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AKM CAPTURE DEVICE

William D. Harwell*

Introduction

The Westar and Palapa satellites were built by Hughes Aircraft of California. They were both of the Hughes HS376 series and identical in external configuration. Both satellites were launched from the orbiting Shuttle during mission STS 41-B in February, 1984. Soon after launch, the Payload Assist Modules on both satellites failed, placing them in useless orbits. In an effort to recover them and the considerable investment each satellite represented, NASA and Hughes undertook the Satellite Retrieval Mission. The mechanism used to capture each of the errant satellites was the AKM (Apogee Kick Motor) Capture Device (ACD) - also referred to as the "Stinger".

Mechanism Requirements

The AKM Capture Device (ACD) had three interface requirements: interface with the Manned Maneuvering Unit (MMU) for transportation to and stabilization of the spacecrafts; interface with each satellite for retrieval; and finally, interface with the Shuttle's Remote Manipulator System (RMS or "robot arm") for satellite transport back to the Orbiter's payload bay. The majority of the design requirements were associated with the capture and release of the satellites. In addition to these unique requirements, the general EVA (Extra-Vehicular Activity), RMS grapple, and RMS manipulation requirements applied. These requirements included thermal, glare, snag, RMS runaway and crewman safety considerations. Finally, a host of contingency features were also needed.

Mechanism Description

The "Stinger" was an EVA crewman operated device which attached to the arms of the MMU. So configured, the crewman flew the MMU/Stinger assemblage from the payload bay to the spinning satellite and aligned himself with the spin axis of the satellite's motor nozzle. He then flew the probe of the Stinger into the nozzle, through the throat, and into the empty motor casing. By actuating a lever on the ACD's control box, a debris cover extended - releasing three independently sprung toggle fingers inside the motor casing. This constituted a "soft-dock." The crewman then operated a threaded shaft which retracted the probe, bringing its fingers into contact with the material surrounding the nozzle throat, as shown in figure 1. The retraction also brought the Stinger's 41 inch diameter ring into contact with the satellite's separation ring, creating a compressive loading of the satellite's nozzle throat and separation ring. This constituted "hard-dock." The astronaut then

*NASA Lyndon B. Johnson Space Center, Houston, Texas.

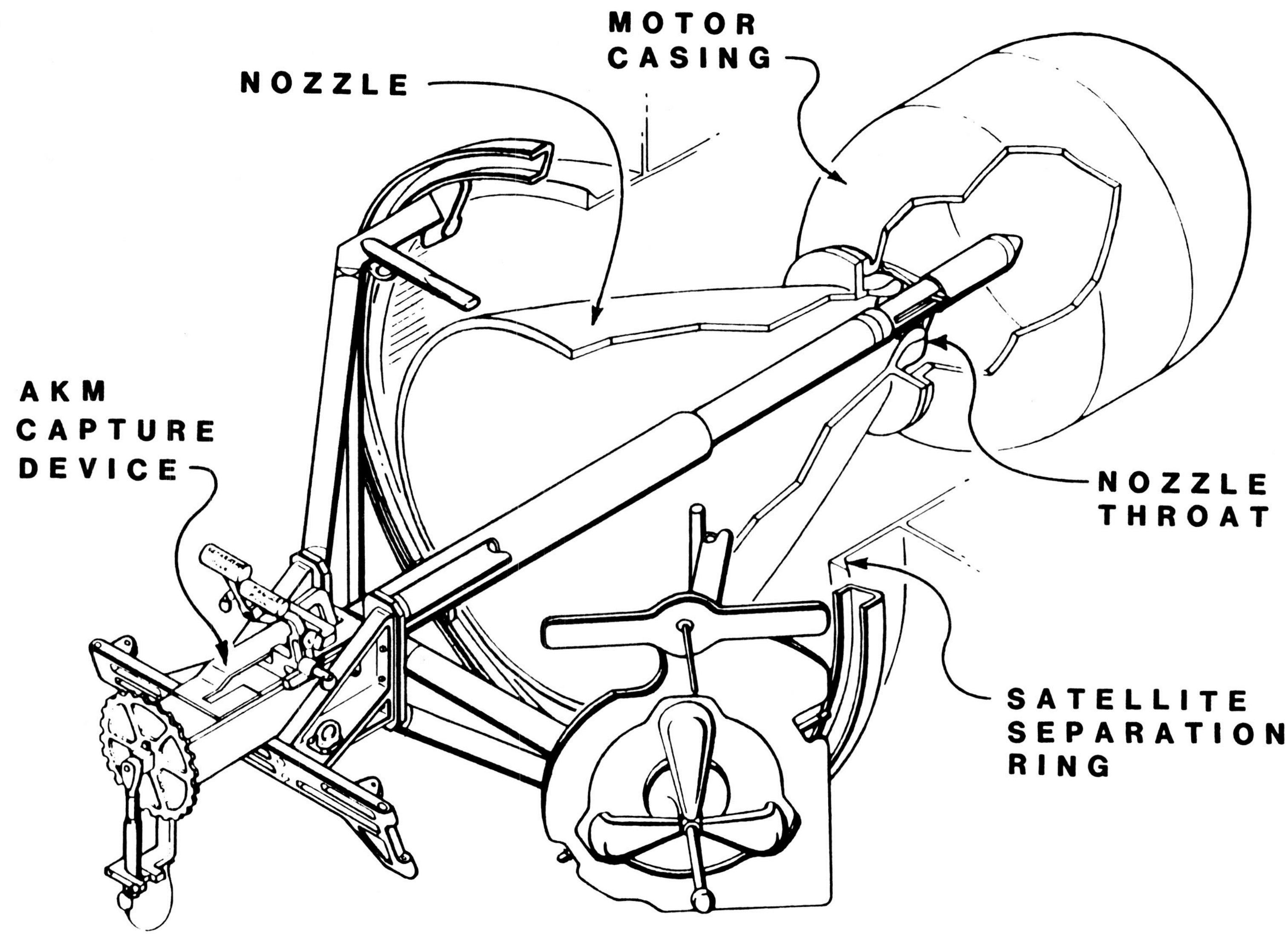

FIGURE 1

AKM CAPTURE DEVICE - ENGAGED

used the MMU's propulsion system and onboard logic to stabilize the satellite for RMS grapple.

Once the satellite was grappled and returned to the payload bay, a number of tasks were performed to prepare it for berthing. Upon completion of these tasks, the crewman actuated a lever which released the probe from the end of the Stinger. The probe remained in the motor casing for the remainder of the mission. The astronaut then re-stowed the remainder of the ACD.

ACD Mechanisms and Controls

The AKM Capture Device (ACD) is comprised of a number of component mechanisms and mechanical controls. These are grouped into four major assemblies (see figure 2), which are; the Probe, Control Box, Support Structure, and Grapple Fixture. Each will be discussed individually.

PROBE ASSEMBLY

The Probe Assembly consists of the following components:

Toggle Finger and Block Assembly
Debris Cover
Debris Cover/Toggle Finger Release Mechanism
Control Box Interface

Toggle Finger and Block Assembly - Three toggle fingers spaced radially around a circular pivot block comprised this assembly. Each finger rotated independently about its pivot from the bias of a torsion spring, thereby increasing the reliability of the assembly. Any single finger was capable of withstanding the loads generated during the capture and handling. Thus, a three-fold failure (no finger opening) had to occur to prevent the preliminary capture or "soft-dock" and subsequent "hard-dock". In addition, the torsion springs which controlled the fingers were sized such that the Manned Maneuvering Unit's (MMU's) thrusters could override and close them if the astronaut prematurely deployed the debris cover prior to penetrating the throat.

Debris Cover - The debris cover was necessary for several reasons. The first was due to uncertainties about the condition of the nozzle throat. The throat was made of a carbon composite which deteriorated to some extent as the fuel was burned. The possibility that particles remaining in the area of the throat could contaminate the ACD toggle assembly and reduce the chances of capturing the satellites dictated the need to protect the toggle assembly. Secondly, the debris cover was given a conical leading profile to help guide the ACD as the probe traveled along the nozzle and through the throat. Finally, the debris cover encased the toggle fingers prior to deployment. Each toggle finger was biased to rotate outward as the cover opened.

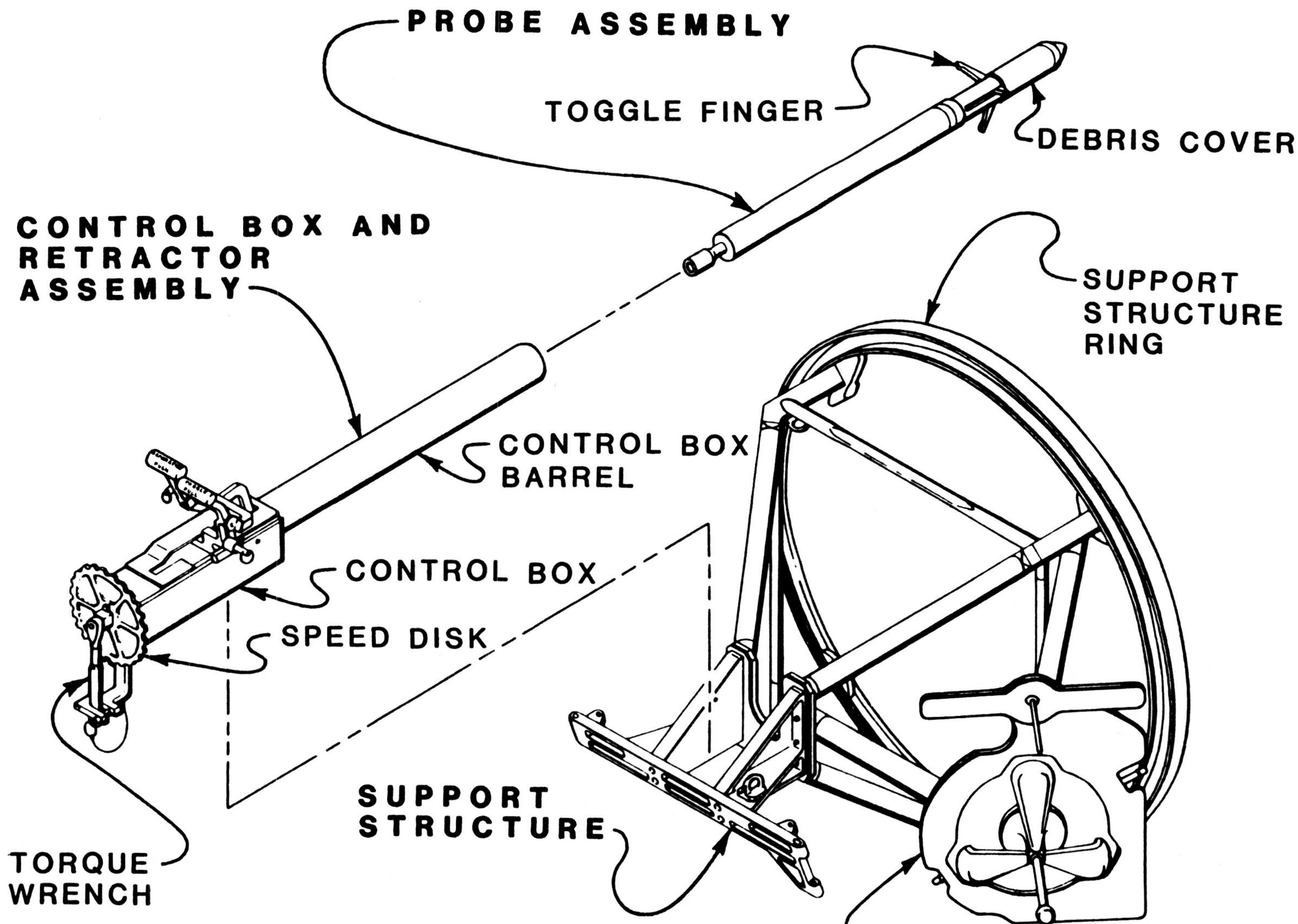

FIGURE 2

AKM CAPTURE DEVICE - EXPLODED VIEW

Debris Cover/Toggle Finger Release Mechanism - The debris cover was attached to a shaft which was deployed by a preloaded compression spring. The end of the shaft was held by a pair of latches which were actuated by a rod in the control box. When actuated, the rod opened the latches releasing the shaft and debris cover, and thereby, the toggle fingers.

Control Box Interface - Each of the satellites were spinning about their axes as they floated in space. The MMU's arms were not designed to withstand the torque associated with despinning the satellites. In an effort to reduce this torque, it was specified that the probe assembly not transmit any torque. This required that it be attached to the control box by a rotating interface. To simplify the design, it was also decided the toggle fingers would not be closed once deployed. Instead, the Stingers' probe assemblies would remain in the satellites. They could be removed rather easily by hand once the satellites were returned to earth. This required that the probe assembly be removeable. Finally, the actuator rod from the control box had to enter the probe to operate the Debris Cover/Toggle Finger Release Mechanism. To accomodate these requirements the shouldered interface on the end of the probe was designed - see figure 2. This interface will be discussed further in the control box portion of this paper.

CONTROL BOX

The ACD's control box was designed primarily for the purposes of deploying the toggle fingers, applying the clamping load, and releasing the probe assembly. However, in addition to these primary functions, several contingency features were provided. Each will be discussed in this section. The control box will be broken down into the following systems for purposes of discussion:

Probe Actuator System
Retractor System
Probe Release System

Probe Actuator System - the function of this system was to deploy the debris cover, thereby releasing the toggle fingers. System elements included the actuator rod, the connecting linkage, and the toggle lever. Operationally, the astronaut would pull the toggle lever at the appropriate time, causing the actuator rod to enter the opening at the end of the probe. Inside the probe, the actuator rod opened latches which held the debris cover shaft. A preloaded compression spring in the probe then extended the cover - a motion which also released the toggle fingers. The secondary responsibilities of this system were to verify the cover had extended and to overcome any binding of the debris cover that may have occurred. The total rotation of the toggle lever was 60 degrees. Of this, the first 15 degrees of motion fired the debris cover. The remaining rotation drove the actuator rod into the cavity the debris cover shaft had vacated, verifying (by the absence of the shaft) deployment of the cover and toggle fingers. Any resistance to complete rotation of the toggle lever indicated the cover did not open completely, if at all. By applying force to the toggle lever the crewman could force the actuator rod forward against the end of the debris cover shaft. This relieved any binding that might have occurred, thereby deploying the cover.

Retractor System - To provide clearance for the toggle fingers to swing outward and to accomodate variances within the throat's surface, the trailing end of the debris cover traveled approximately 4 inches past the plane of the inner throat before its deployment. When the fingers opened, the Stinger and satellite were loosely, but positively coupled. To complete the capture, this coupling had to be rigidized. By retracting the probe into the barrel of the control box, the fingers engaged the material surrounding the throat as the support structure ring came into contact with the satellite's separation ring. The components of the retractor system accomplished this task.

The retractor consisted of a large threaded shaft with a speed disk and a ratcheting, break-over torque wrench on the control box end. The other end was connected through the probe release system to the probe. The initial probe retraction was accomplished by rotating the speed disk, a large circular wheel, until the fingers contacted the throat. This eliminated a significant amount of ratcheting. The final Stinger-to-satellite rigidization was accomplished by operating the torque wrench until it broke over - indicating that a preset clamping force had been achieved. Finally, the retraction system served as a backup to the probe release system. This feature will be discussed in the next section.

Probe Release System - To rigidly attach the probe to the control box while permitting it to rotate, as discussed in the probe's control box interface section, a unique arrangement was implemented. Three, 3/8 inch bearing balls were placed in slots, equidistantly spaced around a bearing sleeve (see figure 3). A second sleeve, the retainer sleeve, slid over the bearing sleeve. A portion of each ball protruded through the inner diameter of the bearing sleeve when the retainer sleeve was closed. These ball segments fit radially around the groove on the end of the probe, preventing it from coming out. The inner diameter of the bearing sleeve and a close tolerance bushing held the probe concentrically in the control box barrel. When the probe release lever was pushed forward, the retainer sleeve slid back. This exposed a groove in the retainer sleeve which permitted the balls to travel out into their respective slots as the probe was removed. Thus, the probe release system provided probe containment while acting as a bearing.

A normal probe release has just been described. However, contingency provisions were made for the situation in which the probe binds and will not release. The probe release system, as mentioned earlier, was connected to the large retractor screw in the control box. When the ACD is securely clamped to the satellite, the retractor is

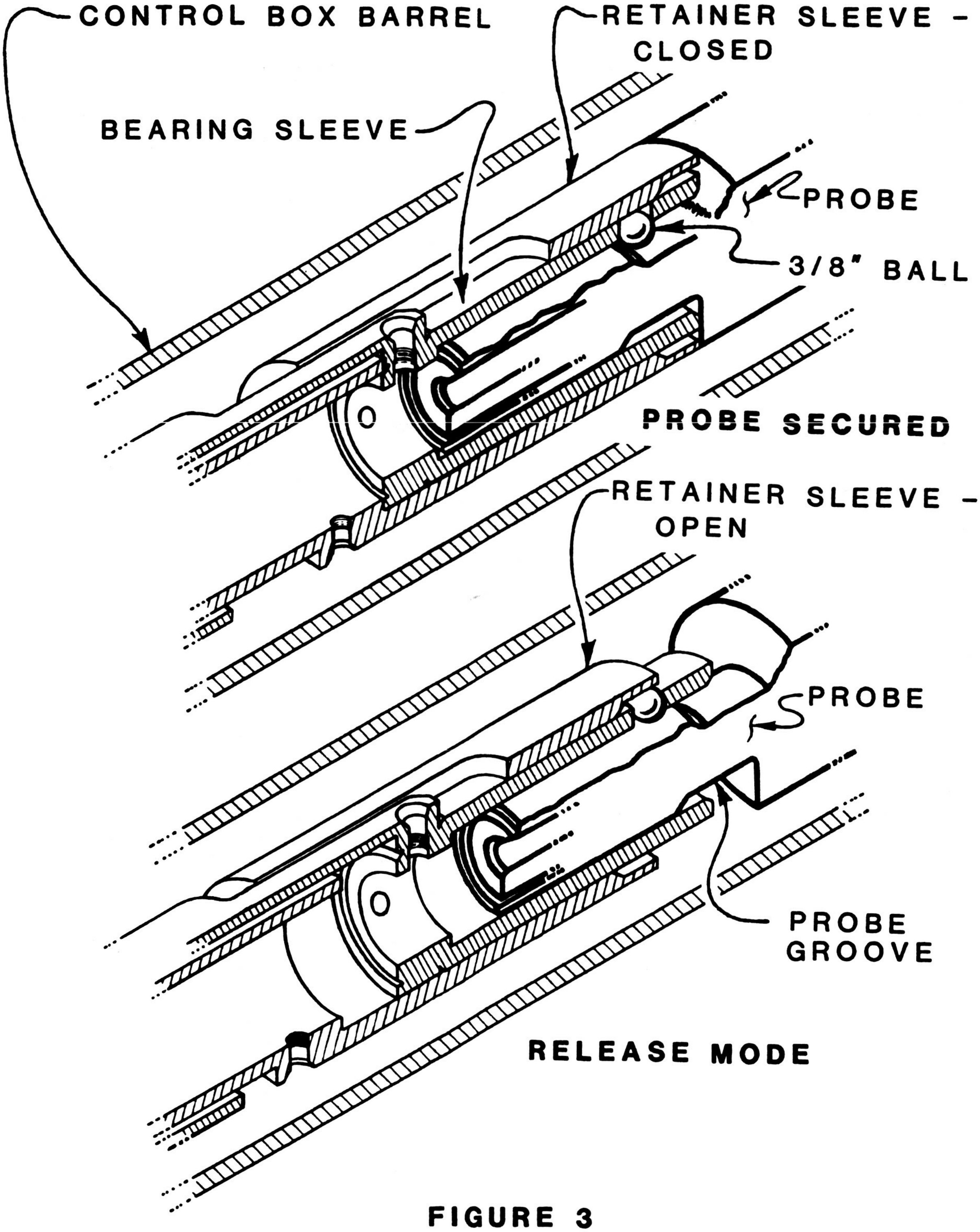

FIGURE 3

PROBE RELEASE SYSTEM

capable of retracting the probe several more inches. If the probe does not slip out of the control box barrel as planned, further operation of the torque wrench will forcibly withdraw the bearing sleeve from the end of the probe, provided the retainer sleeve is slid back. Since the ACD removal from the satellite was necessary for mission success a third method of removal was also incorporated. It involved the removal of the support structure from the control box and will be discussed in the support structure section of this paper.

ACD SUPPORT STRUCTURE

During transportation back to the Shuttle and preparation for berthing, RMS manipulations caused a variety of forces, torques, and moments to be exerted on the ACD. These loads were the results of accelerating and decelerating the satellite, ACD, MMU, and suited crewman combination about the payload bay. Of greater significance was the possibility that while connected to the RMS, an arm runaway could occur. The significantly higher loads that a runaway could create represented the worst load case, and therefore, became the design load criteria by which the support structure was designed. Other considerations in the support structure's design were the MMU's arm bracket and ACD control box interfaces and the protection of the satellite's separation ring.

The ACD's MMU interface was a simple bracket design which mated with the existing MMU arm brackets. The control box interface, however, required a stable attachment of the support structure to the control box which could be easily disassembled for contingency purposes, should the probe not release from the ACD. The separation ring on the bottom of the satellite was the means by which the berthing hardware was attached. If the stinger could not be removed, the spacecraft could not be returned to earth. The control box interface consisted of a cradle into which the control box assembly slid and two attach bolts. The bolt heads mated with the power screwdriver - a battery operated EVA screwdriver capable of generating high torques. If required the bolts and, thus, the structure could be removed from the control box. The entire control box and probe assembly could then be pushed into the motor casing and nozzle, providing clearance for the satellite berthing adapter.

It was specified that the satellite's aluminum separation ring not be damaged during capture. Relative motion between it and the ACD's ring during retrieval could create surface damage that could prevent or hinder proper attachment of the berthing adapter. To eliminate this possiblility, four spring-loaded silicone rubber pads were added to the support structure's legs. As the ACD was tightened on the satellite, these pads came into contact with the separation ring, precluding any damage.

GRAPPLE FIXTURE

Issues arose concerning MMU propellant consumption, time required to transport a satellite back to the payload bay by means of the MMU, possible throat deterioration, and the need to effectively handle the satellite while it was prepared for berthing. Two satellites were to be captured. A considerable amount of propellant would be expended if the astronaut were to fly out to each spacecraft, capture and stablize it, and return each to the Shuttle by means of a single MMU (the second MMU was primarily a backup unit). Additionally, this process required a considerable amount of time in a timeline which was already very long. The possiblity of throat deterioration, as previously noted, was present since the carbon throat was thought to be brittle. Forces generated during transportation could cause some throat breakage and subsequent lack of handling control of the satellite. Finally, once back in the payload bay, the satellite had to be manipulated to prepare it for berthing. This required some stable means of supporting the spacecraft.

These concerns prompted the decision to use the Shuttle's Remote Manipulator System (RMS) to transport and manipulate the MMU/ACD/satellite/crewman assemblage. To accomodate RMS capture, a flight standard grapple fixture was attached to the support structure of the Stinger. Once the satellite was captured and stabilized, the RMS operator grappled the assemblage and returned it to the Orbiter. During the berthing preparations, the MMU crewman remained in place, continually monitoring the satellite for excessive movement which would indicate throat deterioration. If excessive motion occurred, he would operate the torque wrench on the ACD's control box, applying more compressive loading. This, in turn, would rigidize the spacecraft/ACD interface to bring the satellite back under control.

Conclusion

The ACD's were designed, fabricated and certified in seven months. In November of 1984, during two separate EVA's on misson STS 51-A, two separate Stingers were used to sucessfully capture the Westar and the Palapa satellites. They were returned to earth and refurbished (by Hughes Aircraft) for resale.