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Technical Report 32-1419

Capsule System Packaging for Mars Rough Lander

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Preface

The work described in this report was performed by the Engineering Mechanics Division of the Jet Propulsion Laboratory.

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Abstract

The packaging techniques utilized on the Capsule System Advanced Development lander (completed at JPL in June 1968 as an experiment to determine the survivability of a Mars rough lander) are presented. The discussion covers the use of standard components, the flexibility of subsystem location, and the simple integration of electronic assemblies.

The experiment conclusively demonstrates that the assembly packaging techniques utilized (conventional components) are reliable, and that the equipment is relatively easy to design and fabricate (or modify) on a short-time basis.

Capsule System Packaging for Mars Rough Lander

I. Introduction

This report describes the packaging techniques utilized on the Mars lander fabricated and tested by JPL as a part of the Capsule System Advanced Development (CSAD) program. The objective of this packaging effort was to determine the capability of electronic equipment to survive a hard landing similar to that expected under Martian environmental conditions. Three requirements were imposed on the lander assembly: (1) a sterilization cycle to evaluate the effects of extended periods of heat on the equipment, (2) functional testing to demonstrate the capability of the subsystems to function successfully as a working system, and (3) environmental testing to demonstrate adequacy of design under simulated landing conditions. A profile of the sterilization cycle is shown in Fig. 1 and is self-explanatory. The lander is shown in Fig. 2 without its balsa impact limiter; its dimensions as shown are 16 × 6 in. Figure 3 shows the lander assembled in the impact limiter; its dimensions and weight in this configuration are 22 × 9 in. and 63 lb, respectively.

The environmental tests consisted of dropping the lander from a helicopter hovering 250 ft above the impact surface. Figure 4 shows the lander (with instrument boom extended) after impacting a dry lake bed (yielding surface) at about 120 ft/s with an impact force of 1500 g. The lander (again with instrument boom extended) is shown in Fig. 5 after impacting an asphalt runway (nonyielding surface) at the same approximate speed and a 2500-g impact force. Figures 4 and 5 show the condition of the lander after drop tests 1 and 2, respectively.

II. Packaging Philosophy

A. Lander Development

The development of a Mars lander began with a weight limitation of 45 lb. The time schedule was tight and, therefore, much existing technology was utilized. The severe weight limitation and exceedingly short development schedule dictated the following design limitations:

(1) High degree of integration.

(2) High degree of flexibility.

(3) Minimum design and fabrication time.

B. Structural Integration

To fabricate a lander of minimum weight, a high degree of structural integration was required. The equipment had to be integrated as load-bearing members of

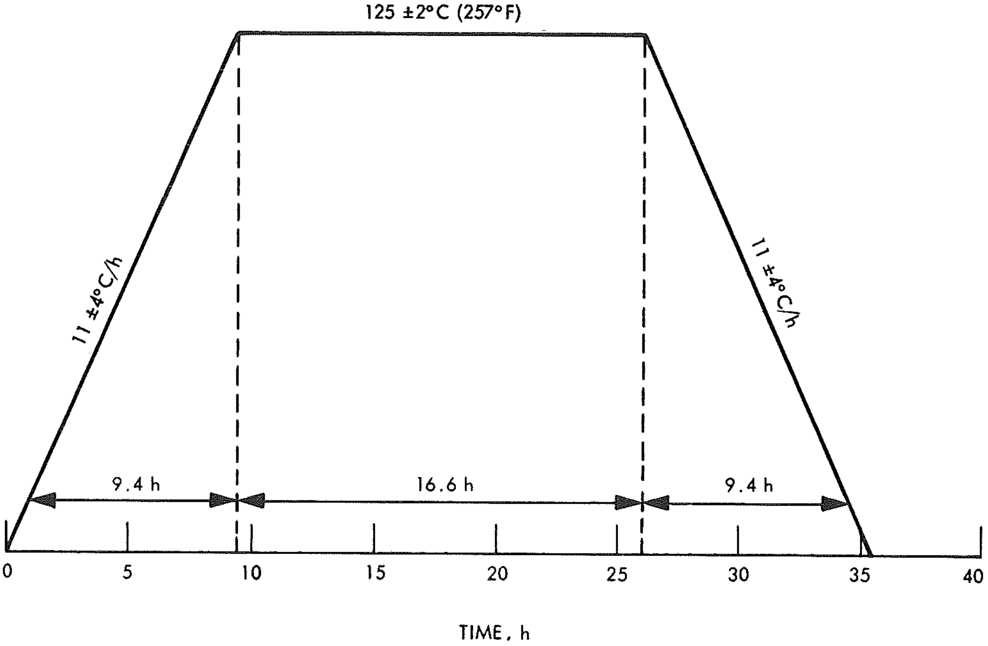


Fig. 1. Typical sterilization cycle profile

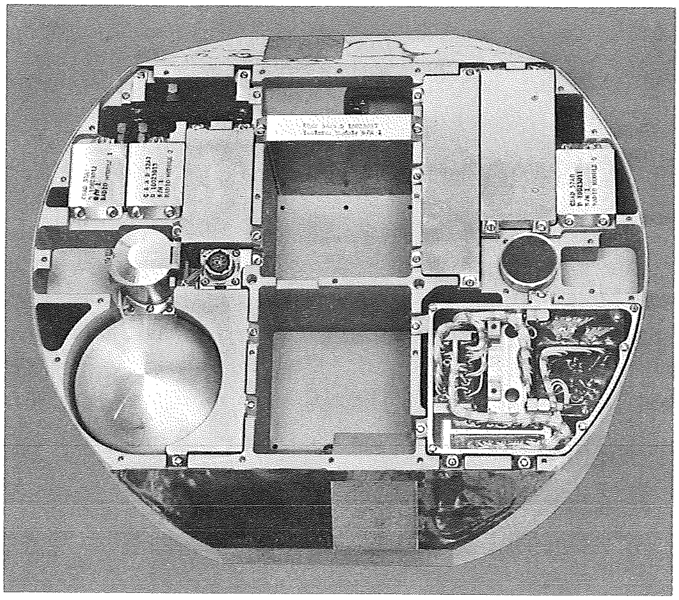


Fig. 2. Lander without impact limiter or battery

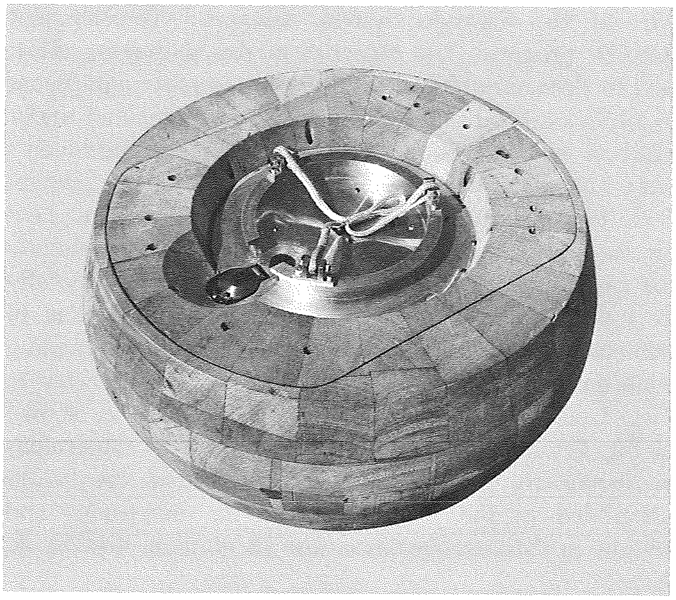


Fig. 3. Lander assembled in balsa impact limiter

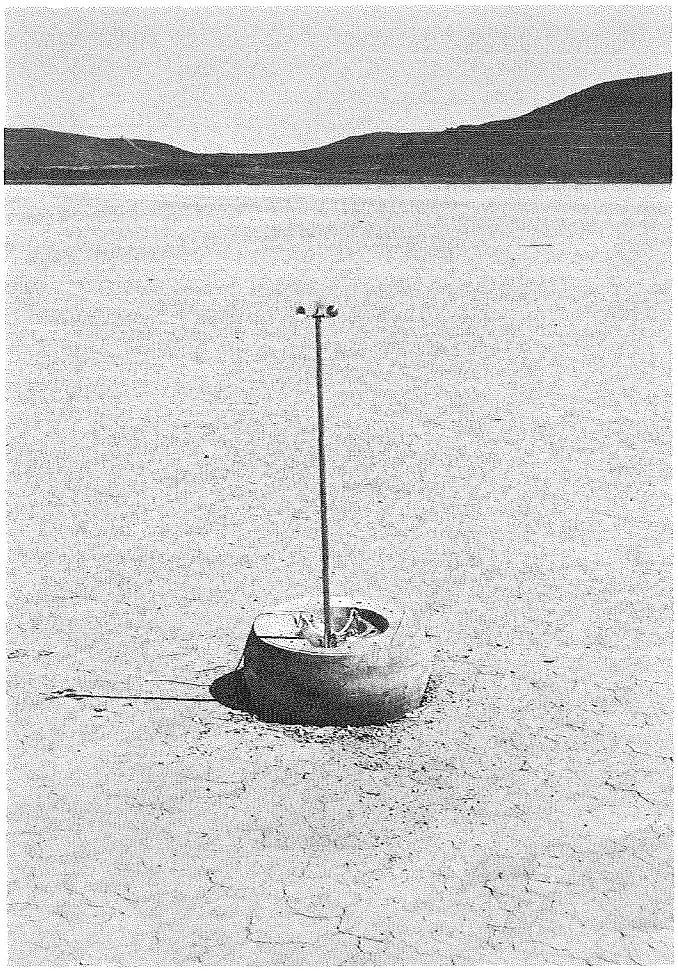


Fig. 4. Lander after drop on dry lake bed (yielding surface)

the structure designed to withstand severe shock environments. The electronic subassemblies were typically designed to resonate above a frequency of 400 Hz. The 400-Hz minimum natural frequency was a design goal for all electronic assemblies. Previous experience has demonstrated that most of the electronic equipment failures recorded during vibration testing were caused by excessive deflections of the surface where electronic components were mounted. Experience has also demonstrated that electronic equipment resonating above a frequency of 400 Hz is generally trouble-free.

C. Design Flexibility

Configurational flexibility was the major design consideration. The majority of the subassemblies were packaged in a standard profile, with uniform attachments to the chassis. The width of each subassembly was made flexible to accommodate special requirements. The philosophy was to incorporate many different facets, such as planar packaging, welded cordwood, and modular packaging. Because of this high degree of standardization, the electronic subassembly packaging design requirements were well defined early in the program. All-around flexibility was maintained in the lander design. Only the structural webs were incorporated in a predetermined position on the chassis. As the lander subsystem became better defined, layouts were made in an attempt to satisfy the following four conflicting regulations:

1. Maintain all subassemblies of a subsystem in the same location.
2. Keep related subsystems in close proximity for shorter cabling.
3. Distribute power dissipation in heat uniformly throughout the lander.
4. Retain lander center of gravity in a predetermined locality.

These requirements were difficult to meet, and the integration of the electronic equipment triggered a series of trade-offs. Some of these trade-offs were:

1. Optimum thermal distribution vs additional cabling.
2. Optimum subsystem center-of-gravity control vs weight constraints.
3. Optimum volumetric efficiency vs flexibility in accommodating design changes.

D. Time Element

Another (and probably the most constraining) design requirement was short development time. In addition to the usual schedule problem for packaging, design, and fabrication, the design approach had to be one that: (1) could be changed without affecting the schedule, (2) could be completed rapidly, and (3) was, because of lack of time for rework or redesign, judged to be environmentally sound from the outset.

E. Payload

The lander payload consists of:

1. A battery.
2. A power conditioning unit.
3. A sequencer and timer.
4. A radio.
5. A chemical heater.

Fig. 5. Lander after drop on asphalt (nonyielding surface)

(6) Two science instrument booms.

(7) An omnidirectional switch.

(8) A data handling subsystem (functional but not part of the lander-operated system).

Because the lander is bistable, there are two booms (one on each face) and a sensing switch that causes the topside boom to extend. The only instrument requiring orientation was the anemometer. Both sides of the lander are easily accessible even with the balsa wood in place; one side houses the system cabling, the other the subsystems.

III. Description of Equipment

A. Chassis

The lander chassis is a disk-shaped unit, 16 × 6 in., made of a structurally integrated payload subdivided into two sections by a main shear plate 4 in. from the top (Fig. 6). The upper portion of the chassis houses all the electronic subsystems that, in a fully assembled condition, form an integral part of the main chassis, since each subsystem has connectors attached to the subchassis. Cutouts in the main shear web allow the subsystem connectors to protrude through the lower section of the chassis for subsystem interconnections. The lower portion of the chassis is designed to house the signal and RF cabling. The chassis is also designed to make the antennas an integral part of the structure. Six cavities were machined and strategically located to look along the orthoradial axis to ensure radio coverage regardless of the position of the lander after impact. Many materials—such as beryllium, titanium, magnesium, and different grades of aluminum—were considered for this application. The candidate best suited to this program was 6061T6 aluminum.

Considerations in selecting a candidate material included cost, weight, sterilizability, fabrication, and weldability, as well as structural and thermal considerations. To enhance the structural integrity of the assembly, lower and upper covers were added. The upper cover (Fig. 7) also houses the battery. The covers are recessed into the chassis to form two additional shear plates for protection in the event of radial impact. The upper cover is fastened to the top of the chassis and the main shear plate. The cover is fastened to the main shear plate by 6 (4-40) screws, and attached to the top of the chassis by 33 screws (31 4-40 and 2 ¼-20). Part of the top cover also forms a housing to support the parachute canister.

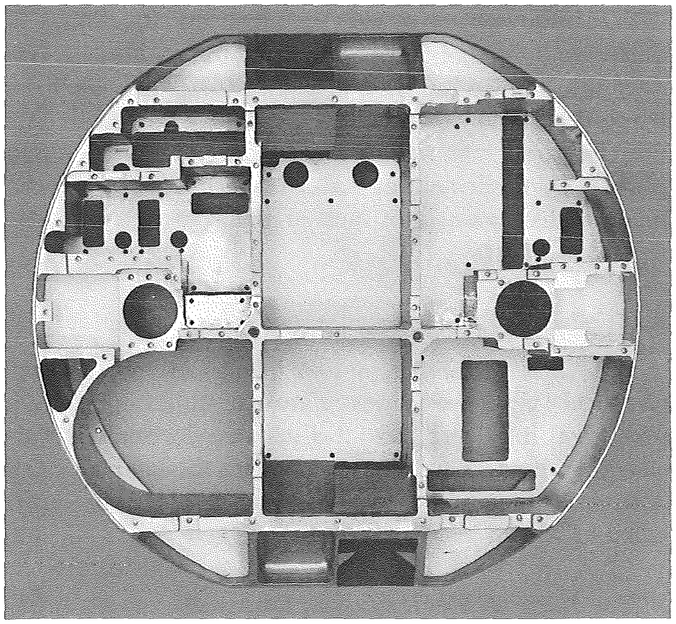


Fig. 6. Lander chassis

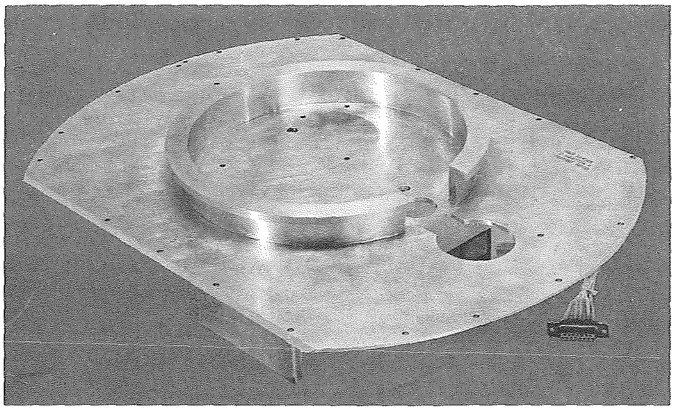


Fig. 7. Upper cover and battery housing (top view)

The lower cover is attached to the chassis by 25 (4-40) screws. Recessed into the chassis are thin-wall, threaded locking inserts to receive the screws. Apart from the 2 (¼-20) screws in the top cover, all screws are 4-40 × ⅜-in. long, high-torque head, A286 nonmagnetic steel.

The main shear plate is also used as a thermal web for the subsystems. Cutouts were made in the covers for boom extrusion and connector disconnects. The latest machining techniques had to be used to fabricate the lander chassis. The chassis drawing was divided into two major drawings: one for all machining and one for the drilling of the holes and cutouts.

The initial objective was to meet the functional requirements without weight limitations. Studies conducted to reduce the weight of the chassis indicated that it could be reduced from 17.2 to 12 lb without affecting the structural integrity of the lander. This was accomplished by implementing special features that were not incorporated because of lack of time (two chassis were fabricated).

B. Cabling

The lander cabling system provides all-separable electrical interconnections between subassembly and peripheral interfaces. To fabricate the electronic harness assembly, it was necessary to simulate the lander chassis. A fixture simulating the chassis was designed and fabricated as shown in Fig. 8.

The harness assembly was fabricated of 24 AWG, 19-strand, silver-plated, high-strength copper alloy wires insulated with 600-V wrapped TFE Teflon, and 22 AWG, 19-strand, silver-plated, annealed, commercially pure copper wires insulated with 600-V wrapped TFE Teflon.

The connectors consist of:

(1) A rack and a panel-polarized shell.

(2) Miniature electric connectors.

(3) Nonmagnetic, class N gold-plated contacts and shell.

(4) Quick-disconnect, circular miniature electrical connectors, with the following modifications:

  (a) Iridite shell finish.

  (b) Silicone connector inserts.

  (c) Heavy gold-plated contacts.

  (d) JPL nonmagnetic requirements met.

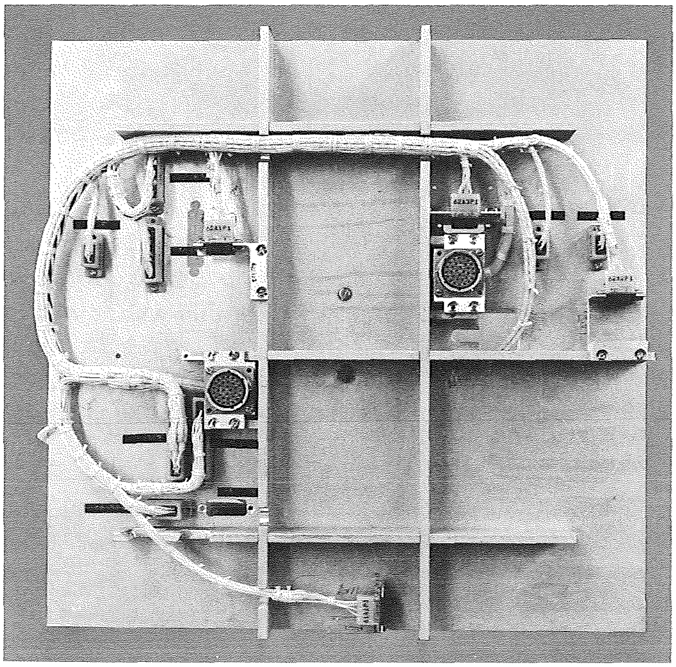


Fig. 8. Harness and fixture assembly

A block diagram of the lander cabling is shown in Fig. 9. After electrical checkout, the harness was potted in accordance with JPL specifications. To reduce the cost of the lander cabling, no harness detail drawings were made, and only a sketch of the assembly was drawn. The harness was fabricated in accordance with the diagram in Fig. 9, and routed per the fixture (see Fig. 8); three harnesses were fabricated. (Radio module 3 not wired.)

Initially, the cabling philosophy was to incorporate a flat-lay cable as the harness. A depth of 1¼ in. was used on the cable side of the chassis; however, because of lack of time, more conventional techniques (as explained above) were used, and the 1¼-in. depth was increased to 2 in. The feasibility of a flexible flat harness was investigated and resulted in the study and fabrication of a harness system (Fig. 10). This harness was not used during any of the CSAD tests.

C. Radio

Only one radio subsystem was fabricated. This subsystem consists of: (1) six antennas (in chassis), (2) a transmitter (Fig. 11) (four modules—0, 1, 2, and 3), (3) an isolator (dummy), and (4) an antenna switch (dummy).

1. Electronic packaging. The electronic packaging for the transmitter consists of terminal boards bonded to the subchassis and discrete components mounted directly to the structure. This determines the shape and size of modules 0, 1, and 2 (the same configuration) and the bracketry to attach module 3 (vendor part) to the main chassis.

The H-shaped subchassis are of 6061T6 aluminum construction, with mounting ears to attach to the top of the chassis and inserts in the base to attach to the main shear web. Input and output RF connectors are placed at the bottom and side of the subchassis, and type D series connectors are attached on the bottom of the chassis.

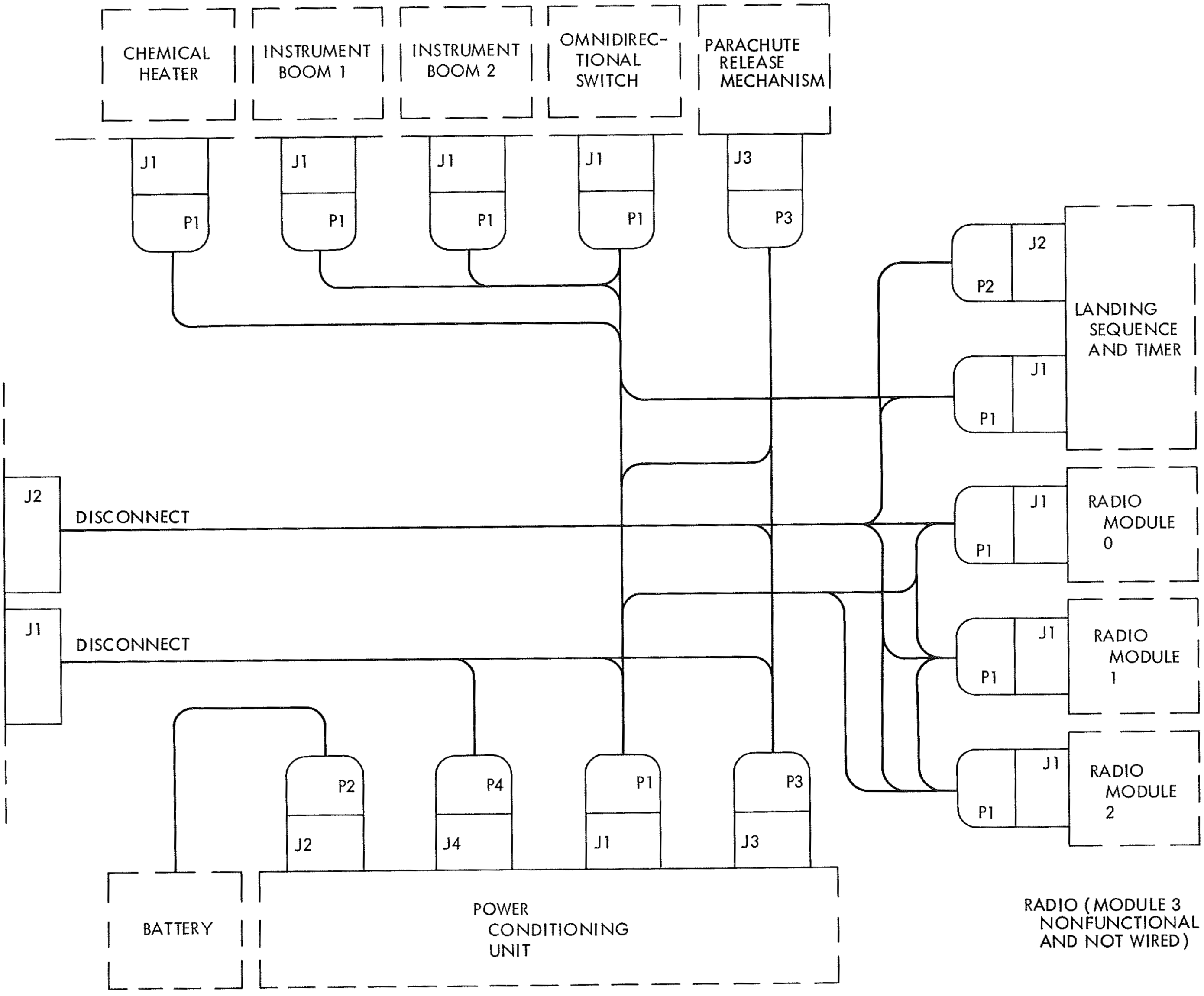
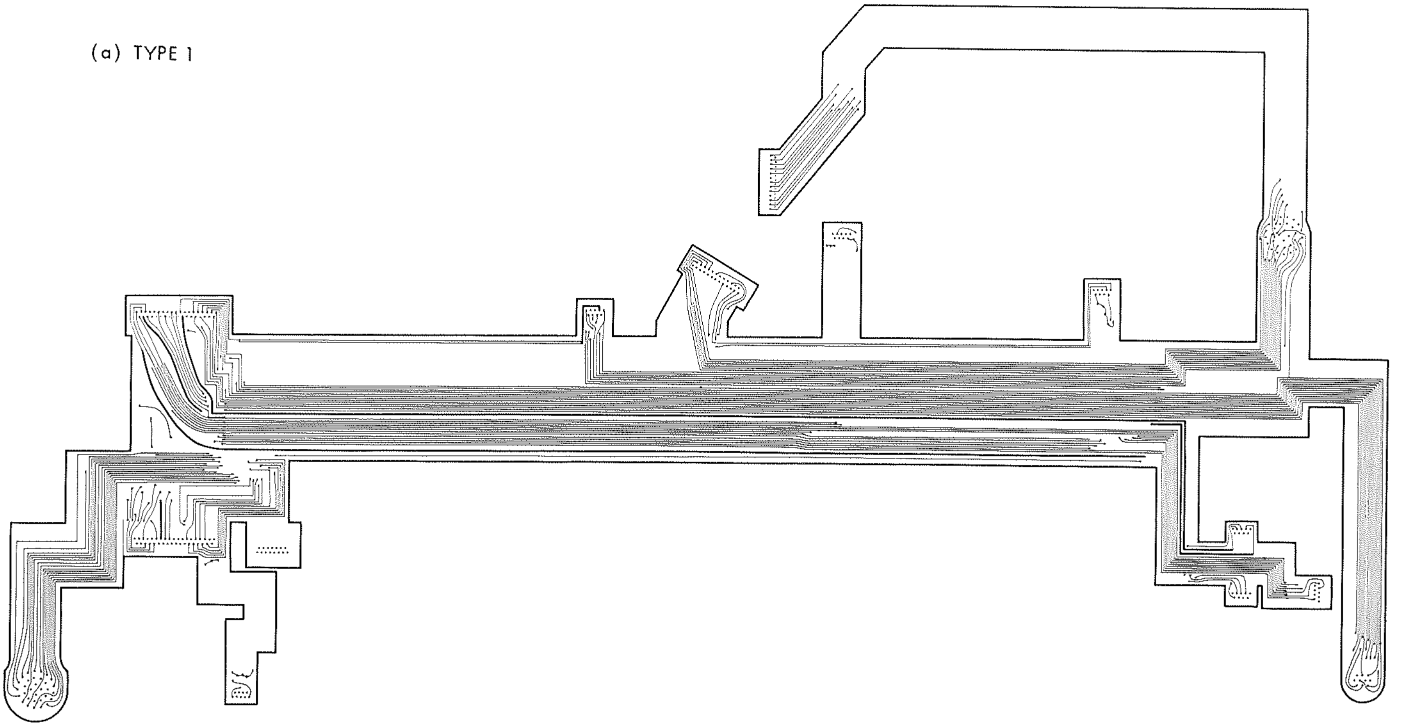


Fig. 9. Cabling block diagram

(a) TYPE 1



(b) TYPE 2

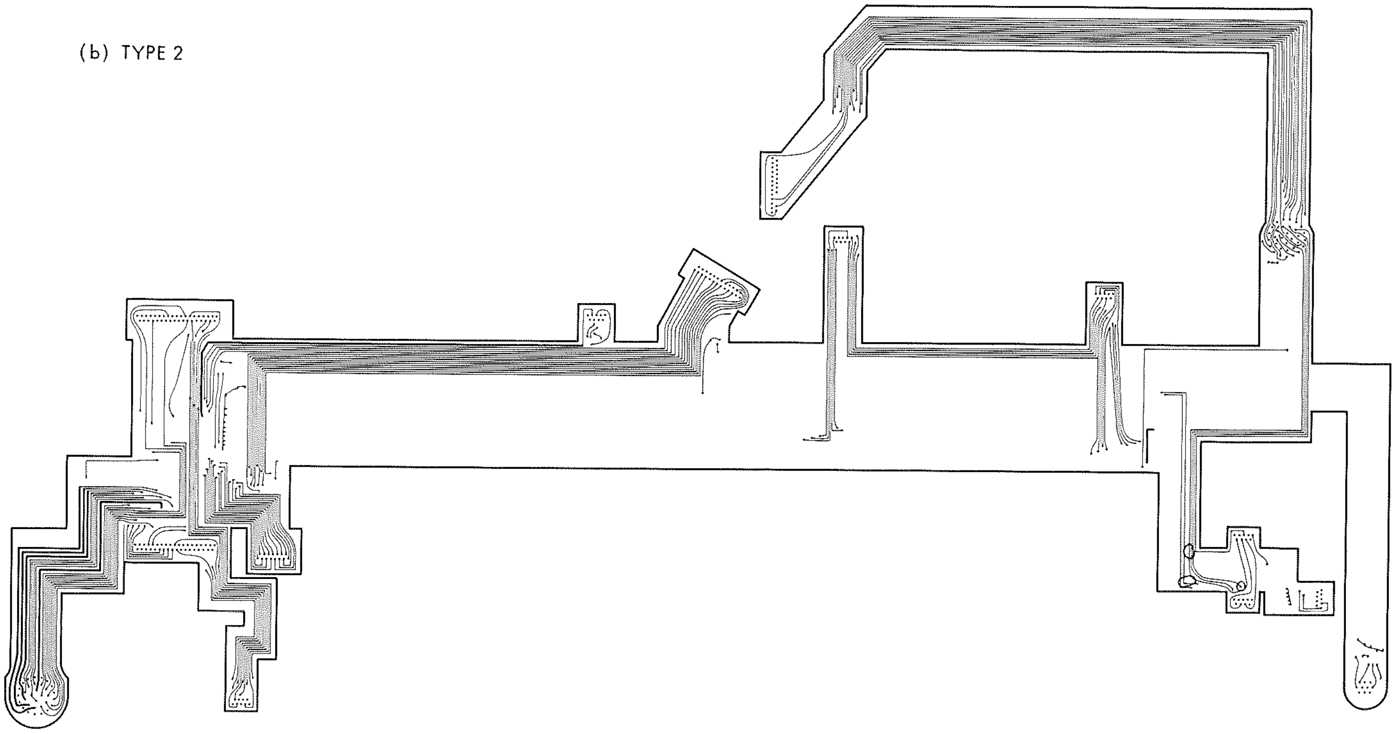


Fig. 10. Flexible harness

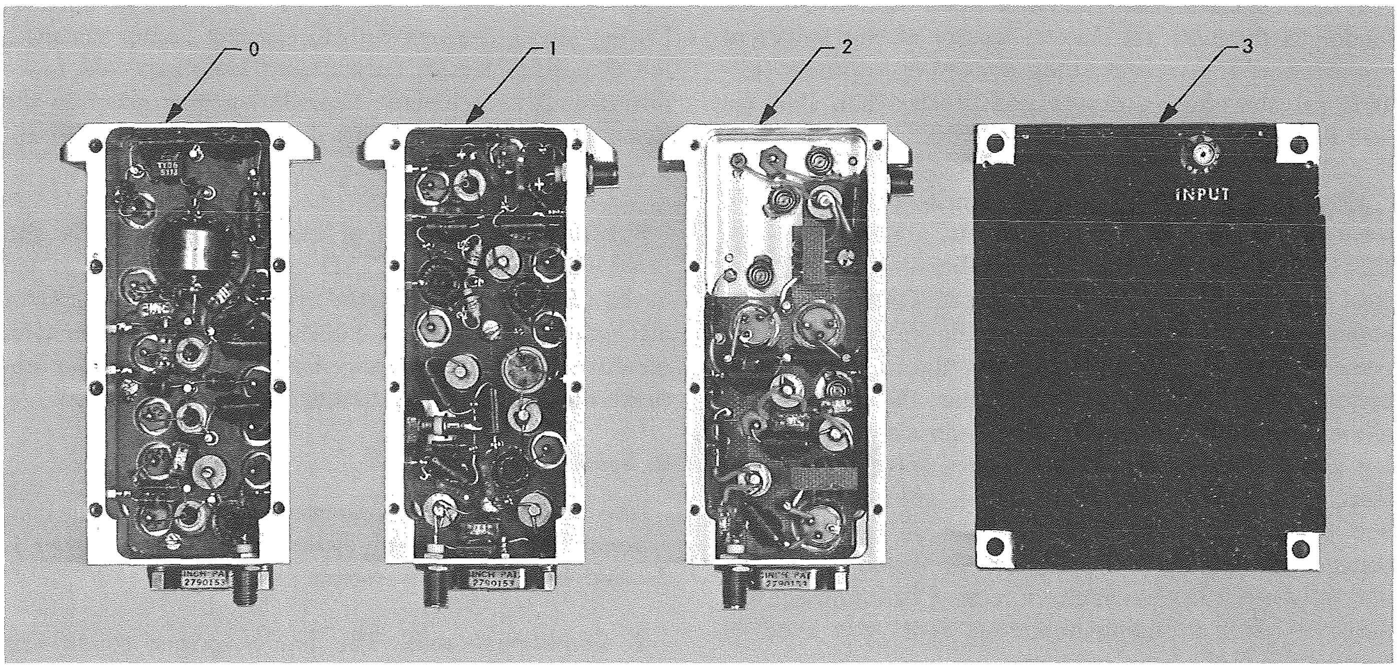


Fig. 11. Lander 5-W transmitter (modules 0–3)

Module 3 is a purchased standard part modified to attach to the chassis (nonfunctional in this configuration).

The isolator and antenna switches (6061T6 aluminum) were dummies housing only the RF connectors and RF interconnect cables. Final interconnects of the radio subsystem were made with semirigid coaxial cables and OSM connectors (right-angle and in-line).

After sterilization, cracks appeared around the solder joints on all of the in-line connectors. Because of the schedule and of the nature of the failure, these connectors were reworked and resterilized. The in-line connectors that could not be inspected without disassembling were replaced with right-angle connectors. The solder failure was believed to be caused by inadequate connector-soldering procedures; only right-angle connectors should be used in new designs.

2. *Antenna packaging.* Each antenna is a square cup formed from a cavity in the chassis. The cup is excited by a probe slanted along one of the cup diagonals (Fig. 12). The probe is an L-shaped rod that is an extension of the center conductor of the input coaxial connector located at the base of the cup. The metallic ridges on the antenna wall provide circularly polarized radiation. The entire cavity is filled with foam to give rigid support to the probe.

The antennas created most of the design problems because of the mechanical and electrical properties desired. At the outset of the program, no material was known to be capable of surviving the impact loads and still be capable of performing electrically after sterilization in the acquired volume. The design criteria allowed only for Eccofoam FP to be used because of the dielectric and loss tangents.

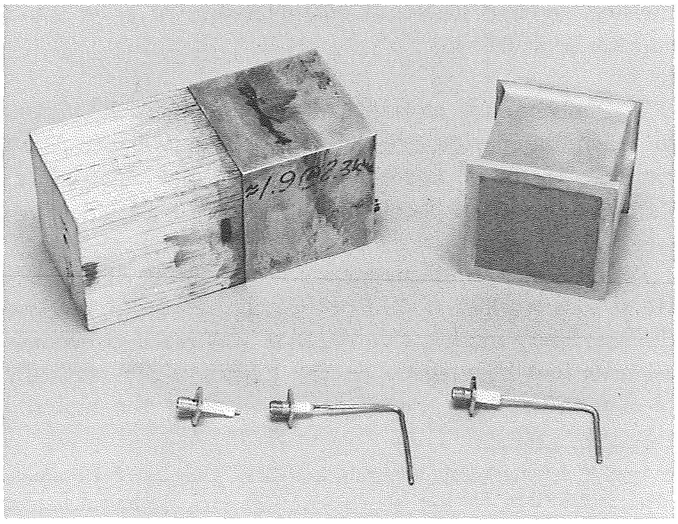


Fig. 12. Antenna and probe

It was estimated that the balsa wood used around the lander to dissipate the kinetic energy of the lander at impact would have a crushing density of approximately 1000 psi; therefore, a design goal greater than 1000 psi was the criterion for the antenna material.

Eccofoam FP has a crushing density of 300 psi and secondary foaming when exposed to a temperature of 125°C. Initially, the probe was fabricated of 0.088-in. steel tubing, and silver-soldered to an OSM 201 in-line connector. This operation caused the connector to become annealed and lose its pin-retention force. This also melted the epoxy resin supporting the probe, and allowed the probe to rotate. The resin also melted during sterilization of the connector. To solve these problems, a one-piece beryllium copper, gold-plated probe was designed with only the housing of the OSM 201 connector being used. To support the probe on impact, and to locate it in the connector, a new Teflon insert was designed, and a high-temperature resin was used to prevent the probe from rotating.

A number of foam materials were evaluated to support the probe in the antenna cavity, but only one could be sterilized and still meet the electrical requirements. The standard material supplied by the manufacturer had a density of 20 lb/ft^3; however, at this density, it did not meet the mechanical requirements, and crushed at 400 psi.

After numerous crushing tests and mixing procedures, along with evaluation of the electrical properties, it was decided to use a mixture with a density of 27.5 lb/ft^3. Initial tests completed on Eccofoam PT* (27.5-lb/ft^3 density) showed electrical characteristics of $\epsilon_T = 1.672$ and $\tan \delta\epsilon = 0.0145$.

The mechanical strength of the Eccofoam PT failed to reach the design goal of more than 1000 psi. With careful control of mixing and curing, the material resisted mechanical-strength tests up to 870 psi.

Because of limited manpower and funding, it was decided that a yield of 870 psi would be satisfactory for the feasibility model. This decision was reached because all tests had been made on the Eccofoam PT statically to determine the compressive strength of the material (this type of test is more severe than actual impact). During lander impacts with the impact limiter installed, the dispersion factors encountered were expected to be different. Although some degradation may occur in the Eccofoam PT materials, this degradation should not appreciably impair the antenna function.

Subsequent evaluation of materials (Imadite Sa and fused silica 50) in the CSAD program for antennas led to the discovery of a material offering potentially greater mechanical strength, and withstanding much higher temperatures, than are necessary for a Mars mission. To fabricate the probe, special tooling had to be designed.

D. Power Subsystem

The lander power subsystem consists of a power conditioner unit and a 5-A-h battery. The lander power is derived from these subsystems.

1. Conditioner unit. The lander power conditioner was fabricated by a contractor, but the packaging techniques were recommended by JPL. Because of the limited volume available, the schematic was divided into specific sections, and modular packaging techniques were used (Fig. 13). Because most power supplies use conventional planar packaging, this resulted in a unique, replaceable, throw-away encapsulated module. The subchassis and the modular frames for three subsystems were fabricated by JPL of 6061T6 aluminum. The transformers were assembled at JPL with magnetic equipment supplied by a vendor. The transformers were then placed into the metal cups, and encapsulated into a frame. The modules were encapsulated with Stycast 1090/11, with the aluminum frames acting as molds. A one-piece harness was fabricated on a small holding fixture, then mounted onto the subchassis. At this time, the back sides of the connectors were sealed with RTV 881 cement; each module was mounted onto the subchassis, and the harness was terminated. Holes were provided in the subchassis to allow any heat to escape and to lighten the structure.

2. Battery. During the design phase of the chassis, the battery played a major role in the configuration. Because the battery was the only source of power, it was deemed necessary to give it as smooth a ride as possible by locating it in the center of the structure. Identical batteries were used for each of the two lander drops.

Material selection for the cell construction was based upon those materials found to be heat-sterilizable in

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*Lane, F. L., Dielectric Constant and Loss Tangent of Eccofoam PT, at 2.3 GHz, for Various Packing Densities, Technical Report 32-1433. Jet Propulsion Laboratory, Pasadena, Calif., Dec. 1, 1969.

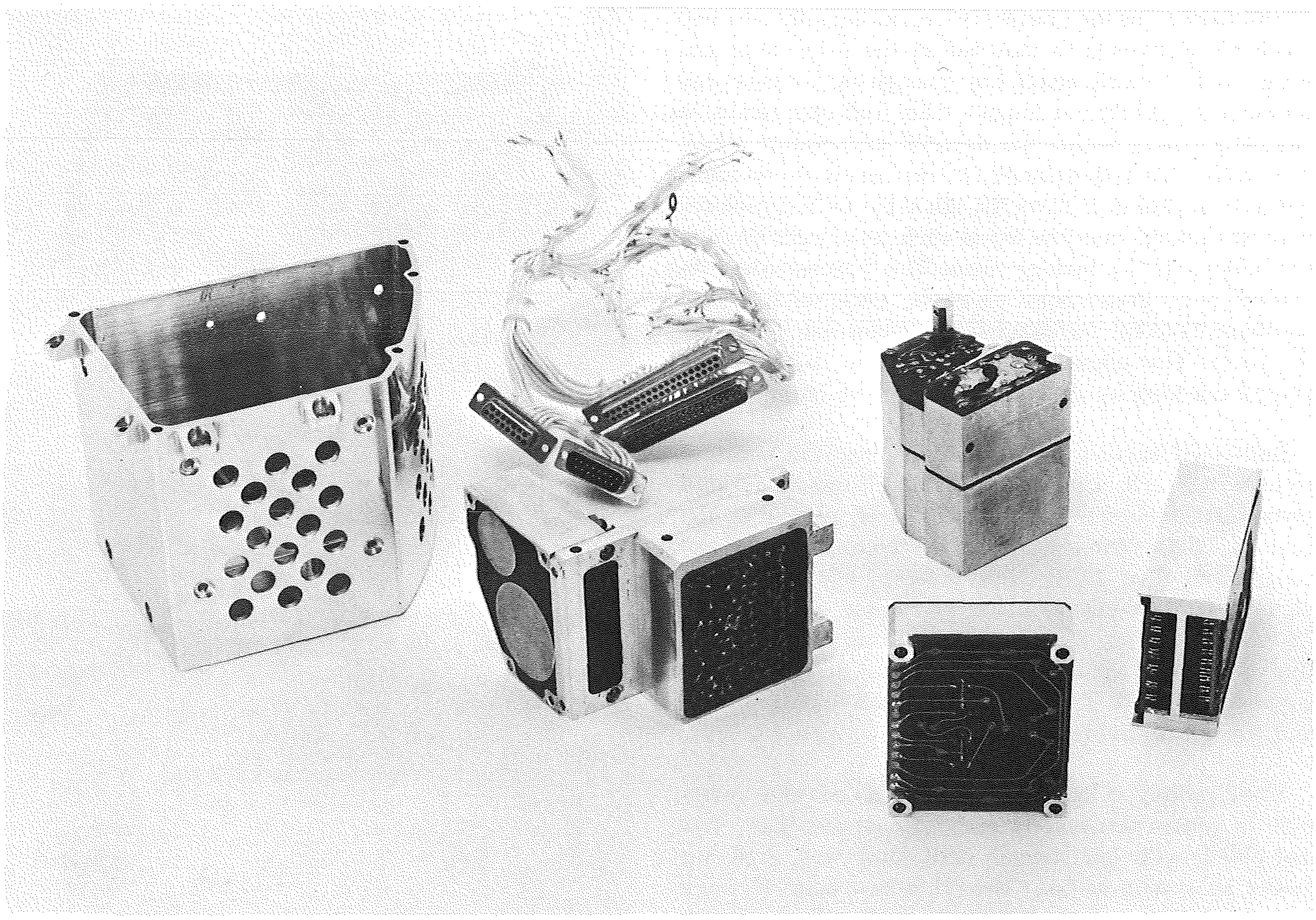


Fig. 13. Power conditioner unit

the JPL heat-sterilizable battery development program. These included polyphenylene oxide 531-801 for the cell case and epoxy resin, Dow DEN 438-EK 85, and Furane Epocast 221/927 for sealing and potting. Radiation-modified polyethylene was used for the separator material. The impact-shock-resistant characteristics of the cells are accomplished by design of the internal electrodes. Both the positive and negative electrodes are fabricated on silver sheet supports. This support structure has a silver tab that enters the subcover of the cell where it is fastened and serves as the electrical connection between the electrode and the cell terminal.

The battery assembly made use of proven techniques, along with new and advanced technology. It is housed in the top cover so that it can be easily removed from the assembly in case of leakage from the cells (Fig. 14). The battery consists of 12 series-connected, sealed, silver–zinc cells rated at 5 A-h. Because of the location

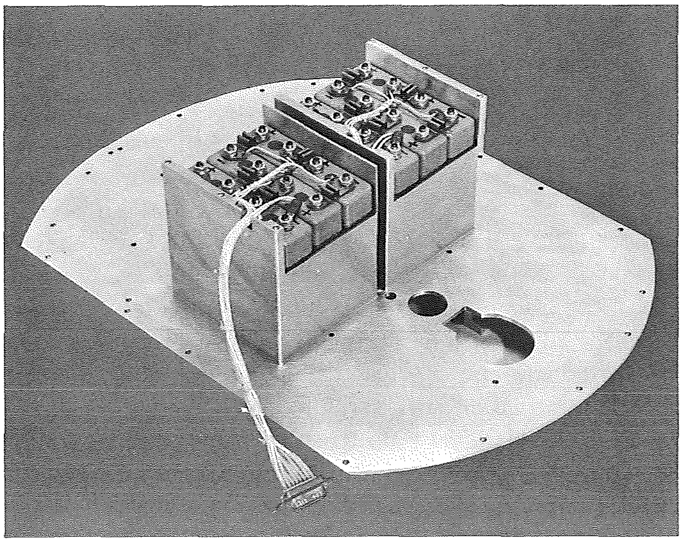


Fig. 14. Battery installed in cover plate housing (view from bottom)

of the battery in the chassis, it had to be split into two 6-cell compartments so that one of the main structural walls in the chassis could run through the battery and improve its stability at impact. This wall also serves to keep the battery within the required temperature range. To satisfy this requirement, it was necessary to interconnect one set of cells to the other by an encapsulated harness running from the top of each set of cells through the bottom of the battery cover. This harness was fabricated with glass–epoxy channels, encapsulated with Solithane 113/300, and bonded to a recess machined into the cover. This allowed the wiring to lie flat, and prevented crushing by stresses applied to the harness.

Individual cavities were machined into the cover to receive each cell; a portion of each cell was filled with Stycast 1090/11, and the 12 cells were placed in the cavities. The entire cavity, to the bottom of the cell cover, was then filled with Stycast. The cells were aligned with an impact cover, and cured at 140°F for 12 h. After curing, the impact cover was removed, and the wiring was terminated. A specially designed interconnect was used. The impact cover was then replaced, and filled with Solithane 113/300.

Three prototype batteries were assembled. One prototype (a system test battery that was not sterilized) was assembled with precharged cells, and was used for lander subsystem testing. The other two batteries were assembled with unformed (not charged) cells, and each was sterilized as part of the complete lander subsystem. Both of these batteries were formation-charged following sterilization, and were used in the two lander drops.

E. Sequencer and Timer

The lander sequencer and timer (LS&T) (Fig. 15) provides timing and sequence service for other lander subsystems. The sequencer and timer was one of the last subsystems to be clarified. This resulted in an all-out effort to meet the schedule, and many shortcuts had to be taken. The schematic was subdivided into stages, and each stage was made into a welded module. To complete the subsystem on time, the Mylar components were fabricated and the welded assembly was sketched. All design information was verbally given by the engineer to the technician. As time went on, detail and assembly drawings were produced, but always after the event.

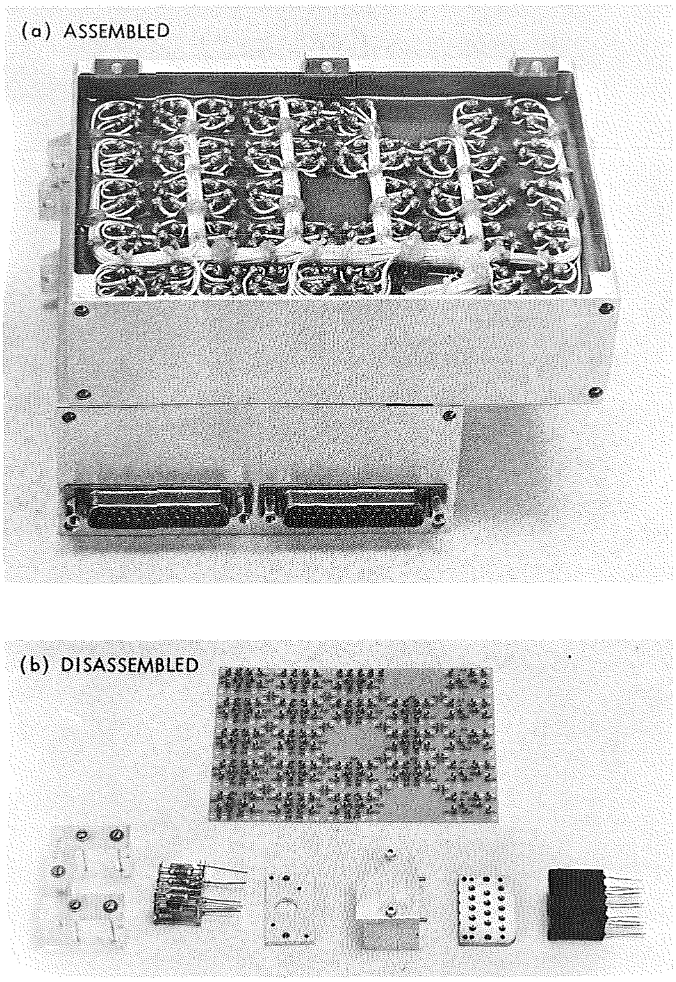


Fig. 15. Sequencer and timer

1. ***Basic assembly.*** The transistors used in the counter stages were obtained from the *Mariner* Mars 1969 program, from a lot that had been improperly X-rayed. Poly-Thermaleze-200 was the insulation on the 38-gage magnetic wire. This insulation was removed by heating with a spiral-wound heater.

Part kits were made up for the welding operation; after being welded, the assemblies were tested electrically. Following the electrical check, the modules were encapsulated. The LS&T consists of 40 welded modules, 4 wiring boards, 11 discrete components, and 2 subchassis. Existing welding schedules were used where applicable. If no JPL welding schedule existed for the component lead materials used, minimum welding schedules were established. These did not necessarily meet the requirements specified for a flight program, but engineering judgments were used to ascertain the reliability of the modules.

The size and shape of the welded module were established early, but were changed to incorporate existing molds and fixtures left over from other programs in order to save time and money. The modules were then encapsulated with Stycast 1090/11, and cured at 250°F. The assembly consists of two subchassis of 6061T6 aluminum. One chassis houses the counter stages; the other houses the miscellaneous stages and most of the discrete components.

Each module has a capacity for 14 leads to protrude through the base. This hole pattern was transferred to the subchassis; leads not used were cut off before installation in the subchassis. The modules were bonded to one side of the subchassis with Solithane 113/300. The bond line was approximately 0.005-in. wide. A terminal board was then bonded to the wiring side of the subchassis. All welded module leads were terminated on both subchassis. The subchassis were positioned side by side, and interconnected with 24-gage wire. A trough was allowed in the subchassis to store the extra length of wire.

The final assembly consisted of encapsulation around welded modules to a depth of 0.250 in. with Solithane 113/300. All terminals were encapsulated, all harness runs spot-bonded, and all connectors sealed. The two subassemblies were fastened together with 4-40 screws before assembly as a unit into the lander chassis. The completed assembly weighs 2¾ lb and occupies a volume of 69.5 in.^{3}.

A spare counter stage was subjected to 1500 *g* in three mutually perpendicular directions, with +28 V applied; the test was repeated at 2500 *g*. The counter stage passed these tests. Two counter stages were exposed to sterilization temperatures, and operated satisfactorily after the test.

2. *Sterilization effects.* After the first sterilization cycle, the lander did not operate normally during system functional testing. The lander was disassembled and each subsystem tested, and the problem was isolated to the LS&T. At the conclusion of the system functional tests, the LS&T was returned to the cognizant engineer for further testing and analysis. It was confirmed that the unit was not operating properly. Diagnostic testing isolated the failure to the feedback loop of one of the 29 identical counter stages in the LS&T. The failure prevented that stage from driving the succeeding stage. This failure mode was duplicated on the LS&T breadboard by placing a 700- to 1500-Ω resistance in series with the emitter of the 2N956 transistor and the magnetic core.

The faulty counter stage was replaced with a presterilized spare counter stage and the LS&T was recoated with its conformal plastic jacketing and placed in an oven to cure at 160°F. The faulty counter stage was bathed in a solution to remove the Stycast potting material and then placed in the same oven about 15 min after the LS&T. After several minutes, it occurred to the engineer that the oven seemed hotter than the nominal 160°F temperature. The thermometer was checked and found to read 362°F. The LS&T was removed immediately and ice packs were applied to cool the unit. After about 20 min, the solution containing the faulty counter stage was removed from the oven and returned to the cognizant engineer along with the LS&T to determine if they had been damaged by the excessive heat. The LS&T was found to be operating nominally and was reinstalled in the lander where it has operated normally since then. The faulty counter stage was retested and found to be operating nominally.

A failure that is no longer a failure is usually difficult at best to analyze. Therefore, a good understanding of the construction and component parts of the malfunctioning counter stage is required for any valid statement of the cause.

As discussed earlier, the failure was duplicated on the LS&T breadboard by placing a resistance in series with the 2N956 transistor and the magnetic core of the feedback loop of the counter stage in question. The 2N956 transistor is classified as a "Hi-Reliability" part originally purchased and screened for the *Mariner* Mars 1969 program. Although it had passed the electrical screening requirements, the X-rays of the unit had been taken from the wrong field of view and they were designated spares and used in the CSAD program. The transistor emitter lead is welded to a post interconnecting with one of ten leads of a transistor-type header that contains the magnetic core. The other header lead passes through the header and terminates at the core. The wound core is potted to the header in RTV cement. The ten leads from the core are wrapped around and soldered to the header leads.

There are several possibilities related to the construction mode that could account for the failure: the transistor, the interconnecting weld joints, or the core-to-header solder joint. Investigation of these possibilities required the irrevocable act of dissolving the Stycast. Therefore, it was decided to X-ray the counter stage to find any potentially bad joints and to temperature-shock the module in an attempt to duplicate the failure. Both attempts were unsuccessful, the Stycast was removed, and the module systematically dissected. It was postulated that a poor weld joint could have accounted for the failure; therefore the weld joints were visually inspected and subjected to pull tests; no anomalous joints were discovered.

The 2N956 transistor was removed from the module for analysis. The transistor was first X-rayed (no anomalies noted) and then examined electrically. A forward emitter–base check indicated that both ball bonds were intact. Subsequent tests against the specification parameters were successful. The unit was then soaked for 18 h at 125°F and retested with no significant change in parameter values. An Au–Al intermetallic growth was found by visual inspection after decapsulation; however, a bond strength test showed the bonds to be firmly attached to the wafer. The transistor met all specifications and no reason could be found for any intermittent operation.

The solder joints were exposed for visual inspection by bathing the magnetic core in an M17 solution that dissolved the RTV cement. (The joints had not been inspected because the cores were delivered in a potted condition.) After enough of the cement had been removed the joints were inspected. The inspector was given no prior information and was instructed to inspect all of the joints and rank them. The joint in question was flagged as the worst of the ten. It was particularly faulted for cold solder, insufficient solder, and poor wetting action.

In view of the facts that:

(1) The failure mode could be duplicated,

(2) The failure was isolated to a particular part of the module,

(3) The cause of failure was isolated to three possibilities, two of which (the weld joint and the transistor) were eliminated by test and inspection,

(4) The sterilization temperature would be sufficient for a poor solder joint to demonstrate a high contact resistance,

(5) The thermal runaway temperature of the oven was almost to the melting point of the solder (362°F vs 367°F) which would allow the solder to flow enough to form a good electrical joint,

it is concluded that the cause of the failure was an exceptionally poor solder joint that corrected itself after the oven reached a temperature at which the solder flowed enough to form a good electrical contact.

F. Data Handling System

The lander data system is not a functional part of the lander system, but a functional entity of its own. Because there was not time to design a data handling system for the lander functions, an electronic package was assembled to determine its survivability (Fig. 16). An operational segment of a *Mariner* Venus 67 data automation system, eight-layer laminated board was mounted in a 6061T6 aluminum chassis fabricated as were the other subchassis. The module was electrically tested, then installed in the lander. When installed, this subsystem could not be checked because of difficulty in removal; consequently, it was not retested until two sterilization cycles and two drops had occurred and 2 mo had elapsed. Upon completion of all lander testing, the module was removed, and tested functionally at 77°F. The system reacted normally, and the temperature of the oven was gradually increased to 257°F while operation of the module was monitored. Operation was still normal and the tests were terminated.

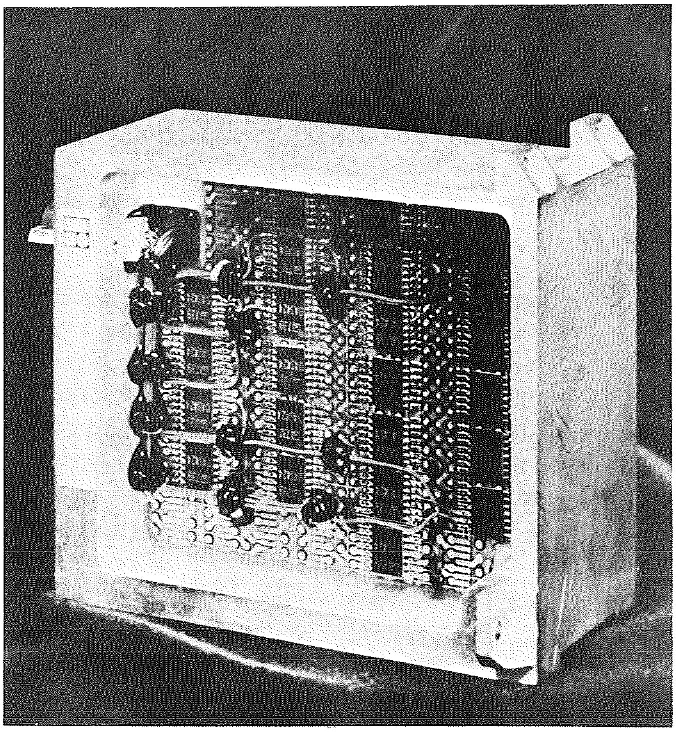


Fig. 16. Data handling system module

G. Heater

The chemical heater is designed to maintain lander equipment temperatures at an acceptable level during the long Martian night. The heater consists of a tank containing 1.4 lb of liquid chlorine trifloride, feeding a reaction bed charged with crystalline boron. A temperature-sensing and -metering valve regulates the flow to the reaction bed. Time would not permit the fabrication of an actual chemical heater; therefore, a dummy heater, simulating the weight and volume, was fabricated.

H. Mechanical Devices

The lander mechanical device subsystem comprises two elements: the instrument boom and the landing-sensor module.

1. Instrument boom. The instrument boom deploys a smaller aerometry package from the lander to a position approximately 6½ ft above the landing surface. Each boom consists of an extendable spring-steel element attached to a housing assembly at the bottom and to the aerometry package at the top. In the stowed configuration, the aerometry package is located within a cavity at the upper end of the instrument boom housing, and held in place by a cover and latch mechanism (Fig. 17). An electrical cable from the aerometry package is routed through the center of the spring element to the cavity at the base of the instrument boom housing. Cutouts in the top and bottom cover of the main structure allow these booms to emerge after impact.

2. Landing-sensor module. The landing-sensor module shown in Fig. 18 serves two independent functions. At the instant the lander contacts the Martian surface, the landing-sensor module signals the lander sequencer to start by providing a momentary circuit closure. The unit is fabricated of 6061T6 aluminum, and houses two g-switches and two omnidirectional mercury switches encapsulated in Stycast 1095/11 epoxy.

I. Impact Limiter

Figure 19 shows the unassembled impact limiter; Figs. 20 and 21 show the lander feasibility model with the functional impact limiter in different phases of installation. The primary function of this impact limiter is

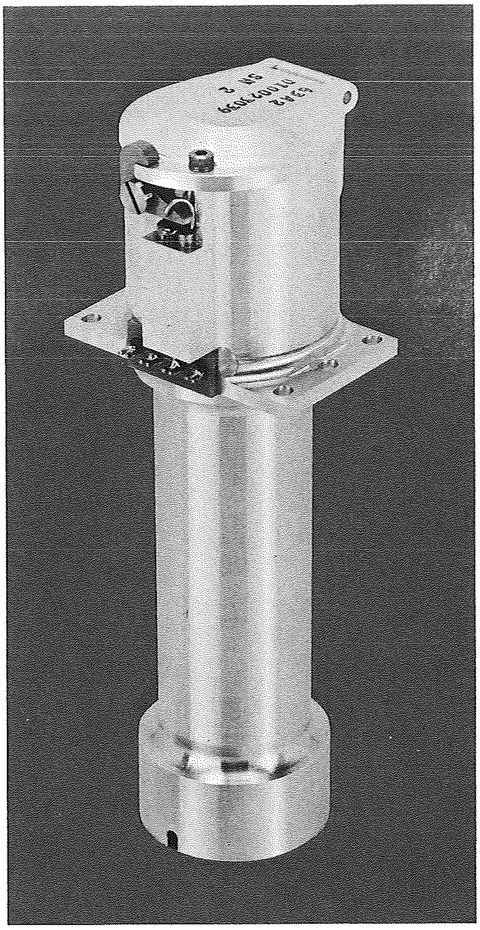


Fig. 17. Instrument boom

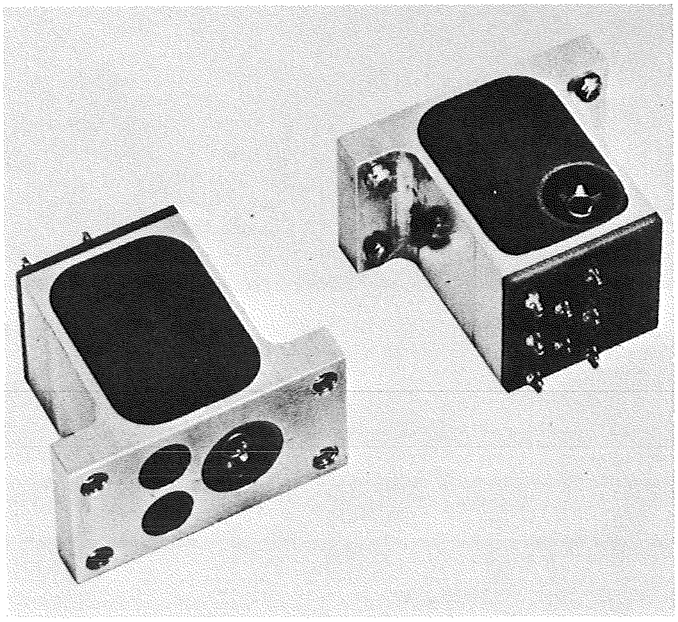


Fig. 18. Landing-sensor module

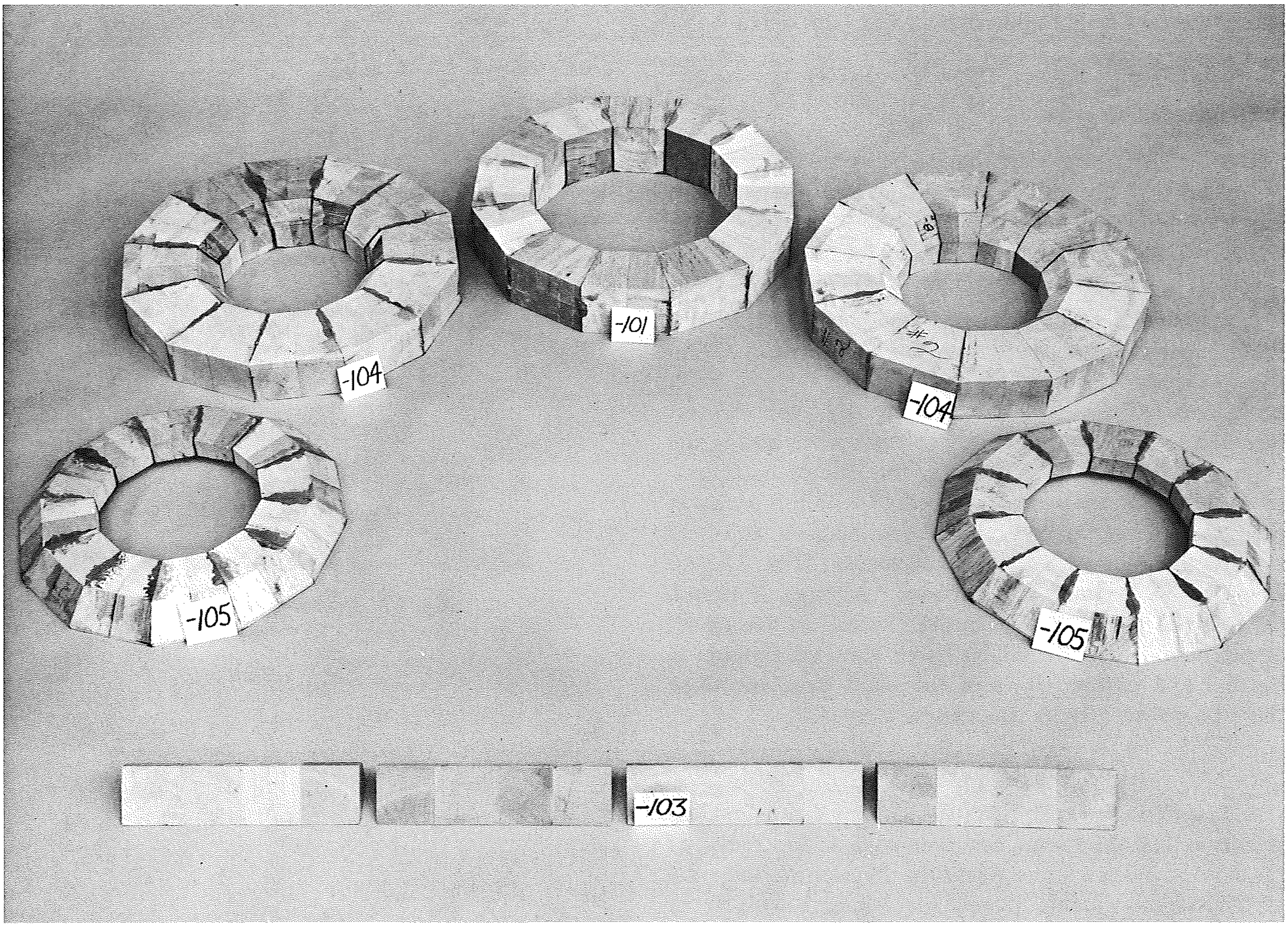
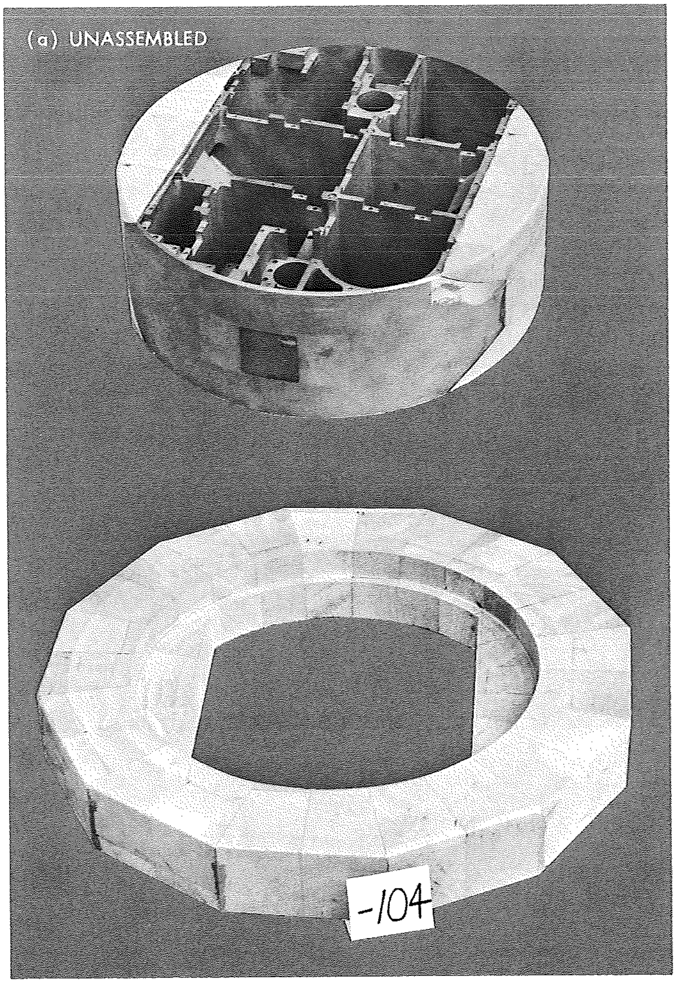


Fig. 19. Balsa impact limiter before assembly



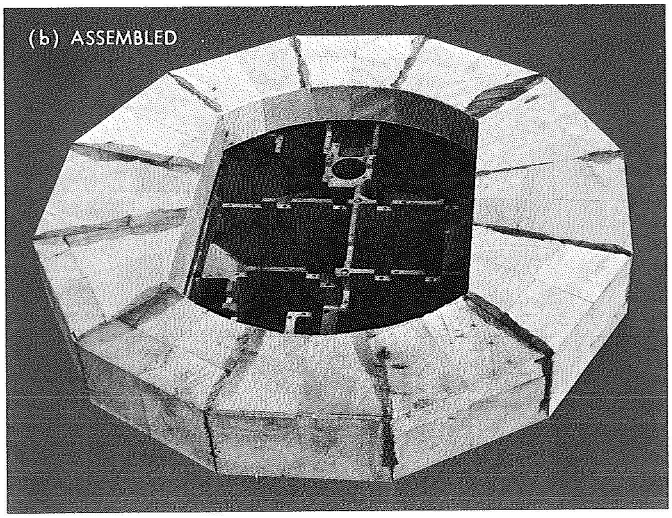
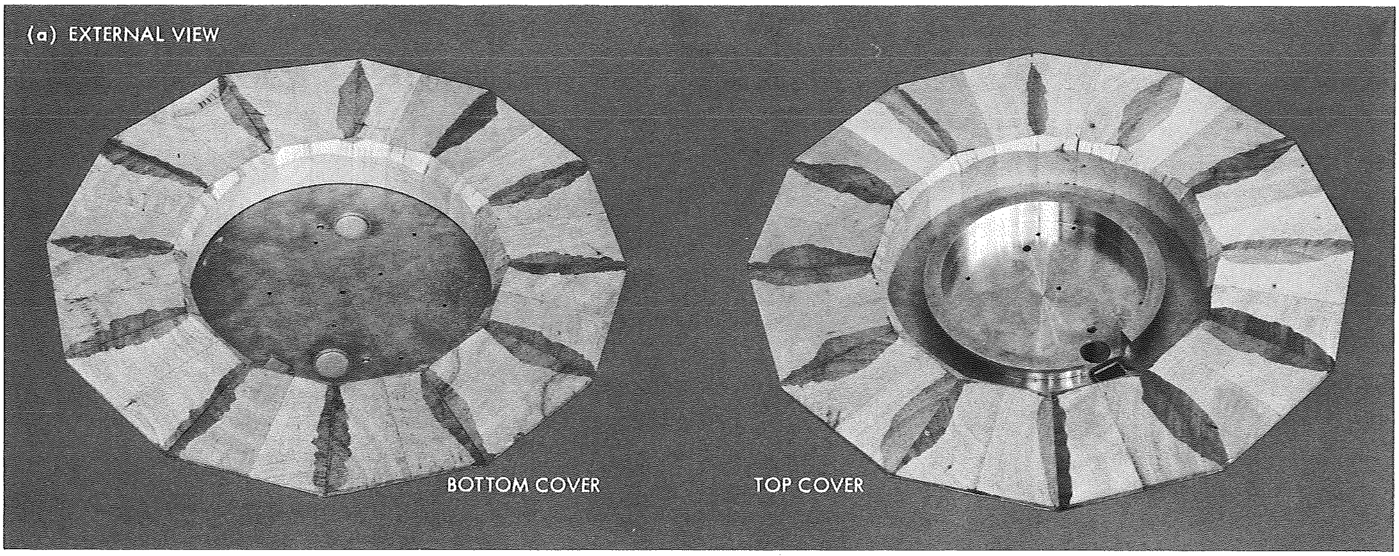


Fig. 20. Lander chassis partially installed in impact limiter



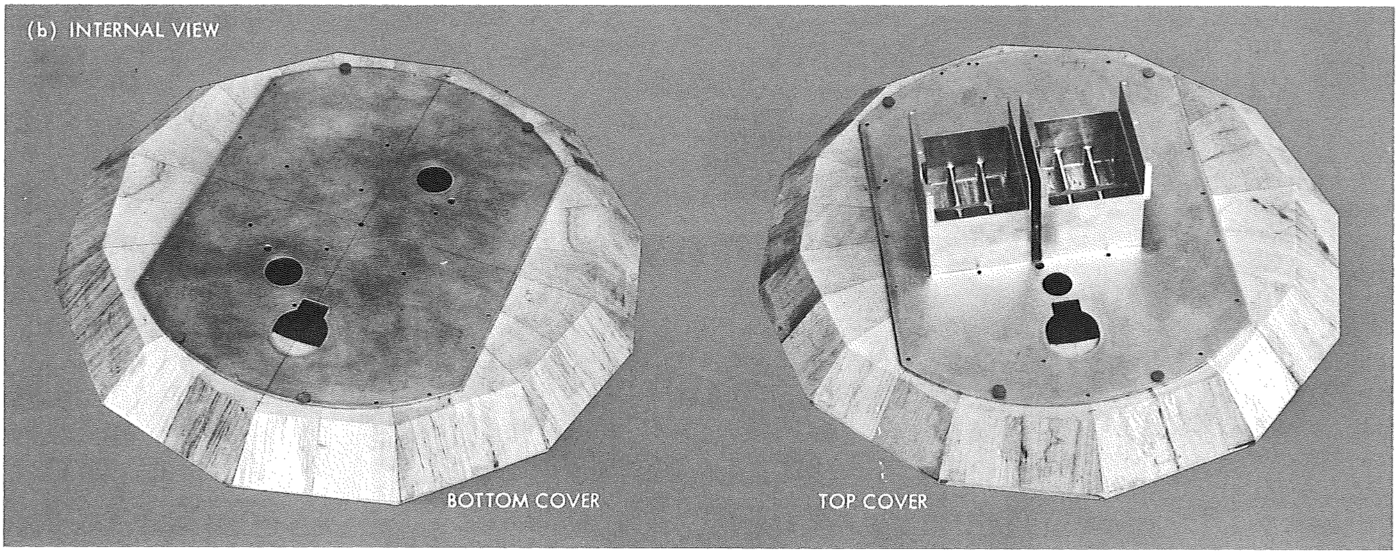


Fig. 21. Balsa cover assembly

to limit the landing shock experienced by the lander to 2500 g. The impact limiter is composed of three separable parts, the main portion of which is bonded to the periphery of the lander chassis, as shown in Fig. 20. Smaller mating parts are bonded to the two lander covers (see Fig. 21). This design provides substantial omnidirectional protection, and still affords accessibility to all of the lander components except the antennas. Individual blocks of balsa (density range 7.5–8.5 lb/ft^3) are used to fabricate the limiter. The wood grain is generally oriented as shown in Fig. 19. The blocks are bonded to each other, and to the lander chassis and covers, with Shell 828/125 epoxy adhesive.

J. General

All subsystem connectors were sealed, all exposed terminals were encapsulated, cable runs were spot-bonded, and all hardware used for mounting the subsystems was spray-coated with molybdenum disulfide (Electrofilm). Every time a subsystem was removed, the inserts were vacuum-cleaned and the removable hardware ultrasonically cleaned before being reused. After all tests were completed, the lander was disassembled, and visual checks were made on the chassis and subsystem; no damage was visible to any subsystem. Some minor damage was evident in the antenna-cavity foam. This was anticipated and did not impair the antenna function.

IV. Conclusion

The documentation effort was very limited; nearly all mechanical parts were fabricated to sketches, and drawings were made after the component proved to be satisfactory. This was necessary because many functions were not known until late in the program. Because of limited manpower, the engineer and designer performed all of the checks that were made in the drawings.

To successfully support a program of this nature, it is very important and necessary to make many engineering judgments, and to have great confidence in the ability of the personnel assigned to the program, because time does not allow many tests to prove a theory. Because of the cost factor, it is also important to make, not necessarily the best part possible, but one that is good enough to meet the requirements specified; at the same time, any possible improvements that can be made during a flight program must be borne in mind.

This was the philosophy used in the design of the lander assembly. Many areas of the lander can now be improved with the knowledge obtained during sterilization and drop tests. New techniques for antenna design have evolved with the development of the feasibility models and it is believed that the packaging of the electronic components can be accomplished with less volume and less weight.

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