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THE APOLLO 14 DOCKING ANOMALY

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ABSTRACT

Six docking attempts were required to achieve initial latch engagement during the Apollo 14 translunar docking event. Although subsequent performance of the docking hardware was normal, the docking probe was retained for a thorough postflight investigation. Pertinent design details of the docking system, the mission events related to the anomaly, and a discussion of the postflight investigation of the cause of the anomaly are presented in this report.

INTRODUCTION

The Apollo lunar-landing missions require that two docking maneuvers be performed: the first is called transposition or translunar docking and the second is referred to as lunar-orbit docking. Because the required dockings had been performed successfully on five previous Apollo missions, docking had become a routine procedure until the Apollo 14 docking anomaly. The Apollo 14 translunar docking required six attempts to achieve capture-latch engagement. Although subsequent mission operations were normal, the docking probe was returned to earth with the spacecraft so that a detailed investigation could be conducted. The purpose of this paper is to present a limited description of the docking mechanism, the associated mission events, and a discussion of the investigation and findings.

The material presented in this paper was derived from the Apollo 14 Mission Anomaly Report prepared by the NASA Manned Spacecraft Center Mission Evaluation Team.

DOCKING SYSTEM DESCRIPTION

The Apollo docking system consists primarily of the probe, mounted on the forward end of the command module (CM), and the drogue, mounted within the lunar module (LM) tunnel (figs. 1 and 2). The docking probe consists of numerous subassemblies; however, a description of only the capture-latch assembly is presented because the Apollo 14 docking anomaly is associated with that area.

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The probe capture-latch assembly (fig. 3) is contained within the self-centering, gimbal-mounted probe head and serves as the method for achieving initial coupling between the CM and LM. The assembly consists of three hooks that are pin mounted to the probe head and that are spring loaded so that the hook protrudes beyond the surface of the probe head. Opposite each of the hook pivot points is a two-piece toggle link that connects the hook to a fixed point on the probe head. When the hook is extended, as shown in figure 3, the toggle link pins are almost in line, providing a means of locking the hook.

Latch locking and release are determined by the axial position of a single, symmetrical spider that is spring loaded to the full-forward, locked position. In this position, a roller on the spider rests beneath each of the hook toggle links so that the hooks cannot be depressed. To unlock the latches, the spider must be moved aft and retained until subsequent latch lock is required.

Spider retention and release (fig. 4) are achieved by means of triggers located within each of the latch hooks. When the spider is moved aft of the triggers and released, pins located on the outer tip of the spider bear against the back face of the trigger and prevent forward travel of the spider. To release the spider, all three triggers must be depressed because one or more triggers will retain the spider in the aft (unlocked) position. The spider can be moved from the forward (locked) to the aft (unlocked) position by manually depressing the plunger in the probe head or by rotating the torque shaft. When the torque shaft is rotated, either by manually actuating the capture-latch release handle or by powering the torque motors in the actuator assembly (fig. 5), the rollers turn in the cam slots and force the cam and the spider aft. When power is removed from the torque motors, the torsion spring on the torque shaft rotates the shaft back and allows the spider to move forward until cocked; that is, the spider pins ride against the back of the triggers.

APOLLO 14 MISSION SEQUENCE

Functional checkout of the Apollo 14 docking probe was completed in August 1970, and the retracted docking probe was installed in the CM docking ring on November 8, 1970. At that time, a tension-tie mechanism was installed between the probe head and the launch escape system (LES) boost protective cover to provide a system compatible with LES abort requirements (fig. 6). As shown in figure 6, the tension-tie installation places the capture latches in a mechanically cocked launch configuration.

On January 31, 1971, after a rain shower, the Apollo 14 spacecraft was launched from the NASA John F. Kennedy Space Center; as part of the normal boost phase of the flight, the LES was jettisoned. This event sheared the pins that attached the tension tie to the probe head, allowing the tension tie to remain with the jettisoned LES and leave an exposed, intact, docking probe. As part of the earth-orbit spacecraft-checkout activity, the crewmen extended the docking probe by operating a switch on the CM main-display panel. This extension sequence also applied power to the probe direct current torque motors to rotate the torque shaft. The crewmen verified proper extension by observing a talkback indicator on the same panel. The spacecraft was then injected into a translunar flight trajectory by firing the S-IVB booster engine.

The transposition and docking events (fig. 7) were initiated by separation of the command and service module (CSM) from the adapter and ejection of the adapter panels that house the LM. Then, the crew translated the CSM approximately 30 meters (100 feet) away from the LM and turned the CSM 180° with a pitch maneuver to aline the CSM and LM in preparation for the docking. Before initiating a CSM/LM closure rate, the crew placed one of the docking switches to the retract position and certified that the probe capture latches were still in the cocked configuration. The CM pilot then experienced five unsuccessful docking attempts.

After docking, the crew examined the probe and drogue and no abnormal operations could be observed; however, there were marks on the drogue, as is shown in figure 8. Although subsequent docking functions were completely normal, the docking probe was returned with the CM.

ANOMALY INVESTIGATION

The initial phase of the anomaly investigation consisted of activity to reduce the list of possible failure modes based on flight data and the crew debriefing. A summary of the docking attempts is presented in table I. The first attempt consisted of four distinct probe/drogue contacts near the drogue apex, whereas each succeeding attempt consisted of withdrawal of the CM and subsequent initiation of a new closure rate. These data support the conclusion that the contact conditions were normal for all docking attempts and capture-latch engagement should have been achieved for the five unsuccessful attempts.

The second conclusion, which is that the capture latches were not in the locked configuration during the unsuccessful attempts, is based on the following reasons.

1. The probe-status talkback displays functioned properly before and after the unsuccessful attempts, indicating proper switch operation and power to the talkback circuits. The talkback displays always indicated that the capture latches were in the cocked position during the unsuccessful attempts.

2. Electrical power to the motors is not required because the system is cocked before flight and the initial capture operation is strictly mechanical and must be triggered by the drogue. Conversely, a review of flight electrical data showed that there was no unexplained current usage during the docking maneuvers because power to the probe torque motors would have retained the latches in the cocked position.

3. Each of the six marks on the drogue resulted from separate contacts by the probe head (fig. 8). A docking impact with locked capture latches should result in three double marks (to match the latch hooks) within 2.54 centimeters (1 inch) of the drogue socket.

Because the latches were not locked, apparently the anomaly was caused by failure of the capture-latch spider to reach the locked position. Therefore, the investigative activity was focused on the items that could influence the position of the spider. The results are summarized as follows.

Analysis

As a result of rain on the launch day, it was possible that water could have entered the probe head and frozen during the boost phase of flight. A maximum of 30 grams of ice could have formed; however, this amount would sublime within 15 minutes, well before the docking event that occurred approximately 3-1/2 hours after launch.

A trajectory analysis, based on Apollo 14 flight-acceleration data, was conducted to determine if the tension-tie shear-pin remnants could have reentered the capture-latch area. This analysis, which was verified by tests, showed that, if the remnants separated from the tension tie, impact would be well out of the capture-latch area.

The mating parts and surfaces of the capture-latch assembly were analyzed to determine if a worst-case tolerance accumulation combined with a 11° K (20° F) thermal gradient would produce interference. In all cases there were no metal-to-metal interferences.

Ancillary Testing

Because improper shearing of the tension-tie shear pins could prevent movement of the capture-latch plunger, various design combinations of pins were shear tested. In each test, the shear was clear, regardless of the allowable pin-to-hole dimensional combination. In addition, the shock load associated with pin shearing had no effect on performance of the latch mechanism.

As part of the acceptance testing of each probe, a capture-latch timing test is performed to record spider travel as a function of time. To determine if shelf life degrades the latch mechanism, a timing test was performed on a probe that had been idle for approximately 5 months (similar to the Apollo 14 probe). The results were compared with previous time traces, and there was no evidence of degradation.

Coincidental with the Apollo 14 investigation, acceptance testing was being performed on the Apollo 16 docking probe when the capture latches failed in a manner symptomatic of the Apollo 14 anomaly. It was determined that, for a given torque-shaft alinement and the lateral load resulting from the torsion spring (fig. 9), the ball end of the shaft would fall into the cam slot. Then, a friction lock would occur between the ball and pin, preventing the ball from riding out of the cam slot. This, in turn, would prevent subsequent movement of the cam and spider train. Upon disassembly, the torque-shaft ball was found to be galled severely.

Apollo 14 Docking-Probe Inspection and Tests

A visual inspection of the probe head revealed several small scratches and burrs on the inner wall of the tension-tie bushing (fig. 10). The scratches were caused by an object moving in the aft direction; the burrs were the material buildup. This burring could have been caused by a foreign particle lodged between the plunger and the wall of the bushing because the initial motion of the plunger is in the aft direction when the capture hooks are depressed. Therefore, foreign particles in the area of the capture-latch plunger were considered a potential failure mode.

During disassembly of the probe, 12 contaminant particles were found. Three of the particles, which were foreign to the probe, were iron oxide, double-back tape, and cadmium particles. The largest of the 12 particles was 0.15 centimeter (0.060 inch) long, and, of those particles large enough to cause mechanical interference, none were hard enough to prevent operation of the mechanism.

After the Apollo 16 probe capture-latch problem, attempts were made to duplicate the problem on the Apollo 14 probe. With the latch assembly in a horizontal position so that the weight of the shaft added to torsion-spring lateral load, one malfunction was experienced during 60 latch cycles. This also remained a potential failure mode.

Tests were conducted to measure capture-latch timing, torque motor output, friction drag, and spring forces. The results were compared with preflight measurements and no significant degradation was noted.

A detailed inspection of each latch-assembly component did not reveal any wear, damage, or out-of-tolerance parts that could be related to the problem.

CONCLUDING REMARKS

The cause of the Apollo 14 docking anomaly was either (1) foreign material (that was subsequently lost) restricting mechanical operation or (2) jamming of the cam. To ensure proper performance for future systems, cleanliness requirements were improved and a design change was implemented to prevent jamming of the cam. Since then, the Apollo 15 and 16 missions have been completed successfully without recurrence of the docking problem.

DISCUSSION

W. W. Weber:
How were the supporting tests correlated with the actual failure environment (for example, zero gravity)? By vertical or horizontal positioning?

Langley:
During postflight testing of the Apollo 14 docking probe, the failure could not be reproduced with the probe in the vertical position (simulating zero gravity). The failure could only be produced with the probe horizontal, so that the weight of the torque shaft produced additional side loading (one failure in 60 activations).

TABLE I. - RELATED DATA AND FILM INVESTIGATION RESULTS

Docking attempt	Estimated velocity, m/sec (ft/sec) (a)	Socket contact time, sec (b)	+X thrusting after contact, sec	Comments
1A	0.03 (0.1)	1.55	None	No thruster activity Contact moderately close to apex
1B	0.043 (0.14 max.)	1.65	None	Contact close to apex
1C	0.043 (0.14 max.)	1.4	0.55	Contact close to apex
1D	0.088 (0.29 max.)	2.35	1.95	Contact close to apex
2	0.122 to 0.152 (0.4 to 0.5)	1.7	None	Contact close to apex
3	0.122 (0.4)	2.45	None	Contact close to apex
4	0.122 to 0.152 (0.4 to 0.5)	6.5	6.2	Contact close to apex
5	0.076 (0.25)	2.9	None	Contact close to apex
6	0.061 (0.2)	In and hard docked	14.3	Contact moderately close to apex Retract cycle began 6.9 seconds after contact Initial latch triggered 11.8 seconds after contact

[a]The system is designed to capture with closing velocities between 0.030 and 0.305 m/sec (0.1 and 1.0 ft/sec) and with initial probe contact within 0.305 meter (12 inches) of the center of the drogue. These criteria were met on all docking attempts.

[b]The maximum capture-latch response time is 80 milliseconds.

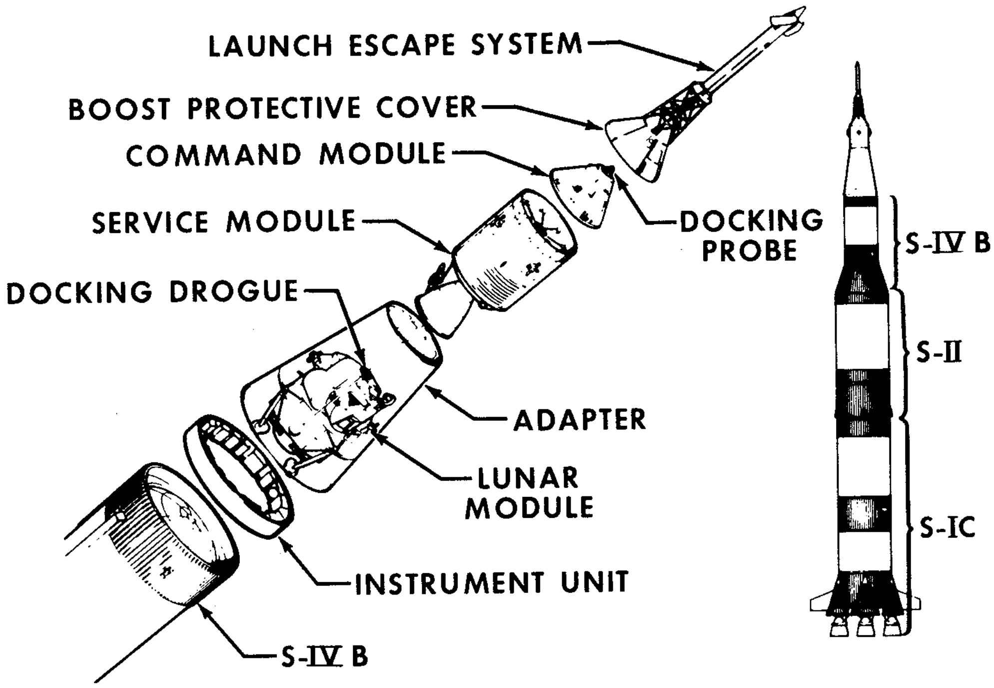

Figure 1. - The Apollo spacecraft.

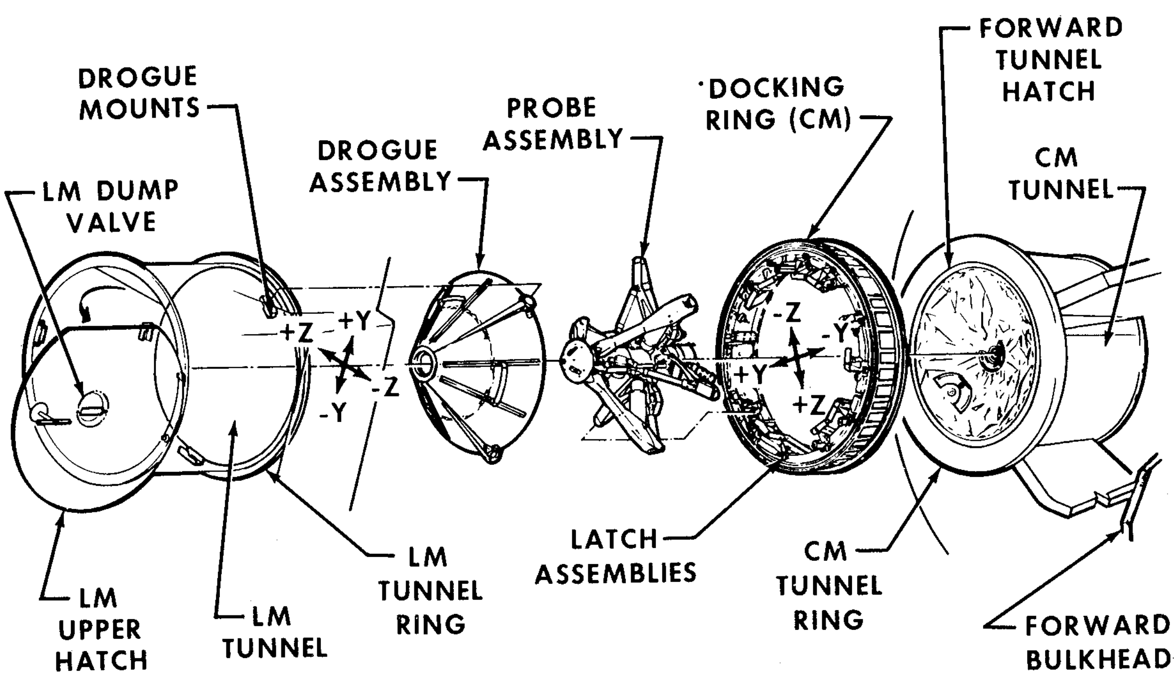

Figure 2. - Major assemblies of the docking system.

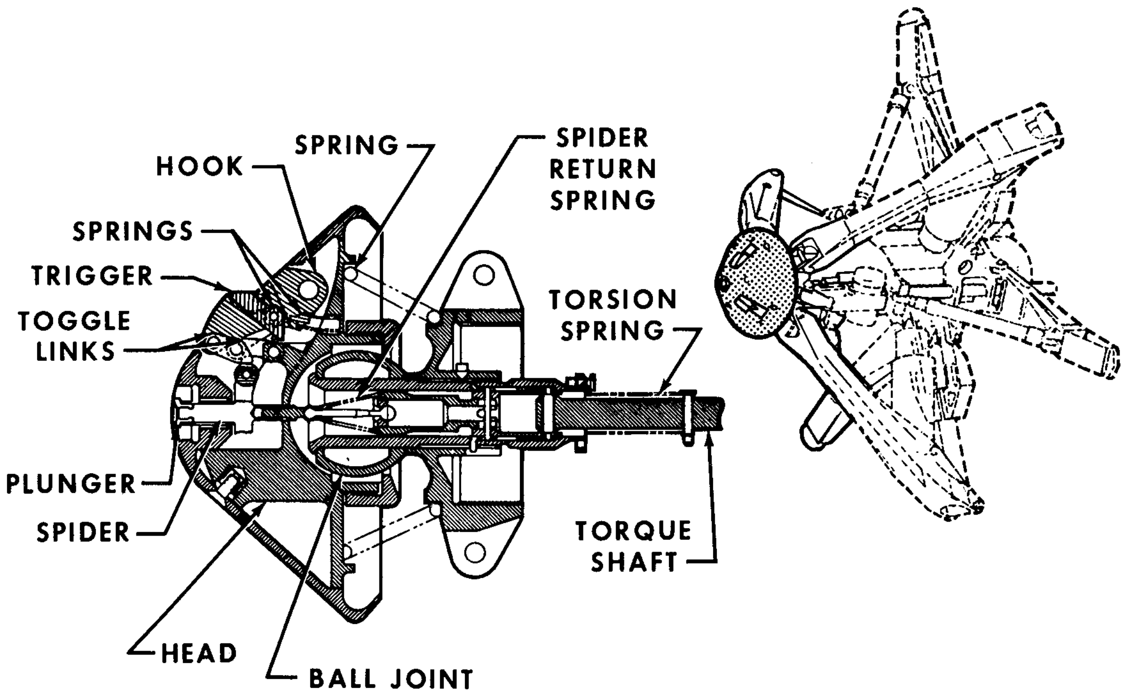

Figure 3. - Probe capture-latch assembly shown in locked position.

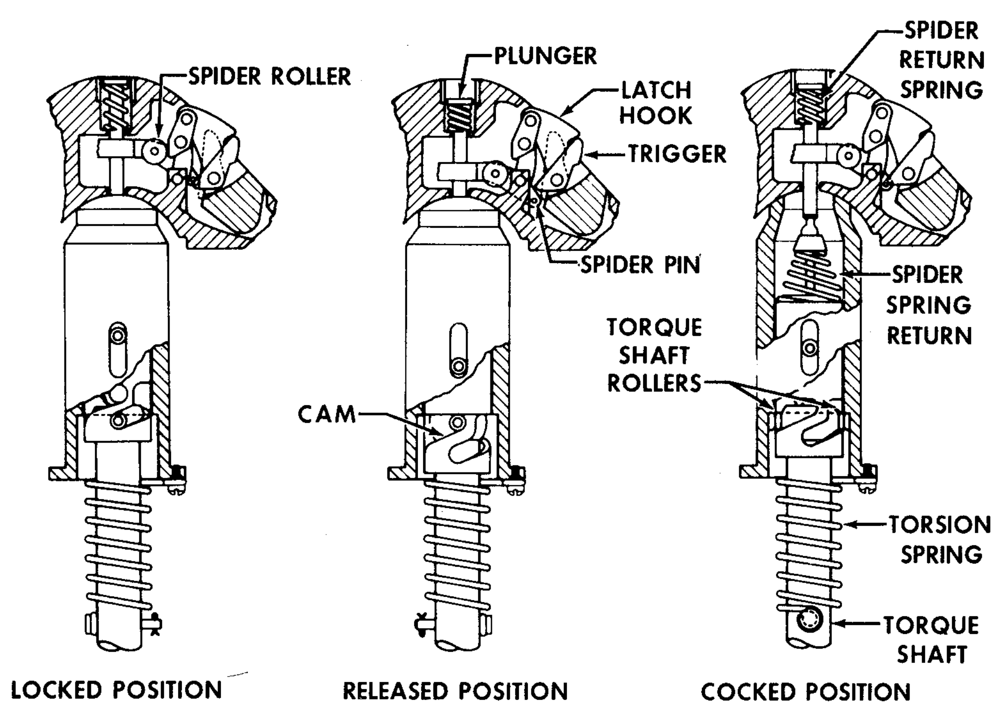

Figure 4. - Relationship of probe latch and cam mechanism.

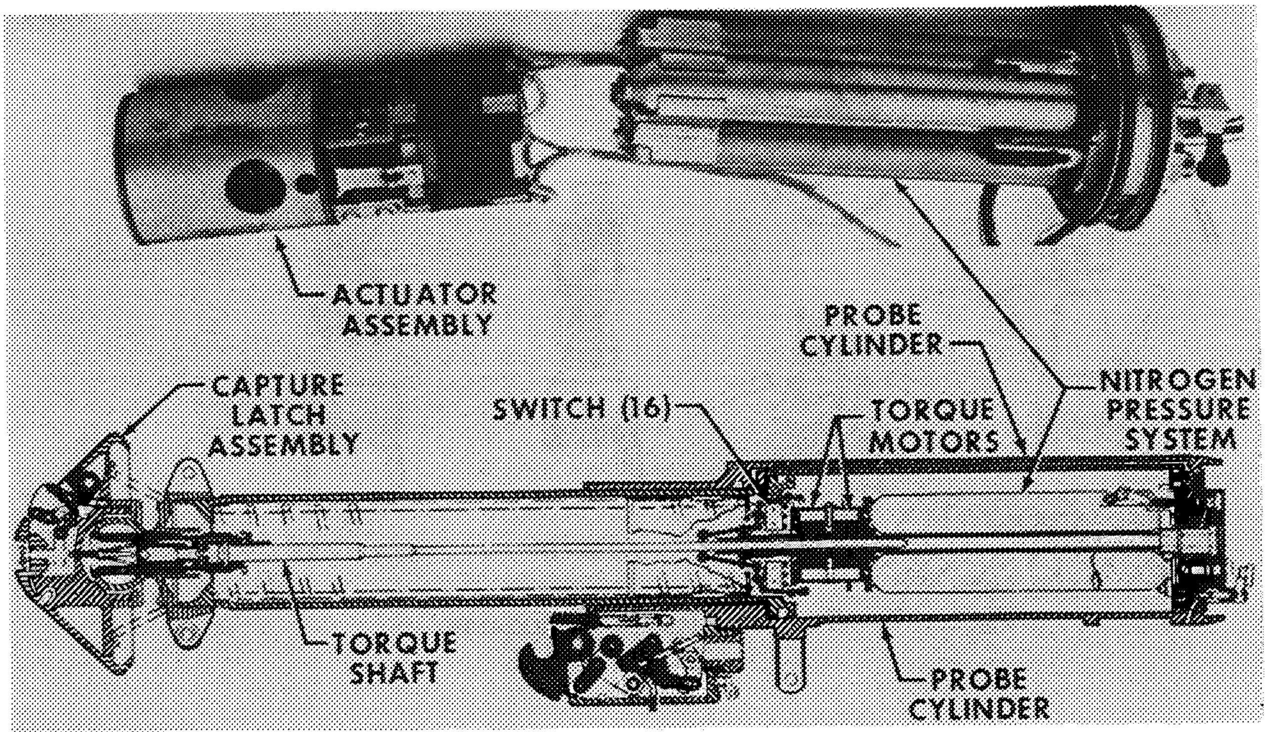

Figure 5. - Cutaway of probe assembly in extended and cocked position.

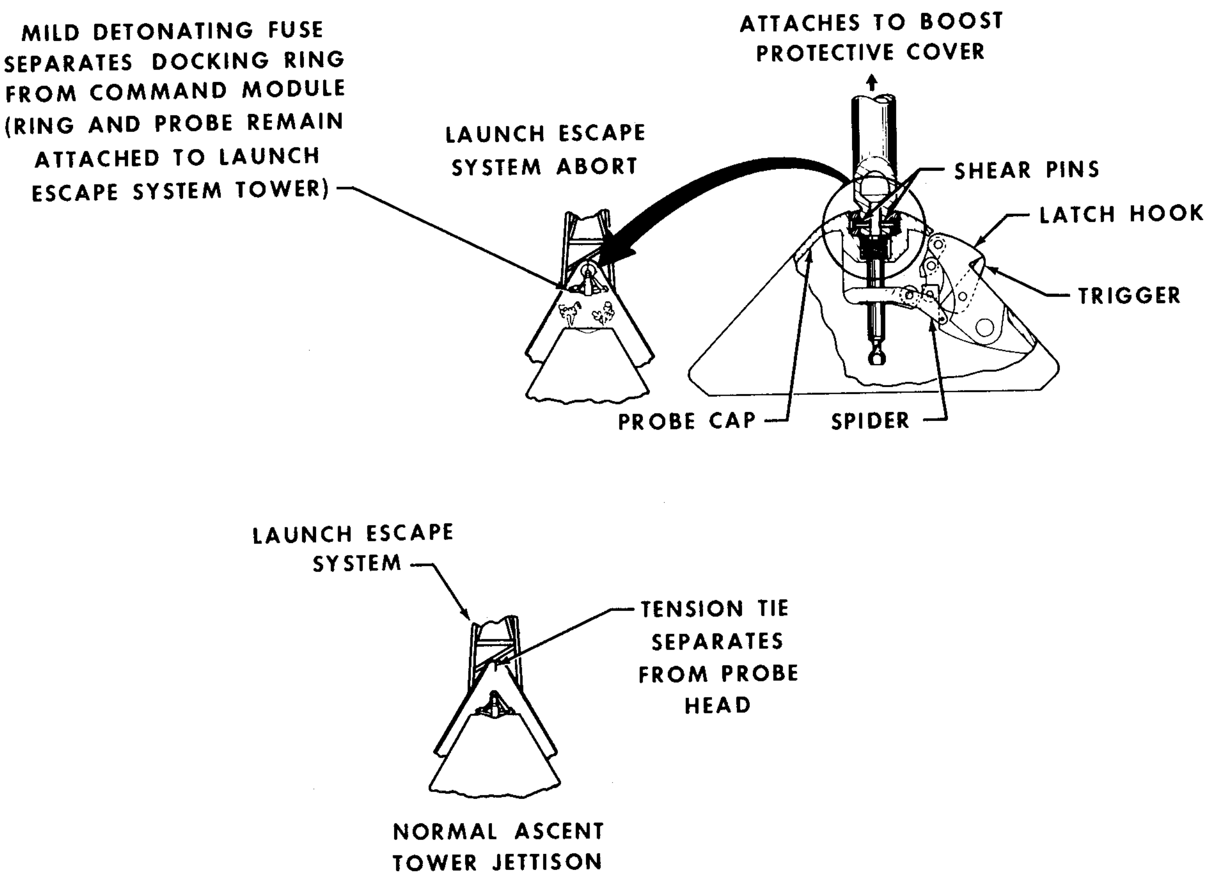

Figure 6. - Tension-tie operation.

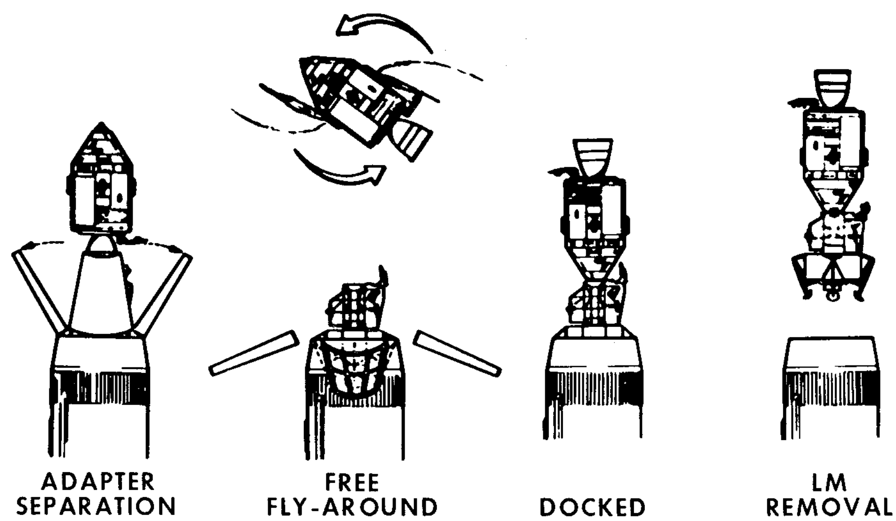

Figure 7. - Transposition and docking.

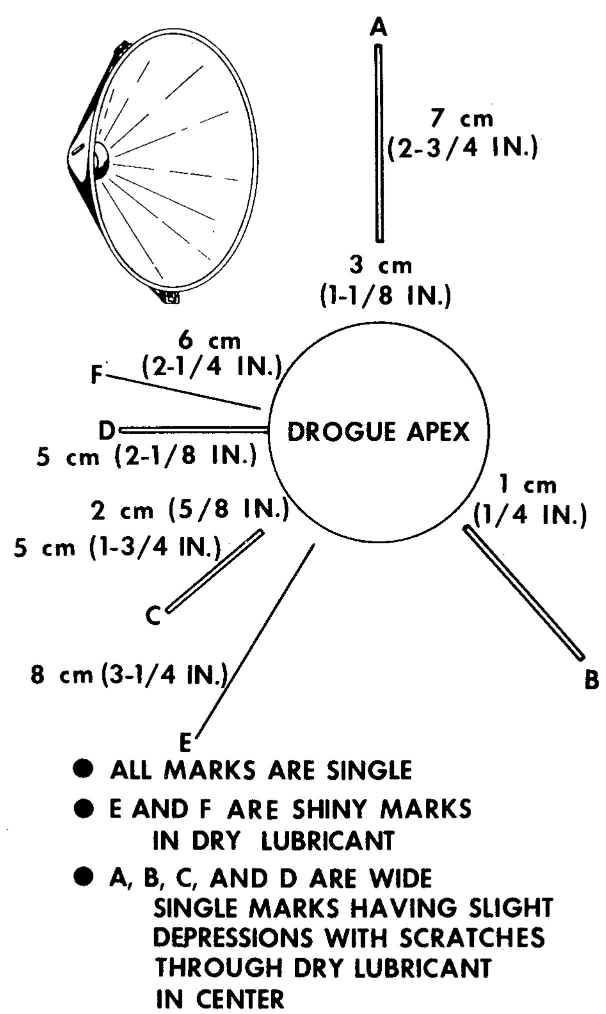

Figure 8. - Drogue assembly and location of radial marks.

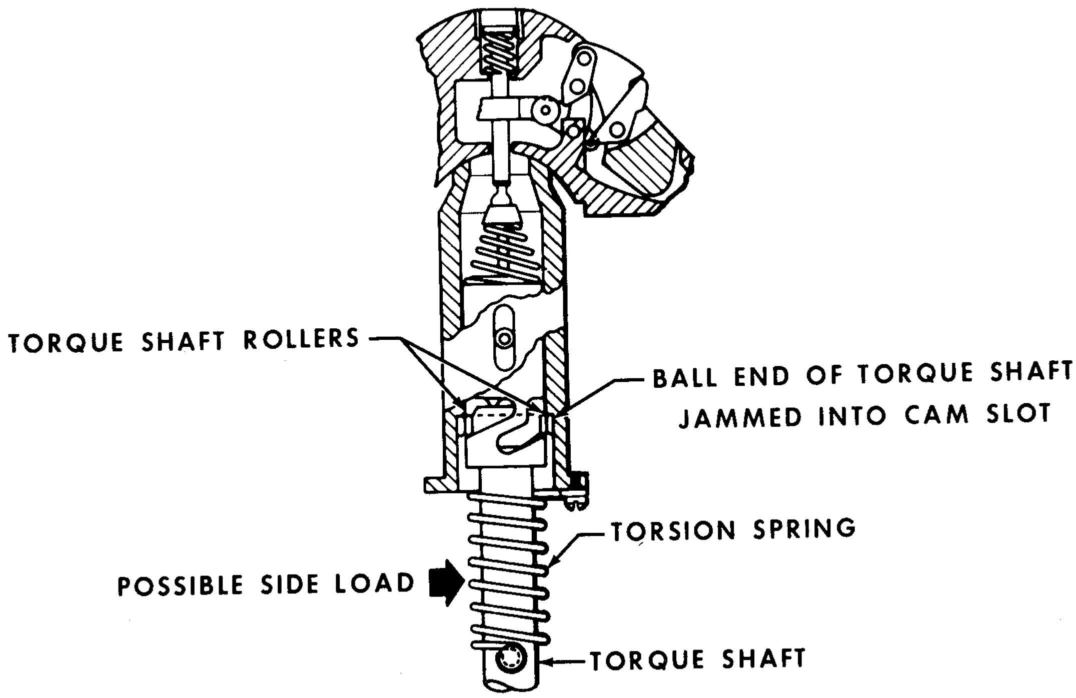

Figure 9. - Side-load reaction on torque-shaft operation.

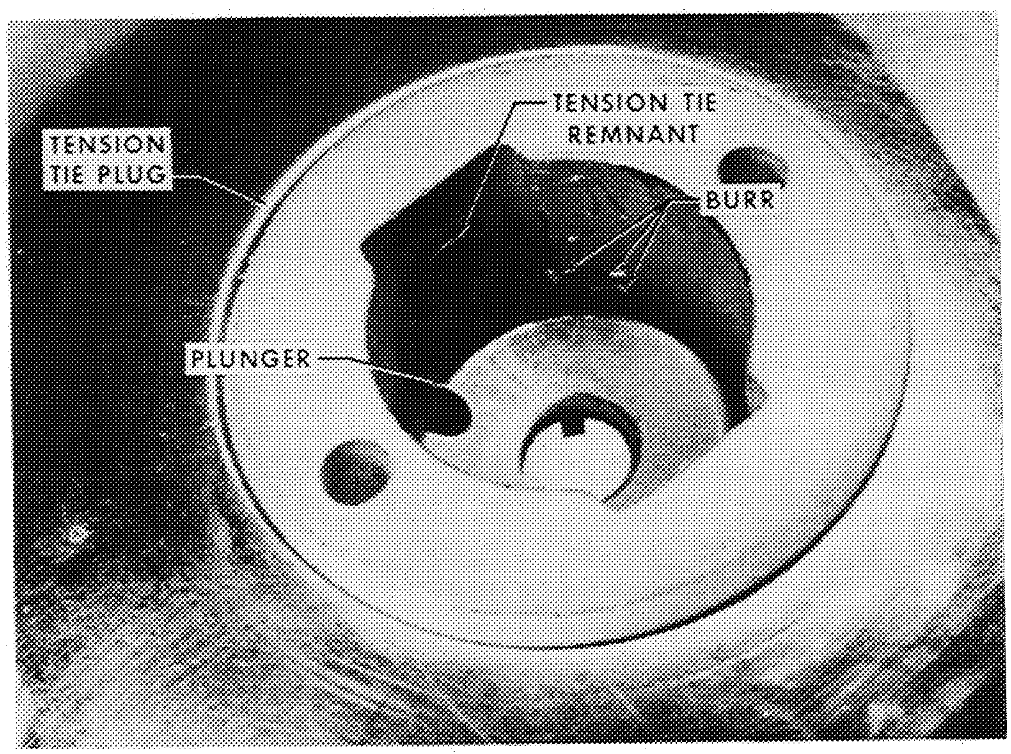

Figure 10. - Scratches and burrs adjacent to capture-latch plunger.