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THE APOLLO 15 DEPLOYABLE BOOM ANOMALY

By Robert D. White*

ABSTRACT

During the Apollo 15 mission, a boom with an attached mass spectrometer was required to retract periodically so that the instrument would not be in the field of view of other experiments. The boom did not fully retract on five of 12 occasions. Data analysis indicated that the boom probably retracted to within approximately 2.54 centimeters (1 inch) of full retraction. The pertinent boom-design details, the events in the mission related to the anomaly, a discussion of the inflight and postflight investigation of the problem, a discussion of the design changes to the boom mechanism as a result of the investigation, and subsequent flight performance are presented in this report.

INTRODUCTION

While the Apollo 15 commander and lunar module pilot were on the lunar surface, the command module pilot completed 34 lunar orbits, operating scientific instrument module (SIM) experiments to obtain data concerning the lunar surface and the lunar environment. One of these experiments involved the use of a mass spectrometer that was deployed from and retracted into the SIM bay by means of a deployable boom mechanism. A boom was necessary because the experiment was used to detect released gases from the lunar surface and, therefore, had to be placed away from the immediate vicinity of the command/service module to minimize any contamination of the instrument by offgassing products of the vehicle. The boom was required to retract periodically so that the mass spectrometer would not be in the field of view of other experiments and also to allow firing of the service propulsion system engine. However, during the Apollo 15 flight, the boom did not fully retract on five of 12 occasions. The problem that occurred in flight, the postflight investigations, and the subsequent design changes and results are discussed in this report.

DEPLOYMENT MECHANISM

Two experiments, a gamma-ray spectrometer and a mass spectrometer, were mounted on similar extendable/retractable boom mechanisms in the SIM bay of the Apollo service module (fig. 1). When deployed, the mass-spectrometer boom extended 762 centimeters (25 feet) and the gamma-ray boom extended 817.8 centimeters

*NASA Manned Spacecraft Center, Houston, Tex.

(26 feet 10 inches). The mass-spectrometer unit that was attached to the end of the boom weighed approximately 11 kilograms (25 pounds). The deployment mechanism (including the jettison mechanism) had dimensions of 33 by 43 by 84 centimeters (13 by 17 by 33 inches) and weighed 41 kilograms (90 pounds).

The boom is formed of two tempered-steel tapes that are 14. 2 centimeters (5. 6 inches) wide and 0. 03 centimeter (0. 012 inch) thick. Before deployment, the tapes are stored flat on two motor-driven reels. As the tape is unreeled during deployment, it assumes its natural C-shaped cross section and joins the other tape to form a circular cross section boom 5. 08 centimeters (2 inches) in diameter (fig. 2). The deployment cycle is terminated by allowing a roller follower on the extend limit switch (fig. 2) to drop through a slot cut in one of the steel tapes, opening the circuit to the extend winding of the reel-drive motors and a talkback indicator that is monitored by the command module pilot. The retraction cycle is terminated when the experiment mounting flange engages the retract limit-switch actuation rod and opens the circuit to the retract winding of the reel-drive motors and to the talkback indicator.

Cycling time of the mass-spectrometer boom assembly is a function of several factors (for example, temperature and available bus voltage). At a nominal 28 V dc, the boom assembly would take approximately 140 seconds for extension and 173 seconds for retraction. Boom-position-monitoring capability is provided by means of talkbacks. However, these boom-status monitors indicate full deployment, full retraction, boom in transit, and boom jettison only; intermediate boom positioning necessitates timing by the crewman.

The experiment is connected electrically to the SIM bay by means of a cable that is coiled around the boom at deployment (fig. 3) and that is stored within the boom-actuating mechanism housing (fig. 2) when the boom is retracted. The experiment power cable is a bundle of 20 electrical conductors and one coil spring wire having a total cross section of 1. 3 centimeters (0. 5 inch). The coil spring is included to control the location of the power cable and the diametrical size of the coils during extension and retraction. The pitch of the coiled cable reverses direction at the midpoint in the cable length so that there is no torsional effect from the spring on the experiment during extension and retraction or while extended and operating. The length of the power cable is approximately 1920 centimeters (63 feet), but, in the relaxed coiled configuration, the length is approximately 260 centimeters (8. 5 feet). A force of approximately 4. 5 kilograms (10 pounds) is required in order to compress or extend the coils from the relaxed position; however, the drive motors will not stall until an excess of 200 kilograms (440 pounds) is applied to the boom.

To guide the power cable into its storage volume during retraction, the mechanism housing is flared at the end and the experiment mounting flange has six fingers attached that act like scoops during retraction (figs. 2 and 3). The flare on the housing has cutouts so that the fingers can push the cable bundle past the housing lip.

Because the retracted experiment and its boom mechanism must be supported in the SIM bay for launch forces, the experiment and the boom are mounted on two rails that are supported by trusses from the bottom side of a SIM-bay shelf (fig. 4). These guide rails also allow the experiment to extend and then retract for support during space-flight acceleration forces with the service propulsion system engine. Linear bearings attached to the experiment pick up the tapered ends of the guide rails during retraction.

Because of the limited mechanical strength of the boom, it must be retracted before any service propulsion system engine firings to avert buckling of the boom, which could damage the service module. If the boom cannot be retracted because of a malfunction, the boom-actuating mechanism, the boom, and the experiment could be jettisoned. The spring-powered jettison mechanism is shown in figure 4. On proper circuit closure, the fusable wire actuator would release the restraining link, and the boom-actuating mechanism, the boom, and the experiment all could be jettisoned at a rate of approximately 213 cm/sec (7 ft/sec).

The mass-spectrometer installation in the SIM includes a thermal and contamination cover (figs. 4 and 5) that closes over the outboard face of the experiment. This protective cover opens with the initial motion of the boom mechanism during extension and closes with the final motion during retraction. The cover prevents heating and contaminant damage to the experiment that would result from reaction control system (RCS) jet firings and effluent dumps.

FLIGHT ANOMALY

During the Apollo 15 flight, the mass-spectrometer boom mechanism was required to retract 12 times. On five of these occasions, the boom did not retract fully. Normally, the deploy/retract talkback indicator is gray when the boom motors are off and the boom is retracted or extended fully. The indicator is "barberpole" when the boom is either extending or retracting. However, because the indicator is wired in series with the drive motors, a half barberpole will usually show if the drive motors stall. When the motors stall, the current increases and causes a voltage drop. The voltage drop then causes the indicator to activate only partially to the barberpole position. The command module pilot noted this half-barberpole condition that indicated stalled motors and, therefore, incomplete retractions.

Telemetry data from the spacecraft electrical buses plotted with a time base indicated that the current driving the retract motors was normal on the five stall occasions until the boom was within 2 to 5 centimeters (0.79 to 1.97 inches) of full retract. At that point, the current increased from a nominal 3 to 4 amperes to the typical stall level of approximately 9 amperes.

A space cold soaking of the fully deployed boom and power cable preceded each anomalous retraction. In every case, after a warmup period in the sun, the boom could be retracted fully after first again extending it approximately a meter. Also, a special inflight test to investigate the boom anomaly was accomplished during the spacecraft coast back to earth. This test supported the theory that the malfunction was related to thermal conditions; that is, after a cold soak, the boom did not retract completely, but, after a subsequent hot soak, retraction was completed.

An inflight photograph of the extended boom (fig. 6) revealed that the power-cable coils remained circular but were not concentric to the boom and appeared to touch the boom on most of its length. The assumption had been made that in zero-g this sagging would not occur significantly because of the coiled spring in the power cable.

The extravehicular activity by the command module pilot to the SIM bay to retrieve film cassettes confirmed the assumption that the boom was within approximately 3 to 4 centimeters (1.18 to 1.57 inches) of full retraction. The boom had stalled before the extravehicular activity and was left in the stalled position for visual inspection by the command module pilot. He reported that the mass-spectrometer thermal cover was approximately 30 to 40 degrees open and that he could see only the tapered tip of the guide rail protruding from the experiment support bearing, as simulated in figure 5. This corresponds to a boom position of approximately 3.5 centimeters (1.38 inches) from full retract, as shown by the data in figure 7.

Although retraction problems occurred, the boom was always manipulated (sun exposure and short recycles) so that the experiment did not have to be jettisoned to allow SPS engine firings. Valuable mass-spectrometer data would have been lost if the stalled boom had been jettisoned. However, only a small percentage of the experiment data-gathering time was lost. The similar boom-deployment mechanism for the gamma-ray spectrometer worked normally throughout the Apollo 15 mission.

PROBLEM INVESTIGATION

No postflight hardware analysis or testing could be conducted with the Apollo 15 boom mechanism because the service module that contained the SIM bay was jettisoned before earth entry. However, because gamma-ray-spectrometer and mass-spectrometer boom mechanisms were to be used on the Apollo 16 mission, an extensive anomaly investigation was conducted in an attempt to correct the problem. The investigation was based on the following list of most probable causes of the anomaly.

1. Cable bunching and jamming at the mechanism housing annulus opening

2. Cable sagging and bunching between flared housing and fingers or experiment bearing

3. Cable service-loop snagging on housing or support structure

4. Interference between guide rails and spectrometer bearing

5. Low-temperature stiffness of the power cable

6. Marginal adjustment or malfunction of the retract limit switch or the actuator rod to the switch

7. Interference between experiment and cover

The investigation started with the following analysis and testing.

1. A documentation review of all pertinent drawings, specifications, analyses, and discrepancy records was conducted to identify any irregularity that may have caused the retract anomaly.

2. A visual inspection of the Apollo 16 mass spectrometer and gamma-ray spectrometer was accomplished at the launch pad while the instruments were installed in the flight configuration. The inspection included a short extension and retraction of each assembly.

3. After return of the Apollo 16 mass-spectrometer boom assembly to the contractor, additional visual inspection and dimension verification were accomplished. In addition, short extensions and retractions were performed at room-ambient conditions under various orientations with respect to gravity to simulate worst-case cable-sagging conditions.

The major problem discovered was that of sagging in the power cable. On a few occasions, the sagging would allow the cable to bunch up and jam or snag between the flared housing and a guide finger or between the flared housing and an experiment support bearing. An abnormality of this kind is shown in figure 8.

This same cable-sagging problem had been observed during the original flight-qualification testing of the deployment mechanism, but most of the sag was attributed to the one-g environment, and the assumption was made that the sag would be confined within the flared housing and the guide fingers during zero-g conditions. Therefore, for the majority of the qualification tests, the cable was counterbalanced when the boom was cycled.

Also, in power-cable developmental tests that were conducted before the qualification testing, no stiffness change was detected in the cable coils when the coils were exercised at room temperature and at 188.15° K (-85° C). This fact was verified during the anomaly investigation.

INVESTIGATION CONCLUSIONS AND CORRECTIVE ACTIONS

After all plausible causes for the Apollo 15 flight anomaly were examined, and based on the analyses and testing discussed in this report, the conclusion was reached that the problem occurred because of one of the following reasons.

1. Improper stacking of the power-cable coils into the annulus of the mechanism housing during retraction

2. Jamming of the power cable either between the experiment support bearing and the mechanism housing or between the guide fingers and the housing

The first possible cause cited could not be corrected in time to support the Apollo Program schedule. The housing annulus opening would have had to be redesigned and, possibly, the cable-coil diameter would have had to be decreased. These changes could not have been accomplished and requalified for flight in time for the Apollo 16 launch. However, for the second possible cause, several simple changes could be made to the existing design and could be tested within the schedule. The following changes were implemented.

1. Tab extensions were added to the flare on the mechanism housing (fig. 9).

2. A second cable clamp was added to retain the cable service loop better at the experiment interface (fig. 9).

3. The inboard experiment-support bearings were modified by adding a ramp to serve as a fairing during cable retraction (fig. 10).

4. The guide fingers on the experiment-mounting flange were extended where possible to improve gathering of a sagging cable (fig. 9). A similar change was made to the Apollo 16 gamma-ray-spectrometer deployment mechanism.

After these modifications were added, the Apollo 16 mass-spectrometer mechanism (with a prototype spectrometer) was tested at room-ambient and low-temperature conditions and at the low-temperature gradients in a vacuum simulating the worst-case low-temperature-gradient environment of lunar orbit. No test anomalies were experienced, and the mechanism performance was nominal.

The mass spectrometer deployment mechanism assembly was completely recycled through standard acceptance-test procedures before return to the launch pad. However, in the event the changes did not solve the problem for the next flight (such as improper stacking of the retracting cable), a proximity switch was also added to each of the spectrometer experiment mechanisms (fig. 10). This switch would indicate when the boom was within 30 centimeters (11.81 inches) of full retract even if the motors did stall. The boom is safe for an SPS engine firing within this 30 centimeters (11.81 inches), and this knowledge could prevent either experiment from being jettisoned if the boom did stall.

CONCLUDING REMARKS

The Apollo 15 mass-spectrometer-deployment mechanism could not be returned for an evaluation to determine the cause of the flight anomaly. A postflight investigation revealed two probable causes; however, the flight schedule for Apollo 16 prevented any extensive redesign of the mechanisms. Only simple modifications could be added to the mechanisms in an attempt to avert the problem from occurring again and also to add a proximity switch to indicate when the boom was in a safe position for service propulsion system engine firing. These modifications were thought to be sufficient because Apollo 16 was the last spacecraft to use these spectrometer mechanisms.

The Apollo 16 mission proved that the changes were not adequate because both mass-spectrometer and gamma-ray boom mechanisms would not always retract fully when commanded. However, the proximity switches on both experiments always indicated they were retracted within 30 centimeters (11.81 inches), saving the experiments from being jettisoned while gathering data in lunar orbit. It is the opinion of this author that the basic problem was improper stacking of the cable into the mechanism housing annulus during retraction; this should be recognized as a significant design problem. If similar concepts of long retractable booms that have an external cable are needed in future space efforts, an ample stowage area should be provided for the cable.

DISCUSSION

D. D. Laine:

Are internal electrical cables being considered by the MSC for future booms of this basic cross-sectional configuration?

White:

There will be no booms with electrical cables used on any other Apollo flight, and I would say that it is too early to know this type of detail for the space-shuttle program.

A. B. Hunter, Jr.:

On the double C-spring boom mast, was there any resistance to twisting and was this a problem? Also, did the outer coiled cable impart any twist to the boom?

White:

The boom tapes did have restraints or clamps located at each end of the boom; however, it was known from ground-based testing that the boom would have 40° to 60° thermal twist. This twist was not a problem with the gamma-ray experiment but the mass spectrometer inlet scoop had to be redesigned. The external power cable did not cause a torsional problem while extended because the pitch of the coiled cable reversed direction at the cable-length midpoint to cancel the torsion from the coil spring.

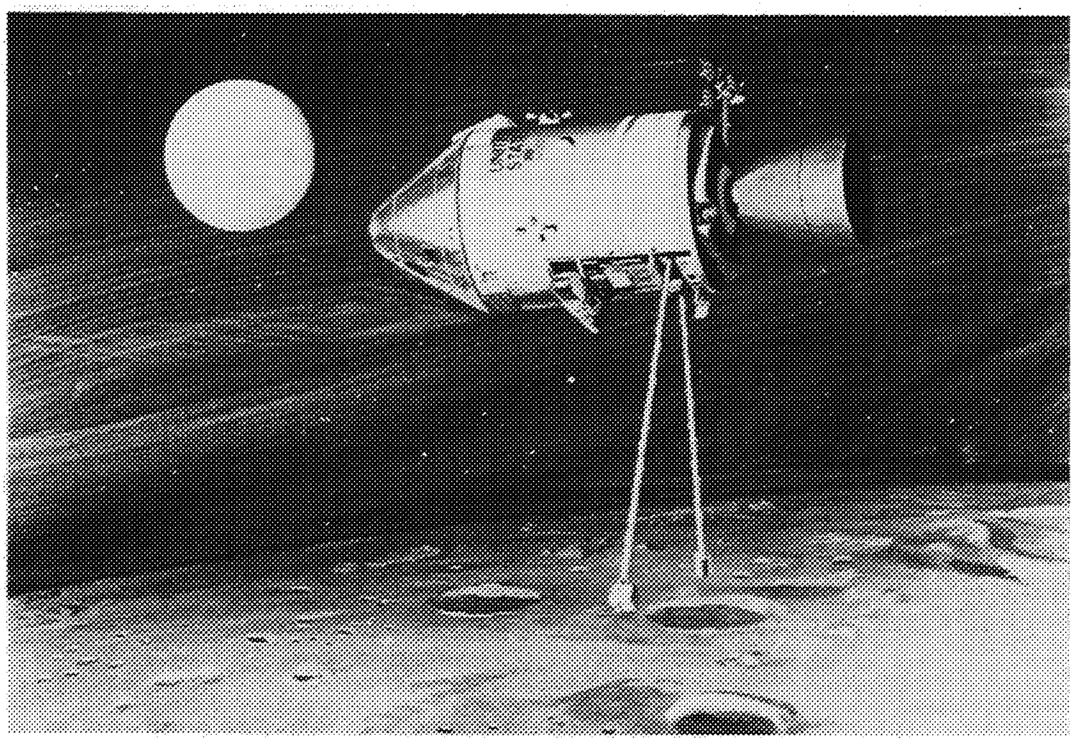

Figure 1. - Apollo SIM-bay experiments.

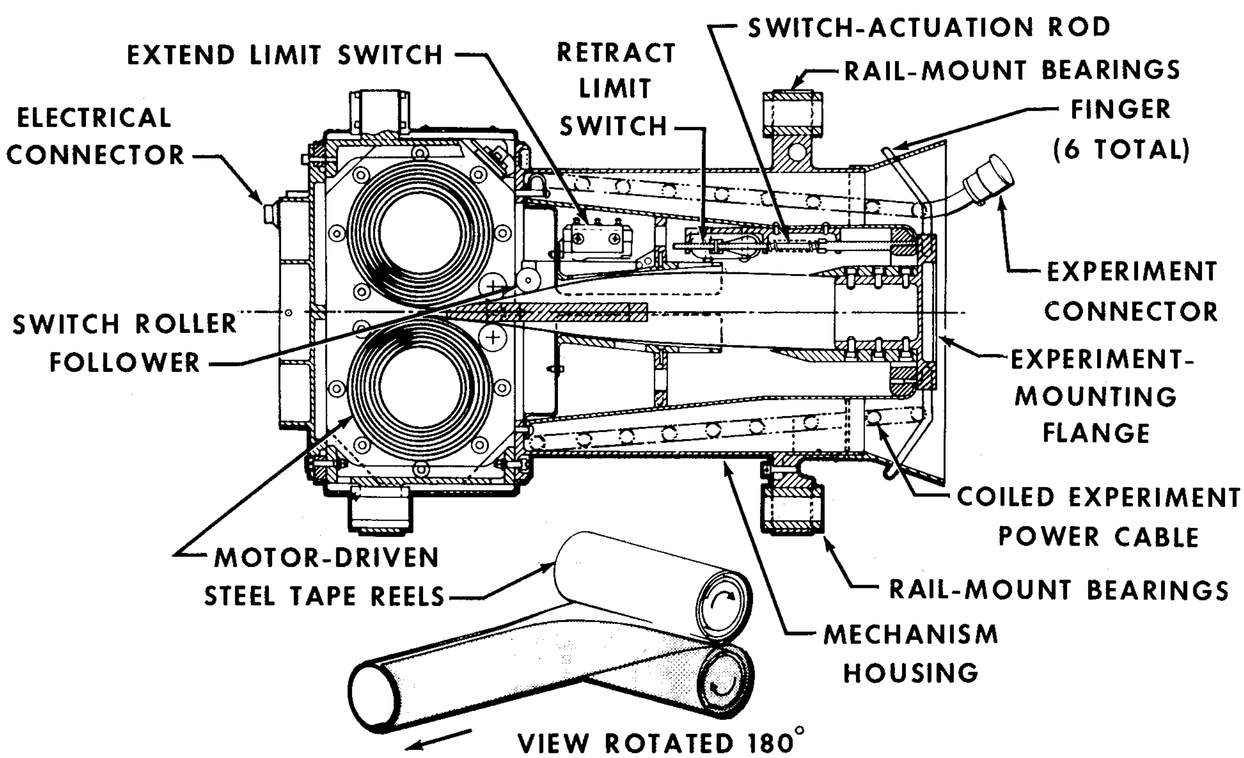

Figure 2. -Mass-spectrometer boom-actuating mechanism.

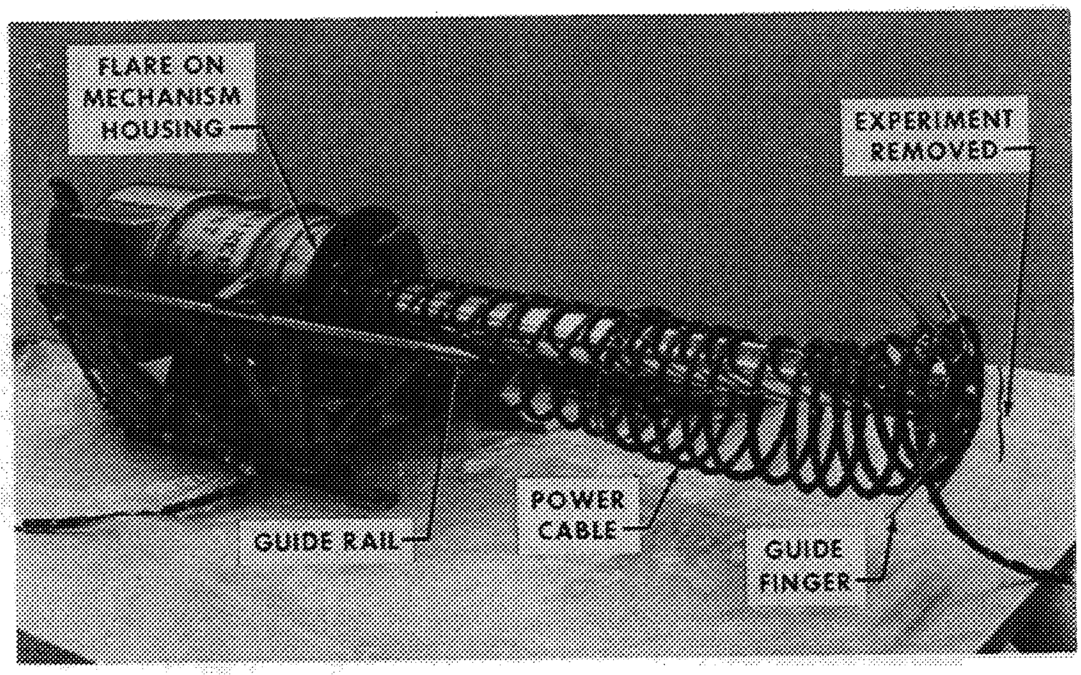

Figure 3. - Mass-spectrometer boom partially extended.

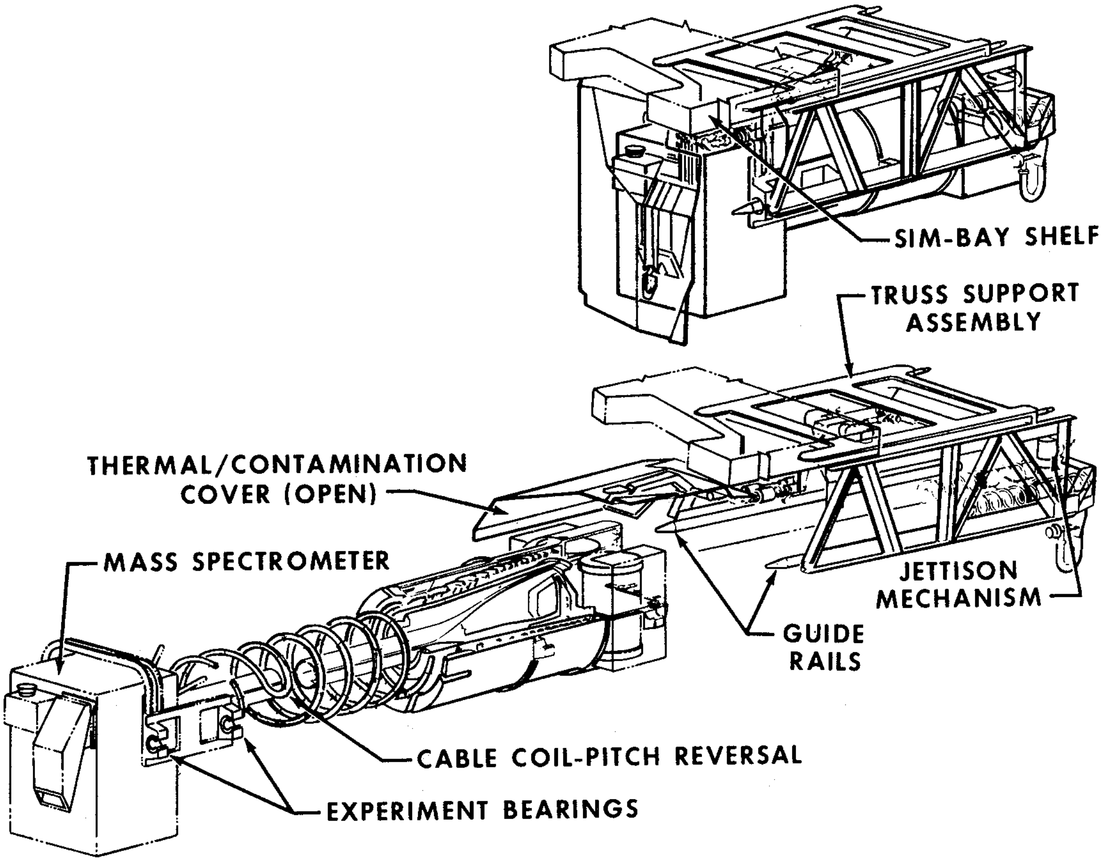

Figure 4. - Deployment mechanism and support structure.

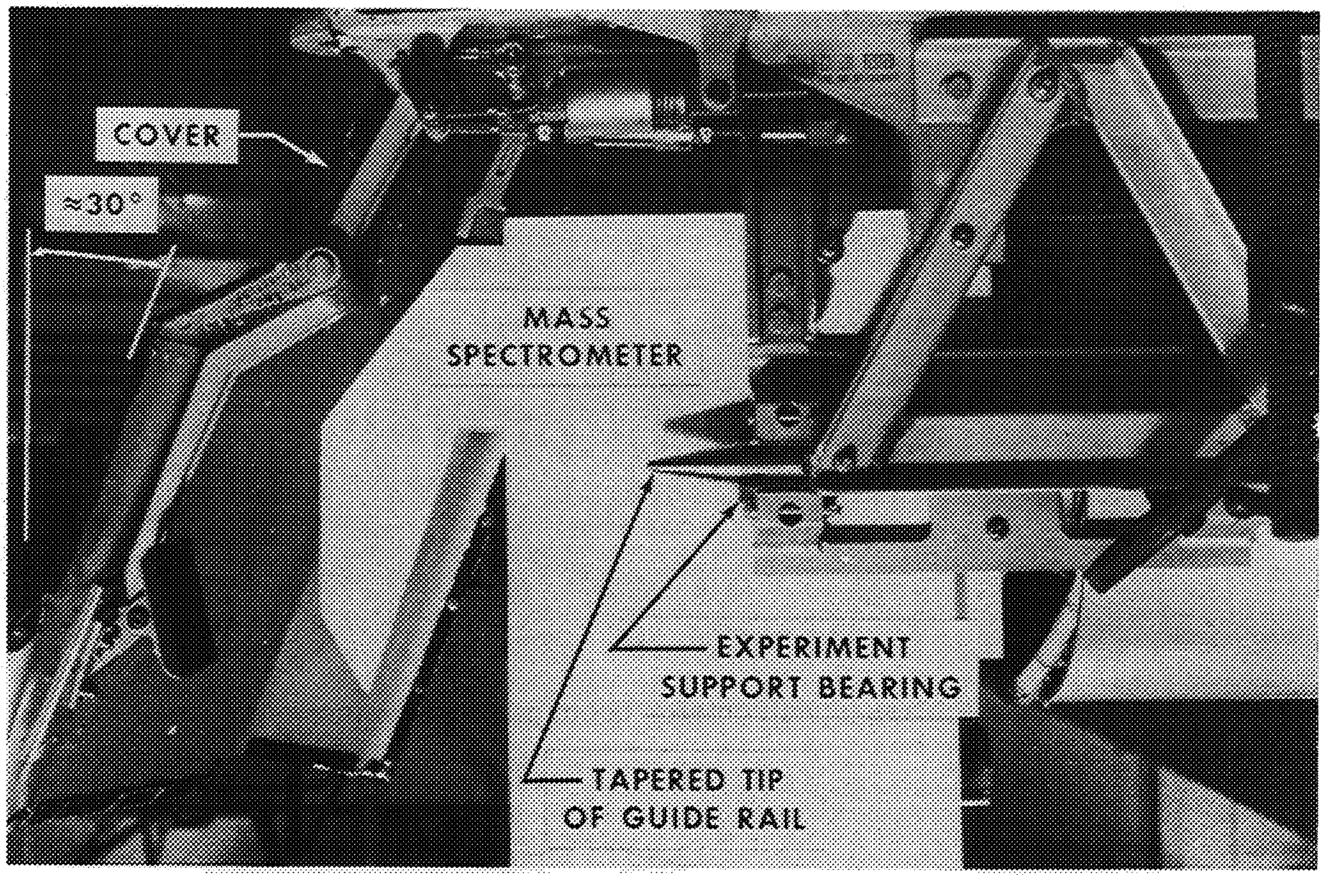

Figure 5. - Simulation of command module pilot observation.

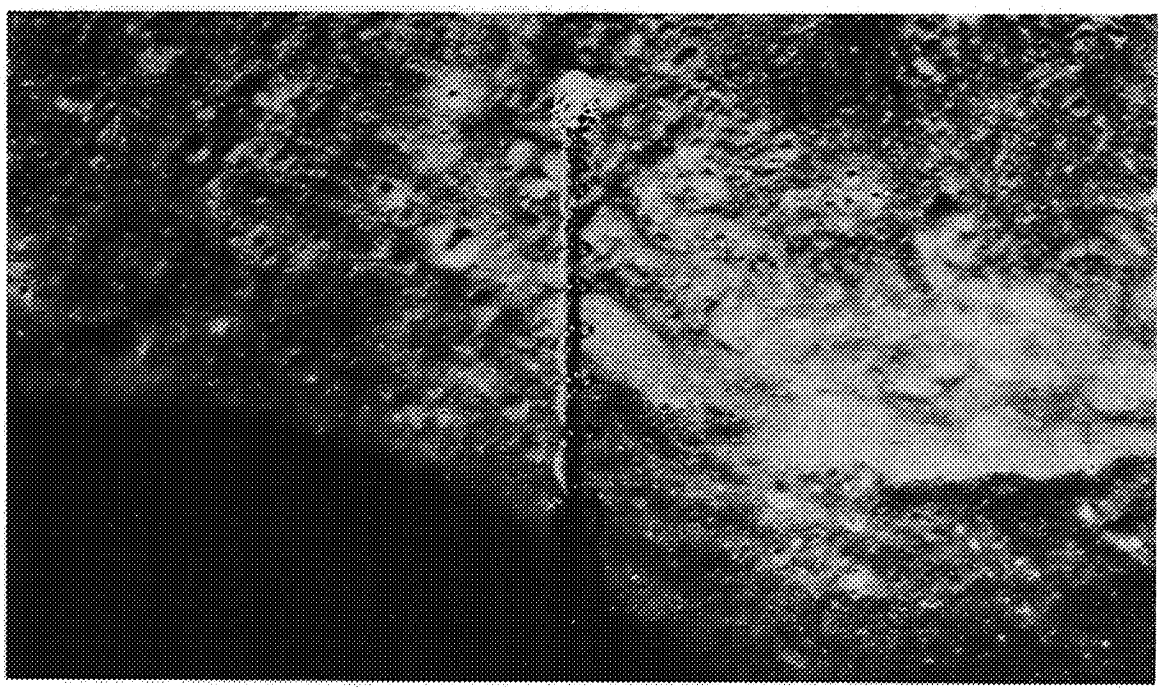

Figure 6. - Boom deployed in lunar orbit.

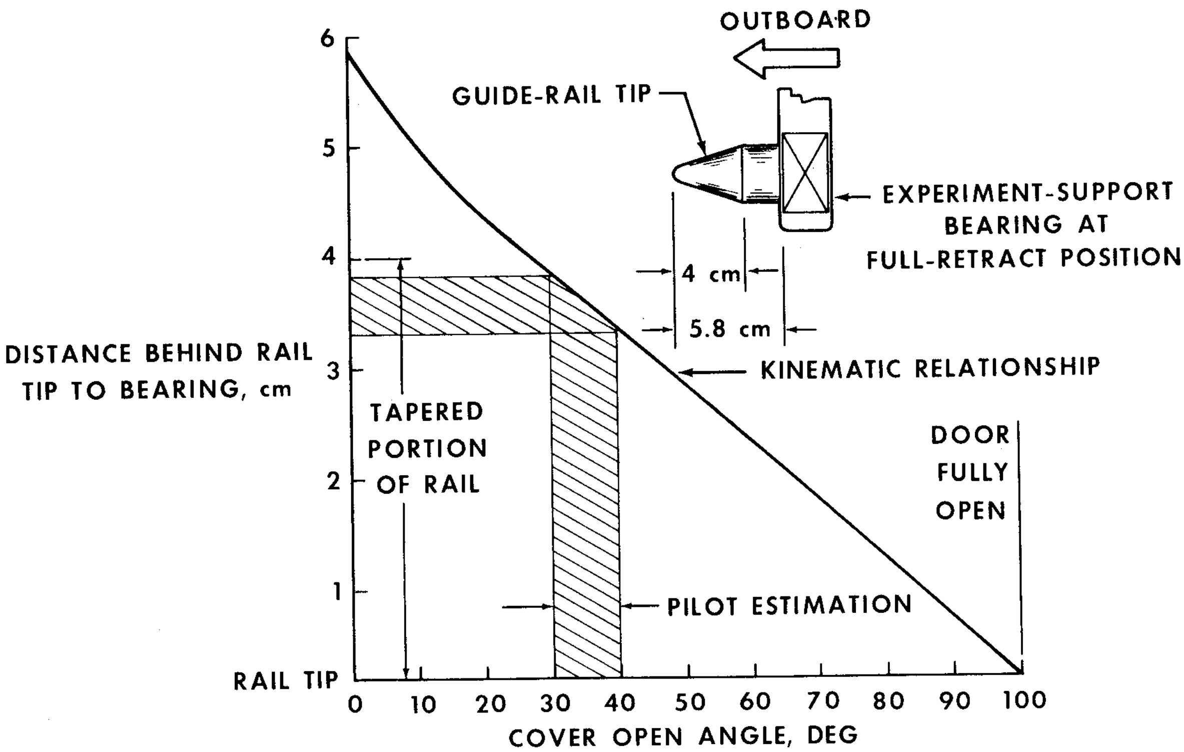

Figure 7. -Relationship of mass-spectrometer cover to bearing position.

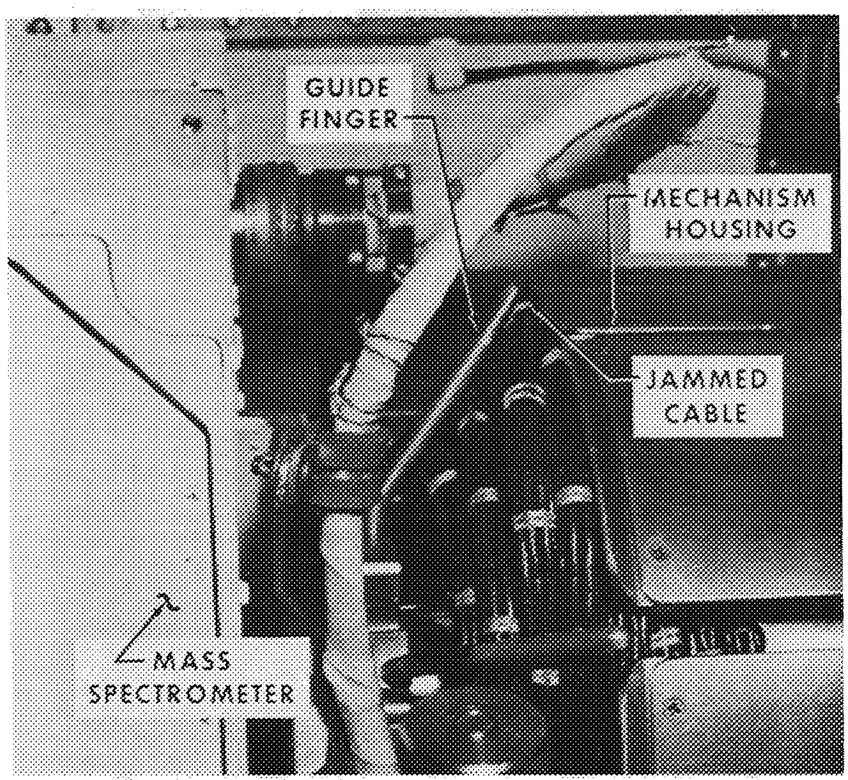

Figure 8. - Boom stall caused by jammed cable.

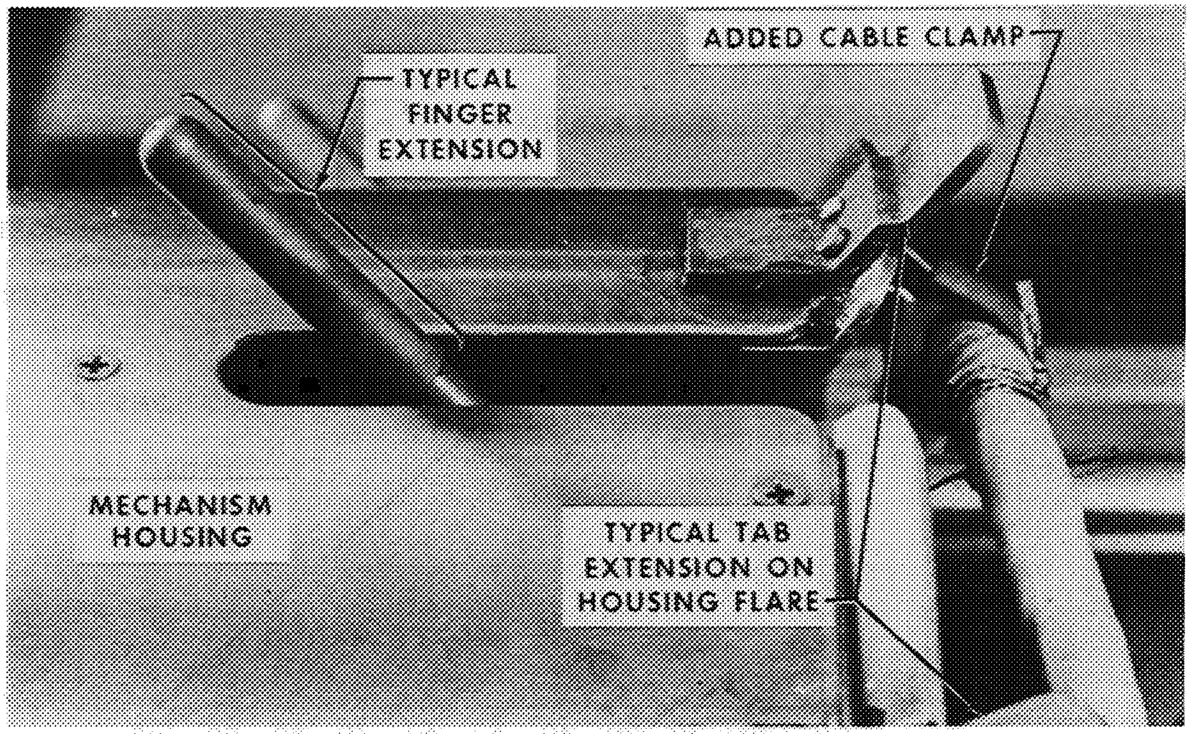

Figure 9. - Design changes to the deployment mechanism.

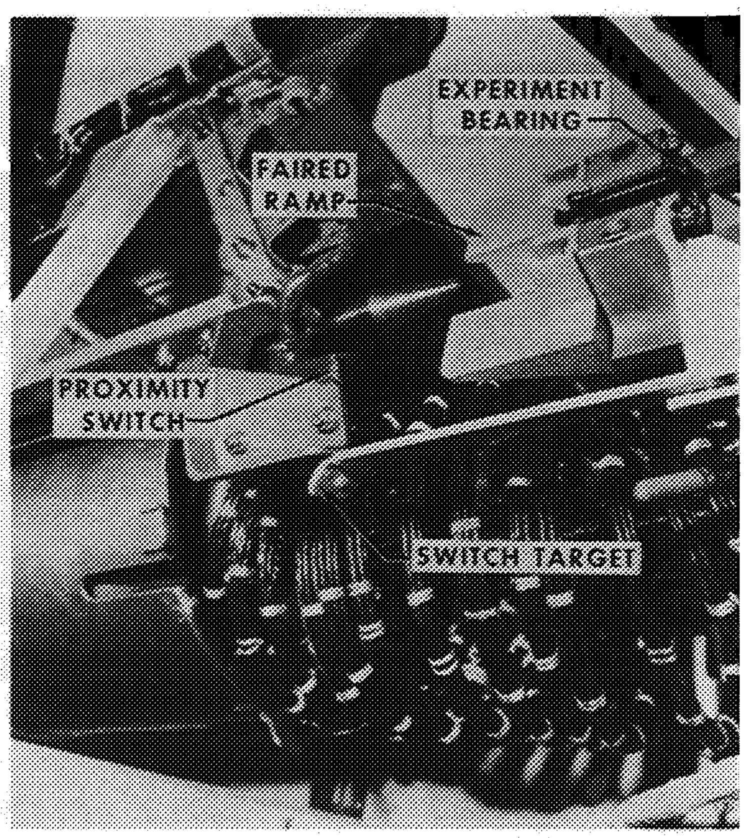

Figure 10. - Additions to the deployment mechanism.