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Development of Mechanisms for a Planetary Landing Parachute System

Thomas H. Mack

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February 15, 1970

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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

An effort was undertaken to develop mechanisms for a planetary landing parachute system that would: (1) keep the parachute from enveloping the lander, and (2) jettison the parachute deployment mortar such that it would not interfere with either the landing system or the postlanding antenna patterns. This document describes the development and testing of such mechanisms.

Development of Mechanisms for a Planetary Landing Parachute System

I. Introduction

This report describes an effort to solve problems that were identified in a system-level advanced development project concerned with an entry capsule and a 60-lb-class rough landing payload for Martian exploration.[1]

The advanced development project, which included the fabrication and testing of many critical subsystems and components, resulted in the identification of two problems associated with the proposed parachute system. The problems were: (1) keeping the parachute from enveloping the lander, and (2) jettisoning the parachute deployment mortar such that it would not interfere with either the landing system or the postlanding antenna patterns. These problems are not considered unique to a particular mission; problem (1) would occur in the development of any planetary landing system in which a parachute was used as the final stage of deceleration, and problem (2) would occur if deployment conditions require the use of a mortar.

The approach used in the effort described herein was to build and functionally test a complete parachute system—this to demonstrate the feasibility of proposed solutions to the problems.

Various concepts were considered, including the use of a radar altimeter to release the lander from the parachute and mortar 80 or 100 ft above the surface. This approach was considered impractical, however, for landers lighter than a few hundred pounds. Also considered was explosively propelling the parachute and mortar away from the lander after touchdown; this too, however, was found to require considerable lander weight. Therefore, in consideration of the lack of sufficient lander weight, neither of these approaches was selected.

The system that was selected is shown in Fig. 1. The mortar is separated from the parachute–lander combination a few seconds after parachute deployment. At this point, the high initial parachute loads have subsided, and there is still enough altitude for the two bodies to separate effectively. The parachute is then rigged such

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[1] The Capsule System Advanced Development project was conducted by the Jet Propulsion Laboratory during 1967 and 1968.

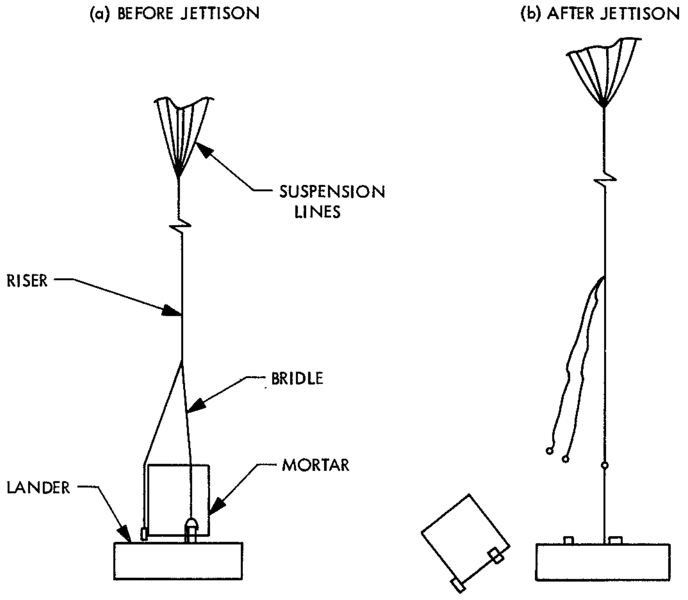

Fig. 1. Mortar jettison scheme

that it glides at a glide ratio of 0.2–0.3:1. When it is cut free from the lander at impact, the parachute glides on past the lander.[2] The development of this concept into functional designs is discussed in Section II.

II. System Development

A. Parachute Modifications

A great deal of work, notably at the Langley Research Center, had already been done in assessing the aerodynamic performance of parachutes for planetary entry. The scope of JPL effort was limited to incorporating the desired gliding feature in an existing parachute with previously demonstrated performance.

The parachute that was selected was a 30-ft-diam (nominal) disk–gap–band type. It has been deployed under simulated Martian entry conditions by Langley Research Center[3] as part of the PEP (Planetary Entry Parachute) program. The configuration and dimensions of the parachute are shown in Fig. 2. The riser length was selected to place the canopy skirt approximately 8 aeroshell diameters aft of a Capsule System Advanced Development-class aeroshell. This was to ensure that the canopy filled in relatively "clean" flow.

Figure 3 illustrates the technique used to obtain the desired gliding characteristics. An elastic bungee cord jumper was used to shorten 6 of the 24 suspension lines. The cord was sized so that it would not be effective during high loading, and thus would not affect the previously tested shape.

1. Gliding test. The adequacy of this configuration for gliding purposes was verified by a free-fall test of the parachute with a simulated payload.

The parachute was loosely packed in a deployment bag (Fig. 4) in which it was organized with a series of break cords to ensure the proper sequence of parachute deployment. The test specimen was carried aloft by a helicopter with a 100-ft-long suspension system. This and all subsequent helicopter drop tests used this suspension system to ensure that the parachute would not become entangled in the helicopter running gear.

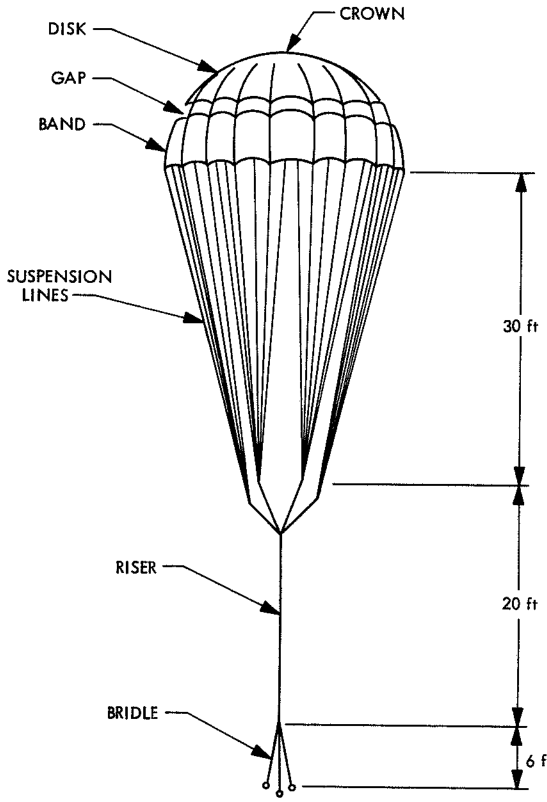

Fig. 2. Disk–gap–band parachute (30-ft nominal diameter)

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[2] There is clearly a "pathological" wind condition in which the magnitude and direction are such that the parachute will be blown back on the lander. However, this condition is considered to be much less likely to occur than that of very little wind from any direction, which would result in envelopment if no gliding were incorporated.

[3] Eckstrom, C. V., and Preisser, J. S., *Flight Test of a 30-Foot Nominal Diameter Disk–Gap–Band Parachute Deployed at a Mach Number of 1.56 and a Dynamic Pressure of 11.4 Pounds per Square Foot,* NASA TM X-1451. Langley Research Center, Langley Station, Va., Sept. 1967.

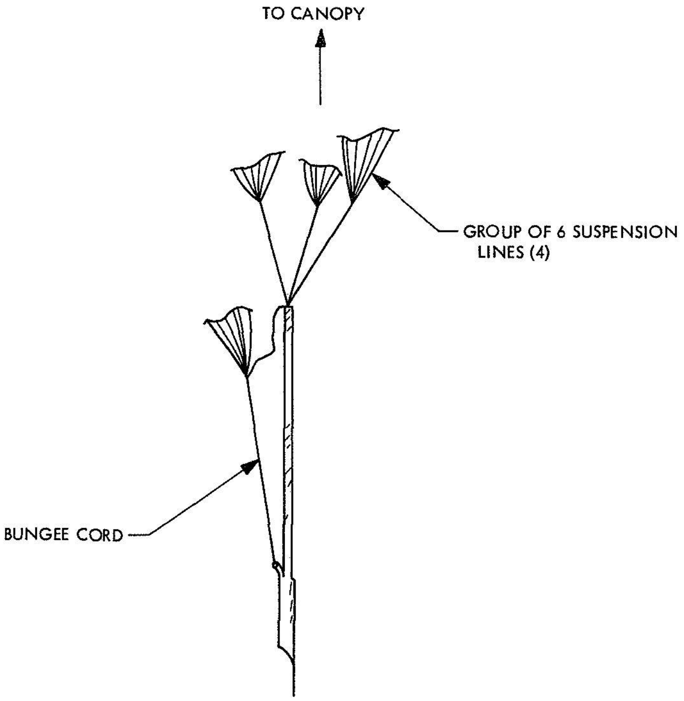

Fig. 3. Gliding technique

A 100-ft length of line with a small weight at the end was attached to the payload to provide: (1) a reference for measuring descent velocity, and (2) a "mark" of the horizontal position of the payload 100 ft above the surface so that glide ratio could be determined (Fig. 5).

The test specimen was dropped from about 1000 ft above ground level and observed and photographed until impact. An in-flight measurement of glide ratio was not achieved, however, because the parachute glided directly away from the camera station. Some luffing of the leading edge of the parachute was observed, which indicated that further shortening of the lines was not advisable in consideration of inflation requirements.[4] Figure 6 shows the parachute in flight and exhibiting a slight luff.

Descent velocity was measured by timing the interval between touchdown of the small weight and the payload. The calculated value was 15 ft/s, which was within 1 ft/s of the predicted value. A slight breeze, which lined up with the glide direction, made glide ratio determination somewhat difficult and inaccurate; the best estimate available was about 0.3:1.

Fig. 4. Parachute pack for gliding test

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[4] It is felt that the achievable glide ratio could be increased somewhat by shortening the lines more gradually (i.e., minimizing the difference in length between any two adjacent lines).

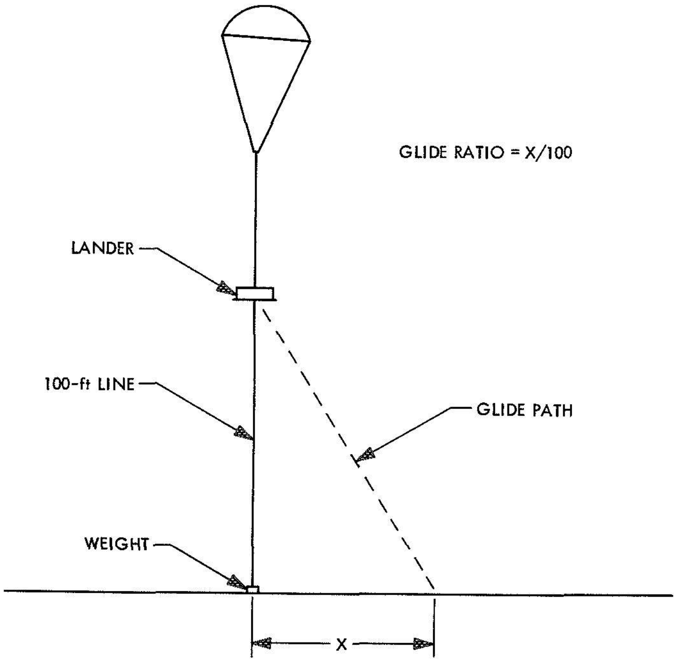

Fig. 5. Glide ratio determination

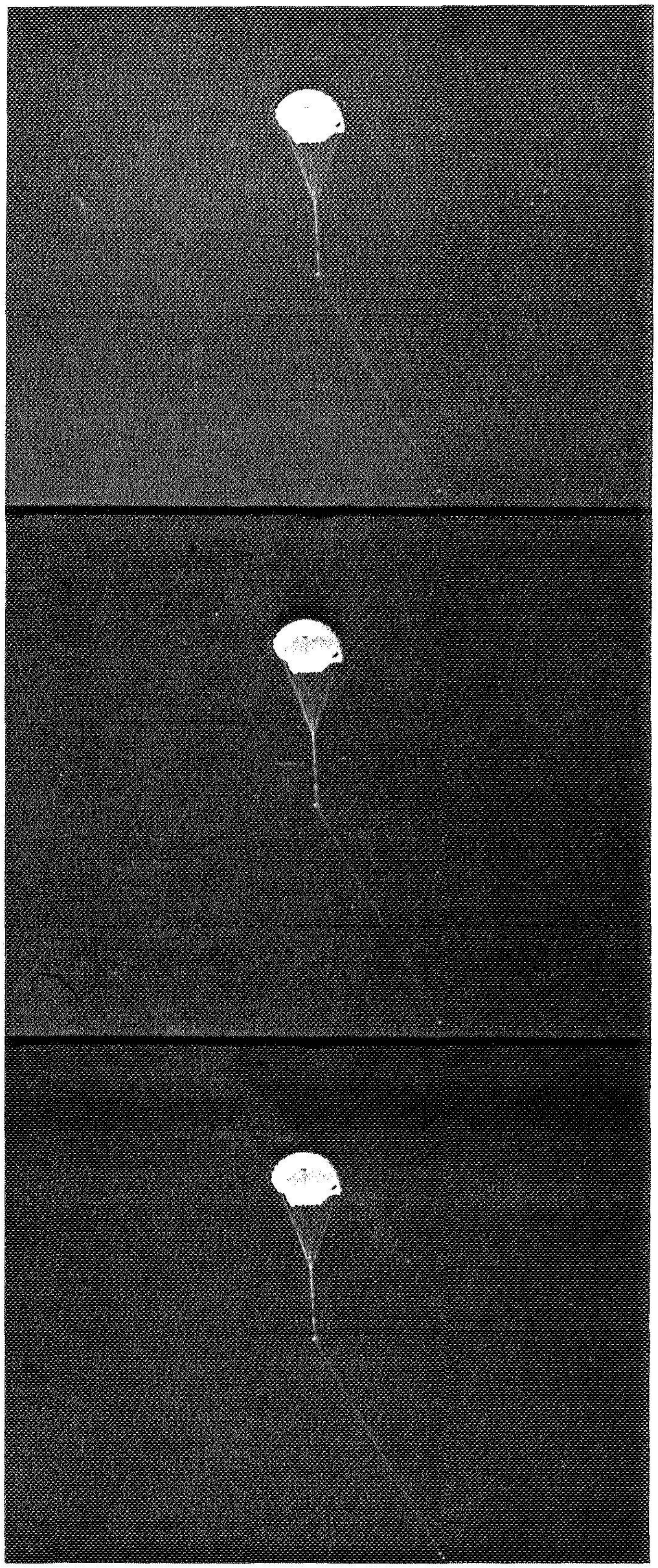

Fig. 6. Views of gliding parachute

2. ***Static deployment test.*** The adequacy of the parachute configuration and the packing scheme envisioned for the flight system was tested in a vertical static deployment test.

The parachute was packed in a cotton-lined nylon deployment bag (Fig. 7) accordion-fashion, and no restraints were used on the suspension lines. The bag mouth tie was completed with several strands of Dacron cord that were designed to break when the parachute deployed. The parachute pack was installed in an epoxy/fiber glass sabot, also shown in Fig. 7, to protect it from the hot mortar gases.

Concurrently, an effort was under way to develop a parachute deployment mortar. This effort ultimately supplied the actual flight mortar; an early ballistic test model was used for the static deployment test. The velocity imparted to the pack was approximately 125 ft/s.

A sequence of photographs from the high-speed (500 frames/s) motion picture coverage of the test is shown in Fig. 8. It should be noted that the pack is in the mortar upside down and makes a 180-deg turn during deployment. Although the deployment occurred without tangling the suspension lines, the lines came out of the pack bunched, and this was deemed unsatisfactory. It

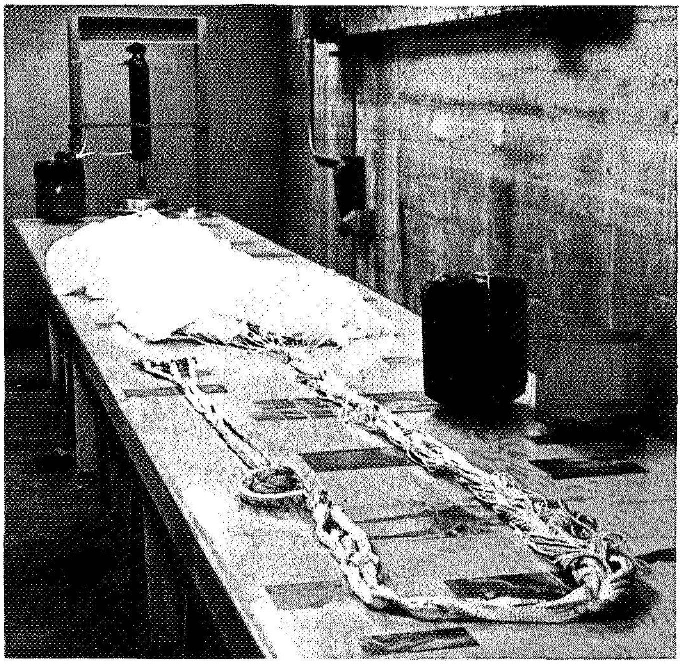

Fig. 7. Parachute pack, sabot, and packing table

was concluded that bunching of the lines could be prevented by keeping the bag mouth closed until the pack had executed the 180-deg turn.

On the later models, a tear-off tab, which was secure until turnaround and insecure thereafter, was added to the pack. The tab was attached to one of the bridle legs, and prevented bag opening until after the pack was substantially turned around. This technique was verified in system static testing (Section III-B).

B. Mortar Release Mechanism

As previously mentioned, it was decided that the mortar should be jettisoned in flight, just after the deceleration load had subsided to substantially its terminal velocity value. It was further concluded that the lander–parachute tie should be a single, centrally attached line after jettison. The latter requirement simplified the final release.

Initially, the parachute is attached to the mortar and lander by a three-legged bridle that straddles the mortar. These three lines are required to carry the high initial loads and to keep the lander in an appropriate attitude. The lines are attached by the three clamps that hold the mortar and lander together. Several seconds after parachute deployment, the clamps are released, mutually disconnecting the lander, mortar, and parachute. The parachute–lander tie is maintained by an extension on

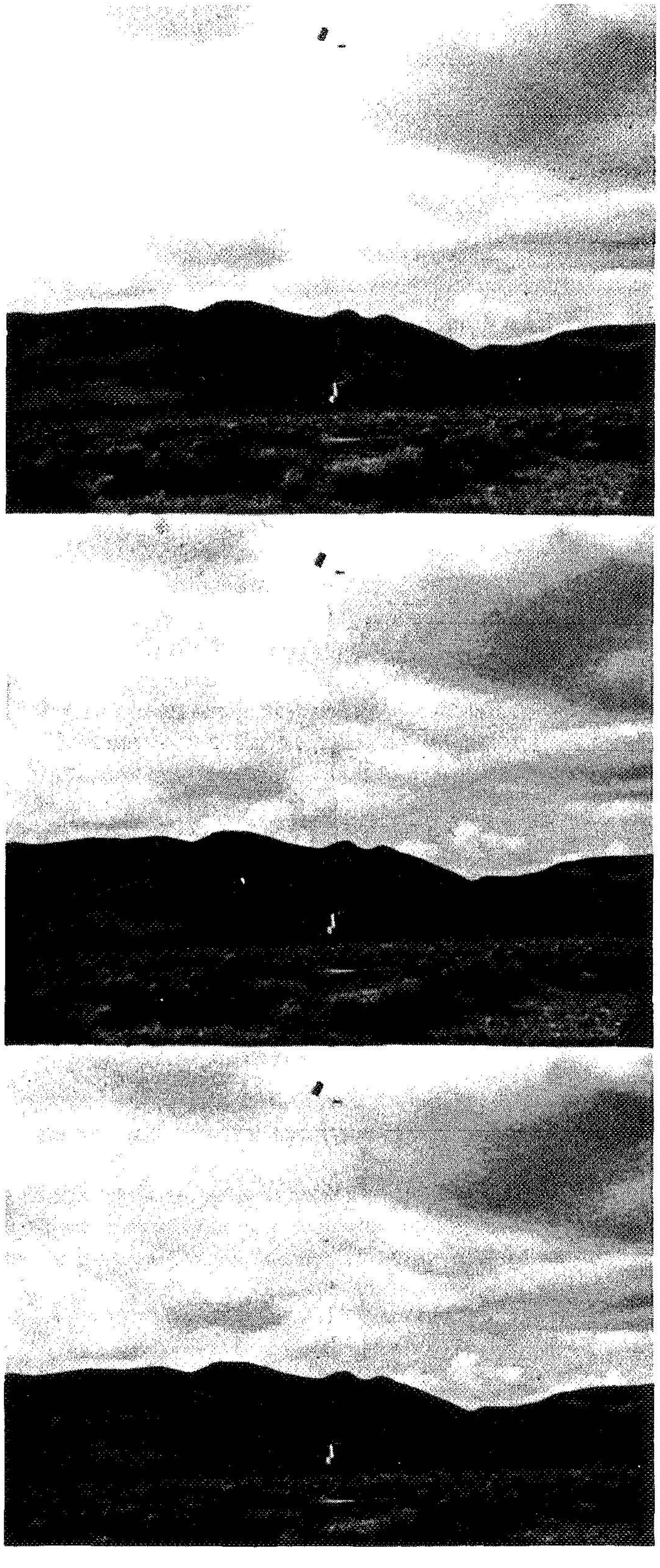

Fig. 8. Views of static test parachute deployment

one of the bridle legs that runs under the mortar to the final parachute release device. Tightening of this extension provides the force to push the mortar off the lander.

Two means of implementing this scheme were developed to the bench test stage.

The first method used an entirely mechanical device to effect release. A special ball-lock device was used at one of the three clamping points. Its action was such that it "armed" itself by shearing a pin under high loading, then released the clamp (at that point) when the load decayed to some preset level. The other two clamp points were arranged such that release of the ball-lock tie freed them. Two types of these were built.

Bench tests of this mechanism were successful. A problem was discovered, however, when the parachute load-time history obtained in the Langley tests was studied in detail. The dynamics of deployment and canopy filling are such that a short-duration load of about 30% of the peak load is experienced about 1 s prior to peak loading. This occurs when the parachute becomes fully extended and the lines become taut. Because of the uncertainties involved, it was not considered practical to set the arming force level between the short-duration load and the peak load. Consequently, some form of dashpot was required to discriminate between the short-duration load and the full-inflation load. This, together with the fact that the ball-lock device turned out to be quite heavy, resulted in abandonment of the scheme.

It was then decided that a fixed-time delay, started at mortar fire, would be used to initiate jettison. The mortar release mechanism as developed is shown in Fig. 9. A cable passing around all three clamps is used to hold them in place. A time-delay cable cutter cuts the cable at the predetermined time (about 10 s after mortar fire), and the clamps are released.

The clamps are essentially Marmon-clamp segments equipped with hooks for attaching the lines. Note that in this scheme no metal parts are retained on the ends of the bridle legs (the loose clamp parts are tethered to the mortar).

The design was adopted for use in the flight test system after successfully passing bench tests.

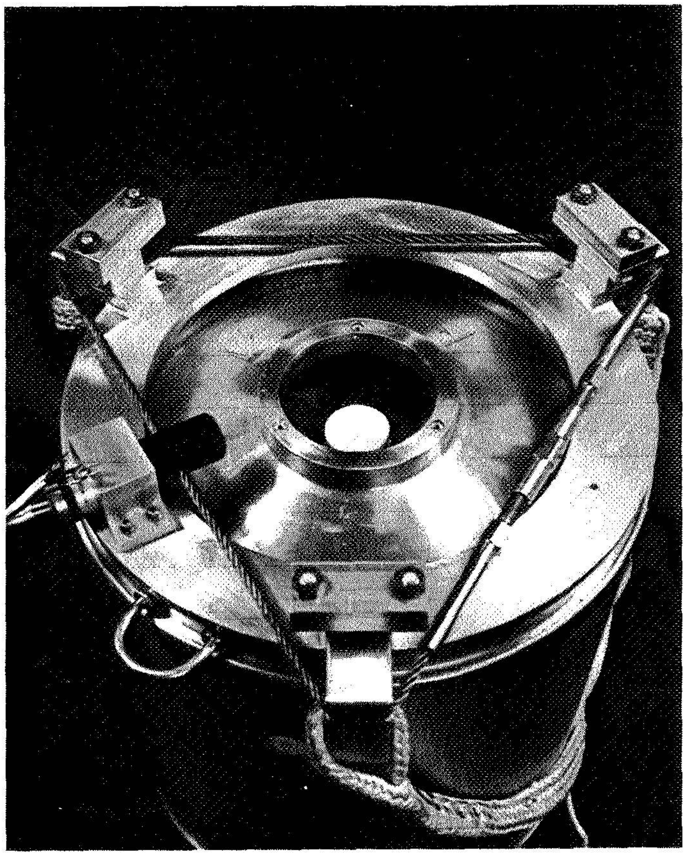

Fig. 9. Flight mortar release mechanism

III. System Testing

A prototype parachute subsystem incorporating the parachute and mortar release mechanism designs was built and tested. It was beyond the scope of this program to test under simulated entry conditions; the test program was limited to a functional demonstration at earth-surface conditions.

Two tests of the complete subsystem were conducted. The first was a static firing of the mortar, mortar release, and final parachute release; it was intended primarily to verify that the test hardware was functioning properly for the next test.

The second and final test was a free-flight drop test incorporating the full functional sequence. Parachute deployment was programmed to occur at the dynamic pressure anticipated in flight; it was recognized, however, that because of the difference in atmospheric density between test and flight conditions, the test could not be considered a valid load test of the parachute.

A. Test Hardware

The test hardware consisted of the parachute pack, the mortar, a simulated lander, and an electronic sequencing and firing assembly. The complete assembly is shown in Fig. 10.

1. ***Parachute pack.*** The parachute pack is essentially as described in Section II-A-1. The sabot is permanently attached to the deployment bag, and the deployment bag is permanently attached to the parachute crown. This is to prevent the sabot from becoming entangled in the helicopter running gear in the event of a premature firing. The bag mouth tie is a "daisy chain" of loops which is completed by several strands of Dacron thread. These threads are broken by a lanyard that becomes taut after the tear-off tab rips off.

2. ***Mortar.*** The flight mortar and its components are shown in Fig. 11. The primary components are a high-strength steel combustion chamber, a base, a barrel, a lid, and a clamping assembly.

The propellant is burned in the combustion chamber at relatively high pressure (10,000 psi peak). The combustion gases are retained by blowout diaphragms until a pressure of about 6000 psi is reached, and then are metered into the main barrel through six small orifices. The peak barrel pressure is 250 psi.

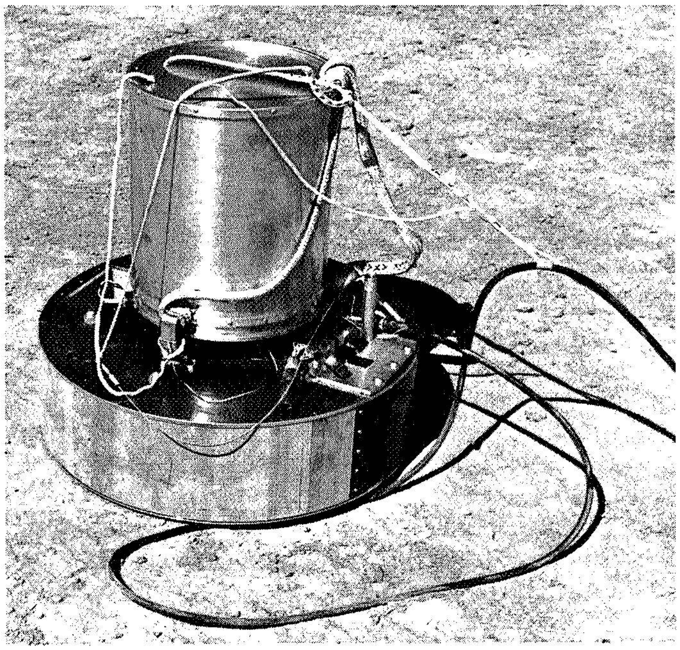

Fig. 10. System test specimen

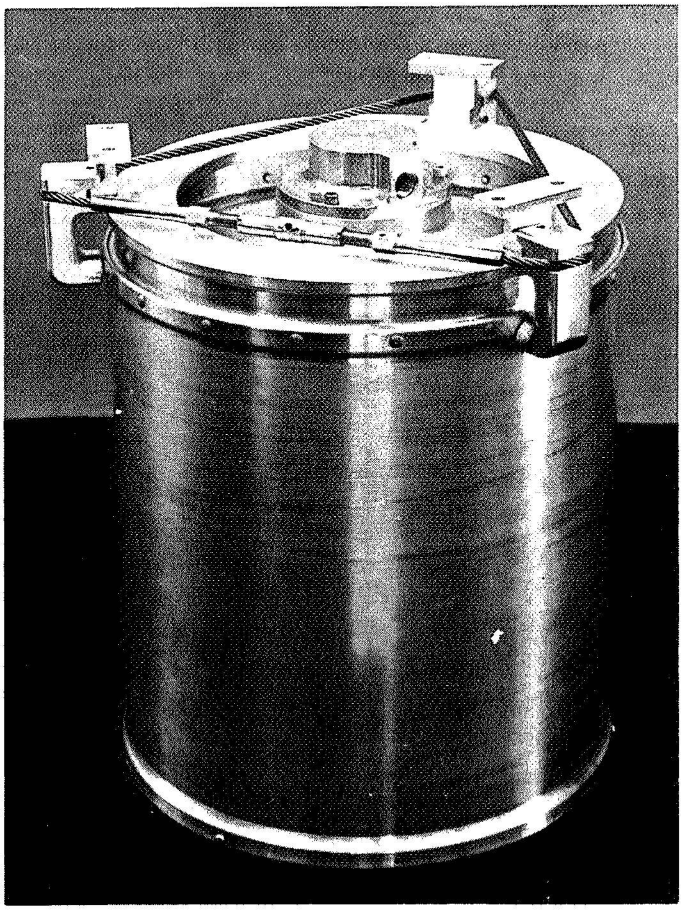

Fig. 11. Flight mortar

The mortar lid is secured to the barrel by means of shear pins. The bridle lines pass out of the mortar through a slot in the lid. The lid is equipped with a 2.5-ft-diam, ribless guide surface parachute. The purpose of this parachute is to stabilize the entire assembly and to provide the required drag to achieve the desired terminal velocity.

The clamping assembly consists of the upper clamp halves, which attach to the mortar barrel; the lower clamp halves, which attach to the lander; and the cable, the cable cutter, and the clamping blocks. It should be noted that the clamping blocks are tethered to the cable, which in turn is tethered to the mortar.

All cabling to the mortar (cable cutter and mortar squib cables) is routed through the cable cutter and is thus severed at release.

3. ***Simulated lander.*** The simulated lander is primarily a structural platform that simulates the anticipated

weight of the lander. It houses the electronic sequencing and firing assembly and the final parachute release, which is a simple cable cutter.

4. ***Electronic sequencing and firing assembly.*** The sequencing and firing assembly consists of a main assembly and battery in the lander; a control box, which is in the helicopter; and an interconnecting cable. The assembly incorporates solid-state components.

The functions and features of this assembly are as follows:

(1) The capability to turn lander power on or off from the helicopter.

(2) A lanyard-actuated switch that is operated by release of the lander from the suspension system. Functioning of this switch will start the timing sequence, providing power is on.

(3) Time-delay and firing circuitry that will fire the mortar cartridges 7 ±1 s after start of the timing sequence. This is sufficient time for the assembly to reach essentially terminal velocity.

(4) Time-delay circuitry to fire the cable cutter 10 ±1 s after mortar fire.

(5) Time-delay circuitry to inhibit the parachute release device until 15 ±2 s after mortar fire. This is required so that parachute deployment or mortar jettison cannot improperly trigger the release device.

(6) An impact switch and firing circuitry to fire the final release cutter on impact.

(7) Flyaway connectors at both ends of the cabling.

B. Static Testing

Prior to the drop test, the entire test item was "flown" through its complete operational sequence on the ground at Goldstone Dry Lake in the Mojave Desert of California. Switches that simulated lanyard and impact switch actuation were included in the helicopter control box.

An abnormally long (250 ft) cable was used to connect the control box to the lander—this for reasons of personnel safety. Two high-speed motion picture cameras provided film coverage.

The test demonstrated that an earlier problem with orderly deployment of the parachute suspension lines had been solved; the films showed that the lines deployed in the proper way.

One abnormality in the sequence was noted. The impact switch circuit did not arm until about 40 s, instead of 22 s as designed. It was subsequently determined that the temporary grounding of the cable cutter leads during cutting upset the sequencer and caused it to start over. This problem was corrected by a minor redesign of the circuit.

C. Free-Flight Deployment Testing

In the free-flight deployment test, the test specimen was carried aloft by a helicopter and dropped from 1500 ft above ground level.

The suspension system (Fig. 12) used to carry the test specimen consisted of a cargo hook connected to a bomb release on the helicopter by 100-ft steel cables and appropriate electrical cabling. The 100-ft separation was established to prevent the parachute from involving the helicopter running gear in the event of premature mortar fire. The cables, one to the cargo hook and one to the lander, were equipped with appropriate flyaway connectors. The helicopter pilot had the option of dropping the test specimen at the cargo hook or, in case of trouble, dropping the entire suspension system at the bomb release. The lanyard that operated the lanyard switch was permanently attached to the hook; the test specimen was suspended by the crown of the small stabilization parachute.

Two 48-frames/s motion picture cameras with long-focal-length lenses covered the test. The cameras and all personnel were located 1000 ft or more from the nominal drop point for safety reasons.

The first attempt at the free-flight deployment test was unsuccessful; none of the events programmed after release occurred. The problem was traced to a faulty ground in the cabling from the helicopter control box to the electronic sequencer. The problem was corrected and the test was repeated.

In the second test, mortar fire, parachute deployment, and mortar jettison occurred as planned and were entirely satisfactory.[5] Although lines that were designed to restrain the mortar lid and the sabot during the deploy-

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[5] Film 881, *Parachute Deployment Test Program,* concerning this and some of the earlier development tests, is available on request from JPL.

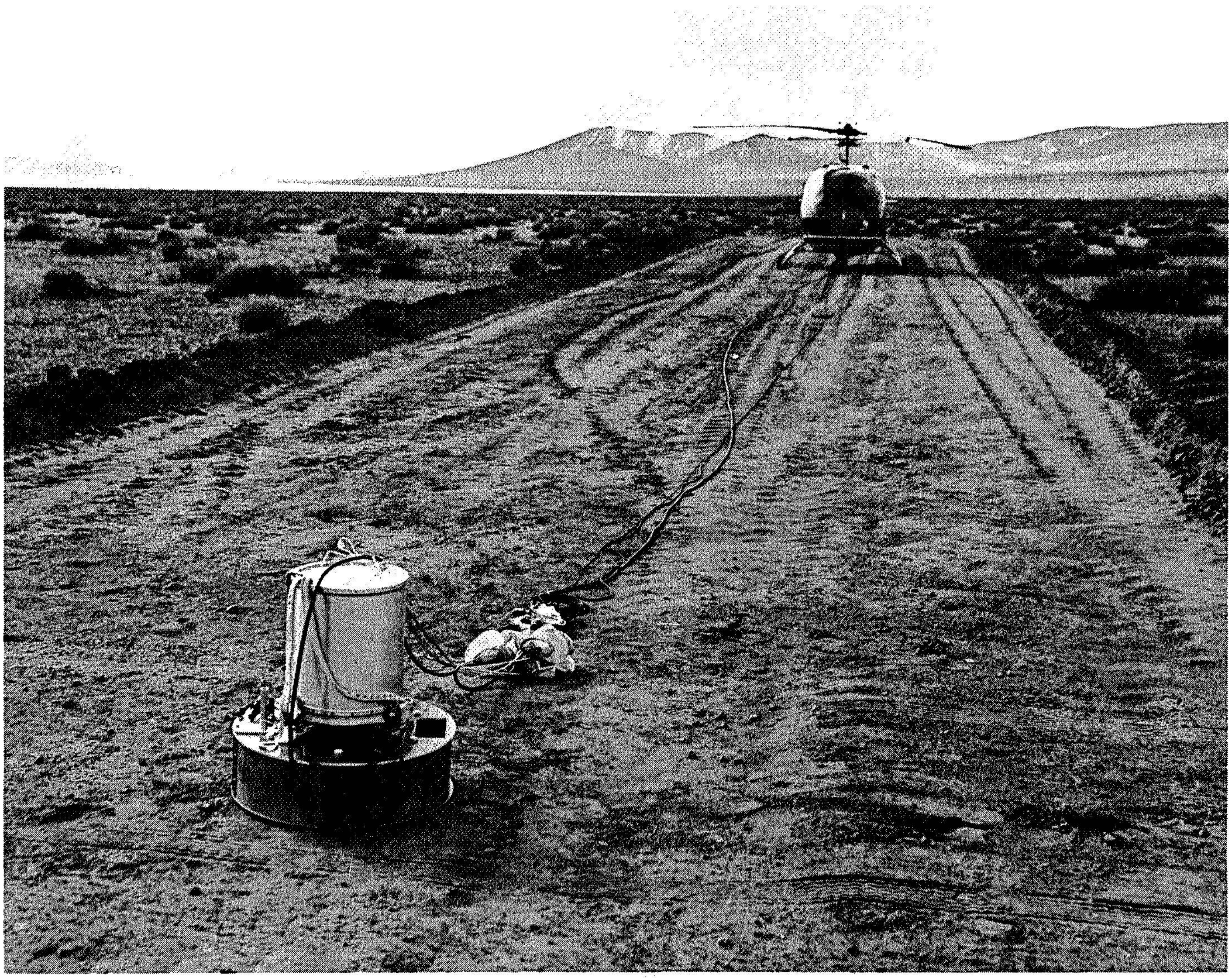

Fig. 12. Drop test specimen suspension system

ment failed, this did not affect the test as such. Figure 13 shows the system shortly after mortar jettison.

Problems were experienced with the gliding and final release features. One of the attachments for the bungee cord failed, apparently during deployment, and, therefore, there was no gliding feature in the test. Also, the electronic sequencer failed to fire the final release cutter; cause of the failure was not determined. These failures were not considered particularly important to the program because the features involved had been demonstrated successfully in the earlier gliding test.

IV. Conclusions

The following conclusions have been reached on the basis of development and testing of mechanisms for a planetary landing parachute system:

(1) The selected scheme for jettisoning the deployment mortar is feasible.

(2) A gliding feature can be incorporated into an otherwise unmodified parachute, and this feature shows some promise as a means of preventing payload envelopment.

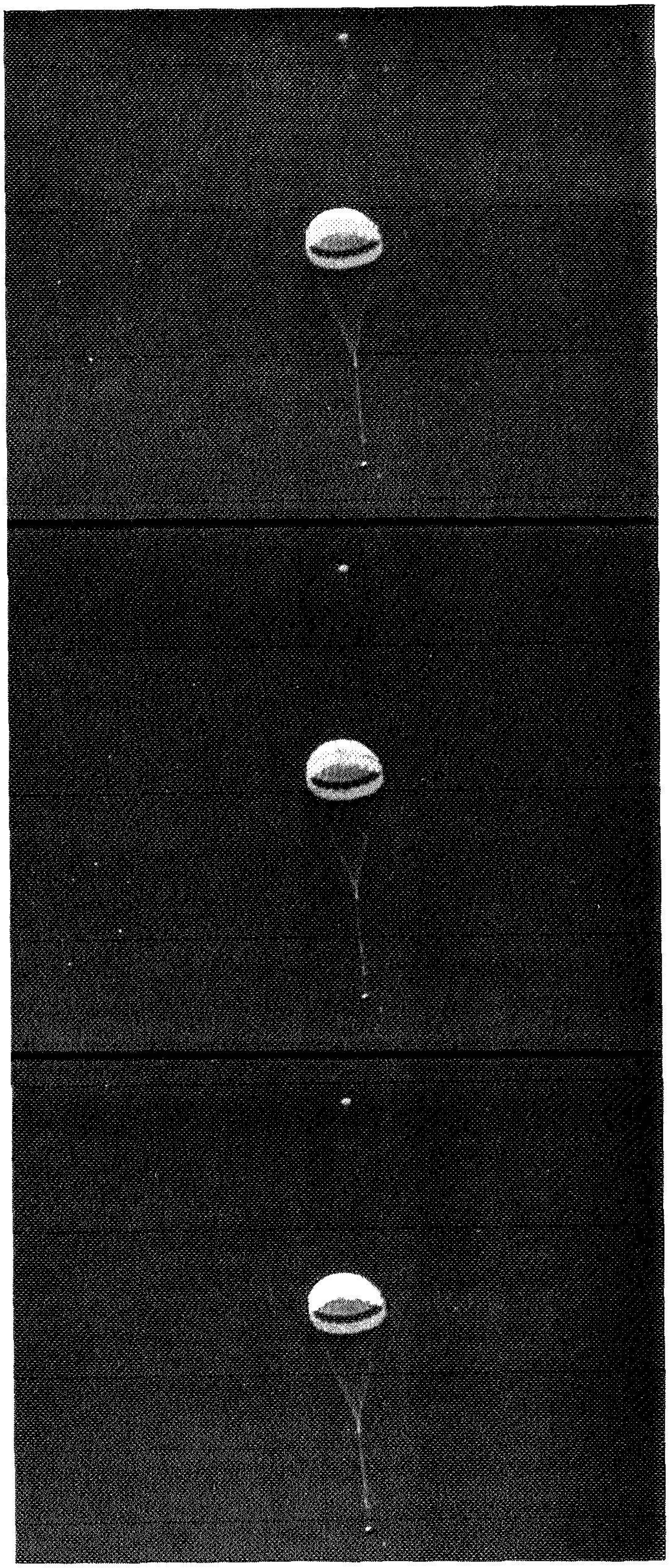

Fig. 13. Views of free-flight deployment test system shortly after mortar jettison

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