A 2-s or 0.1-s mode can be selected by command. When the SS auxiliary decoder power switch is enabled, the 0.1-s mode is automatically selected.

Operation of the timing cycle is as follows: When a motor switch is turned on, the motor and solenoid control is also turned on. Turn-on of the motor and solenoid control initiates operation of either the 2-s or 0.1-s delay circuit, depending on which mode has been selected. At the conclusion of the given delay period, a signal from the delay circuit is sent to the motor control. This signal turns off the motor and solenoid control module and hence, turns off the motor switch. The circuitry is designed so that false turn-on of a motor also initiates the timer cycle, which will turn off the motor after either 2 s or 0.1 s, depending upon the mode the timer is in. Aside from turn-off by means of the delay circuits, the motors may be turned off by the *all motors off* command.

Designation of the four motors along with their functions is as follows:

(1) Retraction: Positions SS mechanism in extension and retraction.

(2) Azimuth: Positions SS mechanism in azimuth.

(3) Elevation: Elevates and lowers SS mechanism.

(4) Scoop: Opens and closes scoop door.

In addition to the four motors, an electromechanical solenoid is provided to disengage the elevation drive train, thus allowing the SS mechanism to be impelled downward by the elevation torque spring to impact the lunar surface. The solenoid functions only in the 2-s timing mode.

F. Surface Sampler Telemetry Signals

In addition to power management, which also includes fusing and current limiting, and command decoding, the SS auxiliary provides four telemetry signals: two digital and two analog. The analog signals are digitized by the spacecraft analog-to-digital converter and transmitted to earth as pulse-code-modulated (PCM) data at rates selected by ground command. Each analog data word is composed of 11 bits. The digital telemetry signals occupy one bit of an 11-bit data word. The surface sampler telemetry words appear in the auxiliary engineering signal processor commutator, which is a 120-word commutator, and on the engineering signal processor mode two commutator, which is a 100-word commutator. During surface sampler operation a bit rate of 4400 bits/s is selected. At this rate, during a 2-s motor activation period, the surface sampler telemetry words are sampled six or seven times, depending upon what part of the sequence the commutation is in when a motor is commanded on.

1. Surface sampler digital telemetry. The SS auxiliary provides two digital telemetry indications: *power on/off* and *command entered.* The *power on/off* signal is derived from the output of the surface sampler *on/off* power switch and indicates a digital *one* when surface sampler power is on and a digital *zero* when surface sampler power is off. The *command entered* signal is derived from the SS auxiliary count register and indicates a digital *one* after four bits have been entered in the command register. Before four bits are entered in the command register, and when the command register is reset, the *command entered* signal indicates a digital *zero.*

2. Surface sampler analog telemetry. The SS auxiliary provides two analog telemetry signals: *electronics temperature* and *motor current.* The *electronics temperature* signal is derived by supplying a current pulse from a constant-current source to a precision temperature-sensitive resistor and reading the voltage drop across the resistor. *Motor current* telemetry is derived by placing a precision 0.04-Ω resistor in the common return lead from all motors and the clutch solenoid. Since only one motor or the solenoid is active at any particular time, only one telemetry signal is required. The voltage developed across the 0.04-Ω resistor is amplified by a factor of 50 before being presented to the analog-to-digital converter and further processed for PCM transmission to earth.

G. Telemetry Modes During Surface Sampler Operation

Since no SS mechanism position information is telemetered, television observation of the mechanism during lunar operation is a necessity. During operation, only a few incremental movements of the SS mechanism are made between television observations. To circumvent turning the television vidicon on and off, which could shorten the life of the vidicon, and to minimize the delay associated with vidicon warm-up time, the television camera is turned on and left on during the majority of surface sampler operations. With the television subsystem active and the spacecraft telemetry system configured for surface sampler telemetry, i.e., one of the analog-to-digital converters on, television PCM data is generated continuously. If this condition were allowed to exist, both television PCM and surface sampler telemetry would be summed together, resulting in erroneous telemetry indications. To solve this problem a connection was made between the output of the SS auxiliary power switch, the television electronic conversion unit, and the television commutator master switches to inhibit television PCM data while the surface sampler was active. This modification permitted three telemetry configurations during surface sampler operational periods, as shown in Table 5.

Table 5. Surface sampler/television telemetry modes

Function	Telemetry
Television on Surface sampler off	Video and television PCM No surface sampler operation No surface sampler PCM data
Television on Surface sampler on	Video but no television PCM Surface sampler operation Surface sampler PCM data
Television off Surface sampler on	No video and no television PCM Surface sampler operation Surface sampler PCM data

H. Surface Sampler Motor Current vs Force Calibration

Since no force or position telemetry provisions were possible because of the limited electrical interfaces in the existing spacecraft harness, surface sampler motor current was selected as a measure of force applied to the lunar surface by the SS mechanism. Because of the complexity of the surface sampler electromechanical system, a surface sampler motor current vs force calibration, using the entire spacecraft communication and ground data handling system, was conducted. This test was conducted at the Air Force Eastern Test Range under earth ambient conditions at a temperature of approximate 68°F and a battery voltage of 22 V dc, 32 days prior to operation of the surface sampler on the lunar surface. Since battery voltage and temperatures in the vicinity of the SS mechanism are also among the telemetered parameters and SS mechanism positioning on the lunar surface can be quite accurately determined by television viewing, the force applied to the lunar surface by the SS mechanism can be calculated. Results of the surface sampler motor current vs force for both the elevation motor operating in the lowering mode (bearing force) and the retraction motor operating in the retracting mode are presented in Figs. 16-19. Plotted values correspond to the last three commutated current samples averaged over two trials for each force loading. All currents were reduced 125 mA to account for the switch current that flows through the shunt but not through the motor.

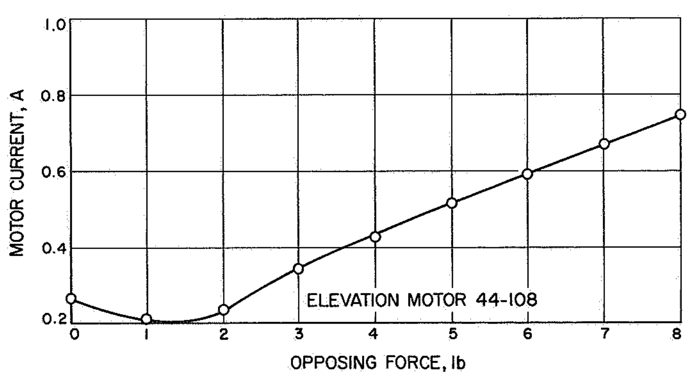


Fig. 16. Elevation motor current vs force at 42-in. extension

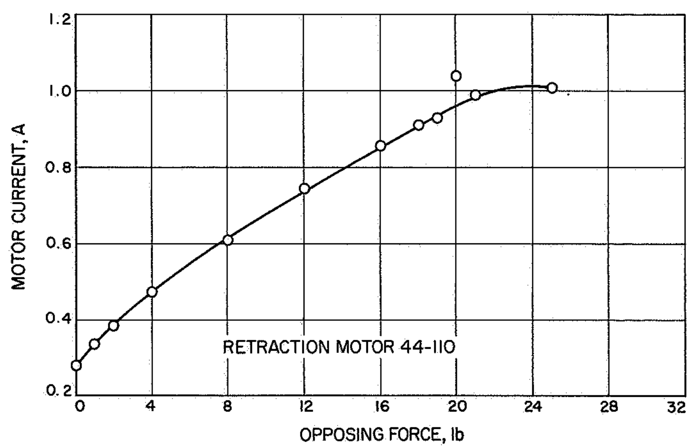


Fig. 17. Retraction motor current vs force at 42-in. extension

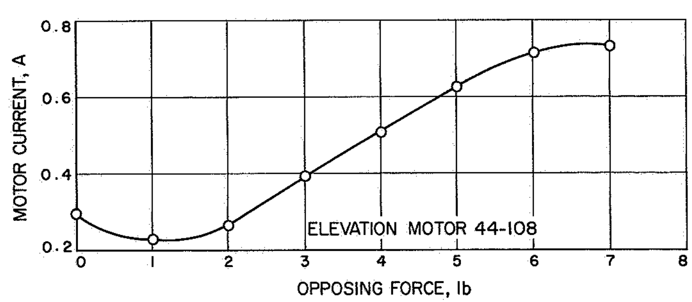


Fig. 18. Elevation motor current vs force at 58-in. extension

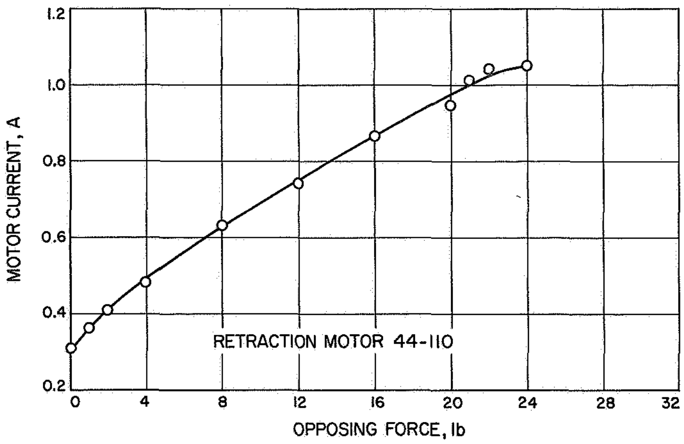


Fig. 19. Retraction motor current vs force at 58-in. extension

IV. Thermal Control Effort on the Surface Sampler

Thermal control of the surface sampler was designed by Hughes Aircraft Company within what were believed to be conservative limits. The compartment containing the SS auxiliary electronic equipment had the capability of maintaining temperatures with prescribed limits of −67 to +257°F for nonoperating conditions and −4 to +158°F under operating conditions. On the flight of *Surveyor III*, the design limits proved not to be conservative, and the temperature of the SS auxiliary with the heater on fell much lower than had been predicted. However, even though the limits were believed to have been exceeded by as much as 30°F, there was no detectable damage to the SS auxiliary electronic system.

The thermal-control design of the SS auxiliary compartment was similar to that of other compartments of the *Surveyor* spacecraft, including the spacecraft auxiliary battery compartment. The thermal-control compartment was composed of an outer canister, a superinsulating blanket formed from 75 sheets of aluminized Mylar, and a radiator plate which was mechanically attached to, but thermally isolated from, the outer canister by fiberglass mounting brackets. The radiator plate acted as the prime radiating surface. The electronic components were all mounted on the internal side of the plate and conducted energy to the top surface, which rejected the energy by radiation.

During transit from earth to moon, the nominal attitude of the spacecraft caused the SS auxiliary to be illuminated on approximately one-eighth of the top plate total area. For this reason, the design incorporated a 5-W heater, which was to maintain the temperature of the electronics at a survivable level. Lunar surface operation of the SS auxiliary appears to have been satisfactory, although data for the lunar surface operation were garbled because of probable shorting in the telemetry system.

The SS mechanism required the greatest effort in analyzing and designing a paint pattern that would keep it operating within the prescribed temperature limits. Actually the SS mechanism is a very rugged piece of equipment, but there were some areas where temperature conditions could present problems. The material selected for the members of the lazy tongs decreased in tensile strength at slightly elevated temperatures (170 to 190°F). However, this was not believed to be a serious problem and no action was taken to change the material.

Another possible temperature problem was associated with the motors. If the temperature of the motor winding were to drop to lower temperatures (−65°F), the resistance of the motor winding would decrease sufficiently to cause the torque produced by the motor to shear its shaft. This problem was more serious and much consideration was given to designing a system that would not fail if it were to experience these temperatures. New shafts were designed that could withstand the torque; the motors could stall and no failure would occur. So that a safety margin would exist, a temperature constraint was imposed with respect to operation of the SS mechanism. However, this turned out to be rather meaningless since no temperature sensor was mounted on the SS mechanism that would indicate a representative temperature.

After the hardware had been designed, Hughes Aircraft analyzed the system and made recommendations regarding the proper finishes that should be incorporated on the various elements. Several alternate recommendations were made, but the final selection of powder blue was prescribed by TV contrast characteristics. The major part of the mechanism was blue, but some portions were white, and some were black.

In an effort to arrive at a representative temperature, HAC suggested an averaging method. They believed that an average value for approximately 11 spacecraft flight sensors would give an indication of the SS mechanism temperature. This method will, in most cases, give a very gross estimate of the temperature.

Transfer functions, averaging, and other methods have been tried on simpler structures, but results were not satisfactory. The *Surveyor* vehicle is a rather complex device when one considers it thermally. The *Surveyor* thermal group have become familiar with the vehicle and can make rather rapid estimates of temperatures of units that are relocated or of new units that are added on. Even with their several years of familiarity with the vehicle, they would apply a tolerance of ±25°F to any best guess they would make. The surface sampler mechanism has very wide permitted temperature operation limits. Therefore it is not too difficult to arrive at a decision regarding operation of the unit based on thermal considerations, providing very unusual thermal conditions do not exist.

Fortunately, the surface sampler on *Surveyor III* was not required to work in the early hours after landing and it was operated in the later hours in such a manner that the lower temperature limit was not approached. If it had to be operated under conditions that could possibly cause it to get too cold, one could only guess and attempt to operate by making decisions on a real-time basis after considering the results of the previous command. Several methods of elevating the motor temperatures to assure safe operation could be used. One would be to operate the motors and be cautious in commanding so that no mechanical limits are approached. The problem of excess torque would not cause any difficulty so long as a mechanical stop was not encountered.

Future spacecraft will have an additional temperature sensor to give a reference point in case any questionable situations might arise. The major concern is the low-temperature limits. The structure and the motors have rather high temperature limits (upper motor temperature limit was 500°F). HAC studies indicated that this limit would not be exceeded.

V. Surface Sampler Structural Aspects

A. Description of Structurally Important Components

To assist in withstanding the loads resulting from the dynamic environment of launch, transit, and touchdown, the surface sampler mechanism is stowed during flight by a lock-link/pin puller arrangement, as shown in Fig. 20. Once the spacecraft has landed on the lunar surface, the pin puller can be activated to release the mechanism for operation.

When the SS mechanism is unlocked, it becomes a "structure" cantilevered about its elevation drive axis, as shown in Fig. 21. The elevation drive can then rotate the extended "structure" about the horizontal elevation axis with enough force to provide digging capability at the shovel tip. During operation on the lunar surface, structural members of the SS mechanism are subjected to significant forces.

Torsion springs, located in the upper and lower joints of the linkage, furnish the force to push the linkage radially outwards. The motor-driven retraction tape, attached to the shovel, applies the necessary force for trenching, digging, and retraction.

A critical force reaction in the SS mechanism is that due to picking operations. That is, the linkage and shovel are allowed to fall to the lunar surface. A pick-assist spring acts in conjunction with the weight of the shovel and linkage to increase the picking force. Because of the nature of the anticipated loads developed during picking, the shovel is fitted with a hardened-steel blade.

B. Summary of Critical Loading Conditions

The critical loading conditions for the SS mechanism can be classified in three categories:

(1) Loads encountered during launch and flight.

(2) Shock loading due to spacecraft touchdown on the lunar surface.

(3) Operational loads due to functional requirements, i.e., picking, digging, etc.

The loads imposed on the SS mechanism in its stowed position during flight are vibratory in nature and are treated as a discrete fatigue spectrum. The shock loading at touchdown is considered as quasi-static and is dependent upon the landing velocity of the spacecraft and its landing attitude. The loading conditions used for the design are summed up in Table 6. Weight and cg data are presented in Fig. 22.

Table 6. Structural loading

Condition	Type	Load, earth g		Remarks
		Z axis (longitudinal)	X, Y axis (lateral)	
Flight	Static	−2.0	±0.4	Loads considered cumulative and applied for 12,000 cycles
	Vibratory	±16.0	±16.0	
Touchdown	Static	−25.0	0	
	Static	−20.0	+15.0	Due to lateral velocity
	Static	+10.0	0	Rebound

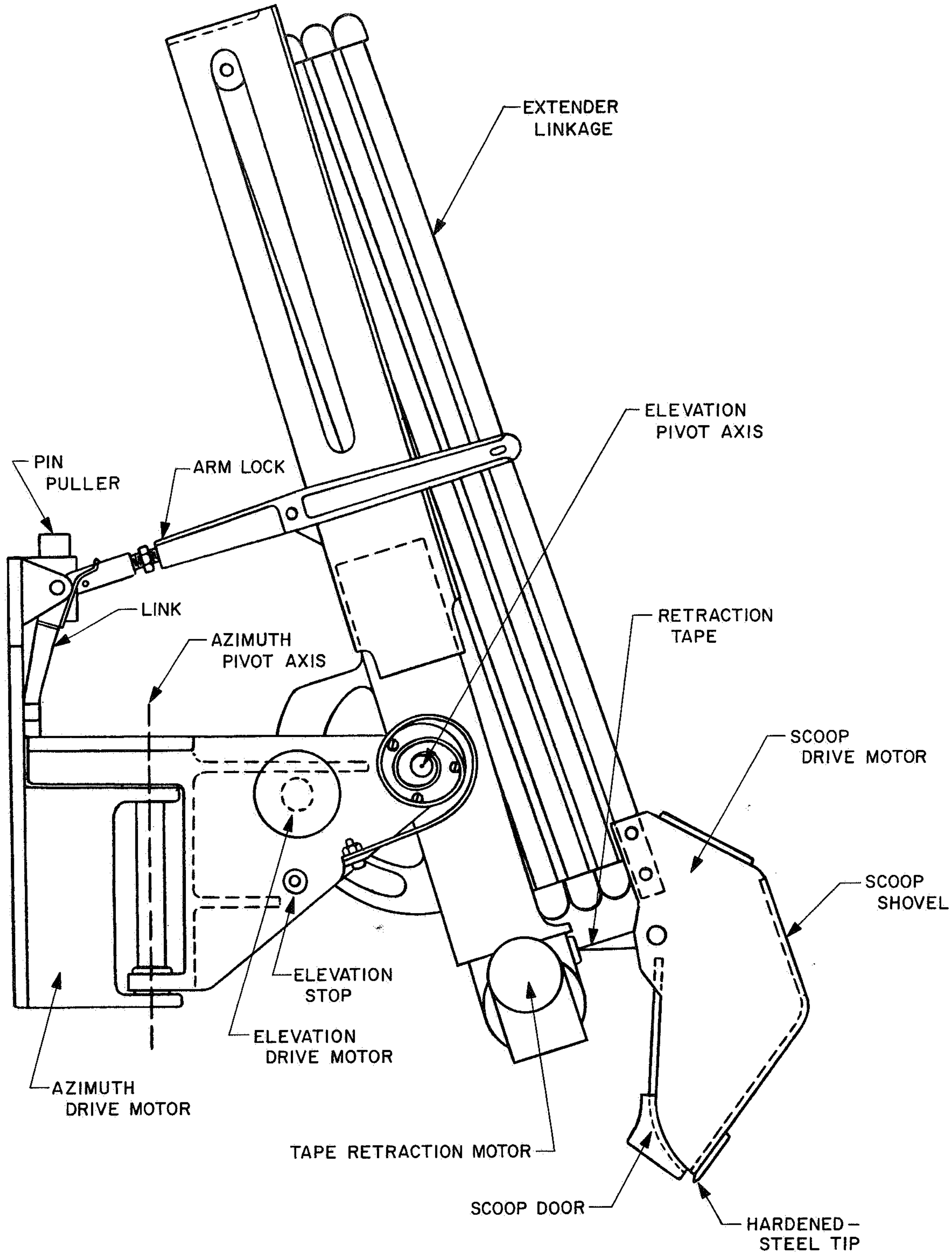


Fig. 20. Surface sampler, stowed configuration

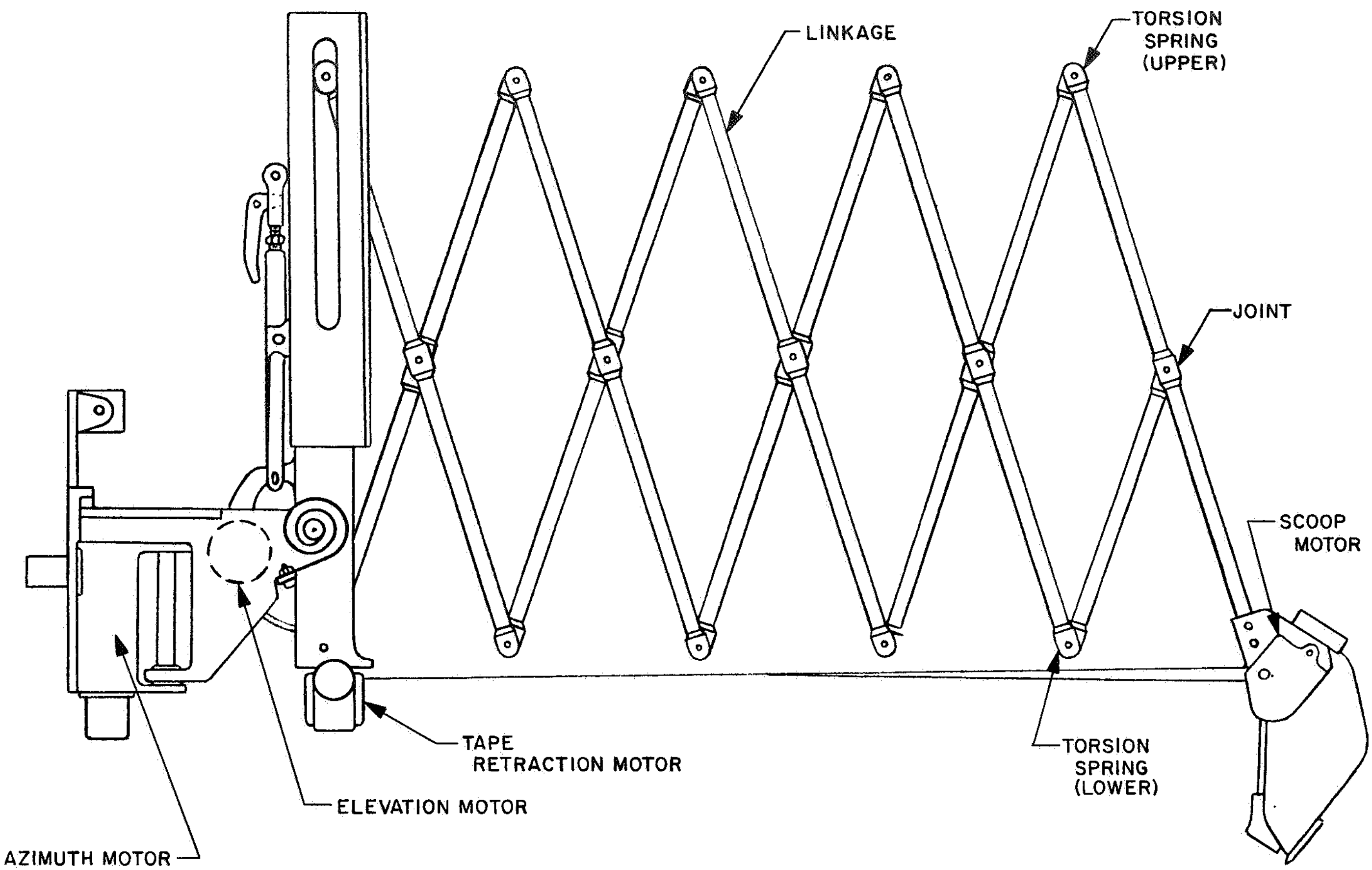


Fig. 21. Surface sampler, extended structure

The operational loads are due entirely to the functional requirements of the SS mechanism and are the result of picking, digging, trenching, scooping, etc. The picking loads are the result of letting the shovel and linkage fall to the surface aided by the pick-assist spring. Three separate loading conditions due to picking were considered, as shown in Figs. 23 and 24.

The other operational loads such as digging, trenching, etc., are derived from the maximum stall torques of the various motors. A typical example of a motor-stall torque force is shown in Fig. 25. Examination of Table 7 discloses the maximum stall torques used for analysis purposes.

Table 7. Maximum stall torques

Motor	Maximum stall torque, in.-lb	Remarks
Azimuth	90.0	Conservative values for analysis purposes, since torques were derived at lowest operating temperatures of motors
Retraction	41.3	
Elevation	68.0	
Scoop	110.00	

C. Design Criteria

Margins of safety computed for the various components were obtained by the standard method of comparing the stress induced by the design loads to the allowable stress of the material.

$$MS \text{ (margin of safety)} = \frac{\text{allowable stress}}{\text{stress due to design load}} - 1$$

A summary of the minimum acceptable margins of safety for the three sources of design loads is as follows:

	Yield	Ultimate
Flight	0.10	0.25
Touchdown	0.10	0.25
Operational	0.10	0.25

Where margins of safety, based upon yield, were adequate and the material or manner of loading presented no unusual problems, margins of safety based upon ultimate strength were not computed.

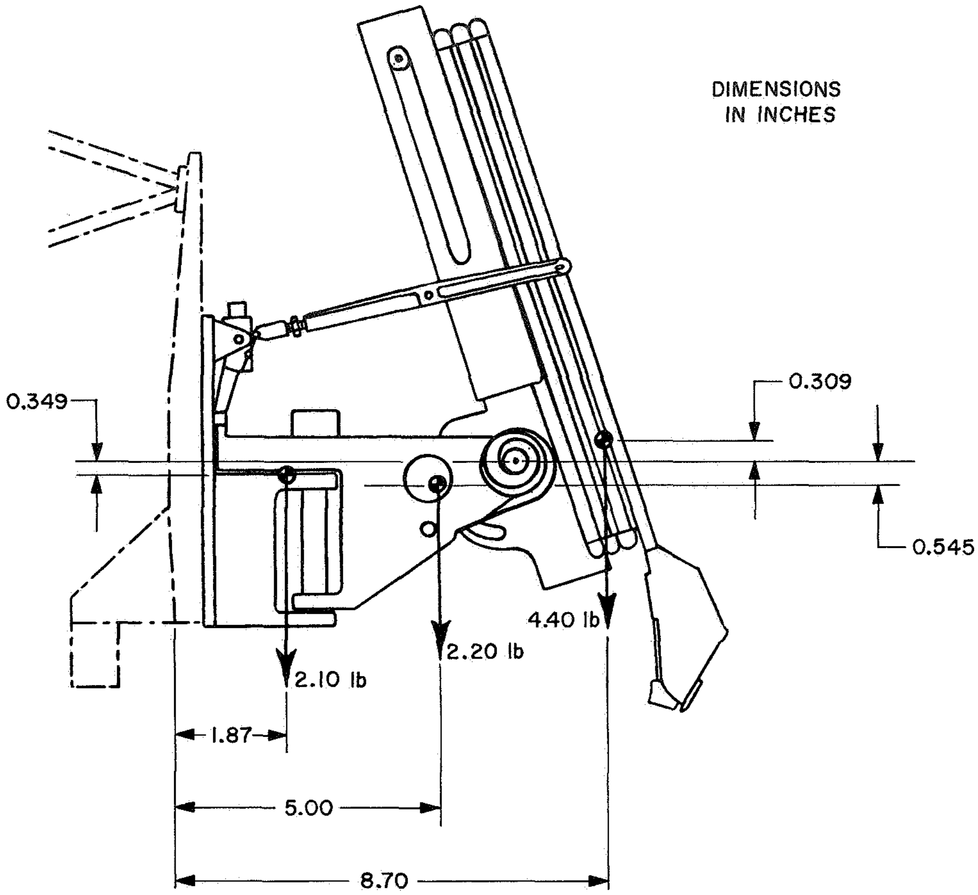


Fig. 22. Surface sampler weights and centers of gravity

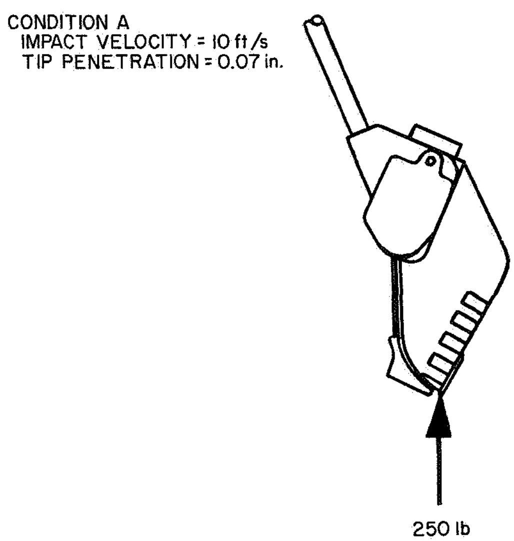


Fig. 23. Picking load on shovel

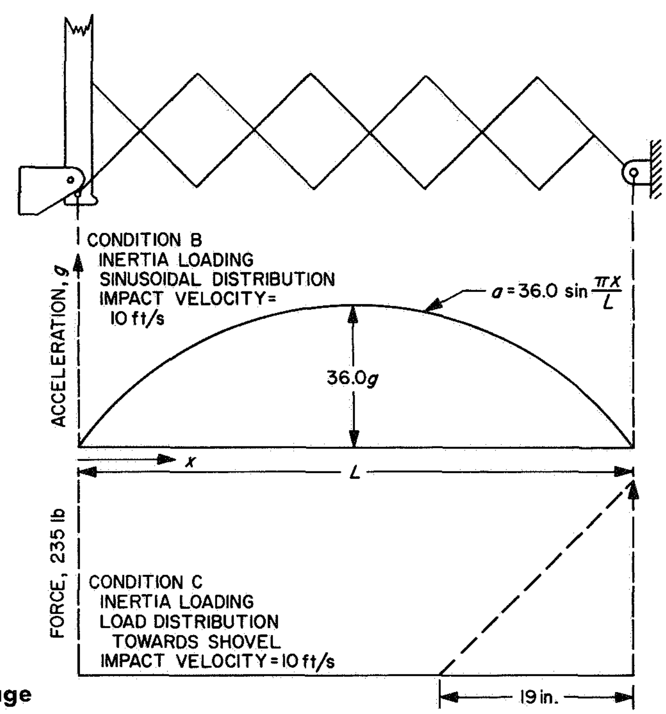


Fig. 24. Picking load on extended linkage

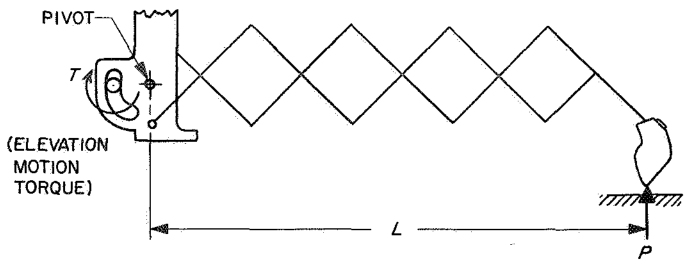


Fig. 25. Motor stall torque loading

As noted in Section V-B, maximum stall torques of the motors were used for operational loads. Since each motor was carefully selected and tested, no additional factor of safety was used for these maximum torques in computing the margin of safety.

Acceptable fatigue life was conservatively based upon Miner's criteria with a factor of 1; i.e., if the sum of the ratios of the cumulative fatigue cycles to the allowable number of fatigue cycles was less than 1, the "structure" was considered acceptable.

D. Summary of Structural Analysis

Suitable stress analysis of all components was accomplished to assure the structural integrity of the SS mechanism.

Analysis was performed for the housings, locking devices, supports, and components such as the gears, shafts, springs, etc. As might be expected, the various motor housings and locking arrangements that hold the SS mechanism components in position experienced their highest stresses during lunar touchdown. In general, the use of standard materials, gages, and fabrication techniques resulted in fairly large margins of safety for the various housings.

The extension linkages were conservatively analyzed at a maximum lunar operating temperature of 250°F for a 100-h exposure; this, coupled with the fact that maximum motor torques (developed only at much lower temperatures) were utilized, resulted in conservative estimates of the linkage stresses.

Stresses in the moving parts of the SS mechanism generally proved to be the most critical. Typical examples in this category would be gear-tooth bending, bending stresses in the springs, motor-shaft torsion, etc.

The computed fatigue stresses, derived from the flight environment, proved to be generally low for practically all components. Indeed, in most instances, the sum of the ratios of the accumulated fatigue cycles to the allowable number of fatigue cycles was negligible.

VI. Surface Sampler Mission Operation

The *Atlas/Centaur* AC-12 launch vehicle bearing *Surveyor III* and the surface sampler subsystem lifted off from Air Force Eastern Test Range, Launch Complex 36-B, on day[4] 107 at 07:05 GMT. Just prior to launch, the temperature inside the thermal control compartment of the SS auxiliary had stabilized at approximately 84°F. Shortly after launch, thermal control of the SS auxiliary was commanded on. This command completes the electrical circuit external to the SS auxiliary and allows the internally mounted thermostat to activate a 5-W heating element as soon as the temperature of the thermostat reaches its lower cycling limit. The lower and upper cycling temperatures of the thermostat are −16.6°F and +10.4°F, respectively. The SS auxiliary is designed to operate over a temperature range of −4 to +158°F and the specification range for nonoperation is −67 to +257°F.

After the spacecraft had assumed its cruise attitude by locking on its celestial references, the sun and the star Canopus, the temperature of the SS auxiliary decreased to −33°F. This was due to a greater than expected degree of shading of the SS auxiliary thermal compartment by the spacecraft solar panel. This assumption was verified during transit by observing the SS auxiliary temperature during several spacecraft gyro drift checks. As the spacecraft would pitch and yaw the temperature of the SS auxiliary would rise at pitch and yaw angles, which allowed the SS auxiliary thermal compartment to be illuminated by the sun.

On day 109 at 23:55 GMT, approximately 9 min prior to spacecraft touchdown, thermal control of the SS auxiliary was terminated by commanding the SS auxiliary heater off, a normal terminal descent procedure. At this time the temperature of the SS auxiliary was −29°, which was well within the lower nonoperating temperature of −67°F. This was no cause for alarm because the normal sequence of events provides reactivation of thermal control shortly after spacecraft touchdown. However, the normal spacecraft sequence of events was not immediately performed. Because of anomalous indications from all spacecraft sensors and, in particular, an indication that a large current drain on the spacecraft power system was

[4]Day number refers to day of year. January 1 = day 1.

occuring, nonstandard procedures were followed. This action ultimately resulted in the SS auxiliary heater not being commanded on until approximately 2½ h after the spacecraft had landed on the lunar surface. During the first few minutes after landing, telemetry indicated that the temperature of the SS auxiliary was −80°F. Considering the landed attitude of the spacecraft and the solar angle at the landing site, the thermal prediction for the SS auxiliary temperature, with the heater off for 2½ h, was −130°F. At this point the lower nonoperating temperature limit of the SS auxiliary had been severely violated.

During investigation of the anomalous spacecraft telemetry situation, which began almost immediately after touchdown, a suggestion was made that turning on the SS auxiliary power might alleviate the telemetry problem. It was suspected that the television auxiliary was on, causing television PCM signals to be summed with the normal spacecraft PCM data. By turning on the SS auxiliary power, the television PCM data would be inhibited by the television frame identification inhibit circuitry of the SS auxiliary. There was considerable interest among spacecraft performance personnel to act on the suggestion, but it was feared that because of the extreme cold to which the SS auxiliary had been exposed, permanent damage could have occurred. Turning on the SS auxiliary power could cause uncontrolled activation of the SS mechanism or cause a large current drain on the spacecraft power system. On day 110 at 01:00 GMT, 56 min after spacecraft touchdown, initial television operation was begun and excellent television performance began to establish confidence that the spacecraft was actually in good condition and that only the spacecraft telemetry system was anomalous. Based upon this observation a decision was made not to attempt activation of the SS auxiliary until the following Goldstone view period, day 111. During the time between the first and second Goldstone view periods, spacecraft telemetry at the 17.2-bit/s rate indicated parameter values that were in the area of the predicted values. Finally, on day 111 at 08:46 GMT, 32 h and 42 min after touchdown, sufficient confidence in the 17.2-bit/s telemetry and thermal predictions had been established to warrant turn-on of the SS auxiliary power. A brief SS auxiliary *power on/off* command sequence was transmitted to the spacecraft, and telemetry indicated that the SS auxiliary power turned on and then off. There was no indication that this sequence caused abnormal spacecraft power consumption. This established that a major portion of the SS auxiliary was functional. With added confidence, an additional surface sampler command sequence was transmitted. This time the SS auxiliary power was commanded on and the surface sampler command register was loaded with a four-digital-bit command. Telemetry indicated that the SS auxiliary power was on and that a command had been entered in the surface sampler command register. The surface sampler command register was reset to its initial condition, which was verified by telemetry, and the SS auxiliary power was commanded off. Telemetry verified proper operation in response to all commands. Fifty-two minutes later, at 09:36 GMT, the SS mechanism was deployed from its stowed position by activating the explosive pin puller. At this time proper operation of all SS mechanism functions was verified except scoop door opening and closing and disengaging the elevation clutch. Because of the anomalous telemetry condition at the 4400-bit/s rate, no valid surface sampler motor current data was obtained. Two attempts were made to measure motor current at the 17.2-bit/s telemetry rate by initiating 90-s, 67%-duty-cycle retraction motor sequences, but each time, telemetry indicated multiple parity errors.

A. Surface Sampler Lunar Operations, Pre-Mission-Planned Sequence

Prior to the *Surveyor III* mission, a specified sequence of surface sampler activities, based upon nominal spacecraft landing conditions, was formulated. Execution of this sequence was repeatedly rehearsed at the Jet Propulsion Laboratory's Space Flight Operations Facility and at the Surveyor Experiment Test Laboratory. Because of the wide variation of lunar surface conditions that could be encountered, the preplanned sequence established only wide- and narrow-angle television surveys of the surface sampler area of operation, specification of six bearing-strength test points with television coverage, and one trenching operation, including a narrow-angle television survey of the trench. A map of the surface sampler area of operation in surface sampler coordinates with an overlay of television coordinates showing the proposed bearing points and trenching area is presented in Fig. 26. Other actvities such as additional bearing tests, additional trenches, impact tests, lunar rock handling, and deposition of lunar surface material on the spacecraft landing pad 2 for television color-filter sequencing were left as options to be selected in accordance with landing-site conditions. A narrow-angle view of the first trench dug by the surface sampler on the moon is shown in Fig. 27.

As part of the pre-mission preparation, three command tapes were prepared and their functions verified. The command tapes are used to automatically transmit the series of commands that are necessary to perform specific surface sampler and television operations. Television tape

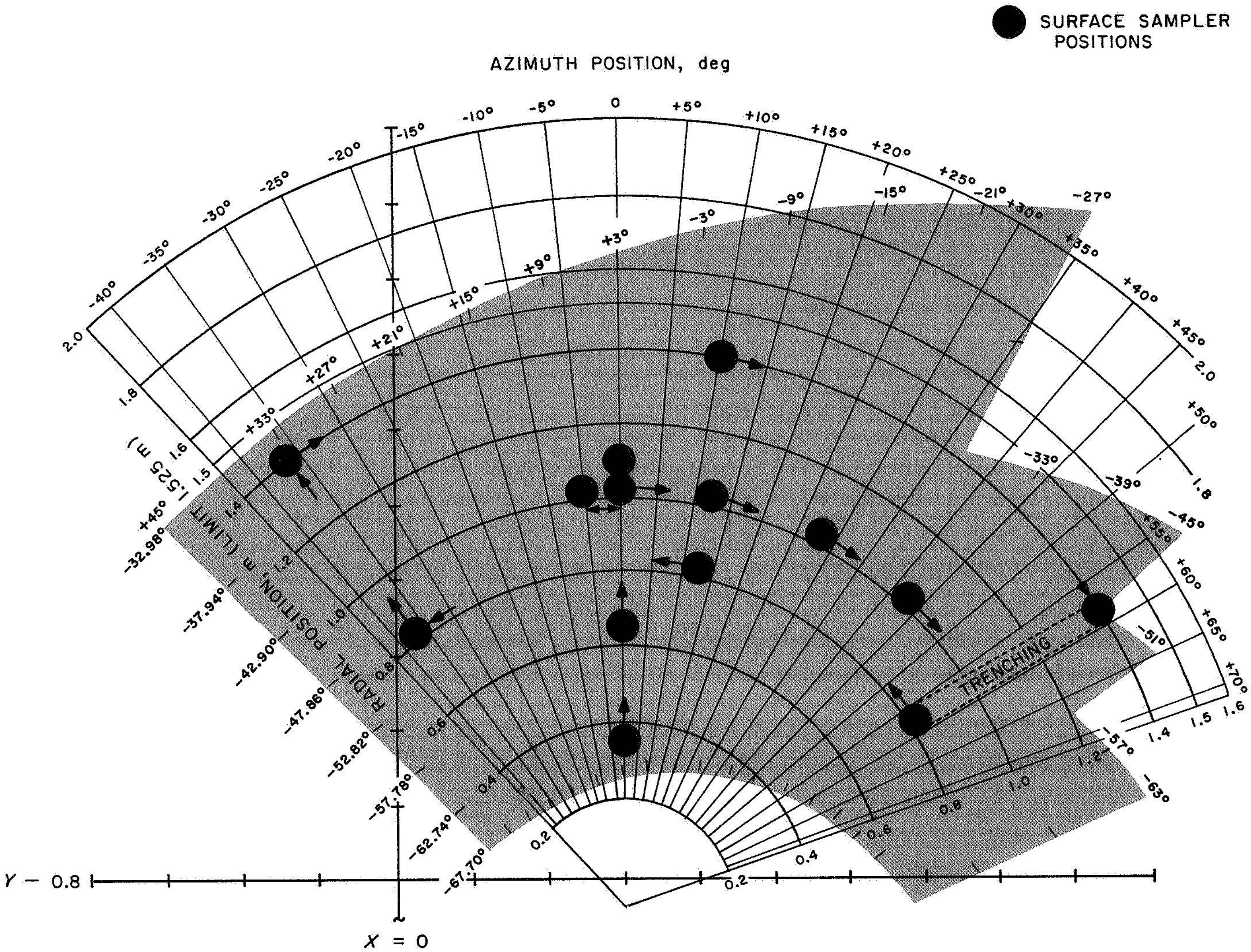


Fig. 26. Pre-mission-planned surface sampler activity

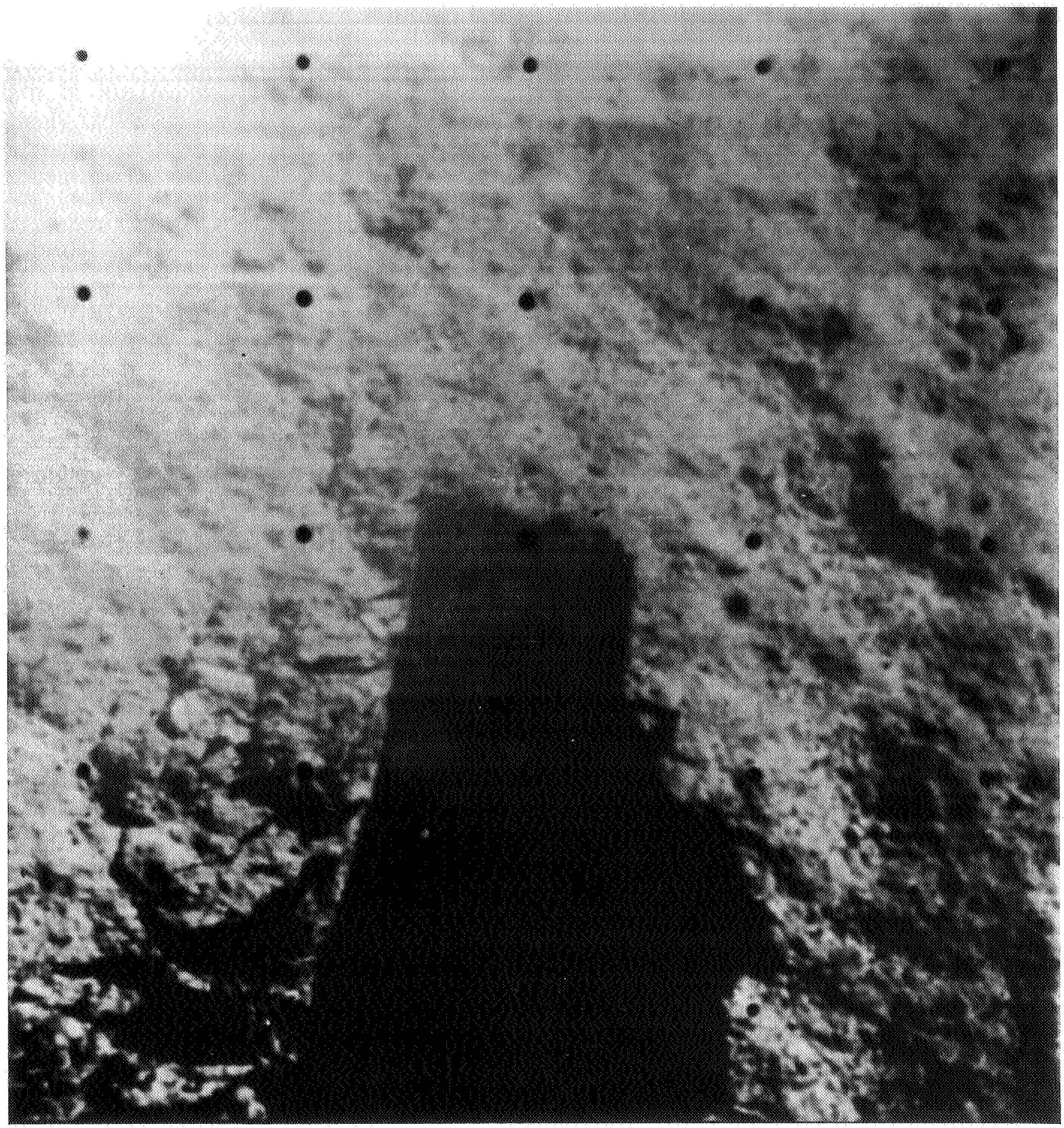


Fig. 27. Narrow-angle view of first trench dug by the surface sampler on the moon

802 automatically transmits the required commands for conducting the narrow- and wide-angle television surveys of the surface sampler area of operation. Surface sampler tape 901 is the command tape for automatically executing the preplanned surface sampler activities and is based upon expected incremental motions of the SS mechanism. Surface sampler tape 902 contains all command functions of the surface sampler and provides operator action interrupts for executing the commands any desired number of times. Table 8 presents the command sequences available from tape 901 and Table 9 is a listing of the commands available from tape 902.

B. Summary of Surveyor *III* Mission First Lunar Day Surface Sampler Activities

The surface sampler operations during the first lunar day were conducted using optional command sequences. The preplanned sequence of surface sampler activities was not used because of spacecraft television viewing difficulties caused by glare in the optical system and other minor TV anomalies.

1. Day 111

Initial surface sampler (SS) power on, 08:46 GMT
Final SS power off, 10:43 GMT
Actual SS power on time, 71 min
Number of interface commands transmitted to SS, 217
Number of SS commands executed, 61

Table 8. Surface sampler command tape 901

Minor sequence number	Surface sampler command
3150	Squib enable
3151	Squib enable backup
3152	Release mechanism
3153	Extend four 2-s steps
3154	Extend five 2-s steps
3155	Retract one 2-s step
3156	Lower one 2-s step
3157	Elevate one 2-s step
3250	Lower two 2-s steps
3251	Rotate left two 0.1-s steps
3252	Rotate right eight 0.1-s steps
3253	Lower ten 0.1-s steps
3254	Elevate two 2-s steps
3255	Rotate left one 2-s step
3256	Extend six 2-s steps
3257	Rotate right one 2-s step
2450	Open scoop N 0.1-s steps
2451	Retract two 2-s steps
2452	Close scoop N 0.1-s steps

Table 9. Surface sampler command tape 902

Minor sequence number	Surface sampler command
2450	Open scoop N 0.1-s steps
2452	Close scoop N 0.1-s steps
2453	Disengage elevation clutch
2454	All motors off
3650	Select fine-timing mode
3651	Extend N 0.1-s steps
3652	Retract N 0.1-s steps
3653	Rotate left N 0.1-s steps
3654	Rotate right N 0.1-s steps
3655	Lower N 0.1-s steps
3656	Elevate N 0.1-s steps
3750	Select coarse-timing mode
3751	Extend N 2-s steps
3752	Retract N 2-s steps
3753	Rotate left N 2-s steps
3754	Rotate right N 2-s steps
3755	Lower N 2-s steps
3756	Elevate N 2-s steps

The surface sampler mechanism was deployed and a functional test was conducted to verify operation in left azimuth, right azimuth, extension, retraction, elevation, and lowering. The SS mechanism did not contact the lunar surface. Figure 28 is a reproduction of the first television picture received during operational verification of the surface sampler.

2. Day 112

Initial SS power on, 04:56 GMT
Final SS power off, 11:33 GMT
Actual SS power on time, 59 min
Number of interface commands transmitted to SS, 558
Number of SS commands executed, 207

One bearing test and one drag through two separate trenches comprised the surface sampler activity during this day. The location of this activity relative to the surface sampler area of operation is presented in Fig. 29 as points A, B, and C, respectively. Figure 30 is a narrow-angle view of a portion of the SS mechanism showing the scoop in the lunar surface at the conclusion of surface sampler activities during day 112.

3. Day 113

Initial SS power on, 05:29 GMT
Final SS power off, 09:50 GMT
Actual SS power on time, 182 min
Number of interface commands transmitted to SS, 332
Number of SS commands executed, 152

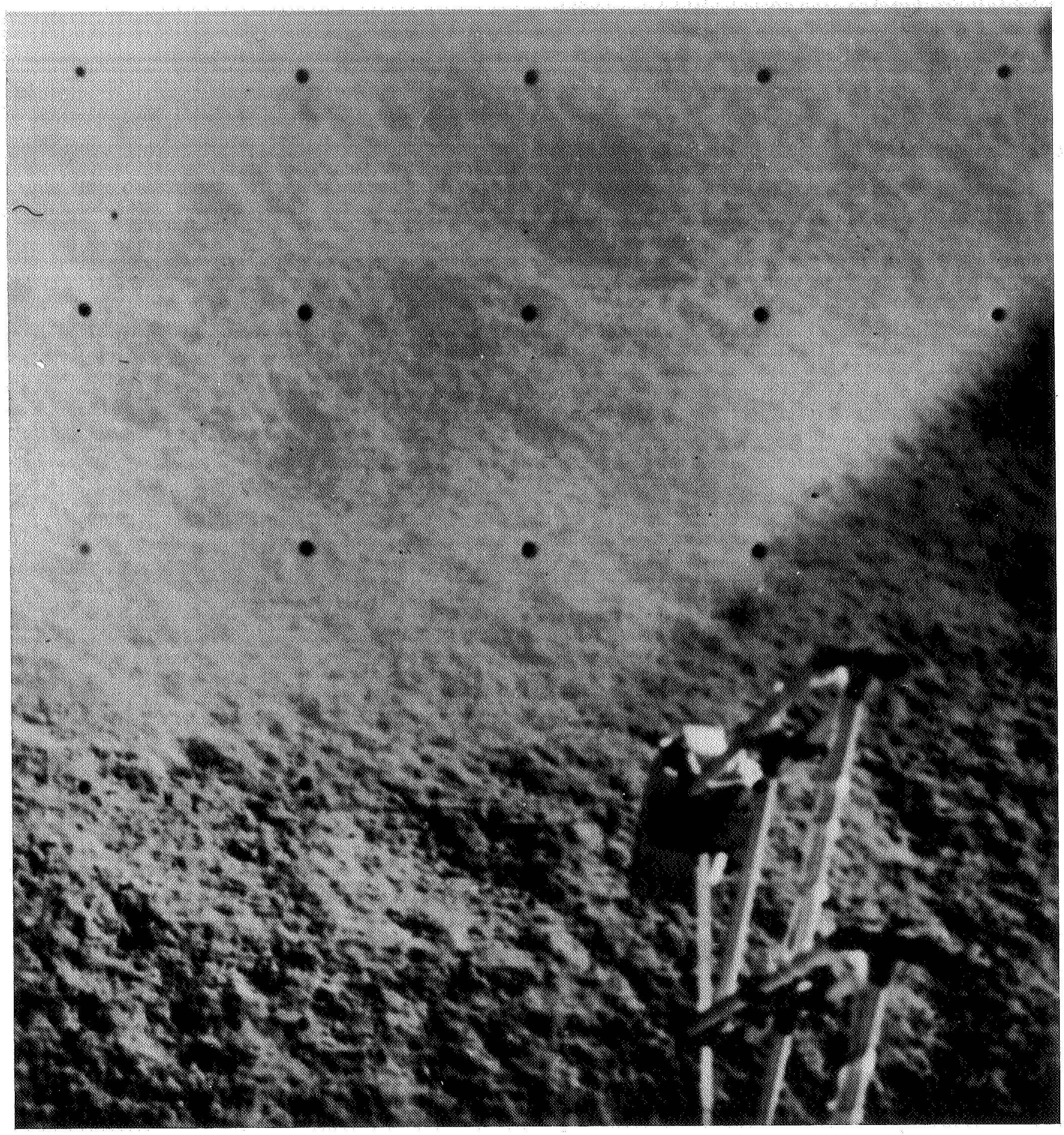


Fig. 28. Surface sampler above the lunar surface

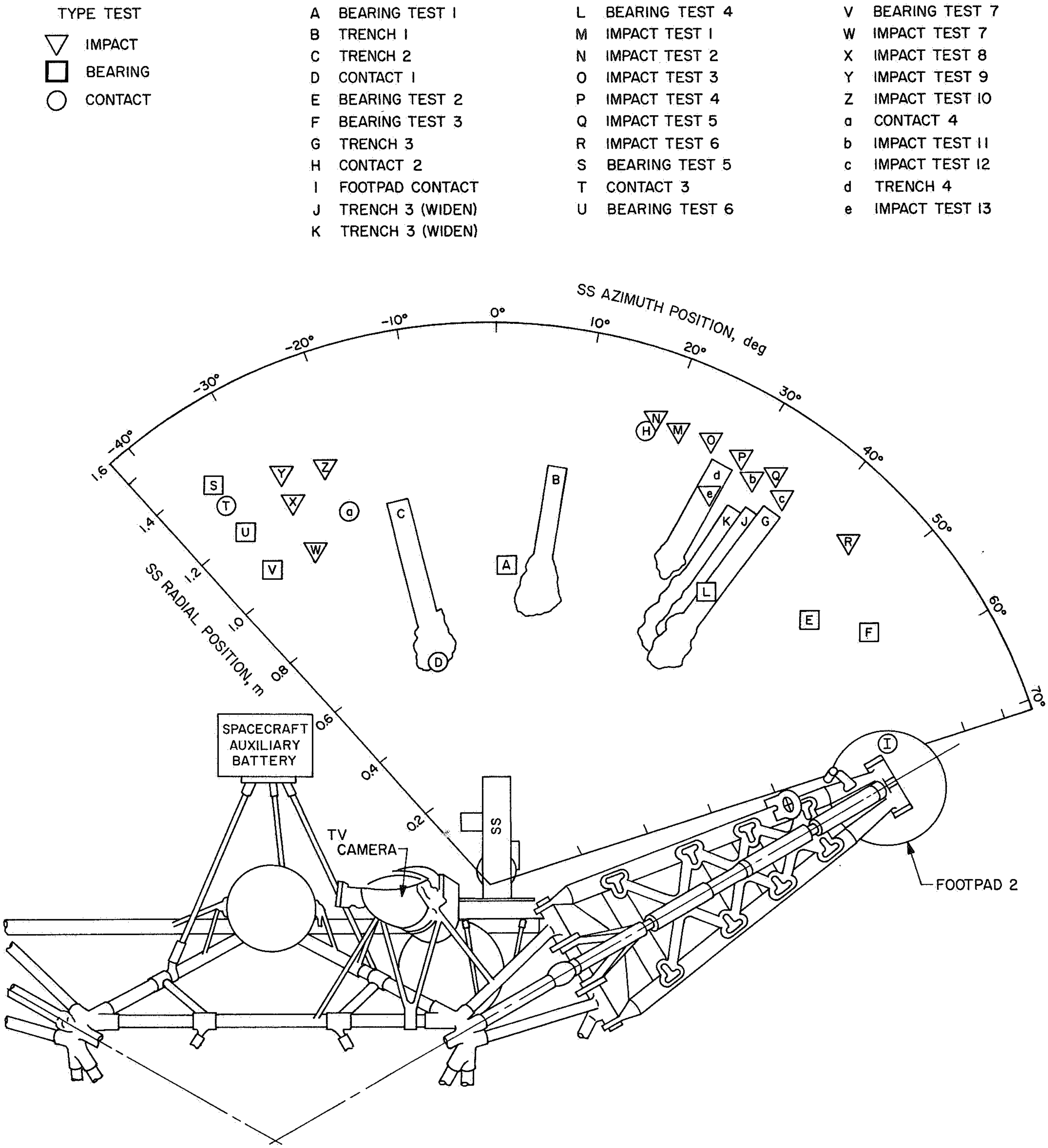


Fig. 29. Surface sampler activity on first lunar day, *Surveyor III* mission

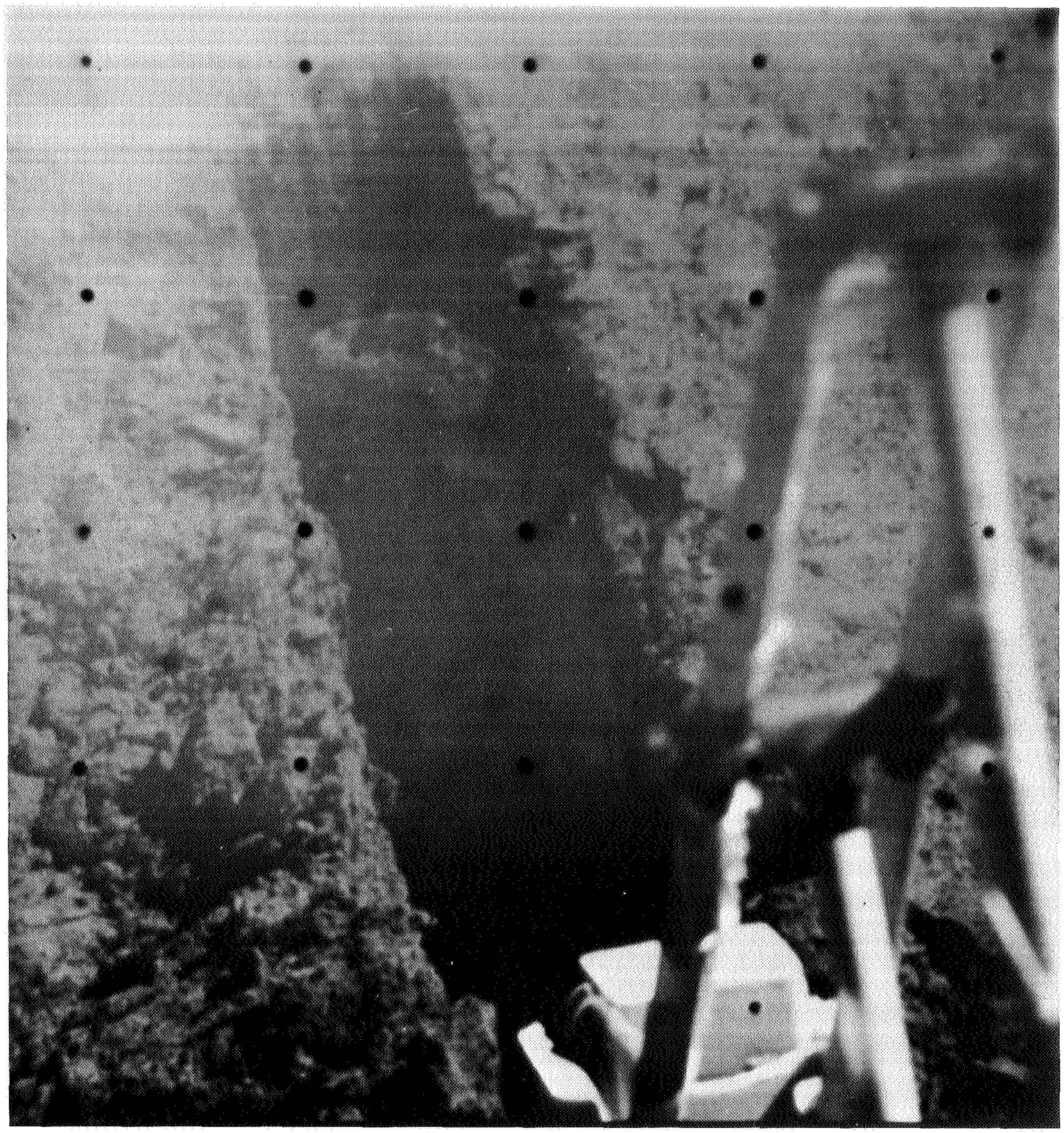


Fig. 30. Surface sampler and second trench

Two dragging operations through trench 2, Fig. 29, point C were conducted. Figure 31 presents a narrow-angle view of a portion of the trench during the second drag. The top of the surface sampler scoop is clearly visible in the photograph.

4. Day 114

Temperature problems in the television camera disallowed surface sampler operations during this Goldstone view period.

Fig. 31. Narrow-angle view of surface sampler having completed a second pass digging a trench. Object near the top was thought to be a rock; later events determined that it was not

5. Day 115

Solar eclipse studies precluded surface sampler operations during this Goldstone view period.

6. Day 116

Initial SS power on, 10:14 GMT
Final SS power off, 11:54 GMT
Actual SS power on time, 48 min
Number of interface commands transmitted to SS, 437
Number of SS commands executed, 184

An attempt was made to pick up what appeared to be a rock at the foot of trench 2, Fig. 29, point D. The object was apparently crushed as the surface sampler scoop door was closed about it. The material in the scoop was transported to the area above the spacecraft landing footpad 2 and deposited on the pad. A narrow-angle color-filter survey of the material on footpad 2 concluded the surface sampler activities for day 116. Figure 32 is a wide-angle view of the SS mechanism on its way to deposit lunar surface material on footpad 2. Figure 33 is a narrow-angle view of the lunar surface material that was deposited on footpad 2.

7. Day 117

Initial SS power on, 07:54 GMT
Final SS power off, 10:38 GMT
Actual SS power on time, 86 min
Number of interface commands transmitted to SS, 413
Number of SS commands executed, 151

Two bearing tests and a third trenching operation in the vicinity of footpad 2 were performed by the surface sampler during this Goldstone view period. This activity is presented in Fig. 29 as points E, F, and G. During the trenching operation, 26 narrow-angle television pictures were taken, one after each of the twenty-six 2-s retraction increments that were required to dig trench 3.

8. Day 118

Initial SS power on, 09:36 GMT
Final SS power off, 13:36 GMT
Actual SS power on time, 168 min
Number of interface commands transmitted to SS, 1276
Number of SS commands executed, 447

A small pebble was picked up (Fig. 29, point H) and transported to the area above the spacecraft footpad 2. The scoop door was opened and the material in the scoop was deposited on footpad 2. A large amount of material remaining in the scoop from a previous trenching operation became dislodged from the scoop and covered the pebble. Attempts to uncover the pebble were unsuccessful. Two trenching operations to widen trench 3 and one bearing test were performed (Fig. 29, points J, K, and L).

9. Day 119

Initial SS power on, 08:59 GMT
Final SS power off, 10:57 GMT
Actual SS power on time, 90 min
Number of interface commands transmitted to SS, 463
Number of SS commands executed, 92

A series of six impact tests with the scoop door closed were performed by elevating the SS mechanism and disengaging the elevation drive clutch, thus allowing the scoop to impact the lunar surface under the influence of the picking torque spring. Impact test 1 was performed from a height of one 2-s elevation step (Fig. 29, point M). Impact tests 2 and 3 were performed from heights of two 2-s elevation steps, (Fig. 29, points N and O).

Impact tests 4, 5, and 6 were performed from heights of four 2-s elevation steps (Fig. 29, points P, Q, and R). Surface sampler activities were concluded by exercising the surface sampler in several of its operational modes to record the size of motion increments provided by the motors.

10. Day 120

Initial SS power on, 15:18 GMT
Final SS power off, 17:03 GMT
Actual SS power on time, 96 min
Number of interface commands transmitted to SS, 610
Number of SS commands executed, 146

A series of three bearing tests (5, 6, and 7) and four impact tests (7, 8, 9, and 10) were performed during this Goldstone view period. Impact tests 7 and 8 were performed by elevating the SS mechanism two 2-s elevation steps above the lunar surface before disengaging the elevation drive clutch. The bearing tests are presented in Fig. 29 as points S, U, and V, and the impact tests as points W, X, Y, and Z. In addition, a small rock was uncovered from the lunar surface. The small rock was located at point a in Fig. 29. Figures 34 and 35 show bearing test operations on the lunar surface.

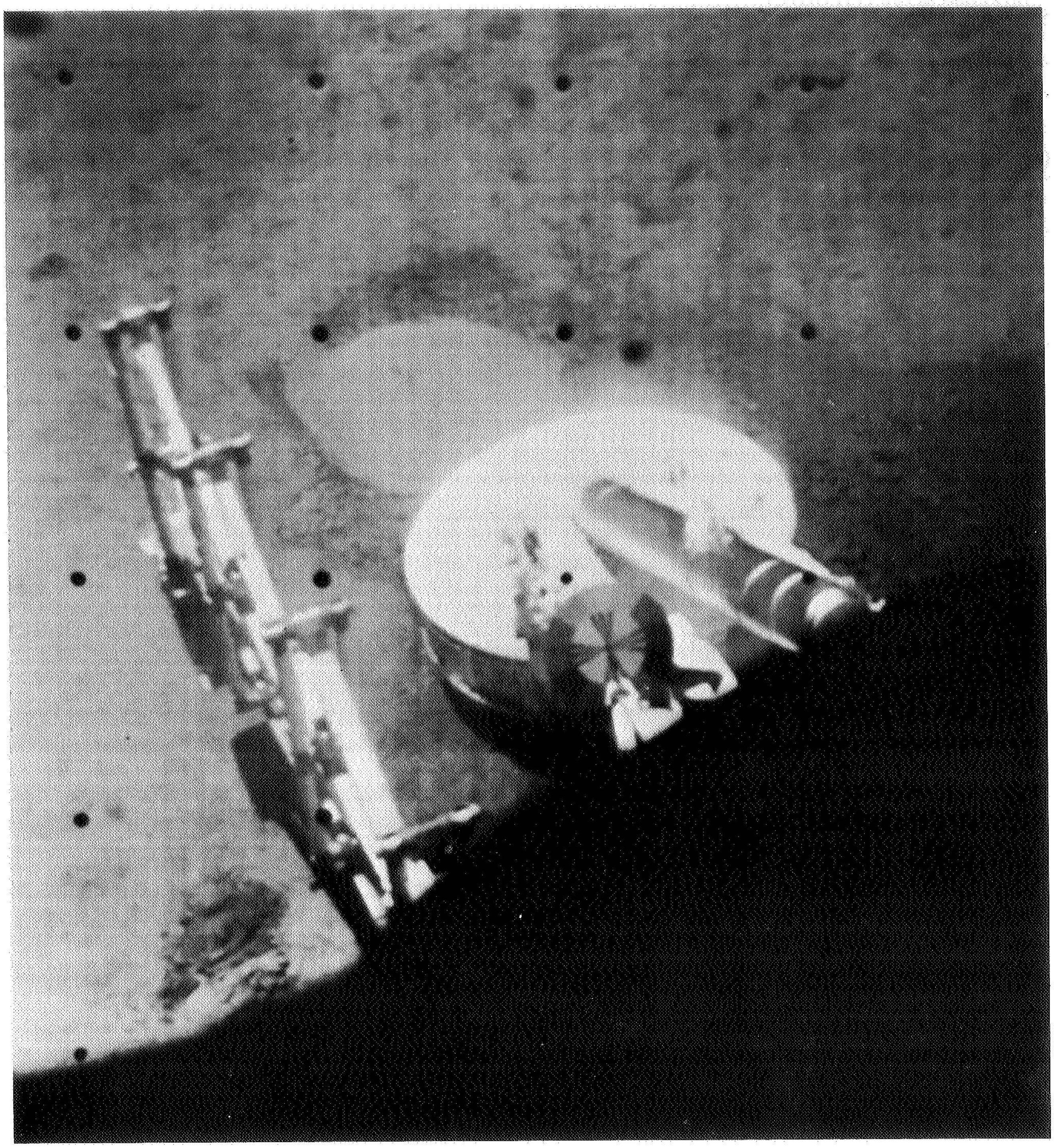


Fig. 32. Approximately two cubic inches of lunar soil in the surface sampler scoop as it approaches footpad 2

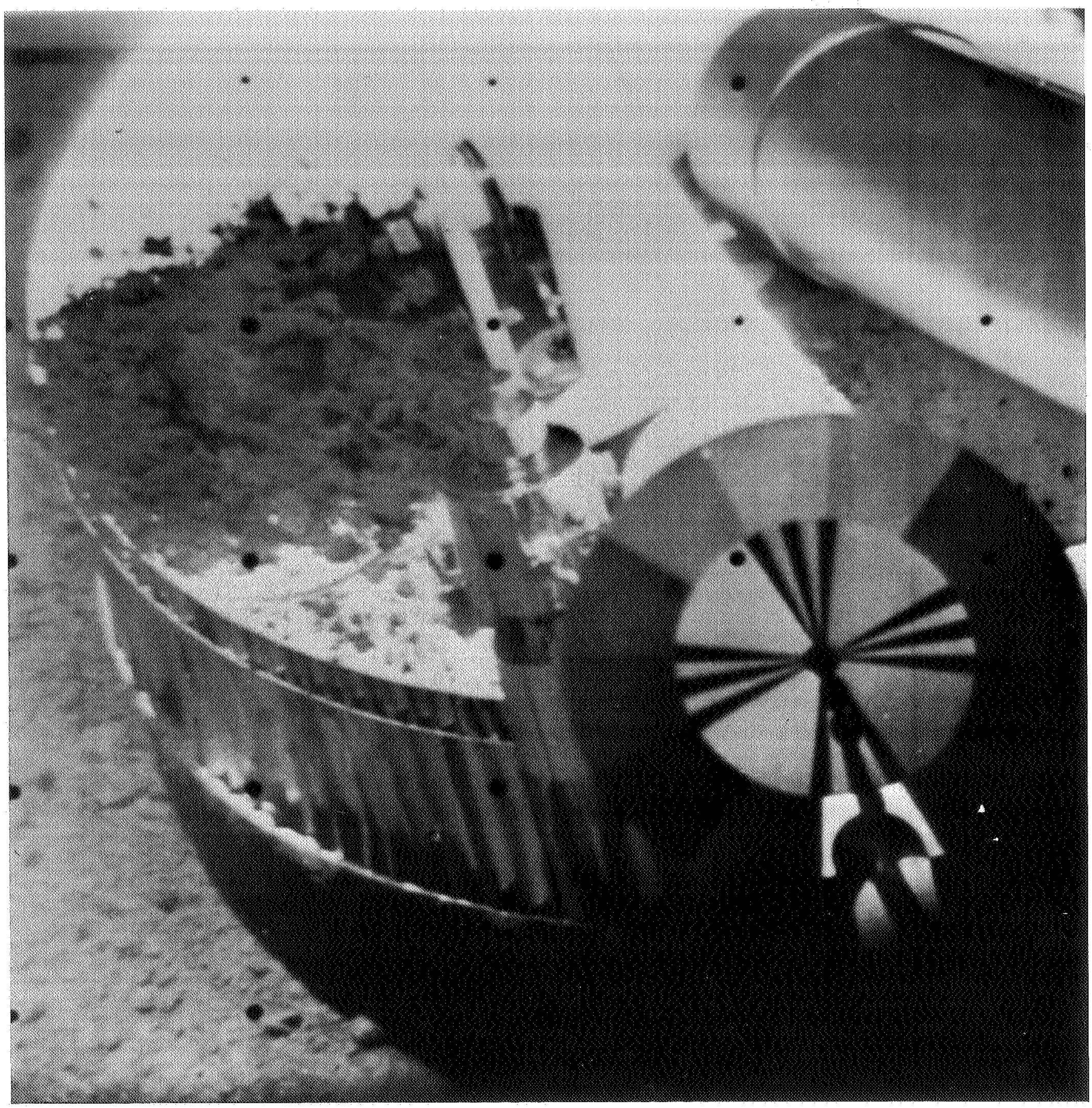


Fig. 33. Lunar soil on footpad 2

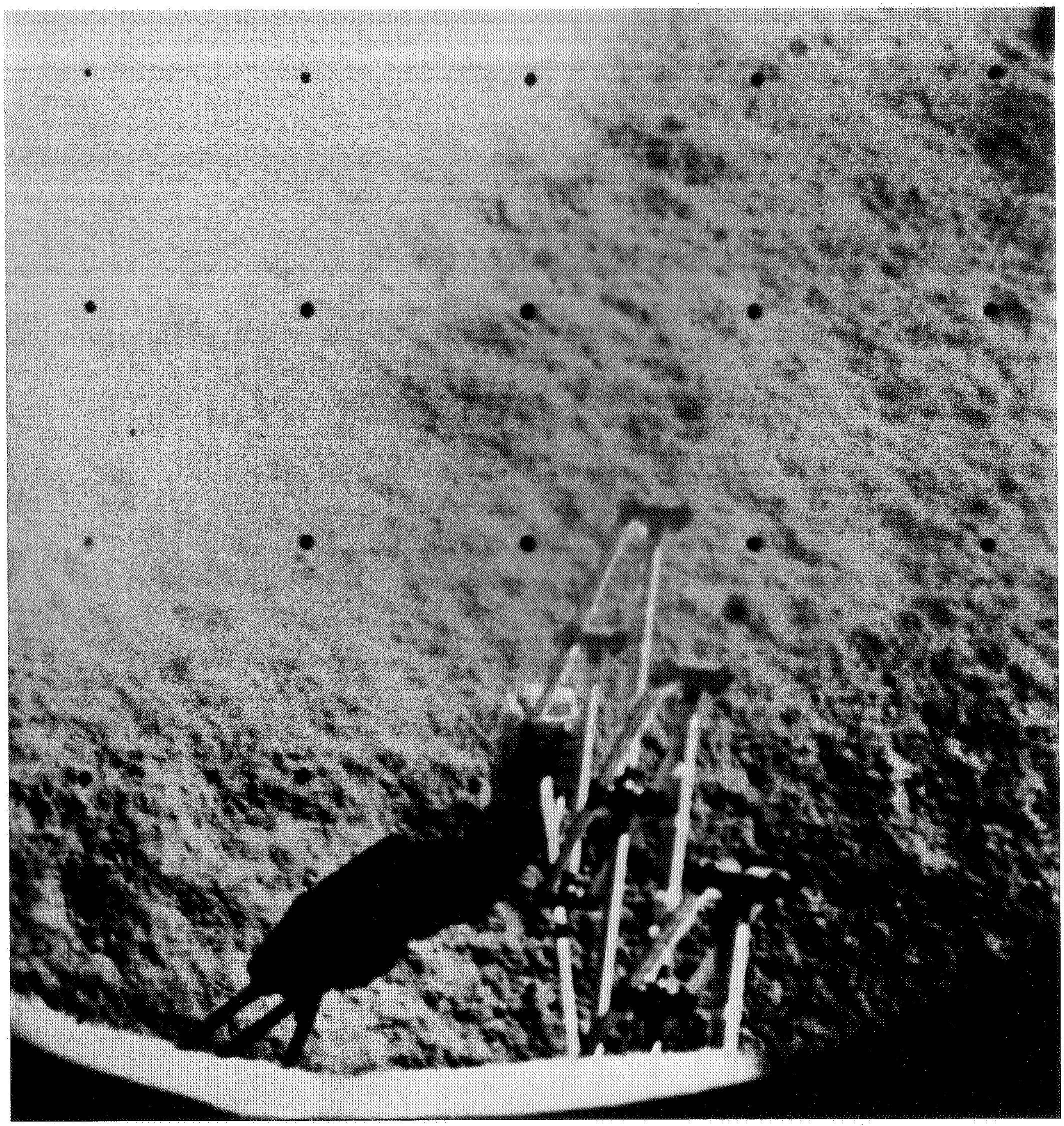


Fig. 34. Surface sampler scoop as it has just contacted the lunar surface in preparation for a bearing test

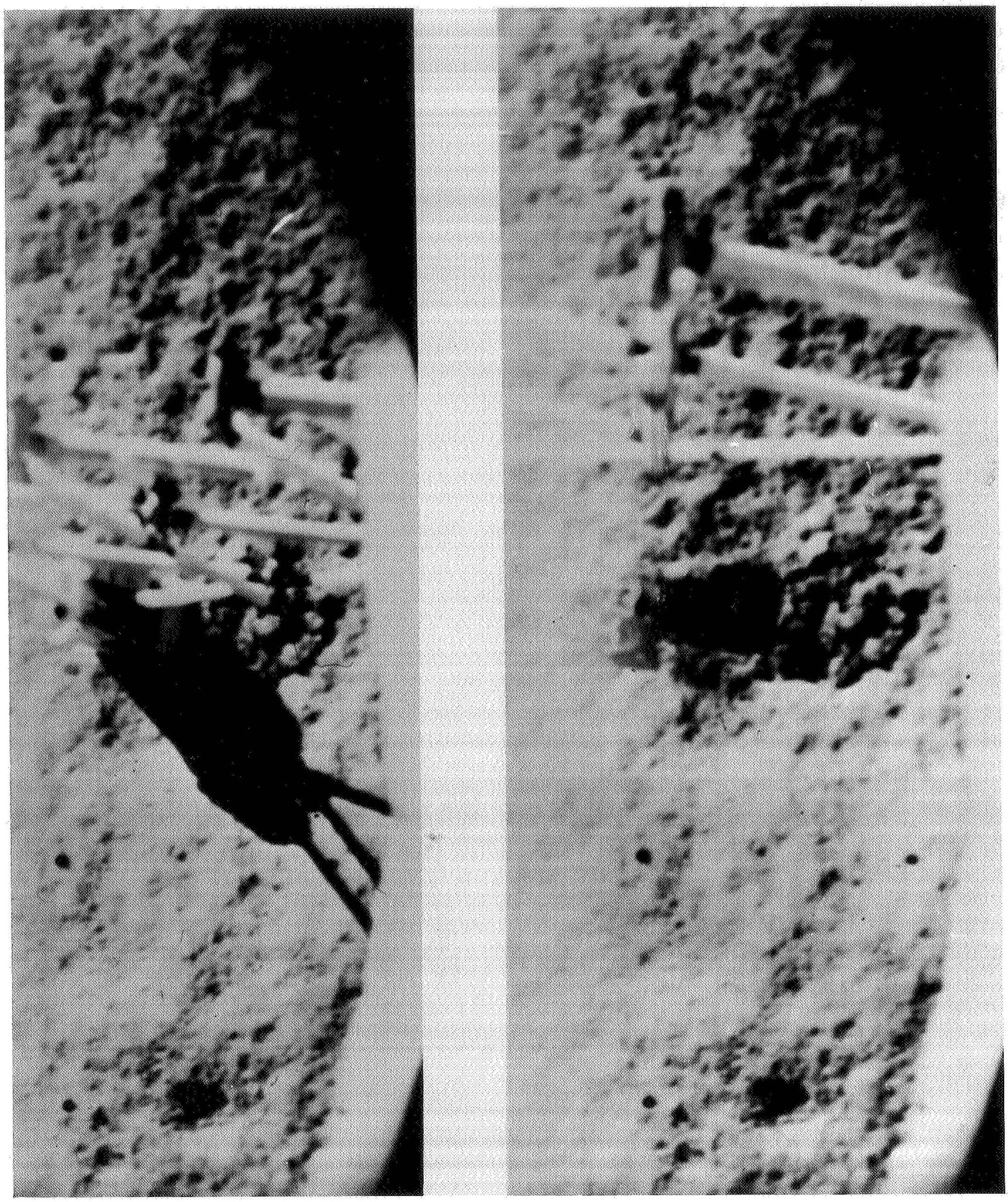


Fig. 35. Lunar bearing test. Depression made by surface sampler scoop pressed into lunar surface

11. Day 121

Initial SS power on, 14:34 GMT
Final SS power off, 17:35 GMT
Actual SS power on time, 153 min
Number of interface commands transmitted to SS, 870
Number of SS commands executed, 276

The small rock discovered on day 120 was picked up with a major portion of the rock protruding from the scoop. A complete color-filter survey of the rock and the surface sampler scoop was performed. During manipulation of the SS mechanism the rock slipped out of the scoop and was not relocated. In addition, three new drags through trench 2 were performed and four impact tests, with the scoop door open, were performed in the floor of trench 2.

12. Day 122

Initial SS power on, 11:47 GMT
Final SS power off, 14:19 GMT
Actual SS power on time, 149 min
Number of interface commands transmitted to SS, 703
Number of SS commands executed, 182

A fourth trench was constructed and three additional impact tests, the first two with the scoop door open and the third with the scoop door closed, were performed during this Goldstone view period. The trench is shown in Fig. 29 as point **d** and the impact points as points **b**, **c**, and **e**. Since this was the last surface sampler activity during the lunar day, an unloaded functional test of the SS mechanism was conducted. This test was performed to record the SS mechanism motion increments. The final position of the SS mechanism is above trench 4.

13. Summary of Surface Sampler Commands and Motor Running Times

Total SS power on time, 18 hr 22 min
Total number of interface commands transmitted to SS, 5879
Total number of SS commands executed, 1898
Total elevation clutch solenoid time, 0.67 min
Total scoop motor running time, 0.70 min
Total azimuth motor running time, 0.45 min
Total elevation motor running time, 5.93 min
Total retraction motor running time, 22.8 min

Bibliography

Le Croissette, D. H., and Chandler, C. E., "The Design and Use of the Surface Sampler on the Lunar Spacecraft Surveyor III," ISA preprint P1-4-PHYMMID-67, paper presented at the 22nd Annual Conference and Exhibit, Sept. 11–14, 1967, Chicago, Ill.

Scott, R. F., "Soil Mechanics Considerations in the Testing of Lunar Soil Models," in *The Lunar Surface Layer*. Edited by J. W. Salisbury and T. E. Glaser, Academic Press, Inc., New York, 1964.

Scott, R. F., "Lunar Problems in Soil Engineering," *Soil Mech. Found. Eng.*, Vol. 91, SM-1, p. 1, Jan. 1965.

Surveyor III Mission Report: Part I. Mission Description and Performance, Sept. 1, 1967; *Part II. Scientific Results*, June 1, 1967, Technical Report 32-1177. Jet Propulsion Laboratory, Pasadena, Calif.

Appendix

Surveyor III Milestone Chart

SURVEYOR MISSION C & D
SIMPLIFIED SOIL MECHANICS SURFACE SAMPLER SUBSYSTEM SCHEDULE