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PAYLOAD INSTALLATION AND DEPLOYMENT AID FOR SPACE SHUTTLE ORBITER SPACECRAFT REMOTE MANIPULATOR SYSTEM

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ABSTRACT

Early developmental testing of the Remote Manipulator System (RMS) revealed that on-orbit handling of various payloads on the Space Shuttle Orbiter Spacecraft may prove to be beyond the capability of the system without the assistance of a handling aid.

An aid concept known as the PIDA (Payload Installation and Deployment Aid) is presented as a way to assist the RMS by relaxing the accuracy required during payload handling in the payload bay. The aid concept was designed and developed to move payloads through a prescribed path between the confined quarters of the payload bay and a position outside the critical maneuvering area of the Orbiter.

An androgynous docking mechanism is used at the payload/PIDA interfaces for normal docking functions that also serves as the structural connection between the payload and the Orbiter, that is capable of being loosened to prevent transfer of loads between a stowed payload and the PIDA structure. A gearmotor driven drum/cable system is used in the docking mechanism in a unique manner to center the attenuator assembly, align the ring and guide assembly (docking interface) in roll, pitch, and yaw, and rigidize the mechanism at a nominal position. A description of the design requirements and the modes of operation of the various functions of the deployment and the docking mechanisms are covered.

INTRODUCTION

The conceptual design study and operational simulations of the Remote Manipulator System (RMS) in the JSC Manipulator Development Facility (MDF) identified a need for an aid in the handling of large payloads into and out of the cargo bay by the manipulator.

In response to this need, a payload handling aid concept was designed and developed for use with the RMS.

The initial design concept was turned into prototype hardware for test and evaluation and this developed into a second set of prototype hardware that helped to define the concept as it is presently known and described in the following sections.

The initial concept of the deployment mechanism contained one rotating arm assembly to be used in conjunction with the RMS/operator for payload handling.

After building and testing prototype hardware of the Aid with a prototype of the manipulator, it was discovered that the RMS operator was unable to follow the arc path required to keep the payload aligned. It was concluded that the handling aid should be capable of moving the payload between the stowed and deployed positions automatically without the assistance of the RMS in the control loop but that the RMS would be in complete control of the payload during docking or undocking with the payload/orbiter interfaces on the handling aid mechanism.

The resulting aid concept, depicted in Figure 1, known as the PIDA (Payload Installation and Deployment Aid), is presently being fabricated as flight-like hardware for engineering development test and evaluation in the JSC Manipulator Development Facility. This effort is intended to develop the aid concept to a state of readiness for a minimum lead time for flight hardware and at the same time developing the electromechanical actuator and the docking mechanism for potential use in other applications.

REQUIREMENTS

The basic requirements that were imposed on the Payload Installation and Deployment Aid concept are:

- o Provide line of sight docking points outside of critical maneuvering area.
- o Utilize single point capture steps as opposed to multi-points requiring simultaneous capture.
- o Use mechanism to move the payload from deployed to stowed position without exceeding a 75mm (3.0 inch) payload clearance envelope.
- o Accommodate payloads ranging up to 4.57 meters (15 ft) dia by 18.3 meters (60 ft) long and 289 kN (65,000 lbs) weight.
- o Accommodate payload contact velocities up to 30mm/sec (.10 ft/sec) and .011 rad/sec with a lateral mismatch of 150mm (6.0 inches) maximum and angular mismatches of $\pm 15^\circ$ in pitch and yaw and $\pm 10^\circ$ in roll.
- o Design to stow in a confined space under the closed doors with a large payload in the cargo bay.
- o Utilize existing longeron bridge fitting attachments for structural connection.

PIDA ASSY DESCRIPTION

The PIDA assembly shown in Figure 6 is made up of a deploy/stow mechanism, an interface mechanism, an electromechanical rotary actuator with its respective electronic controls, and a base, with a jettison interface, that connects the assembly to the Orbiter longeron bridge fitting on installation.

The operation of the assembly between the stowed and deployed positions, shown in Figure 7, is done remotely from the RMS operator's station. The operator can select the degree of deployment desired and monitor its position from a display of the optical encoder data that is used to control the drive motors and keep them synchronized to within one-tenth of a degree. Preprogramming for a specific payload provides the control of the master drive to accelerate and then decelerate the payload to stop at the desired point without overrun or excessive structural loads on the PIDA structure or the Orbiter longeron attach points. The accuracy provided by the control system offers precise pointing of payloads and opens the possibility of limited tracking using the PIDA drive system with added tracking sensors.

DEPLOY/STOW MECHANISM

The basic purpose of the deploy/stow mechanism is to control the movement of the payload positively and accurately between the stowed and deployed positions and to locate the payload in a deploy position that is away from the Orbiter, outside of the critical maneuvering area but with the docking interfaces in the line of sight of the RMS operator. Design guidelines required that the movement between the stowed and deployed positions be provided without exceeding a 75mm (3.0 inches) payload clearance envelope and that the deployed position be located for a minimum clearance of 50cm (19.5 inches) between the payload and the Orbiter. The configuration had to permit the mechanism to be stowed in a confined space under the closed door and radiator with a large payload 4.57 meters (15 feet) diameter by 18.3 meters (60 feet) long in the payload bay.

The original version of the present deployment mechanism employed a two-stage actuation as shown in Figure 3. The first stage used a pivot point close to the tangency of the payload on one side for an upward z-z axis path of withdrawal and the second stage utilized a pivot point at the docking mechanism interface to swing the payload outboard to a noncritical maneuvering area for payload/PIDA docking. The two stages were driven from a single actuator on each arm assembly that required a clutching operation for the change over from one stage to the other.

Due to the complexity of the two-stage actuation, a single actuator drive mechanism, shown in Figure 4, with a continuous integrated motion was conceived to replace it while at the same time closely approximating the motion desired. A trial and error graphical approach was used to define the mechanism necessary to provide the desired motion. At the onset, the graphical layout was intended to identify the constraints for an analytical approach but it was concluded that the graphical approach would be quicker to complete the geometry definition.

The four bar mechanism shown in Figure 5 has a tubular drive arm member that is connected at one end to the base and the other end to the crank arm on the interface mechanism. A drag link that serves as a tension/compression tie between the base and the end of the crank arm provides the linkage to turn the crank arm as the main arm is driven from one position to another by an Electro-mechanical Rotary Actuator. As the main arm rotates through an angle of 56° , the crank arm rotates the interface mechanism $102^\circ 37'$ for an angular displacement ratio of 1.83:1. The total rotation of the payload axis relative to the Orbiter axis is the sum of these two angles or $158^\circ 37'$.

Note in Figure 4 how the initial part of the C.G. path approximates an upward (z-z axis) linear withdrawal by a low amplitude sinusoidal movement. The movement of the longeron trunnion next to the mechanism, shown in detail "Z", provided an upward and outboard movement that although unplanned was found to be acceptable in the mating envelope of the retention fitting halves.

INTERFACE MECHANISM

The payload/PIDA interface mechanism, shown in Figures 8 and 9, includes a docking mechanism for the RMS operator to connect or disconnect the payload from the deploy/stow mechanism and a structural connection to positively hold the payload during deploy or stow actuation to aid accurate positioning of the payload in the payload bay. After the payload has been placed in the fully stowed position, the structural connection through the PIDA is loosened to provide compliance in order to force the retention fittings to be the primary load paths. The mechanism provides the basic functional modes of docking, such as, compliance, capture, energy absorption, alignment and rigidization in addition to the stowed position compliance.

. Docking Compliance

The purpose of docking compliance is to allow the two mating sides of the interface to align in order that the capture latches can operate. The mechanism on the active side of the docking interface moves as required for alignment except for lateral compliance.

The lateral compliance and attenuation is not an active part of the mechanism, but is accommodated by the dynamics of the Orbiter and payload interreactions.

The axial compliance and attenuation, both compression and extension, is furnished by a hydraulic-type attenuator that has internal spring action to return it to a nominal position that is preloaded in both directions.

The roll alignment movement is permitted by the outer part of the ring and guide assembly being free to rotate relative to the center part of the assembly. The two parts are connected through two ball bearings and are spring loaded to a nominal position by the spring preload.

The pitch and yaw compliance is provided by a "U" joint located between the center of the interface ring and the attenuator assembly.

Docking Capture

The guides on the interface ring are sized for 152mm (6.0 inches) lateral misalignment (which includes the mismatch due to $\pm 15^\circ$ pitch or yaw) in combination with a roll misalignment of $\pm 10^\circ$. The guide configuration provides lateral forces to act on the Orbiter and payload for dynamic lateral compliance to permit the capture latches to engage. The capture latches are designed such that, if insufficient latches are engaged to react capture loads, none will remain engaged. Any two latches are able to react the capture loads. If only

one latch is engaged, the force vectors act in a direction upon the latch during a separation motion such that the toggle linkage of the latch will collapse to allow the two docking surfaces to separate freely. The capture latches serve a dual role in as much as they are also used as the structural latches to secure the payload to the Orbiter after the docking phase is complete.

Energy Absorption

A payload with kinetic energy relative to the Orbiter, contacts the docking interface causing the attenuator assembly to be compressed. During this compression stroke, hydraulic fluid is metered from the head end to the rod end of the attenuator. Part of the kinetic energy is dissipated by the fluid metering and the remainder is stored in the attenuator spring as potential energy. At the end of the compression stroke, the spring forces the attenuator to extend toward the nominal position transferring the potential energy back into the payload as kinetic energy. During this extension stroke, the fluid is metered from the rod end to the head end of the attenuator, further dissipating energy. As the attenuator reaches its nominal position the attenuator spring reverses its force direction to once again store the undissipated energy as potential energy. The residual energy is dissipated by the subsequent extension and compression strokes with rapidly decaying amplitude so that ultimately all motion is arrested and the interface returned to the nominal position.

Alignment and Rigidization

Roll, pitch and yaw alignment across the interface is provided by the ring and guide assembly on each side mating with the one on the other side of the interface. This allows a payload to be positioned accurately even in installations employing only one PIDA assembly.

Realignment of the ring and guide assembly on the active half of the docking interface, with its mechanism is accomplished by the use of three pusher rods and a cable drive system. The action of taking up cable slack in three cable assemblies forces the three pusher rods to extend to a nominal position and retracts the active ring and guide assembly in contact with the ends of these pusher rods for alignment and rigidization. The ends of these rods are hemispherical and contact a conical seat on the surface of the other part of the interface ring to provide the camming action necessary to realign the ring in roll, pitch, and yaw. Actuation is provided by an electromechanical actuator driving a cable drum through a gear train. The electric motor has a brake that is energized to hold the mechanism rigid after the drive motor has stalled out, to preload the cable assemblies, and is then turned off.

The holding requirement of the mechanism is based on an interface moment of 678 N-m (500 lb-ft) as determined from dynamic analysis of the payload/Orbiter system using math modeling.

The inside of the cable drum has two cam surfaces located symmetrically opposite each other to actuate two cam followers, one on each side of the attenuator, to force it to a centered position or free it to allow the attenuator to pivot during the stowed position compliance movement. In the upper

half of Figure 9 the attenuator is held centered and the lower half of the view shows the cam surface away from the cam follower to allow the attenuator to pivot.

STOWED POSITION COMPLIANCE

The payload retention system requires that the payload be permitted to have a three axis movement to accommodate thermal deflections. This necessitated that the PIDA have the same freedom if it is not to act as a primary structural connection for a stowed payload. The x-x axis freedom is provided by floating one of the passive docking interfaces on the payload with it being spring loaded to a center or nominal contact position. The y-y axis and z-z axis movement is provided by retracting the three pusher rods to allow the attenuator to stroke and backing off the two cam followers to permit the attenuator to pivot in the y-z plane.

ELECTROMECHANICAL ROTARY ACTUATOR

The electromechanical rotary actuator designed and fabricated to drive the deploy/stow mechanism was sized to provide a maximum torque of 1356 N-m (1000 lb-ft) at a rate of one degree per second. This is accomplished through the use of a gear box with two high ratio planetary drives, a 24/1 input stage and a 32/1 output stage, resulting in an overall ratio of 768/1 for the actuator in conjunction with a 5.4 N-m (4.0 lb-ft) 28 volt direct current electric motor.

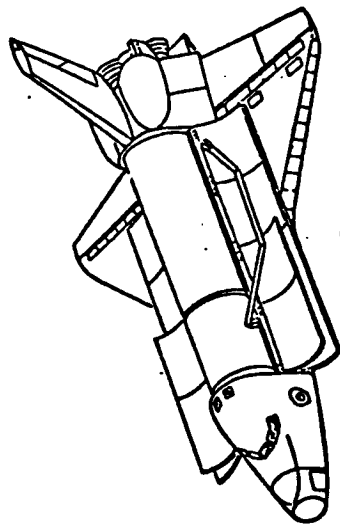
CONCLUSIONS

The Orbiter baseline configuration does not include the PIDA handling aid concept. Further test and evaluation both on-earth and on-orbit will be required to resolve the need for a handling aid to assist the Remote Manipulator System (RMS) on the Orbiter.

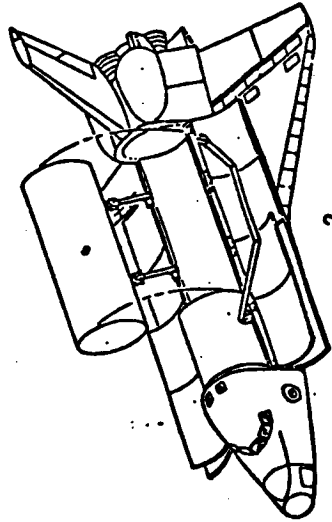
Tests results on prototype hardware indicate that the PIDA payload handling aid concept can be of significant help to the RMS operator by relaxing the control requirements and promises to enhance payload bay packaging density and payload maintenance access.

Initiation of the development of the PIDA concept has been effective in reducing the long-lead time required for flight hardware. A continuation of this development will provide hardware that with minimal changes could be flown as an on-orbit experiment with a RMS and a test payload to evaluate the overall payload handling capability of the Orbiter.

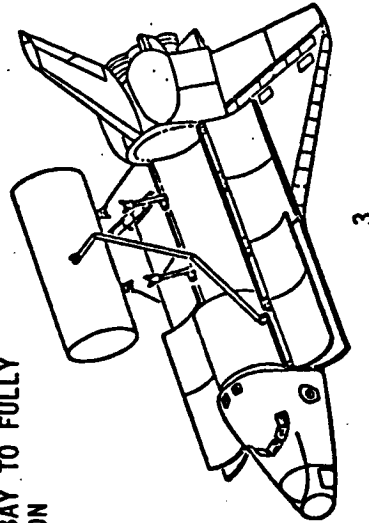
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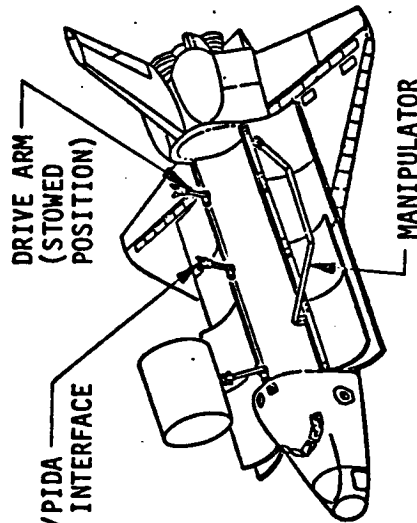
RETENTION FITTINGS UNLOCKED TO
RELEASE PAYLOAD & PAYLOAD/PIDA
INTERFACES RIGIDIZED (MANIPULATOR
MOVED CLEAR OF PAYLOAD)



SYNCHRONIZED DRIVE ARMS ROLL
PAYLOAD OUT OF BAY TO FULLY
DEPLOYED POSITION



PAYLOAD GRAPPLED BY MANIPULATOR,
PAYLOAD/PIDA INTERFACES UNDOCKED &
PAYLOAD POSITIONED FOR RELEASE



4
REPEAT STEPS 1 & 2
TO HOLD PAYLOAD
FOR POINTING,
INFLIGHT MAINTEN-
ANCE ACCESS OR
ORBITAL ASSEMBLY

FIGURE 1
DEPLOYMENT SEQUENCE

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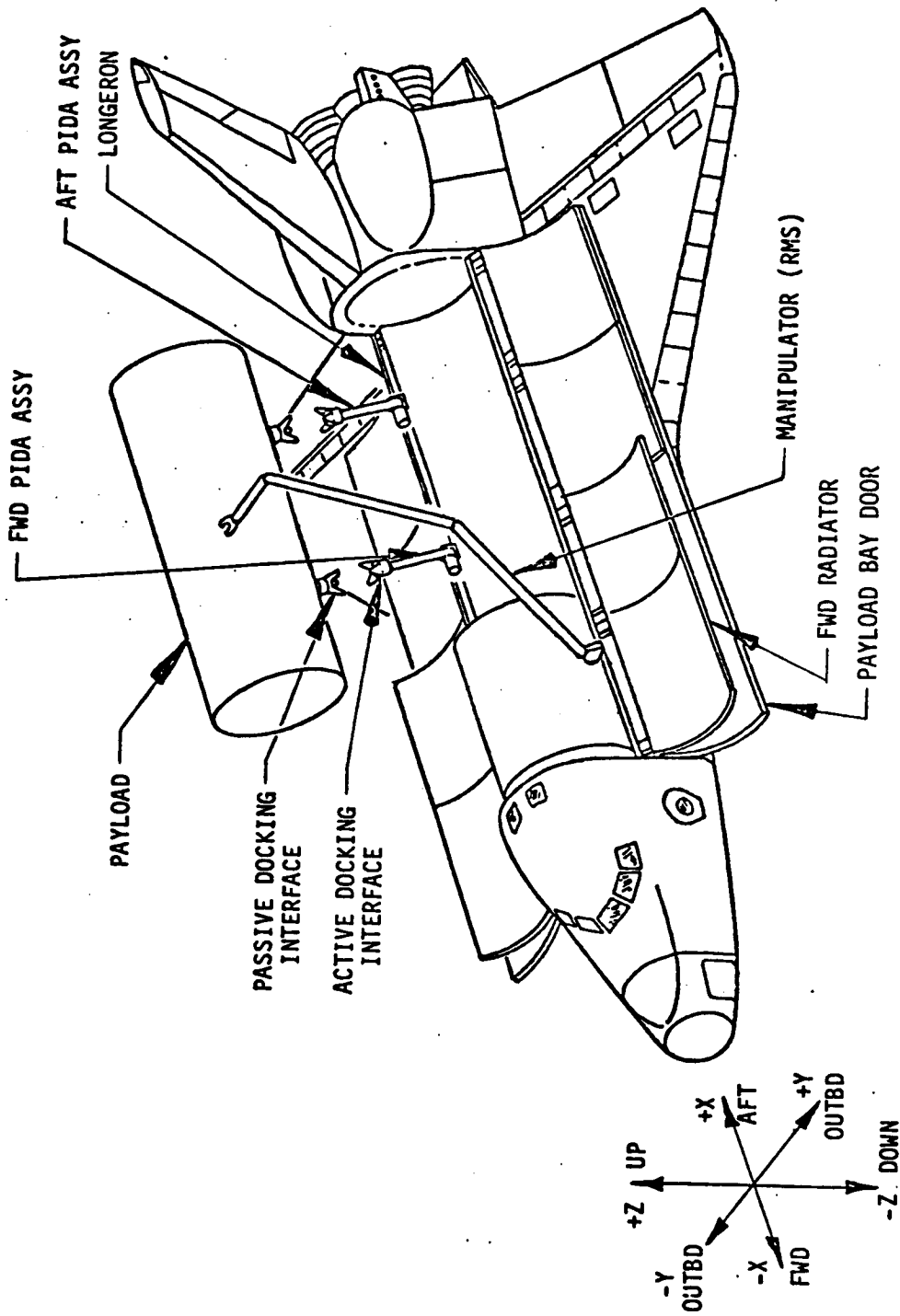
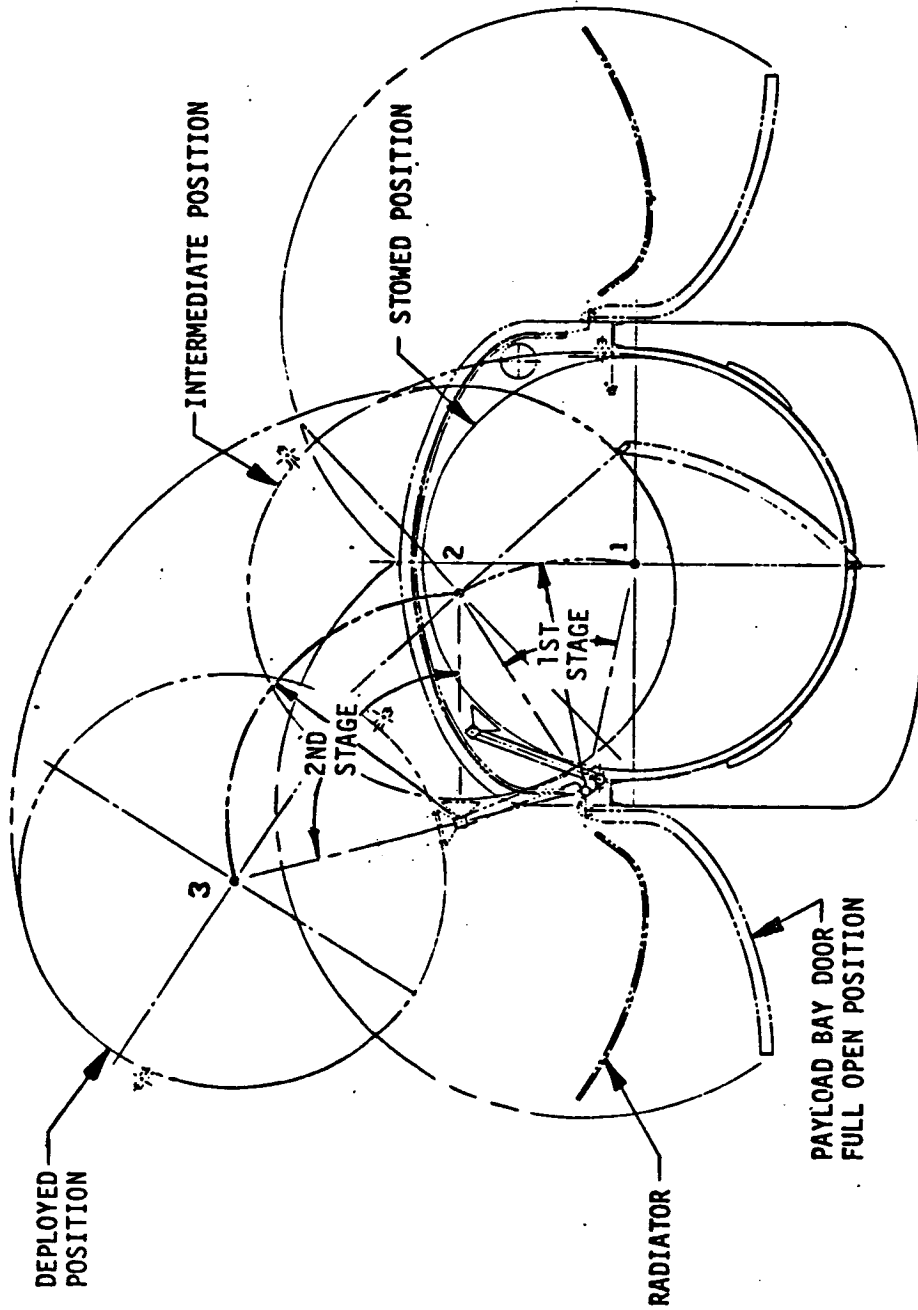


FIGURE 2
NOMENCLATURE

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VIEW LOOKING AFT

FIGURE 3
2 STAGE DEPLOY/STOW ACTUATION

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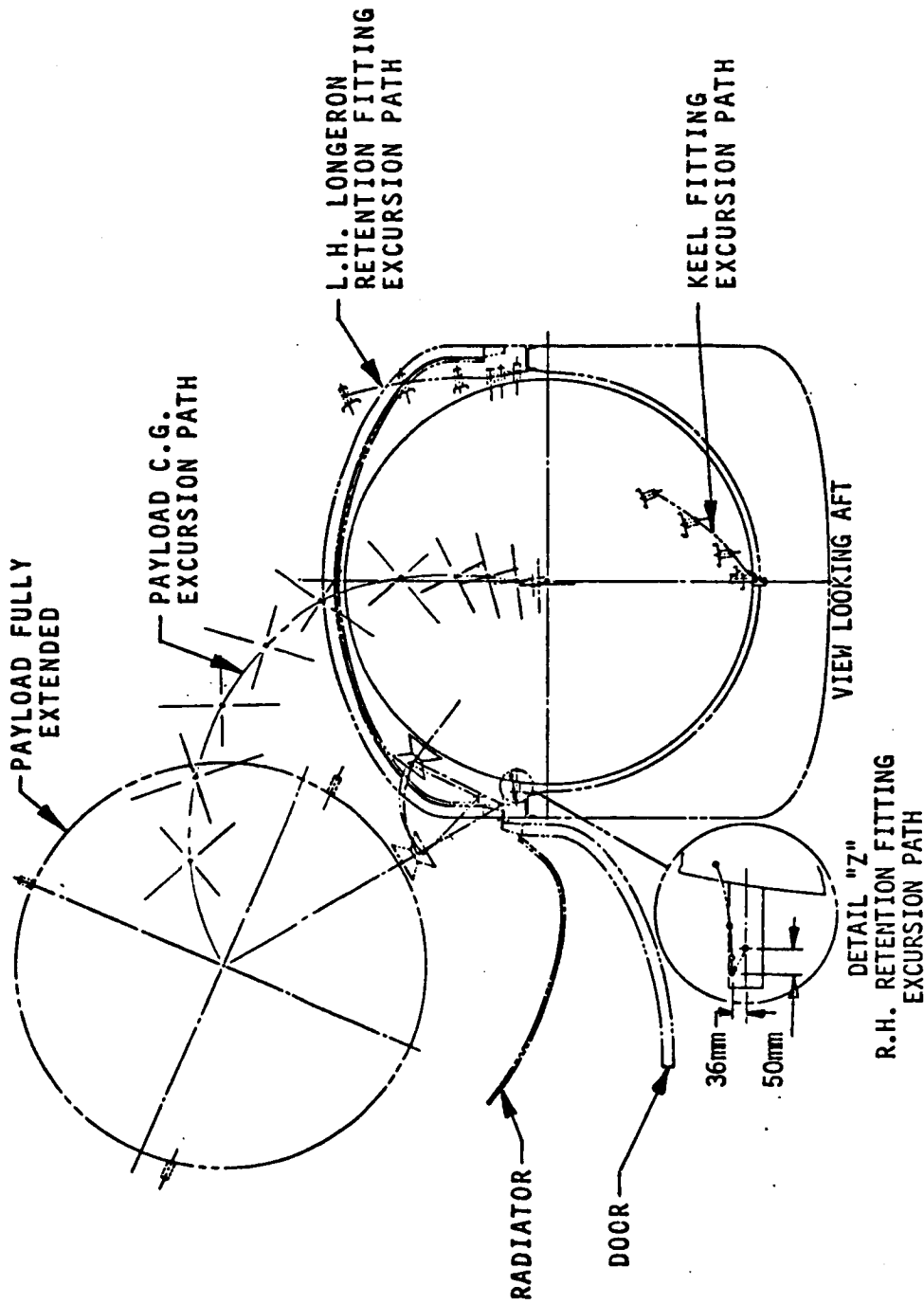


FIGURE 4
SINGLE STAGE DEPLOY/STOW ACTUATION

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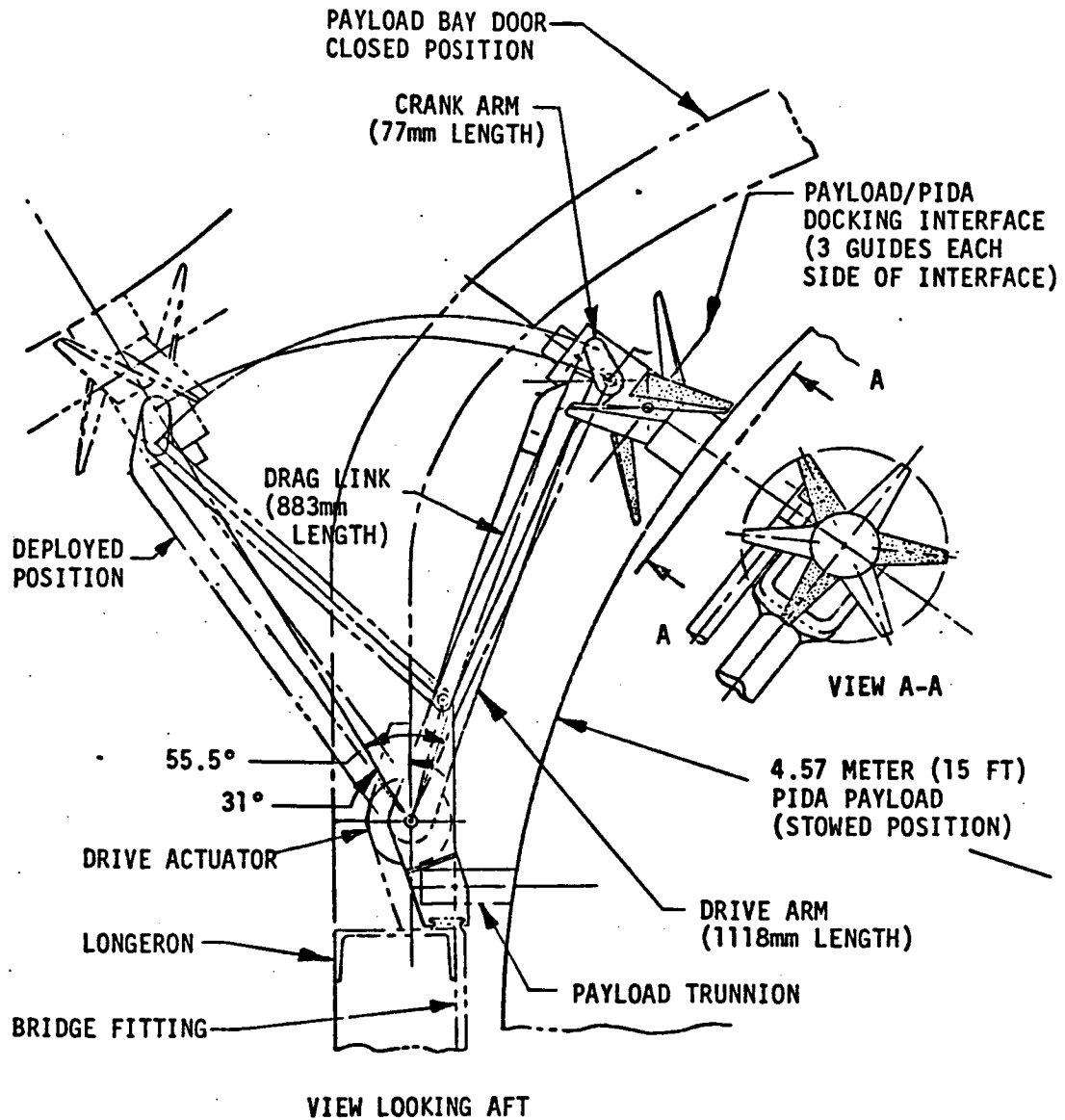


FIGURE 5
DEPLOY/STOW MECHANISM

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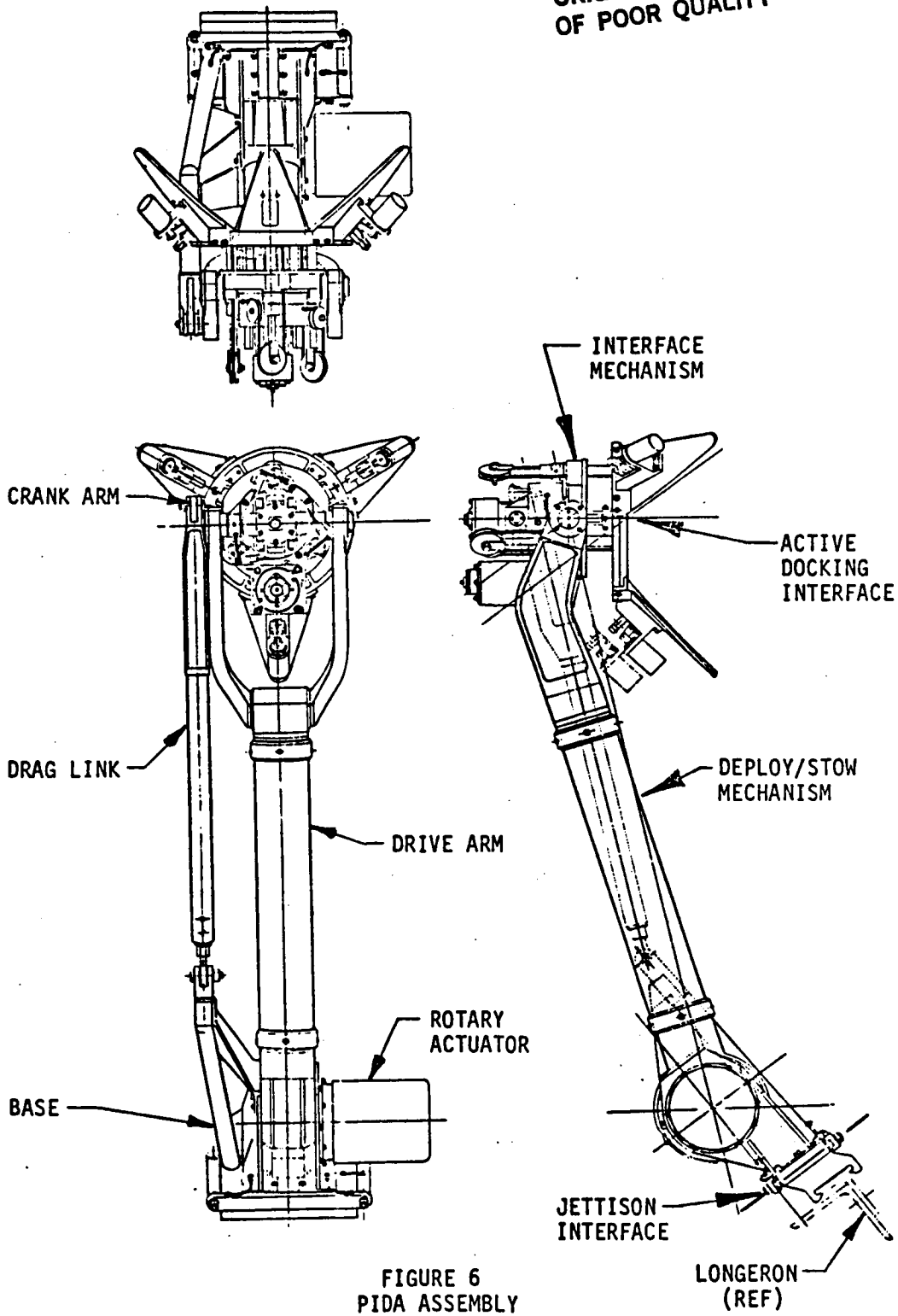


FIGURE 6
PIDA ASSEMBLY

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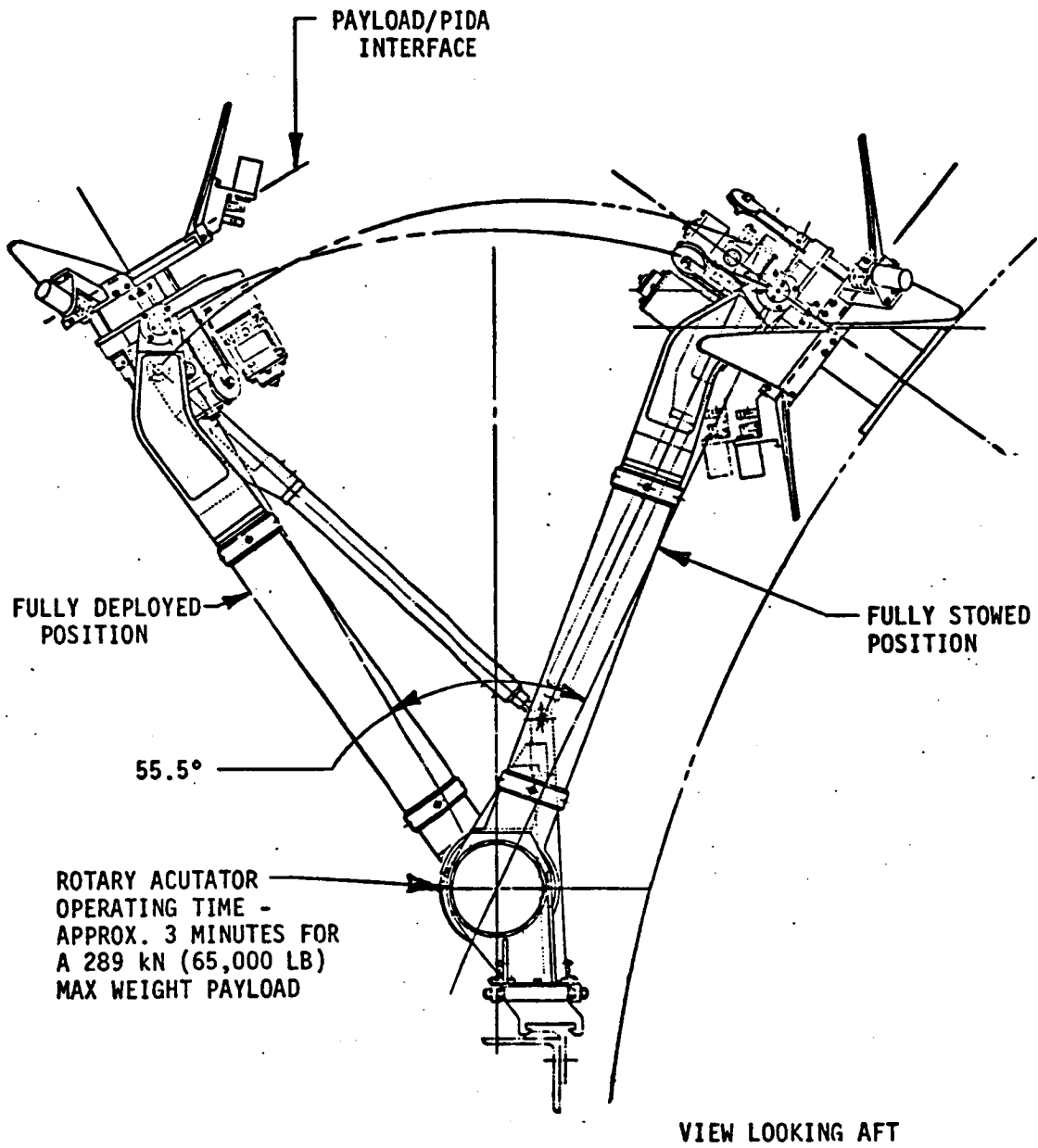


FIGURE 7
PIDA ASSY
OPERATING POSITIONS

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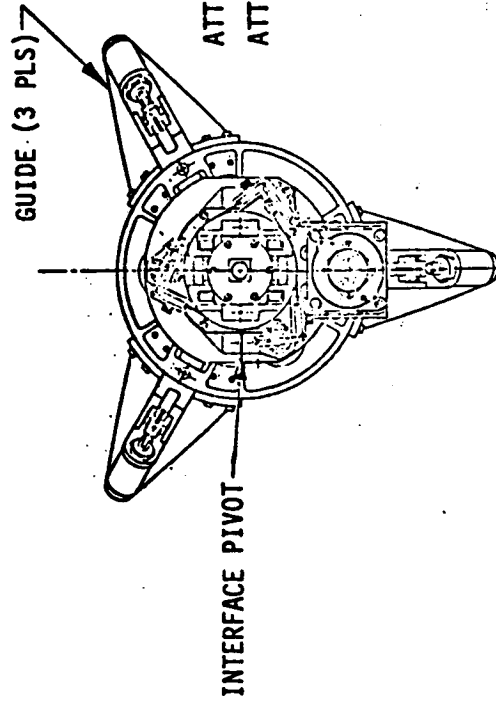
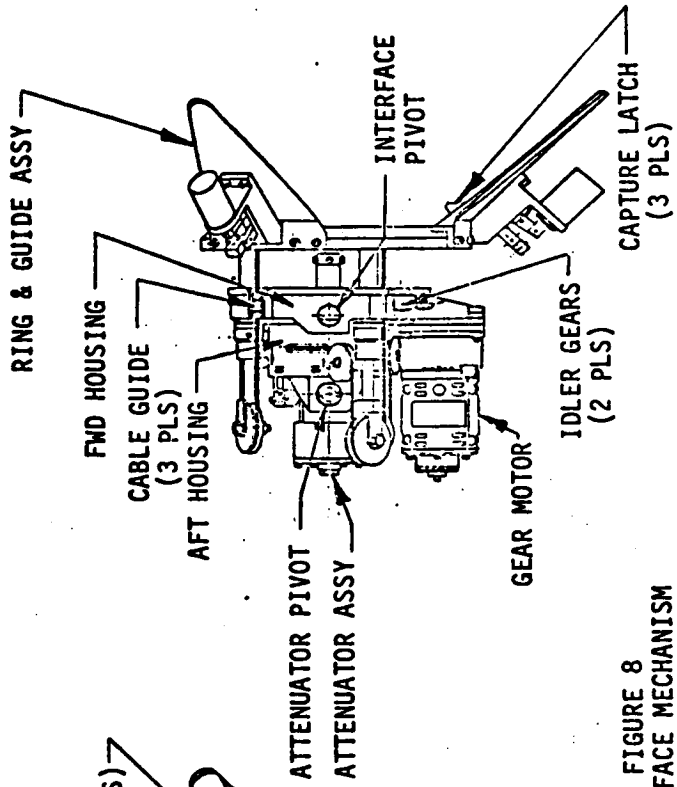
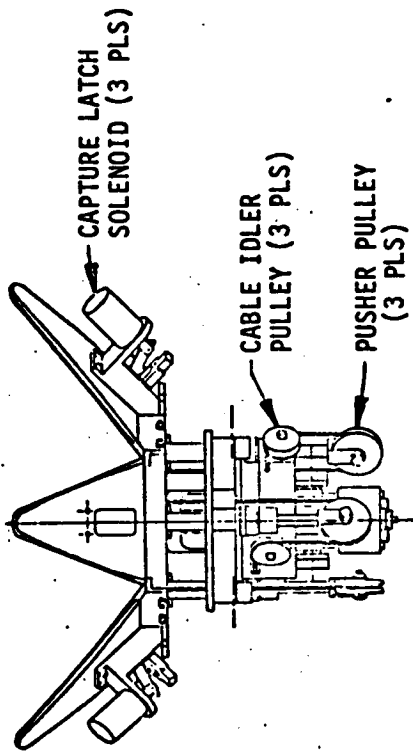


FIGURE 8
INTERFACE MECHANISM

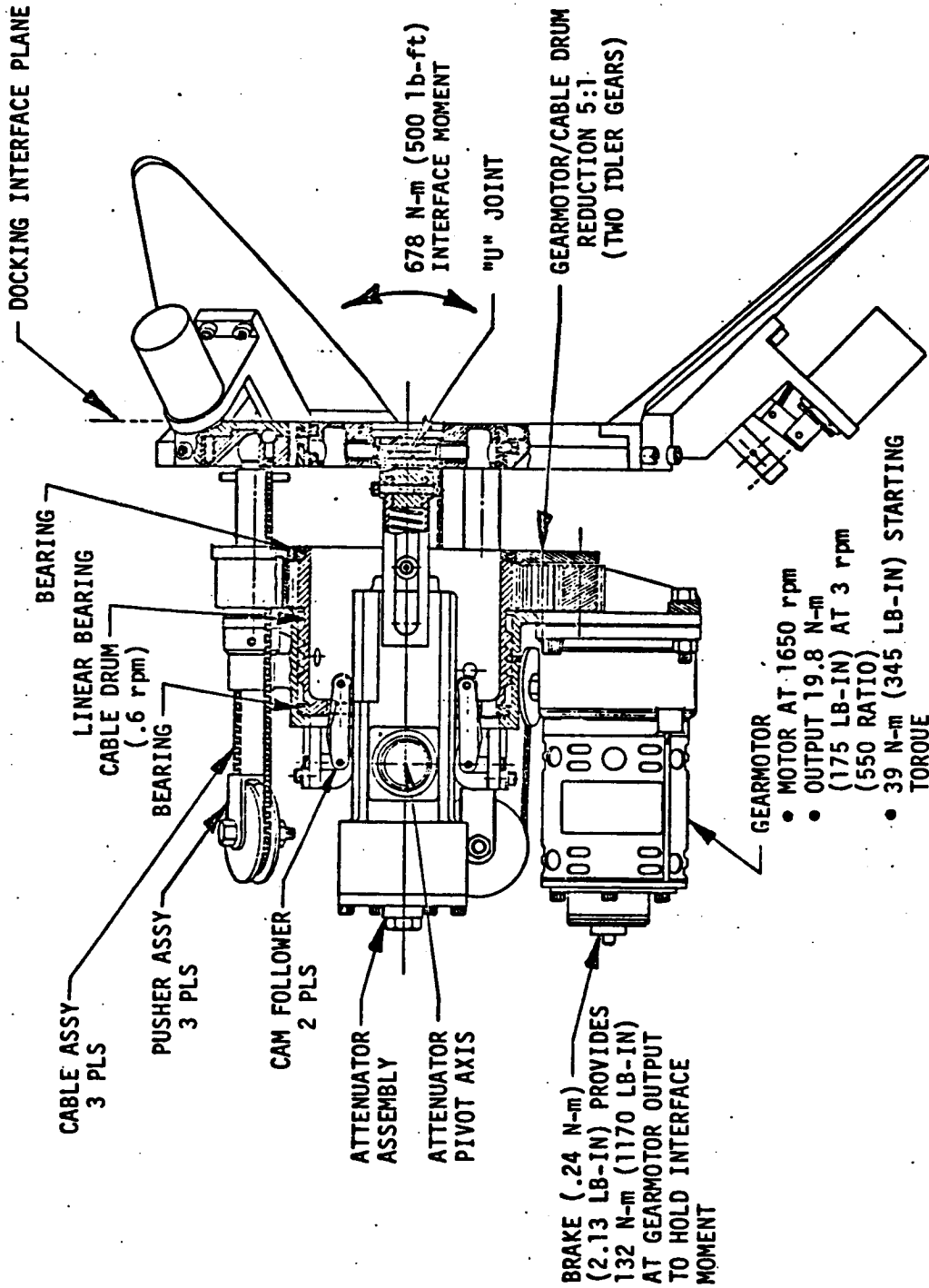


FIGURE 9
INTERFACE MECHANISM