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SYSTEM REQUIREMENTS AND DESIGN FEATURES OF SPACE STATION REMOTE MANIPULATOR SYSTEM MECHANISMS

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ABSTRACT

The Space Station Remote Manipulator System (SSRMS) is a long robotic arm for handling large objects/payloads on the International Space Station "Freedom." The mechanical components of the SSRMS include seven joints, two latching end effectors (LEEs) and two boom assemblies. The joints and LEEs are complex aerospace mechanisms. This paper presents the system requirements and design features of these mechanisms.

All seven joints of the SSRMS have identical functional performance. The two LEEs are identical. This feature allows either end of the SSRMS to be used as tip or base. As compared to the end effector of the Shuttle Remote Manipulator System, the LEE has a latch and umbilical mechanism in addition to the snare and rigidize mechanisms. The latches increase the interface preload and allow large payloads (up to 116,000 Kg) to be handled. The umbilical connectors provide power, data and video signal transfer capability to/from the SSRMS.

INTRODUCTION

The Space Station Program "Freedom" is a joint venture of the United States, Canada, Japan and the European Space Agency. Canada's contribution to this Program is to provide the Mobile Servicing System (MSS). The Space Station Remote Manipulator System is a key system of the MSS (Ref. 1). Spar Aerospace Limited is the prime contractor for the development of the MSS for the Canadian Space Agency.

The SSRMS is a 17.6 m (57.3 ft.) long robotic arm to be used for handling large objects on the Space Station. It consists of seven joints, two latching end effectors (LEEs), two boom assemblies, two arm computer units (ACUs), video cameras and associated equipment. The physical configuration of the SSRMS is

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shown in Figure 1. Each boom assembly has a hinge mechanism for compact stowage of the SSRMS during launch. These hinges are locked in the straight position of the boom assemblies for operation on the Space Station. The joints and the LEEs are complex aerospace mechanisms. The seven joints, each representing a rotational degree of freedom, provide maneuvering and positioning capabilities to the arm. The LEE at the base provides structural and electrical (power, data and video) connections to the Space Station. The tip LEE is used for payload capture and release. The design of the base and the tip LEEs are identical. This provides operational flexibility using either end as the tip or base. Also, the SSRMS can relocate itself on the Space Station.

This paper presents the system requirements and design features of the SSRMS joints and LEE mechanisms. Several trade studies were carried out prior to establishing the requirements and design concepts. Many breadboard tests were conducted to demonstrate the functionality of the mechanisms. The results of such studies and tests have been utilized for the design of the LEEs and the joints. The data and the experience gathered over a decade of the Shuttle Remote Manipulator System (SRMS) operation and during testing and refurbishing of its components have been of great significance in conceiving enhanced features for the SSRMS mechanisms.

The design data and numerical values presented in this paper represent the current state of the development and should be considered preliminary at this stage as the detail design work is in process.

SYSTEM REQUIREMENTS

A summary of the SSRMS system requirements considered for the design of the joints and LEEs are as follows:

o The SSRMS is required to operate in the extravehicular environment of the Space Station. As shown in Figure 2, the Mobile Remote Servicer Base System (Ref.3) is the base for SSRMS operations. However, the SSRMS can also operate in a stand-alone configuration from a Power and Data Grapple Fixture (PDGF) located on the Space Station. Figure 3 shows a physical configuration of the PDGF. The joints and LEE mechanisms assist in performing the following tasks of the SSRMS:

(a) Space Station construction, assembly and maintenance

(b) Payload handling and servicing (The design case payloads are defined in Table 1)

(c) Capture and handling of free flyers (Figure 4 shows the use of the LEE for holding the Shuttle Orbiter)

(d) Support to extravehicular activities and Space Station safe haven.

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Table 1: SSRMS Payloads, Maximum Tip Velocity and Stopping Distance Requirements

Payload Size			Translational & Rotational Velocity		Translational and rotational stopping distance	
Mass	Length	Diameter				
Kg.	m	m	m/sec.	deg./sec	m	Deg.
0 (Unloaded Arm)	-	-	0.37	4.0	0.61	3.0
20900	4.5	17.0	0.022	0.24	0.61	3.8
116000	24.1	34.3	0.012	0.04	1.09	5.7

o The tip end effector has to be compatible with the SRMS-type Grapple Fixtures defined in Reference 2.

o The capture operation of the SSRMS shall accommodate the following misalignment of the grapple probe:

Linear misalignment   = 0 to 0.1 m axial direction,

                        ± 0.1 m radial direction

Angular misalignment   = ± 10 Deg. roll,

                        ± 15 Deg pitch and yaw

o The specified performance in terms of the tip velocity and worst case stopping distances with respect to the base of the SSRMS are given in Table 1.

o The SSRMS is required to transfer electrical power, data and video resources to and from the attached payload. The required power transfer capability is 1800 watts average and 2500 watts peak. The data transfer requires two 1553B data buses. The video capability requires transfer of up to three simultaneous composite NTSC video channels.

o Thermal Requirements

Thermal control is to be independent of other MSS and Space Station items. The specified temperature limits for the components of the SSRMS are given in Table 2.

o Structural Requirements

(a) Yield safety factor   = 1.1 (minimum value)
(b) Ultimate safety factor   = 1.5 (minimum value)
(c) Scatter factor for fatigue = 4
(d) Stiffness and Strength are to be maximized within the constraint of the mass.

Table 2: Component Temperature Limits (Deg., C)

Component	Operational		Acceptance		Qualification		Survival	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
Gears,Bearings	135	-25	140	-30	151	-41	155	-50
Motor Windings	180	-25	185	-30	196	-41	200	-50
Brakes	99	-25	104	-30	115	-41	120	-50
Cables & Connectors	135	-70	140	-75	151	-86	155	-90
Electronics	65	-20	70	-25	81	-36	85	-50

o Reliability and Failure Tolerance Requirements

   (a) Single failure tolerant design

   (b) Automatic safing following any failure

o System Lifetime

   The SSRMS is required to operate on orbit for 30 years with periodic maintenance and refurbishment.

JOINT MECHANISM DESIGN

The physical configuration of the SSRMS joints is given in Figure 5. A block diagram representing the joint components and their interfaces is given in Figure 7. Each joint has two major assemblies, viz. joint drive module (JDM) and the housing assembly, as shown in Figure 6.

The JDM constitutes the mechanism part of the joint. The JDM is housed in the housing assembly. The joint electronic units mounted on the joint housing control the operation of the joint. All the seven joints have the identical JDM. The three pitch joints (shoulder pitch, elbow pitch and wrist pitch joints) have identical housing assemblies. The remaining four joints (two roll and two yaw joints) also have identical housing assemblies. The housing assembly for the pitch joints differs slightly from the housing assembly of the roll/yaw joints.

The main components for the JDM are as follows:

   (a) Two identical Joint Motor Modules (JMM1 and JMM2)
   (b) G1/G2 Gear Box
   (c) Joint Angle Resolver (JAR) Assembly
   (d) Extra Vehicular Activity (EVA) Drive

A brief design description of the JDM components is as follows:

Joint Motor Module (JMM)

Each JMM consists of:

(i)   Brushless permanent magnet DC motor
(ii)   Motor Resolver for motor rate sensing and commutation
(iii) Redundantly wound electromechanical brake.

Each JMM is capable of driving, stopping and holding the joint in the desired position. Only one JMM is operational at any time. Normally the backdriving torque of the motor is used for stopping the joint. The brakes are used under emergency conditions (e.g., joint runaway). The brakes of both the JMMs engage and disengage simultaneously. Also the brakes engage automatically when the power to the joint is turned off or lost due to a power failure.

G1/G2 Gear Box

The G1/G2 Gear Box is a two-stage speed reducer. The overall speed reduction achieved is 1845:1 from the motor shaft to the joint output. The design of the gear box is based on the proven design of the SRMS joints.

JAR Assembly

The JAR assembly consists of two identical JARs (JAR1 and JAR2) mounted on a common shaft. The function of the JAR is to measure angular position of the joint. This measurement is used for close loop control of the joint and establishing the SSRMS tip position.

EVA Drive

An EVA drive has been provided for manual operation of the joints. This drive bypasses the JMMs and the joint can be driven in case of a jammed JMM.

Joint Thermal Protection and Thermal Control

Passive means supplemented by film heaters have been used for thermal protection of the joints. The hardware for thermal protection consists of the following items:

(i)   Multilayer insulation (MLI) blankets
(ii)   White paint for radiator surfaces
(iii) Film heaters
(iv)   Thermistors for temperature sensing and electronic
       thermostats for heater control.

Joint Performance Data

Each of the SSRMS joints has the following performance

(a) Joint Travel Range:

     (i) With software stops   = ± 270 deg.
     (ii) position of hard stops = ± 281 deg.

(b) Joint Output Torque

    (i) Servo controlled torque   = 1044 N-m (Minimum)
    (ii) Brake torque of both JMMs   = 1630 N-m (Minimum)
         (Brakes of both JMMs engage &
         Disengage simultaneously)

(c) Maximum joint angular velocity   = 5.0 deg./sec

LEE MECHANISM DESIGN

Figure 9 illustrates the configuration of the LEE. A block
diagram representing the LEE components and interfaces is
shown in Figure 8. The LEE consists of the following mechanisms:

(a) Snare mechanism
(b) Rigidize mechanism
(c) Latch and Umbilical mechanism
(d) EVA drive
(e) Force moment sensor (FMS).

All these mechanisms are housed in a shell structure which also
supports two LEE electronic units (LEU1 and LEU2) and a video
camera. The FMS is to be used for measuring and limiting the force
at the SSRMS tip. The concept and the requirements of FMS are under
investigation. A brief description of the other mechanisms is
as follows:

Snare and Rigidize Mechanisms

The concept and the functions of these mechanisms are similar to
SRMS snare and rigidize mechanism. As illustrated in Figure 8, the
snare and rigidize mechanisms are driven by independent motor
modules, i.e., MS1 and MR1 or MS2 and MR2.

Latch and Umbilical Mechanism

This mechanism provides a stiff structural link and electrical
connection at the end of the SSRMS. Figure 10 illustrates the
concept of a latch with an umbilical connector in its center. There
are four such latches mounted externally to the LEE shell. These
latches are driven by an internally mounted motor module (ML1 or
ML2). The operation of this mechanism is carried out in two
stages. In the first stage, only the latches are connected to
the PDGF. The second stage operation consists of mating the
electrical connectors with the PDGF. The latching operation can
be performed only after completion of the snare and rigidize
operations.

A payload can be captured by using any one of the following
combinations of the LEE operations:

(i)   snare and rigidize
(ii)   snare, rigidize and latch
(iii) snare, rigidize, latch and mate electrical connectors.

EVA Drive for Latch Mechanism

The LEE design includes an EVA drive for EVA operation of the Latch and Umbilical mechanism.

Thermal Protection and Thermal Control Provisions

The passive/semipassive means are provided for the thermal protection of the LEE. The hardware used for thermal protection is similar to the joint thermal hardware. The operation of the heaters is controlled by one of the two LEUs.

LEE Performance Data

(a) The LEE snare and rigidize mechanisms are similar to the SRMS snare and rigidize mechanism. These mechanisms meet the specified requirements for misalignment.

(b) The normal time for completion of the snare, rigidize, latch and umbilical mate operations is as follows:

        Snare   = 3 sec.
        Rigidize = 25 sec.
        Latch   = 60 sec.
        Mate   = 60 sec.

A fast capture mode has also been provided in which the snare, rigidize and latch operations are completed within 30 sec. This fast mode is useful for the capture of free flyers.

(c) The load transfer capability of the LEE is as follows:

    (i) 950 N-m Torque and 1220 N-m Bending Moment when snared and rigidized, allowing 3 deg. separation at the interface.
    (ii) 3120 N-m Moment about any axis and 1110 N axial/shear force when snared, rigidized and latched and no separation at the interface.

SUMMARY OF KEY DEGIGN FEATURES OF JOINT & LEE MECHANISMS

o After snaring and rigidization of the LEE, the engagement of latches provides a stiff structural interface for the payloads. This makes the SSRMS capable of handling high inertia payloads, as given in Table 1.

o The umbilical connectors provide the power, data and video links between the payload and the Space Station.

o The LEE snare and rigidize mechanisms are similar to the SRMS End Effector design. This permits the use of SSRMS to capture and maneuver payloads fitted with SRMS-type grapple fixtures.

o EVA drives for joints and LEE latch mechanisms have been provided for emergency EVA operation of the SSRMS.

o The Joint Drive Module (JDM) is a commonality item for all the seven joints and it is on-orbit replaceable. The joints and LEE are also on-orbit replaceable.

REFERENCES

1. D.A. Bassett et al., "Mobile Servicing System Flight Operations and Support", Presented at 39th International Aeronautical Congress of the IAF, Bangalore, India, October 8-15, 1988.

2. NSTS 07700, Vol. xiv, Appendix 8, "System Description and Design Data for Payload Deployment and Retrieval System", Rev. J, 1988.

3. Kumar, R. et al., "Concept and Design Considerations for Mobile Servicer Base System of MSS for the Space Station" CASI Symposium on Space Station, Ottawa, Canada, November 1989.
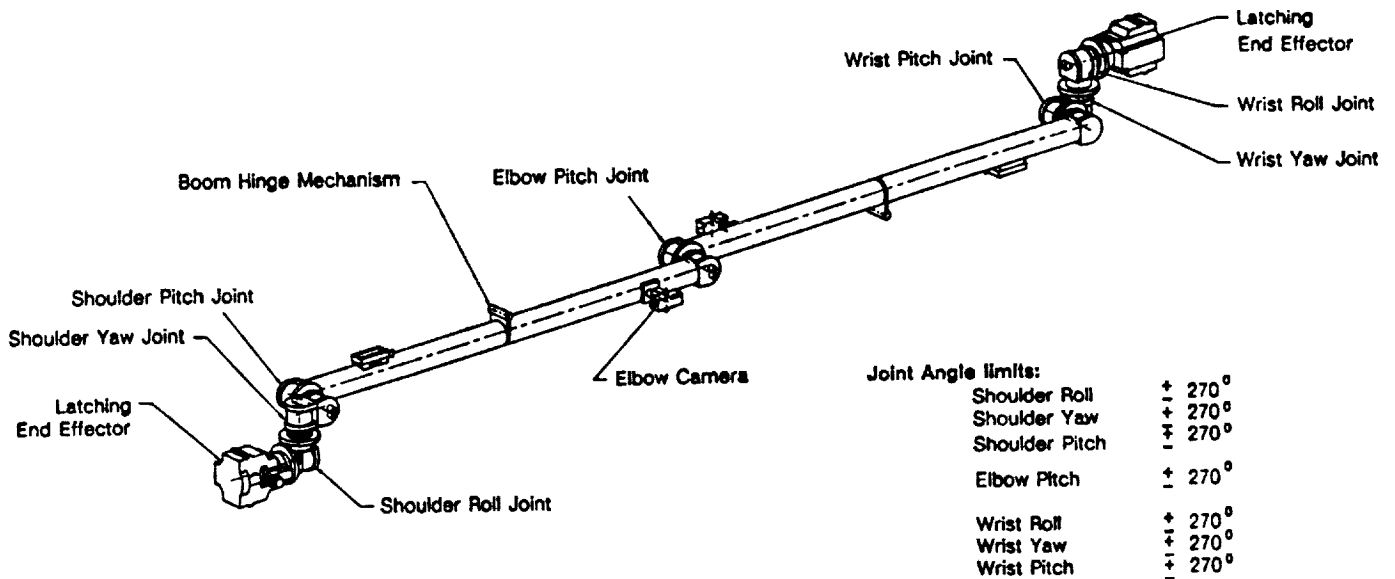
FIGURE 1: PHYSICAL CONFIGURATION OF THE SPACE STATION REMOTE MANIPULATOR SYSTEM (SSRMS)

Space Station Remote Manipulator System (SSRMS)

Special Purpose Dextrous Manipulator (SPDM)

(SPDM) I/F (PDGF)

Mobile Remote Servicer Base System (MBS)

MRS Tool

Mobile Transporter (MT)
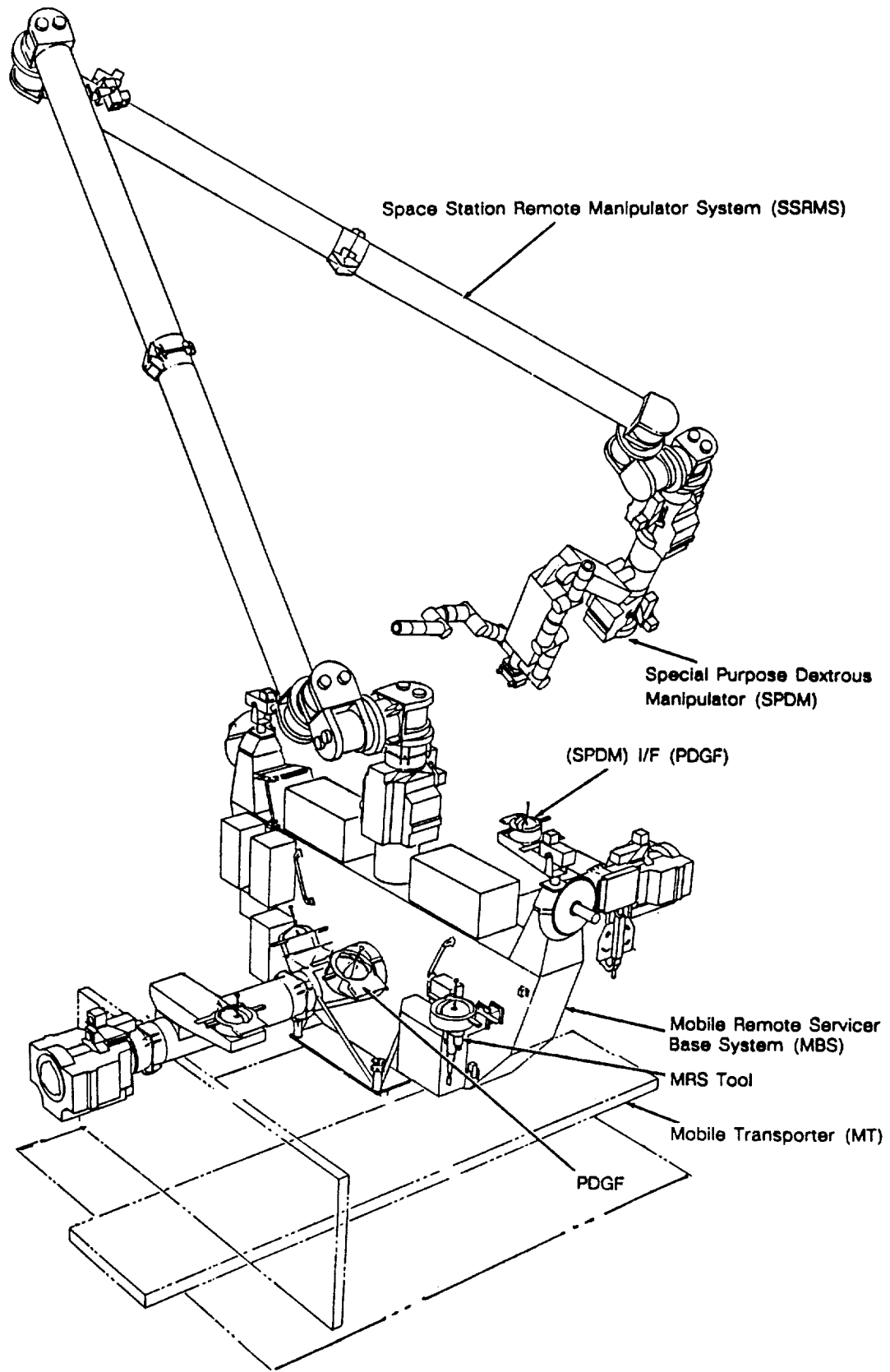
PDGF

FIGURE 2: SSRMS OPERATION ON THE SPACE STATION FROM THE MOBILE REMOTE SERVICER BASE SYSTEM

Grapple Target

Z

X

PDGF/SS
Electrical
Connectors (4)

Grapple Shaft

PDGF/LEE
Electrical
Connectors (4)

Locator
Inserts (6)

Y

PDGF Mounting
Ring

Pocket For
Latches

Location Cam Assembly

Base Plate Assembly

Face Plate

EVA Grapple Shaft Release   PDGF Release Bolts
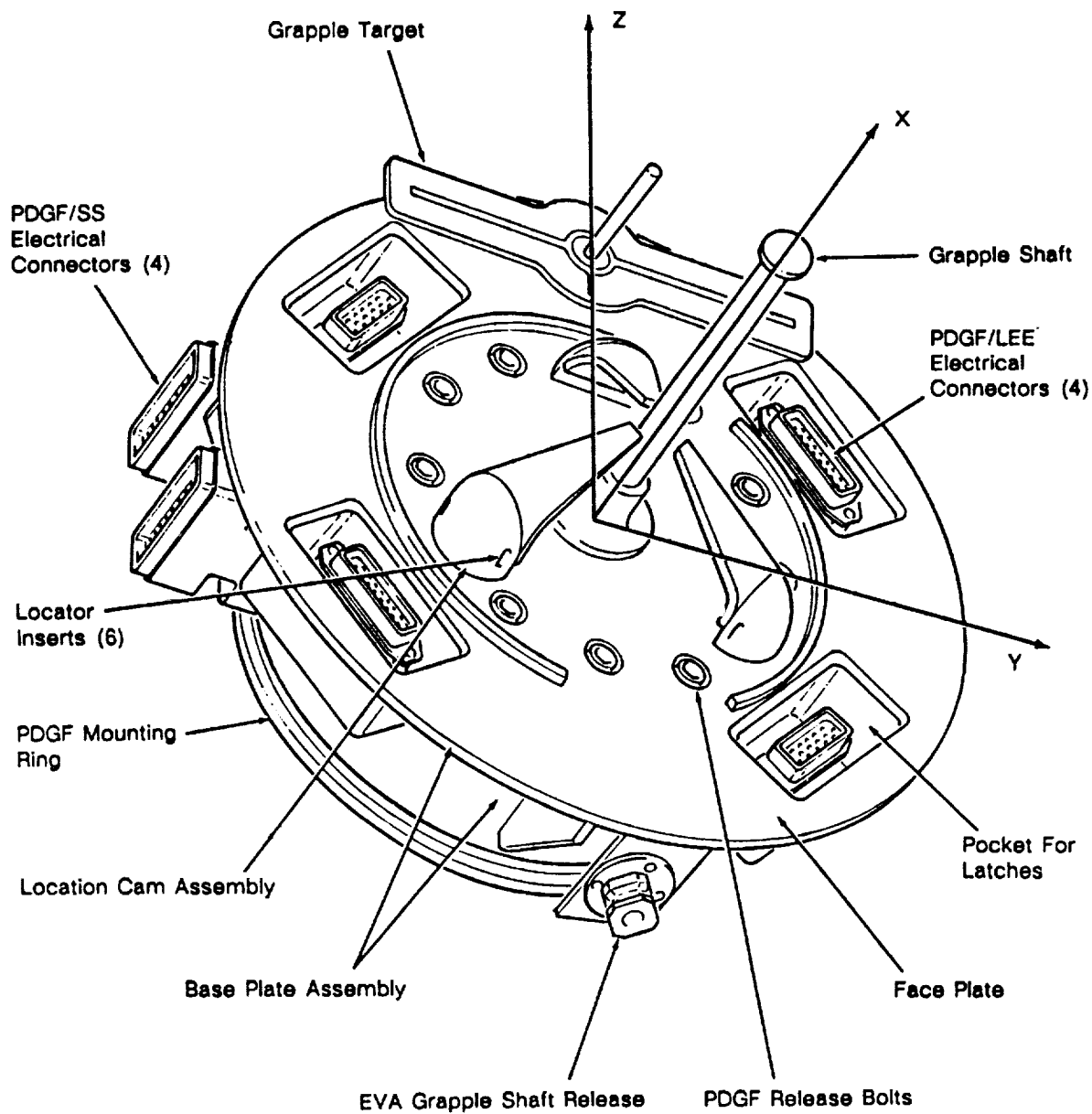
FIGURE 3: CONCEPT OF POWER AND DATA GRAPPLE FIXTURE (PDGF)

Latching End Effector Mechanisms
Holding the Shuttle Orbiter

Space Station Truss
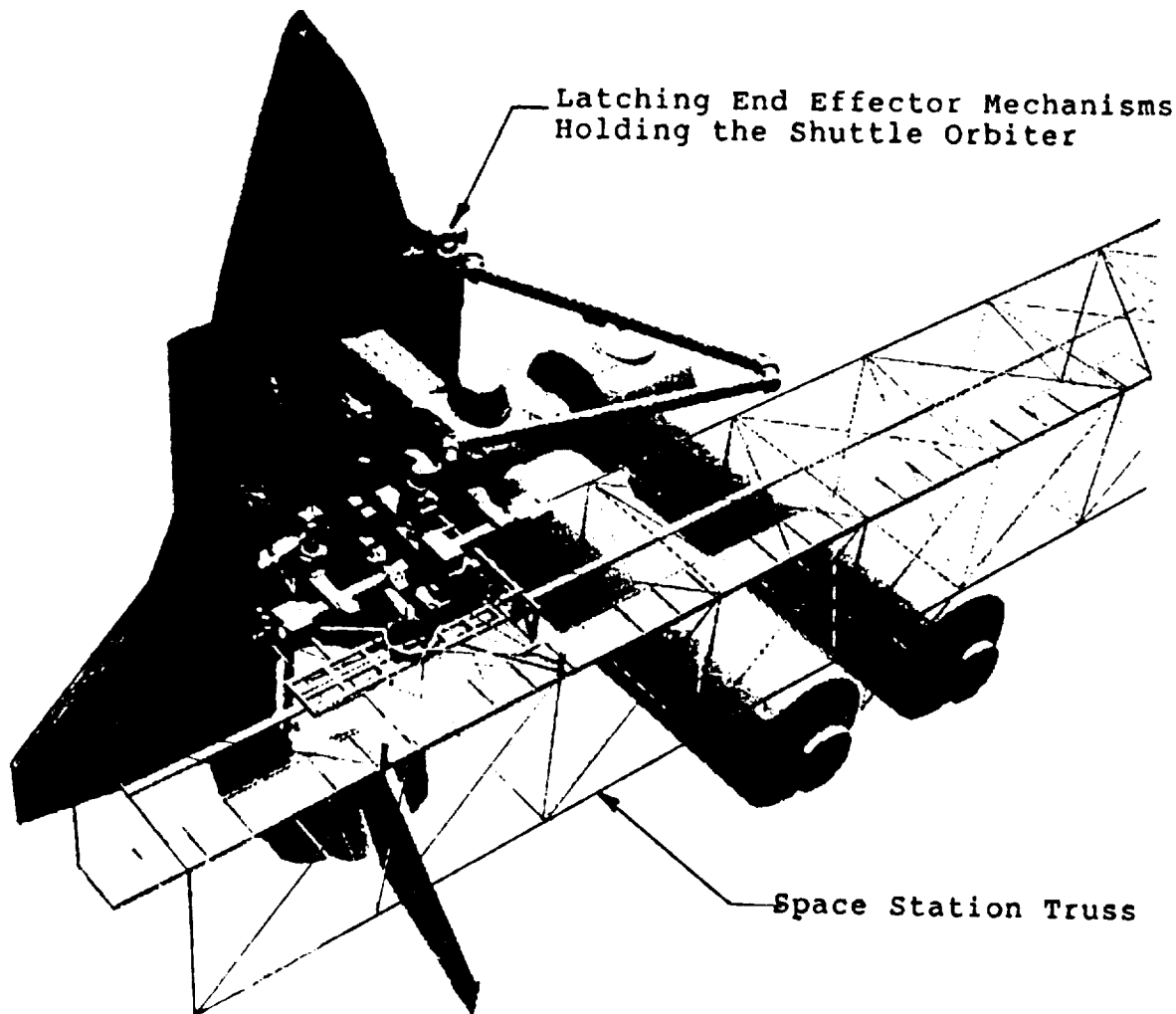
FIGURE 4: USE OF THE LEE FOR HOLDING THE SHUTTLE ORBITER

Joint Angle
Resolver (JAR)

G2 Gearbox

G1 Gearbox

Joint Inner
Housing

Joint Outer
Housing

JDM ORU
Bolt Attachment

Joint Drive
Module (JDM)

Joint Crossing
Cable Harness
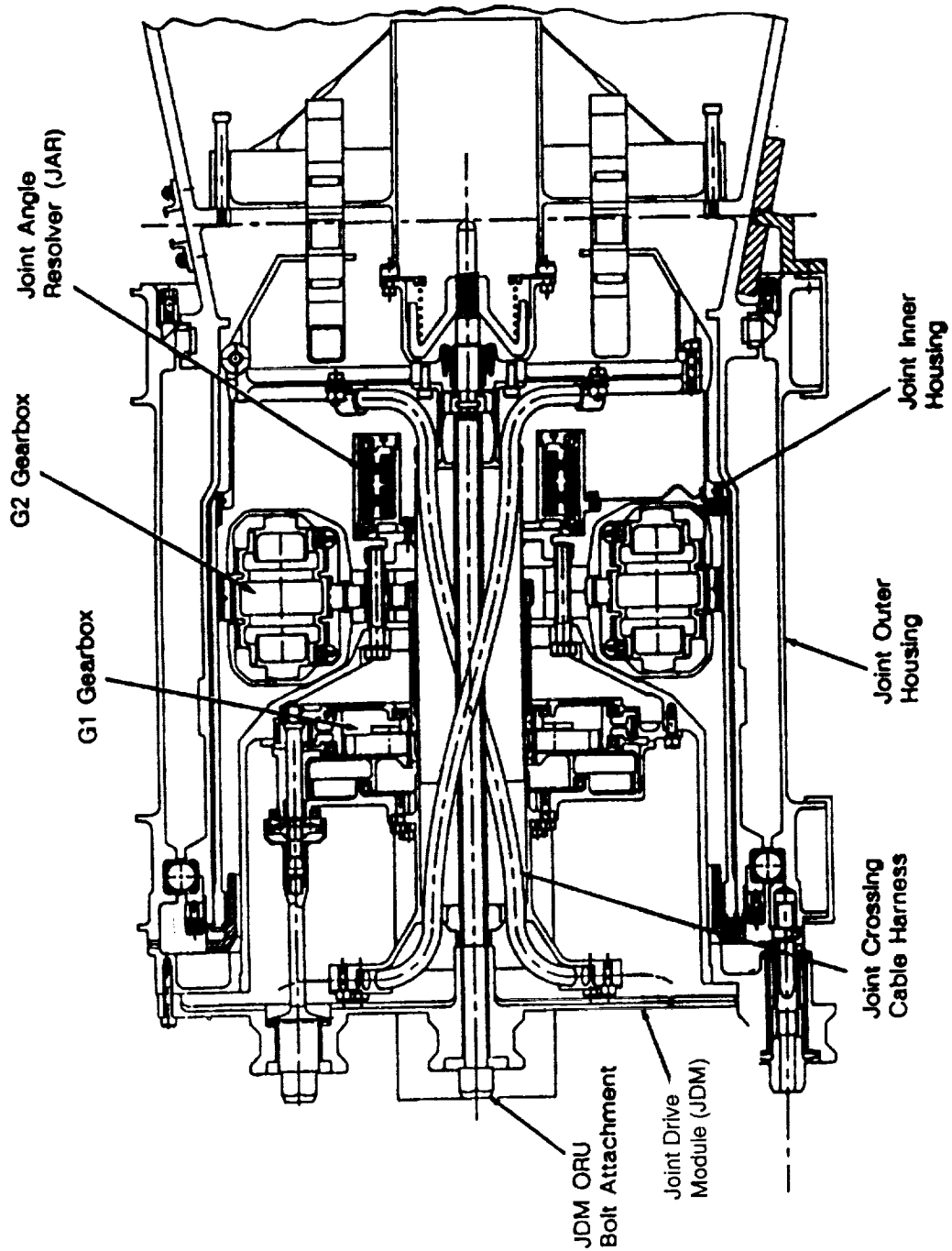
FIGURE 5 : Joint Cross Section

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JOINT HOUSING ASSEMBLY

JOINT HOUSING
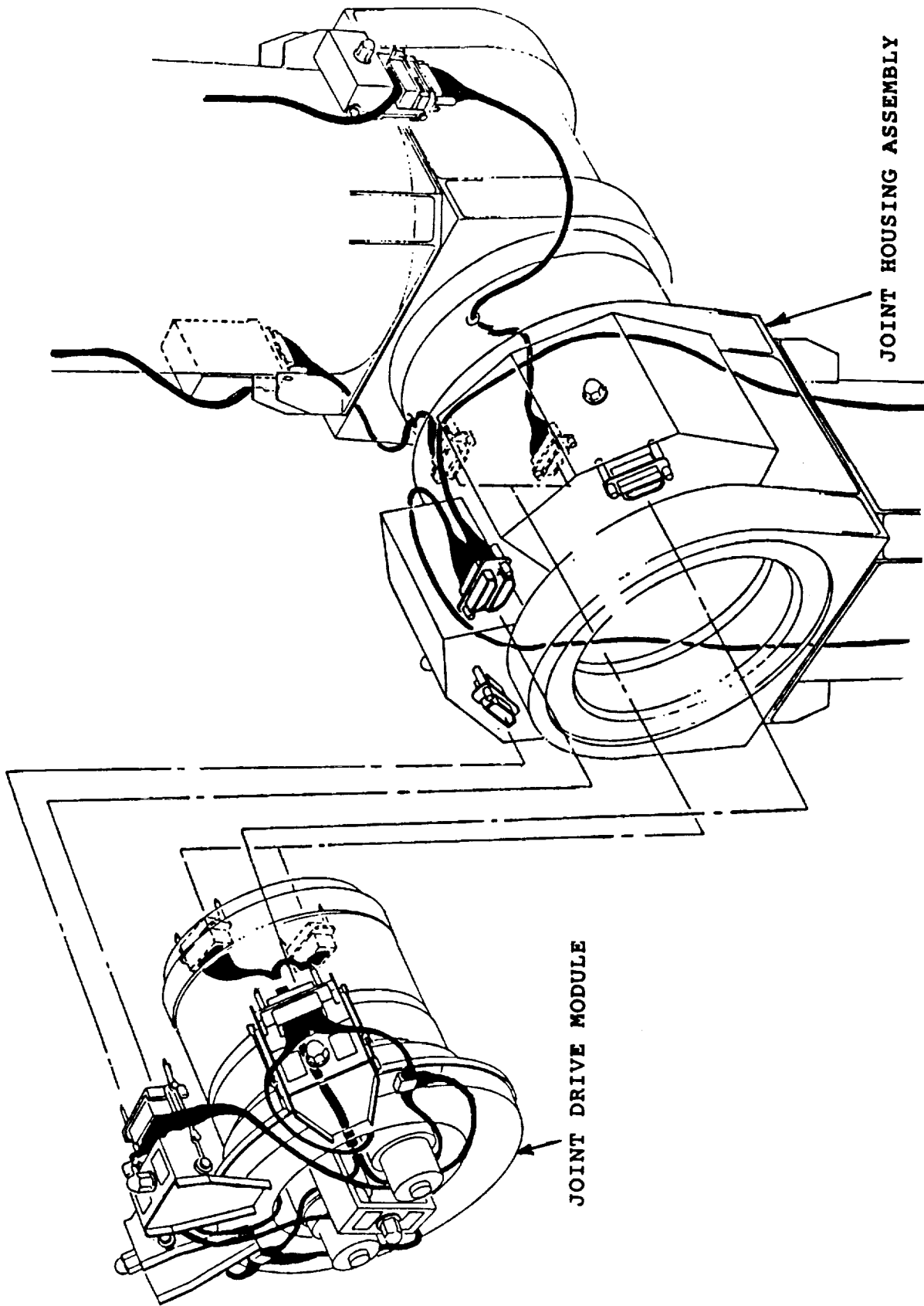
JOINT DRIVE MODULE

FIGURE 6: JOINT DRIVE MODULE AND JOINT HOUSING

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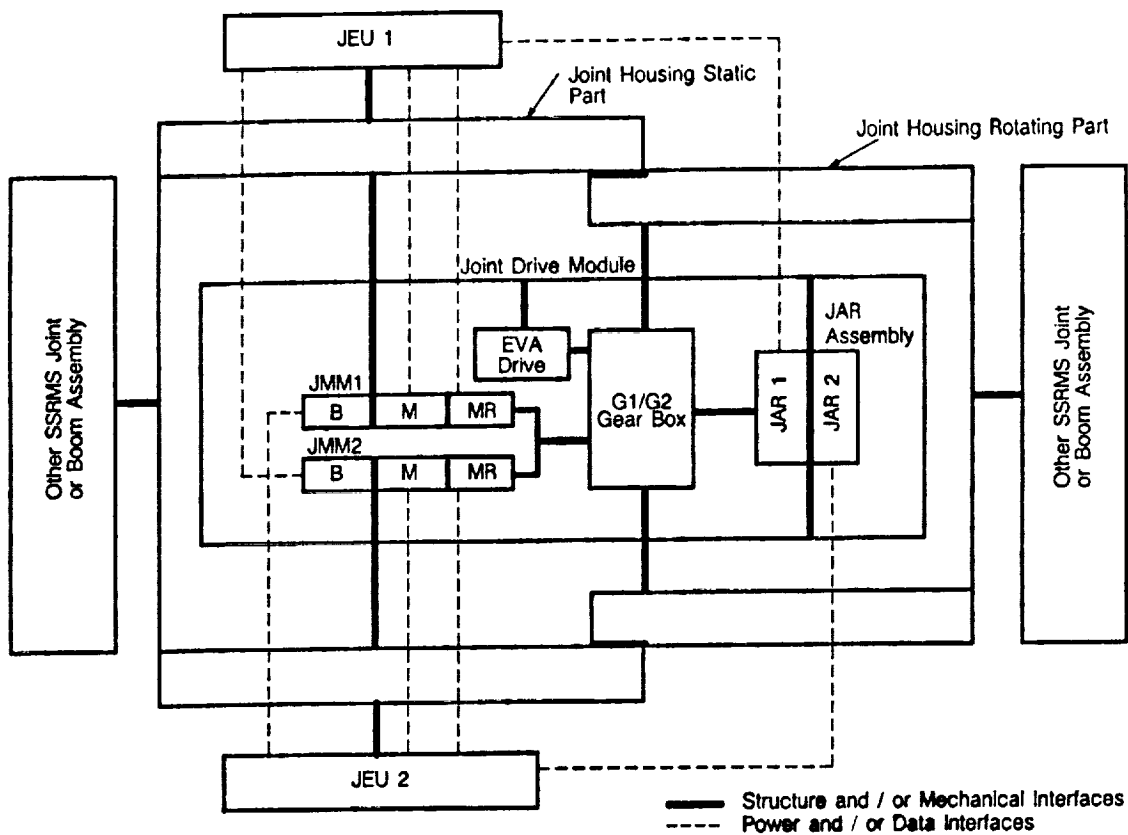
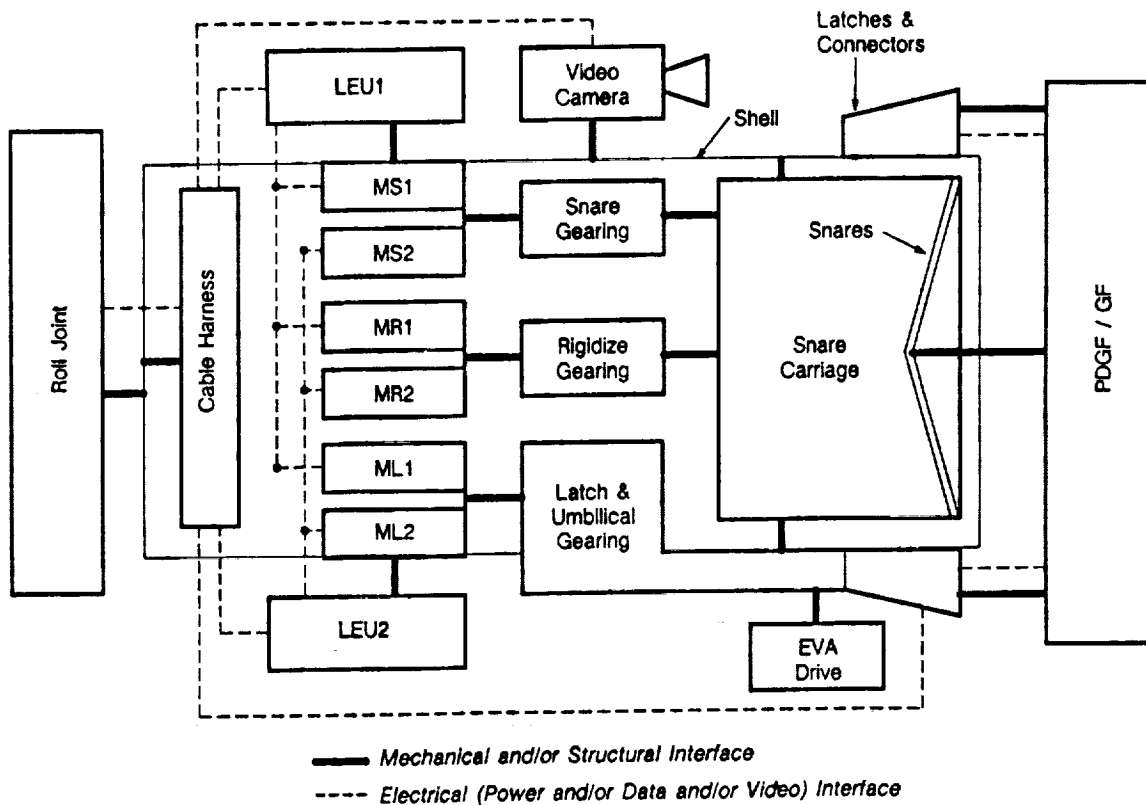## FIGURE 7: BLOCK DIAGRAM REPRESENTING JOINT COMPONENTS AND INTERFACES

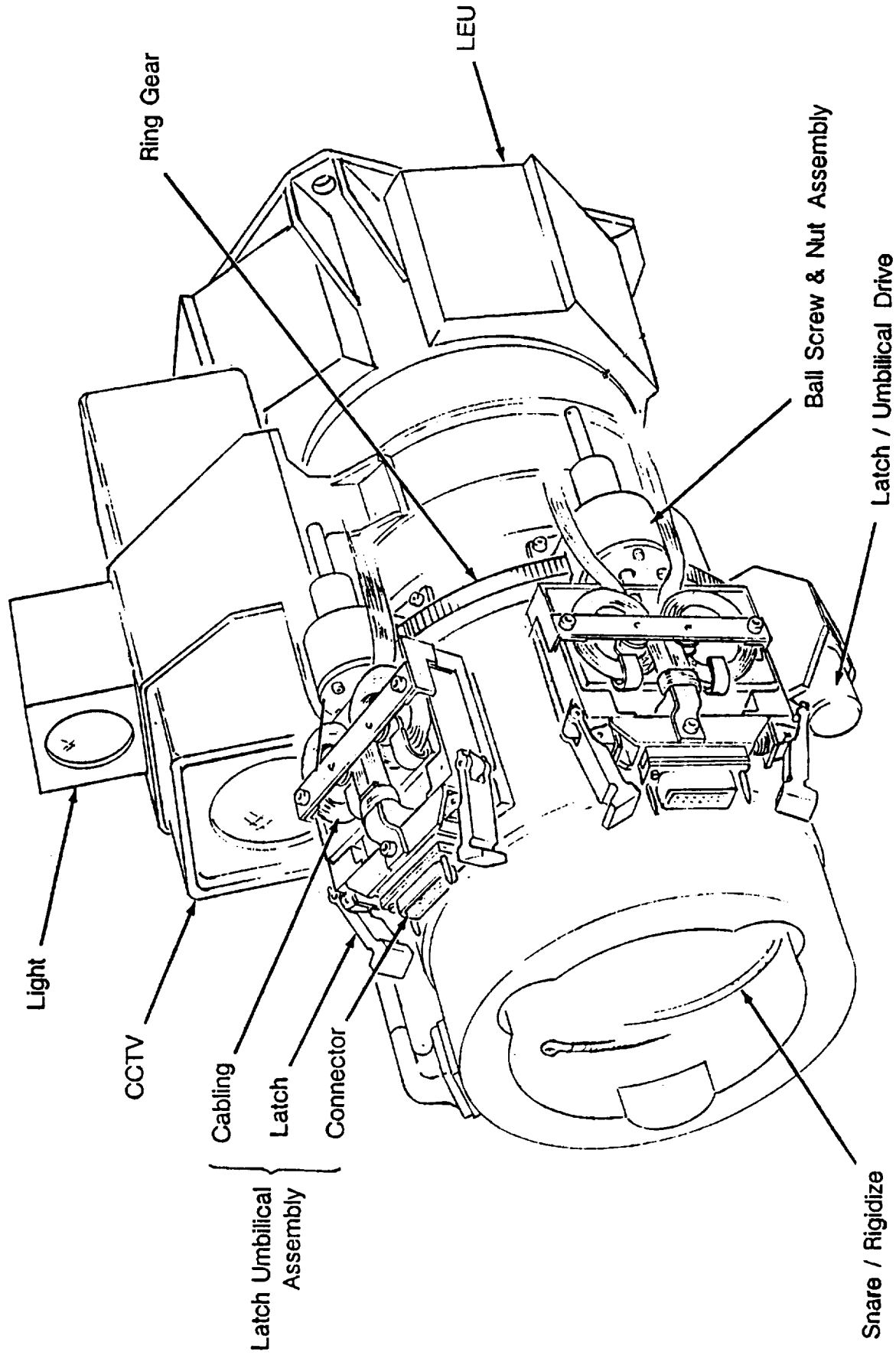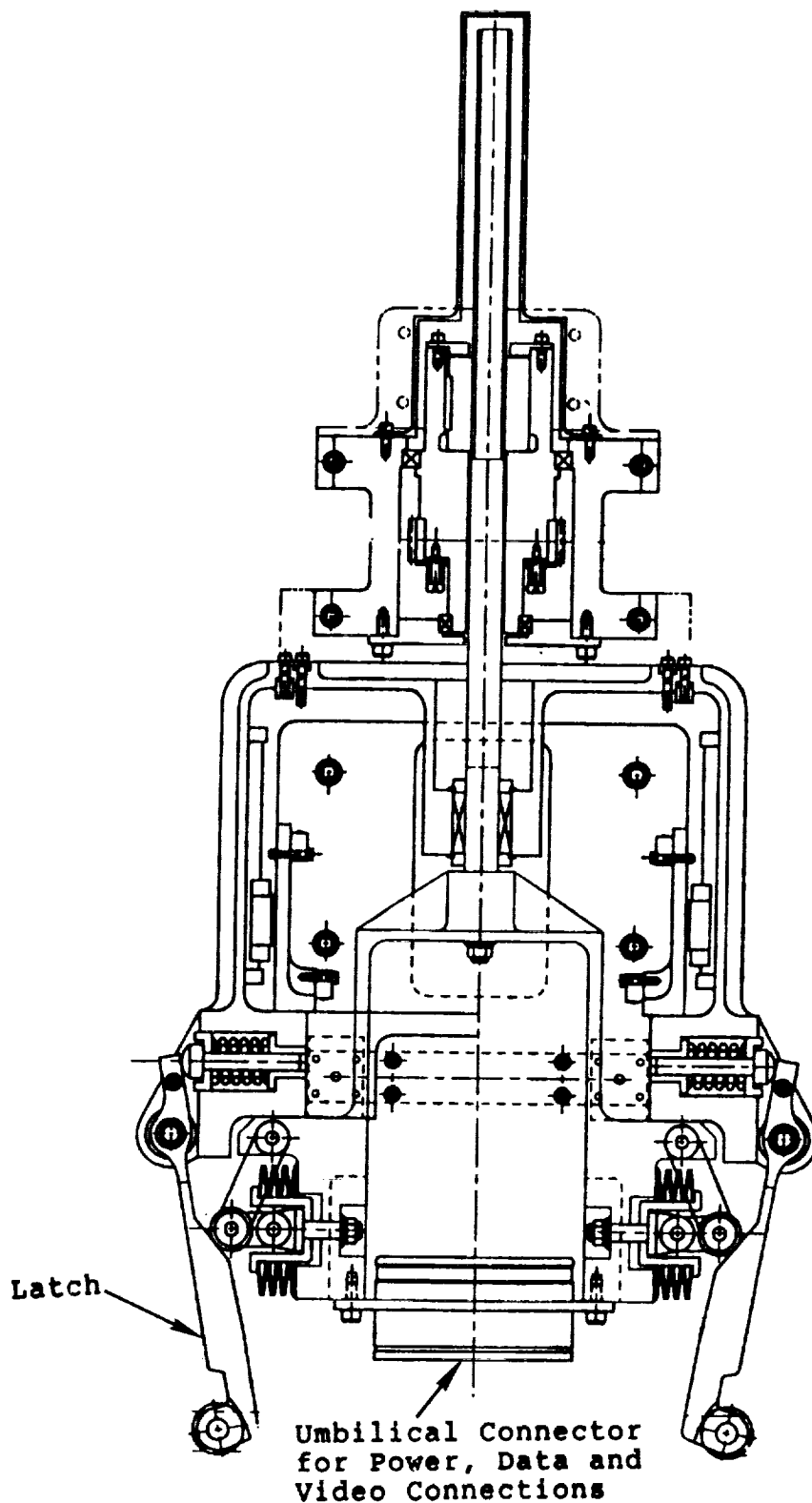## FIGURE 8: BLOCK DIAGRAM REPRESENTING THE LEE COMPONENTS AND INTERFACES

FIGURE 9: LATCHING END EFFECTOR CONCEPT

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Latch

Umbilical Connector
for Power, Data and
Video Connections

Note: Four such Latches are mounted on
LEE Shell for mating with Payload PDGF.

FIGURE 10.   CONCEPT OF LATCH AND UMBILICAL CONNECTORS FOR THE LEE

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