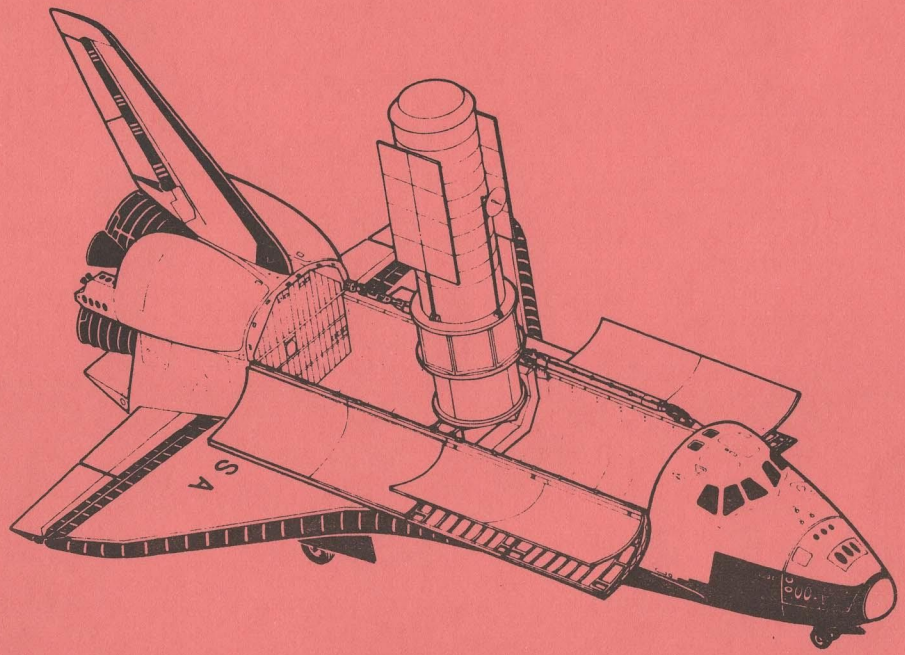
Charles M Smith

Payload Deployment and Retrieval System Overview Workbook

PDRS OV 2102



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Mission Operations Directorate
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Flight Training Branch

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Payload Deployment and Retrieval System Overview Workbook PDRS OV 2102

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Foreword

This book is organized into sections. Each section discusses a major aspect or portion of the payload deployment and retrieval system (PDRS). Each section is basically independent of other sections and can usually be studied independently of the other sections. You should begin each section by reading the learning material. Supporting material is provided to assist you and should be studied as required. If you are already familiar with the material, then you may decide to skip immediately to the next learning material.

This training material is part of a series of lectures, handouts, and workbooks for instruction on PDRS.

This training package should be studied before attending any classroom session on this material or taking any lesson for which this is a prerequisite.

The PDRS lesson sequence chart shows where this lesson fits in the series, the prerequisites for each lesson, and the optimum presentation order. The lesson sequence charts are located in the Space Shuttle Training Program catalog.

This material is for training purposes only; it should not be used as a source of operational data.

At the end of the book there is a lesson critique sheet. The lesson critique sheet is used to obtain your comments on this workbook. Please fill it out and mail to the instructor when you have completed this workbook.

If you have any additional questions or comments on this training manual, you should direct them to the person in charge of this manual:

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Section 1: Introduction

Discussion

The payload deployment and retrieval system (PDRS) consists of the hardware, software, and interfaces required to remotely retain and control the movements of a specified object, usually a payload, and to remotely observe or monitor objects or activities.

In order to meet these objectives, the PDRS utilizes the remote manipulator system (RMS), the payload retention latch assemblies (PRLAs), the manipulator positioning mechanisms/manipulator retention latches (MPMs/MRLs), payload handling aids and guides, closed circuit television (CCTV) system, and general purpose computers (GPCs). This workbook is intended to introduce these items in sufficient detail to familiarize the user with the components, assemblies, and systems in order to allow subsequent detailed instruction on the PDRS.

References

The following National Aeronautics and Space Administration/Johnson Space Center (NASA/JSC) publications were used as references in the development of this overview manual:

- JSC-17525, PDRS Console Handbook, Volume II, March 21, 1984.
- Shuttle Flight Operations Manual, Volume 16, Payload Deployment and Retrieval System, June 1, 1981.
- PDRS 2103, Payload Deployment and Retrieval System Video Text, September 10, 1983.
- JSC-17321, Flight Data File In-Flight Maintenance (IFM) Checklist, All Vehicles, July 15, 1983.
- JSC-17322, Flight Data File Data Processing System Dictionary, All Vehicle, Revision F, March 27, 1985.
- NSTS 07700, NSTS Level II Program Definition and Requirements, Volume XIV, Space Shuttle Systems Payload Accommodations, Appendix 8, System Description and Design Requirements for the Payload Deployment and Retrieval System.

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Section 2: Remote Manipulator System

Introduction

The RMS is the mechanical arm portion of the PDRS that maneuvers a payload from the cargo bay to its deployment position and then releases it. The RMS can also grapple a free-flying payload, maneuver it to the cargo bay, and then berth it in the Orbiter.

The basic RMS configuration consists of a manipulator arm plus supporting equipment located along the port longeron of the Orbiter vehicle (figure 2-1). An individual arm is 50 ft 3 in. long and has a 15-in. diameter. An arm consists of six joints connected via structural members and has a payload capturing device on the end.

Original concepts called for an optional second arm. This second arm would be placed along the starboard longeron; Space Shuttle Program decisions have, however, essentially deleted consideration of the starboard arm. As will be seen later in this workbook, residual references to the starboard arm still exist.

The RMS structure is attached to an MPM which, in turn, attaches to the Orbiter longeron. When cradled, the arm rests on three MPM pedestals that contain MRLs for securing the arm during launch, entry, and orbital maneuvering system (OMS) burns. On orbit, the MPM deploys the arm to an Orbiter outboard position by "rolling the arm out." The MRLs unlatch to allow RMS operations. The MPM and MRL systems are described in section 3.

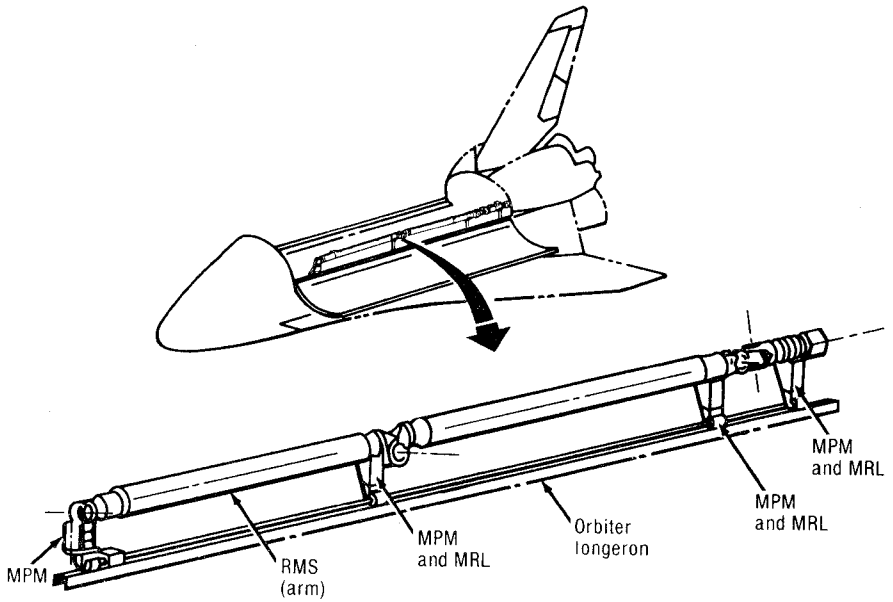

Figure 2-1.– Manipulator arm.

The arm may be controlled by the operator with or without computer assistance from the system monitoring (SM) GPC. In computer-assisted operating modes, the movement of the tip of the arm or other predefined point, known as the point of resolution (POR), is controlled by the operator using the display and control (D&C) panel and one of the following:

- Two three-degree-of-freedom (DOF) hand controllers (manual augmented modes)
- An Orbiter GPC (automatic modes)
- A rotary joint selection switch and a joint drive switch (single mode).

The manual augmented and automatic modes allow multiple joints to be controlled by the operator at the same time. Single mode, however, allows only one joint at a time to be controlled.

Additional single-joint modes are available that control individual joints without computer assistance. These modes of operation also utilize a rotary joint selection switch and a joint drive switch. These switches direct hardwired commands to individual joints from the D&C panel.

The arm incorporates several features to permit safe operation of the arm. These features include the following:

- A backup mode of operation,which uses a separate power source, is provided to enable the manipulator arm to continue to be operated in a single-joint mode of operation.
- Built-in test equipment (BITE) is provided to assist the operator in the detection of malfunctions and faults. For certain malfunctions, BITE fault detection will stop arm motion.
- Brakes are provided to prevent movement of the arm during temporary stop conditions and to stop the arm in an emergency.
- A jettison system is provided to allow separation of the arm from the Orbiter if the arm cannot be safely restowed.

Operation of the arm is based on a man-in-the-loop concept. The arm is controlled by the arm operator who makes command inputs based on visual, out-the-window feedback information from the CCTV's and information available on the D&C panel as shown in figure 2-2. Visual contact is imperative since collision avoidance (Orbiter to payload, Orbiter to arm, payload to arm, and payload to payload) is maintained by the operator's visual determination of arm/Orbiter/payload relations to one another. Successful operations depend heavily on available visual information.

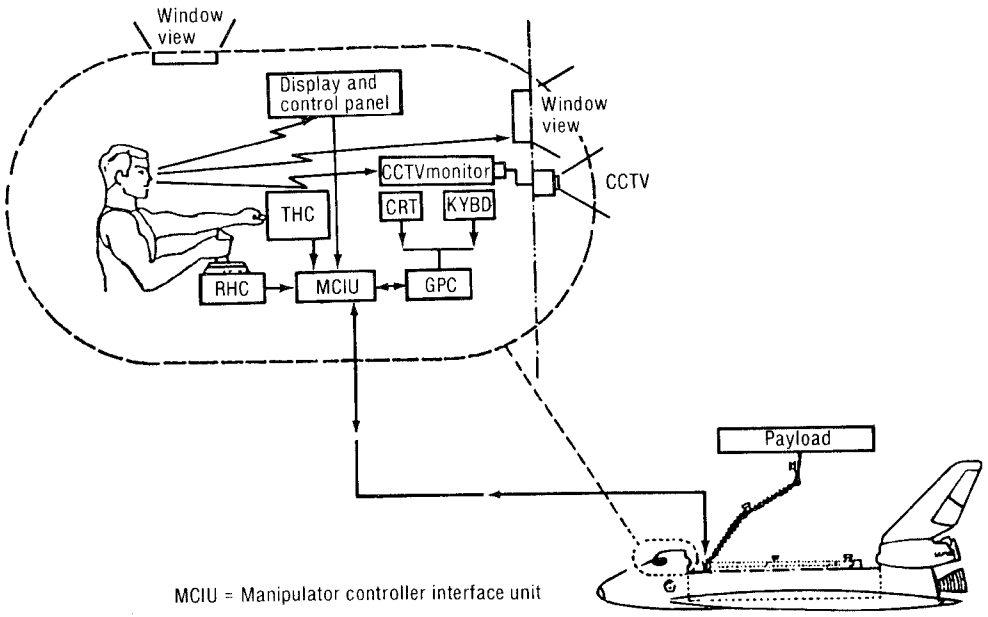

Figure 2-2.– Shuttle RMS.

The RMS modes of operation may be categorized as

- Automatic modes
- Manual augmented modes
- Manual single-joint drive mode
- Direct drive mode
- Backup drive mode.

There are two types of automatic modes. One type is a group of auto sequences that become part of the RMS software prior to launch. On orbit, the GPC will maneuver the arm through the auto sequence selected by the RMS operator until a final position and attitude are reached by the arm.

The other type is initiated on orbit. The RMS operator can maneuver the arm from its existing position and attitude to a desired position and attitude by entering the desired position and attitude into the GPC via the computer keyboard. When directed, the computer will maneuver the arm to the desired position and attitude.

Operation in a manual augmented mode results in one or more joints being driven simultaneously to translate and rotate the end of the arm in response to operator control inputs. Manual augmented modes consist of four separate modes, each mode defining a different coordinate system. The manual augmented modes include Orbiter unloaded, end effector (EE), Orbiter loaded, and payload operating modes. Two three-DOF hand controllers are used to command resolved rates for each of the six joints of the arm. The rotational hand controller (RHC) provides the resolved roll, pitch, and yaw rotations without inducing translations. The translational hand controller (THC) provides for resolved up/down, left/right, and fore/aft movement with respect to the appropriate coordinate system without inducing rotations.

Single-joint drive mode allows movement of the arm on a joint-by-joint basis, using a switch located on the control panel. The commands go through the GPC in this mode, as in the two previous modes (i.e., it is a computer-assisted mode).

Direct drive mode allows movement of the arm on a joint-by-joint basis, using hardwired commands from the D&C panel to the joint drive motors. Direct drive is not a computer-assisted mode of operation.

Backup drive control is through redundant hardware and allows movement of the arm on a joint-by-joint basis, using hardwired commands from the D&C panel to the joint drive motors. Backup drive also is not a computer-assisted mode of operation.

RMS Construction and Components

The following paragraphs discuss in general the RMS components, their functions, quantity, and location. General physical characteristics of the components may be found in appendix A. RMS systems performance data and limitations may be found in appendix B.

Display and Control Panel

The D&C panel assembly is located at the aft station (see figure 2-3) and performs the following primary functions.

- Primary control
- Display function
- Backup control
- D&C electronics and Orbiter/THC/RHC wiring interfaces.

The following paragraphs briefly state the purposes of the items found on the D&C panels (panels A8L and A8U).

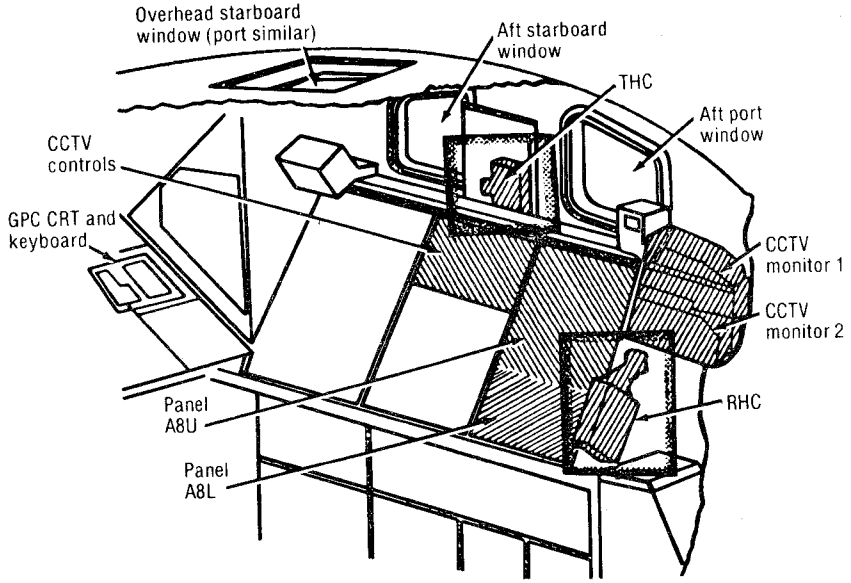

Figure 2-3.– RMS displays and controls, aft station.

Panel A8L. See figure 2-4.

- RMS power and select switches - The RMS power and select switches are used in conjunction with one another and provide the ability to power either the starboard or port RMS. The RMS POWER switch alone will power the manipulator controller interface unit (MCIU) when placed in the PRIMARY power position.
- HEATER switches - The HEATER switches apply power to the port and starboard RMS heater systems A and B.
- The remaining switches and talkbacks on this panel deal with the MPMs and MRLs. They will be discussed in section 3 of this manual.

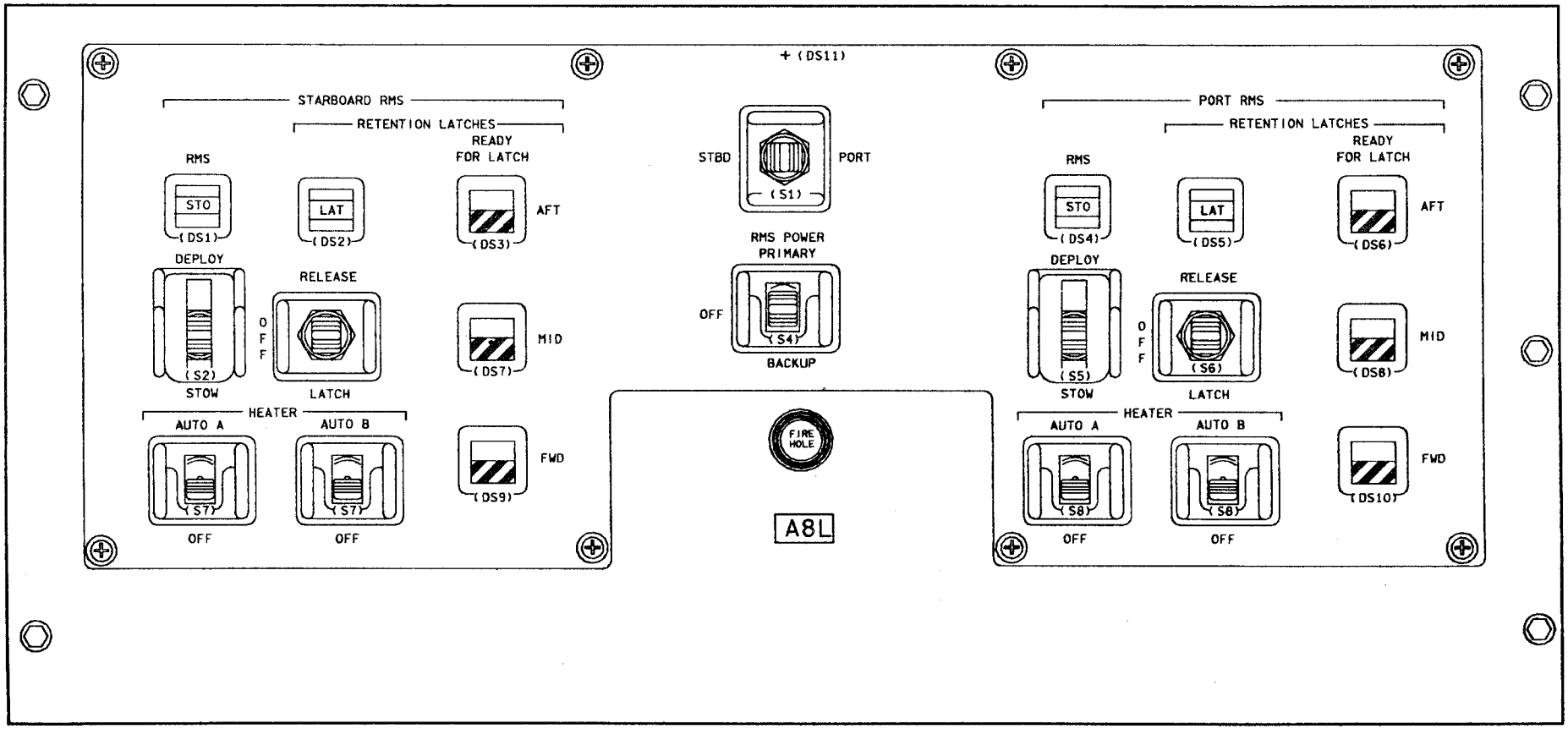

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Figure 2-4.– Panel A8L.

Panel A8U. See figure 2-5.

- MODE select rotary switch - The MODE select rotary switch selects the operating mode that will be used to control the arm.
- ENTER pushbutton - The ENTER pushbutton enters the mode selection into the GPC for all but DIRECT mode.
- Mode indicator light matrix - The mode indicator light matrix indicates the current RMS operating mode.
- AUTO SEQ switch - The AUTO SEQ switch starts or stops an auto sequence.
- READY light and IN PROGRESS light - The READY light and IN PROGRESS light indicate the status of an auto sequence.
- BRAKES switch and talkback - The BRAKES switch applies and removes the brakes from the arm joints. The BRAKES talkback indicates the current status of the brakes (OFF/ON).
- SAFING switch and talkback - The SAFING switch allows the operator to bring the arm to rest or to cancel the safing condition. The SAFING talkback indicates gray when safing is not in progress.
- SOFTWARE STOP talkback - The SOFTWARE STOP talkback indicates barberpole when a joint has reached its software limit of travel and the GPC has commanded arm motion to stop.
- RMS MASTER ALARM - The RMS MASTER ALARM signals the operator that an RMS caution and warning (C&W) annunciator light has been activated.
- RMS C&W light matrix - The RMS C&W light matrix annunciates RMS system problems as they occur.
- RATE meter - The RATE meter indicates the commanded and actual translation speed of the POR.
- MIN RATE talkback - The MIN RATE talkback indicates the selection status of vernier/coarse rates.

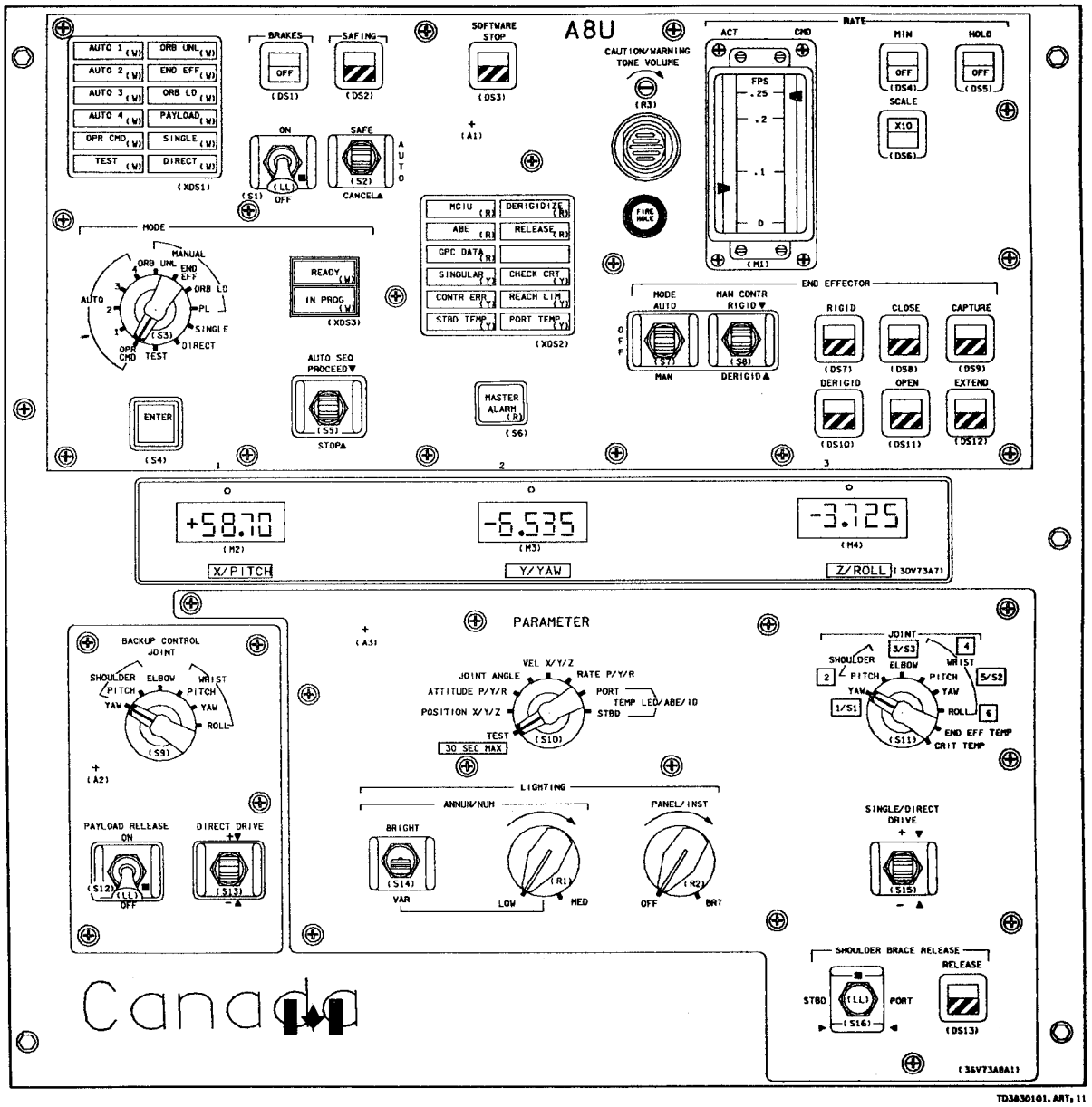

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Figure 2-5.– Panel A8U.

- RATE HOLD talkback - The RATE HOLD talkback indicates the selection status of rate hold.
- RATE SCALE talkback - The RATE SCALE talkback indicates the effective scales on the translational rate meter.
- EE MODE switch - The EE MODE switch allows the operator to select either auto or manual operation of the EE snares.
- EE MANUAL CONTROL switch - The EE MANUAL CONTROL switch allows positioning of the EE snare carriage to be controlled manually.
- EE status talkbacks - The EE status talkbacks provide the operator with information concerning positioning of the snare carriage and the open/closed state of the snares.
- Digital indicators - The three light emitting diode (LED) readouts display data selected by the PARAMETER select rotary switch.
- PARAMETER select rotary switch - The PARAMETER select rotary switch allows the operator to select the information to be displayed on panel A8U digital indicators.
- JOINT select rotary switch - The JOINT select rotary switch selects the joint that will be driven if single or direct drive modes are selected by the operator.
- SINGLE/DIRECT DRIVE switch - The SINGLE/DIRECT DRIVE switch allows the operator to drive the joint selected by the JOINT rotary switch in single and direct modes.
- SHOULDER BRACE RELEASE switch and talkback - The SHOULDER BRACE RELEASE switch allows the operator to release the RMS shoulder brace mechanism. The talkback indicates the release status of the mechanism.
- LIGHTING ANNUN/NUM switch - BRIGHT fixes the brightness of all panel annunciator lights to a maximum level, while VAR enables a potentiometer to control the panel lights.
- LIGHTING ANNUN/NUM potentiometer - Allows the operator to vary the brightness of all panel annunciator lights. This switch is used in conjunction with the LIGHTING ANNUN/NUM switch.
- LIGHTING PANEL/INST potentiometer - Allows the operator to vary the brightness of panel talkbacks.
- BACKUP CONTROL JOINT select rotary switch - This switch selects the joint to be driven when in backup modes of operation.
- BACKUP CONTROL DIRECT DRIVE switch - This switch drives the joint selected by the BACKUP CONTROL JOINT rotary switch.
- BACKUP CONTROL PAYLOAD RELEASE switch - Commands release of payload in backup mode of operation.

Manipulator Controller Interface Unit

The principal function of the MCIU is to handle the exchange of information between the Orbiter GPC and the RMS. The MCIU performs manipulation of data but does not have any significant data processing functions other than controlling the EE auto capture/rigidization sequence logic.

The MCIU is considered to be an IFM item. A spare MCIU is usually flown on RMS flights. The MCIU is located behind

panel L17; the spare MCIU is stowed in a middeck locker. Procedures for changing out the MCIU are contained in the all vehicle IFM Checklist.

Translational Hand Controller

The THC (see figure 2-6) allows an operator to control the three-dimensional linear motion of the RMS POR by means of manual inputs. The POR velocity commands are proportional to the deflection of the controller.

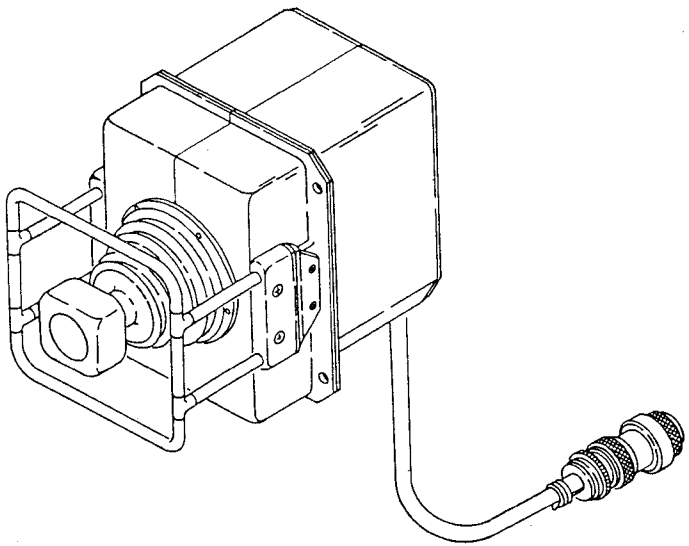


Figure 2-6.– Translational hand controller.

The controller provides three independent electrical inputs to the MCIU, one for each control axis. The THC incorporates a spring and viscous damper in each axis which provide suitable force feel characteristics to aid the operator in his/her task.

Rotational Hand Controller

The RHC (see figure 2-7) is a three-axis controller which provides electrical control signals for pitch, yaw, and roll control of the RMS. Control signals are proportional to manual input displacements in each of the three mutually perpendicular axes. The RHC also provides additional RMS controls through three switches located on the handgrip. The three switches are:

- RATE HOLD pushbutton - The RATE HOLD pushbutton is mounted on the left half of the grip assembly and is thumb-operated. The pushbotton is used to maintain the POR translational and rotational rate at a commanded value. Rate hold is engaged when the pushbutton is pushed in momentarily. Rate hold is disengaged when the pushbutton is pushed in again momentarily. The rates can be biased once rate hold has been actuated and the hand controllers have been returned to detent by deflecting a hand controller a second time.

- RATE switch - The vernier/coarse RATE switch is a slide switch that produces the signal used by the RMS software to determine the POR rate limits. The switch is configured to produce a coarse command in the forward direction (away from the operator). The position of the switch in the backward direction (towards the operator) produces vernier rates.

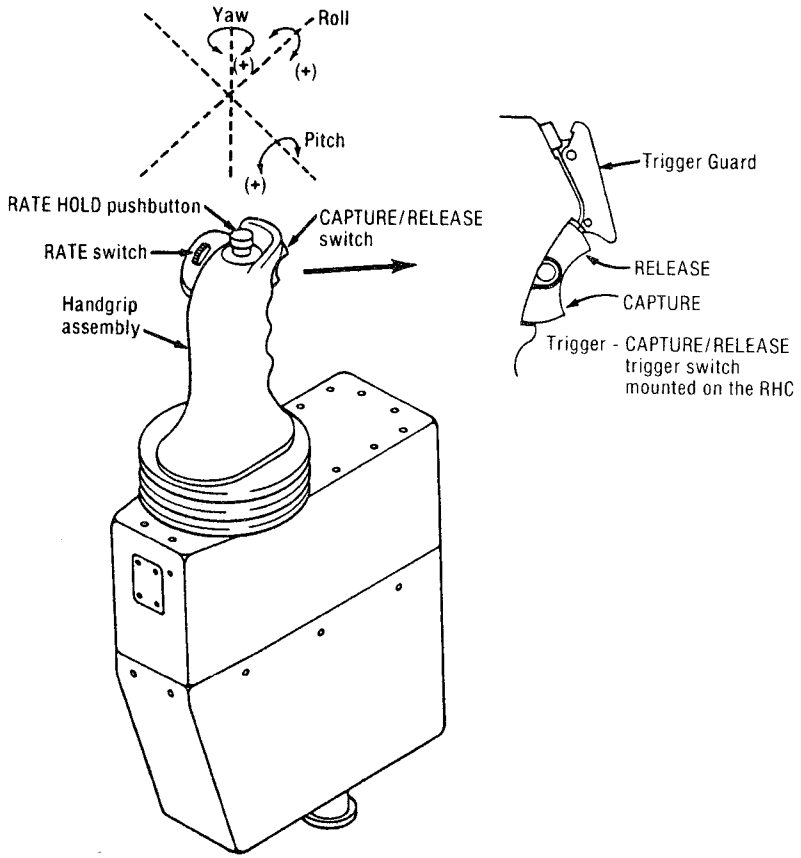


Figure 2-7.– Rotational hand controller.

- CAPTURE/RELEASE switch - The CAPTURE/RELEASE switch is mounted on the right half of the grip assembly and is used to effect capture and release of payloads. The lower part of the switch sends the capture signal to the EE and the upper part sends the release signal. A finger-operated guard is provided over the release part of the switch to prevent inadvertent actuation during normal operation of the RHC.

Manipulator Arm Drive System

Each joint of the manipulator arm is driven electromechanically, and the drive trains for all joints are similiar except for gear ratio.

Joint Motor Modules. Each of the six joints utilizes an identical, reversible, brushless dc motor that is used in both prime and backup modes of operation. Commutation for each motor is provided by a commutation scanner assembly. The motor module assembly (see figure 2-8) consists of

- Motor
- Commutator
- Tachometer
- Brake.

The drive motor is held in a quiescent state by the brakes, which apply a brake pad to a contact surface on the motor shaft. Continous application of 28 V dc to the brake is required to disengage the brake.

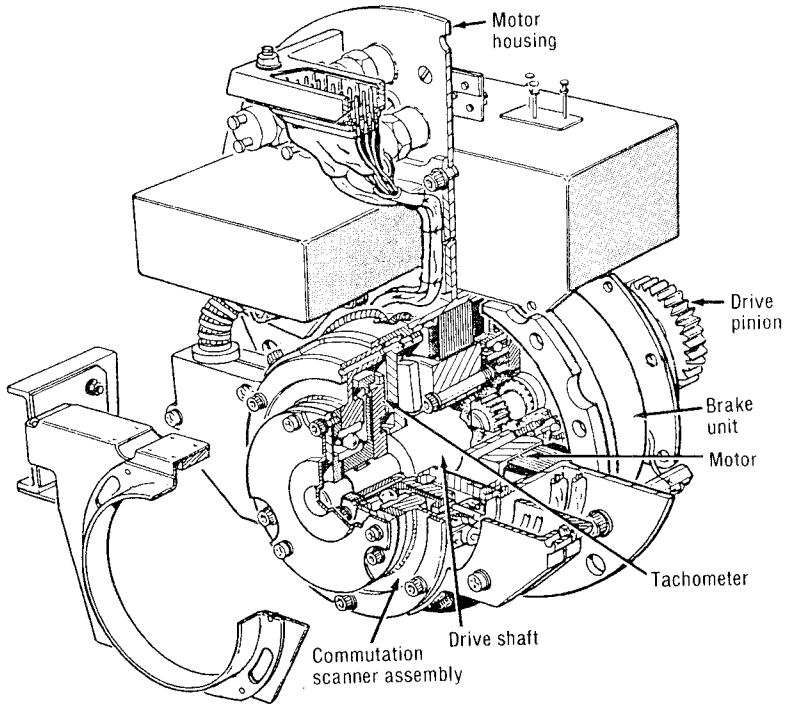


Figure 2-8.– Motor module.

Joint Gear Train. Each joint contains a gear train which differ in gearing ratios. Dry lubrication is used throughout the gear trains. Backlash is minimized by the use of close tolerance gears and a backlash control device.

Joint Encoder. An electro-optical encoder is fitted to the gear box output of each joint. The encoder is used to sense the angular position of the joint. The encoder uses an LED light source and a single disk. The encoder in the wrist roll-joint has a hole in the center to allow cables to pass through.

Servo Power Amplifier. Each manipulator arm contains six servo power amplifiers (SPAs), one for each joint. Each SPA is associated with a motor module and a position encoder. The major function of the SPA is to provide a drive signal to the motor in response to digital control signals generated by the GPC and supplied through the MCIU or to a direct drive command signal from the D&C panel.

Joint Power Conditioner. There are two joint power conditioners (JPCs) per manipulator arm. One is located in the shoulder joint and serves the shoulder and elbow joints. The second JPC is located in the wrist joint and serves the three wrist joints. The function of the JPC is to convert the + 28-V-dc bus to provide secondary regulated supply voltages at ± 15 V, + 10 V and + 5.1 V dc to the SPA, motor commutators, and position encoders.

Backup Drive Amplifier. There is only one backup drive amplifier (BDA) per manipulator arm, and it is located in the shoulder shop replaceable unit (SRU). It is a backup unit to any of the SPAs, in the event of a failure of an SPA or its associated JPC.

The main functions of the BDA are

- Conditions 28-V-dc backup bus voltage for arm use
- Provides drive signal to the selected joint motor.

Mechanical Arm Assembly

The manipulator arm drive system components (discussed on page 2-10), the arm cable harness, and arm structural components form the mechanical arm assembly. The structural components consist of joint housings, electronic housings, and arm booms.

Joints and Joint Degree of Freedom. The RMS mechanical arm assembly has three joints as follows:

Joint	DOF
Shoulder	Pitch and yaw
Elbow	Pitch
Wrist	Pitch, yaw, and roll

Each joint is fitted with a mechanical stop that is capable of stopping the joint from moving. This mechanical stop is known as the hard stop.

Shoulder Brace. The shoulder brace is designed to minimize the high-pitch-axis moment loading on the shoulder pitch gear train during the launch environment. A schematic diagram of the brace is shown in figure 2-9.

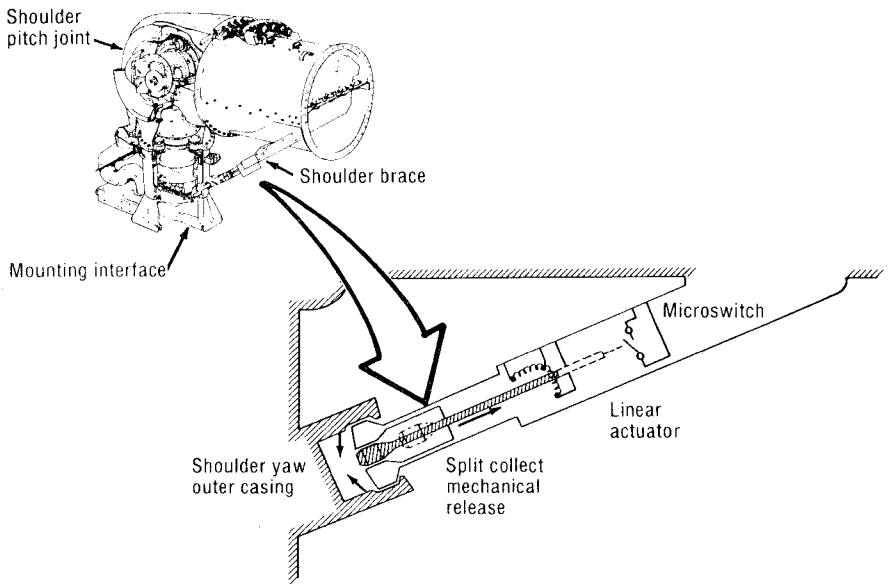


Figure 2-9.– Shoulder brace.

The actuating device is a single-phase, 400-Hz, 114-V-ac motor acting through a reducing gearbox and lead screw to provide linear motion to the actuating shaft. This linear motion expands the collet fingers into engagement with the locking stub.

The shoulder brace is designed to enable ground engagement of the release mechanism using an external power source. No requirement exists to relatch the brace before reentry and landing. A release talkback on the D&C panel is activated by a microswitch within the actuator when the actuating shaft is at the end of its withdrawal stroke.

The shoulder brace requires 8 seconds to release when commanded. The release command should be held for 10 seconds to assure that the actuator has fully withdrawn from the collet fingers.

Arm Boom Assemblies. The arm boom assemblies comprise two thin-walled tubular sections called the upper and lower arms. The arm booms are structures designed to meet stiffness criteria. In order to achieve an efficient stiffness/weight design and to maintain simplicity of construction, a circular section graphite/epoxy composite design is implemented. End flanges are made of aluminum alloy and are bonded and bolted to the graphite/epoxy tubular sections. Provisions are made for the installation of electrical cable harness assemblies along the length of each arm.

Adjacent to the lower arm and elbow joint interface is a mount for installation of an optional elbow CCTV camera and pan/tilt unit (PTU).

Arm Cable Harness. The wire harnesses are designed to minimize electrical cross-talk and electromagnetic interference. They are of a weight-efficient design and are installed on the outside of the upper and lower arm booms, utilizing a lightweight mounting technique with adhesive Kapton tape. Sufficient slack is allowed for relative thermal expansion and contraction between the cables and arm booms and for movement of the joints.

Manipulator Arm Thermal Protection Kit

The RMS incorporates active and passive thermal control systems in the form of thermostatically operated heaters and thermal insulation blankets. The thermal protection is implemented by hardware that falls into four main categories.

- Thermal blankets
- White paint that minimizes external heat input and maximizes heat radiation due to heat generated by electronics contained within the arm
- Heaters and thermostats
- Thermistors

Of these, only the thermal blankets comprise the thermal protection kit line replaceable unit (LRU). The other hardware is installed with the individual joints.

Thermal Insulation Blankets. The main function of the thermal blankets is to isolate the manipulator arm from the space environment, while minimizing both the magnitude and specular content of reflected solar energy from the surface of the manipulator arm. The blanket configuration is a five-layer buildup with an outer layer having acceptable absorptance, emittance, and specular reflectance properties.

Blanket Attachment. Blanket-to-blanket attachment or blanket attachment to the arm is accomplished using various fastening methods depending on the location. The three main methods are as follows:

- Velcro hook and loop fastening
- Snap fastenings
- Lacing

The selected method ensures security of attachment to other blanket pieces or to the arm. It also ensures that sufficient blanket overlap exists to prevent heat loss while allowing outgassing. The most commonly used method for fastening the blankets is the Velcro hook and loop.

RMS CCTV/Light System

A Government-furnished equipment (GFE) CCTV camera and a viewing light are mounted on the roll section of the wrist joint; the wrist-mounted CCTV does not have pan/tilt capability. The capability exists for an optional second CCTV camera with a PTU to be mounted at the elbow joint.

The primary use of the RMS CCTV/light system is to facilitate payload handling operations. However, the RMS CCTV/light can be used for Orbiter/payload inspection purposes.

Four possible flight configurations are available as follows:

- Wrist CCTV camera only
- Wrist camera and viewing light
- Wrist and elbow CCTV systems
- Wrist and elbow CCTV systems and wrist viewing light

The wrist CCTV and light are shown in figure 2-10; the elbow CCTV is shown in figure 2-11.

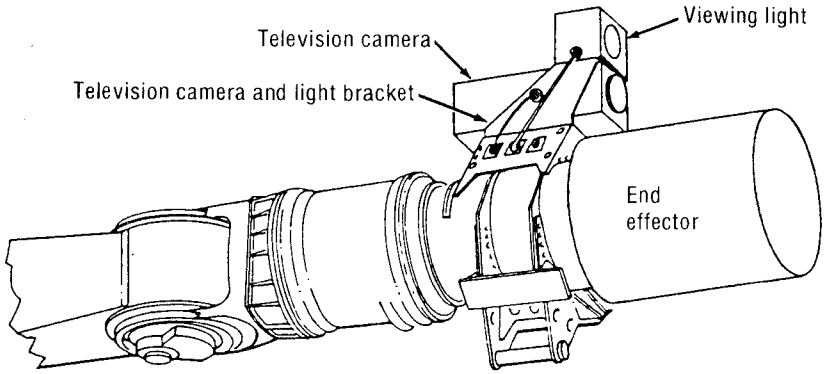


Figure 2-10.– Wrist CCTV and light configuration.

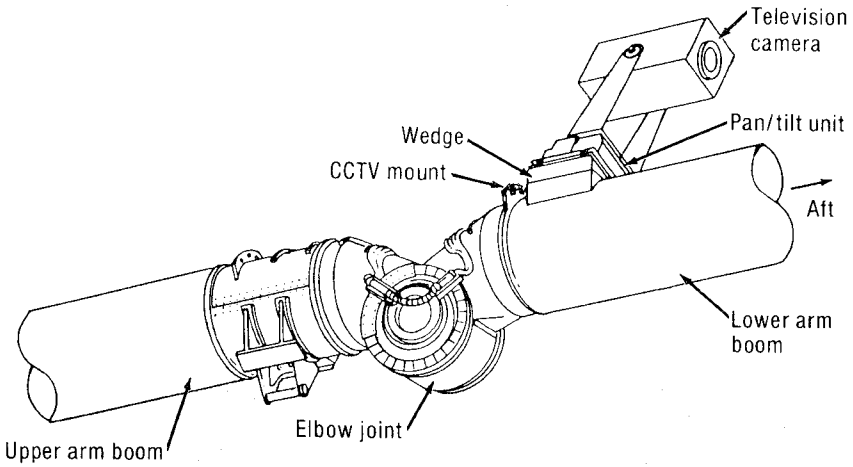


Figure 2-11.– Elbow CCTV system.

Standard End Effector

The purposes of the standard EE (figure 2-12) are

- To effect the capture of a payload by the RMS and to keep the payload attached to the EE
- To enable the release of a previously captured payload
- To provide power and command/data return capability to a payload.

Two of these purposes are met by the standard EE drive system which provides

- Capture/release - Capture/release is achieved by a rotating ring at the open end of the unit used to open and close three wire snares around the payload-mounted grapple fixture. The standard grapple fixture is illustrated in figure 2-13.
- Rigidize/derigidize - Rigidize/derigidize is achieved when the snares are withdrawn into the EE. This action tensions the snare wires to pull the grapple fixture into key oriented, full contact with the EE. The snares are moved as an assembly by a carriage mechanism.

The capture and rigidization sequence is shown in figure 2-14.

The third purpose of the standard EE is provided by a special purpose end effector (SPEE) electrical connector. The connector provides 2 lines for + 28-V-dc power and 16 lines for command signals, data return, low amperage heater circuits, etc.

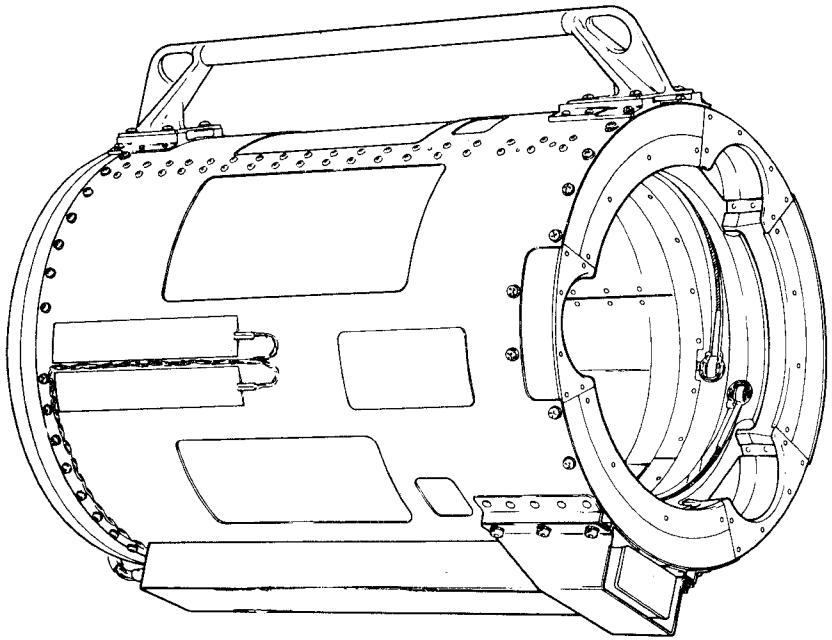


Figure 2-12.– Standard end effector.

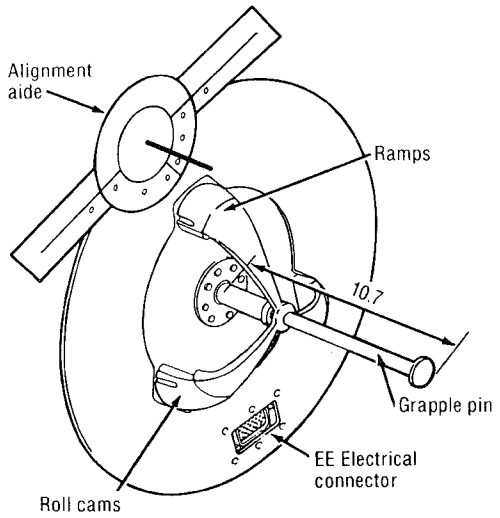


Figure 2-13.– Standard grapple fixture.

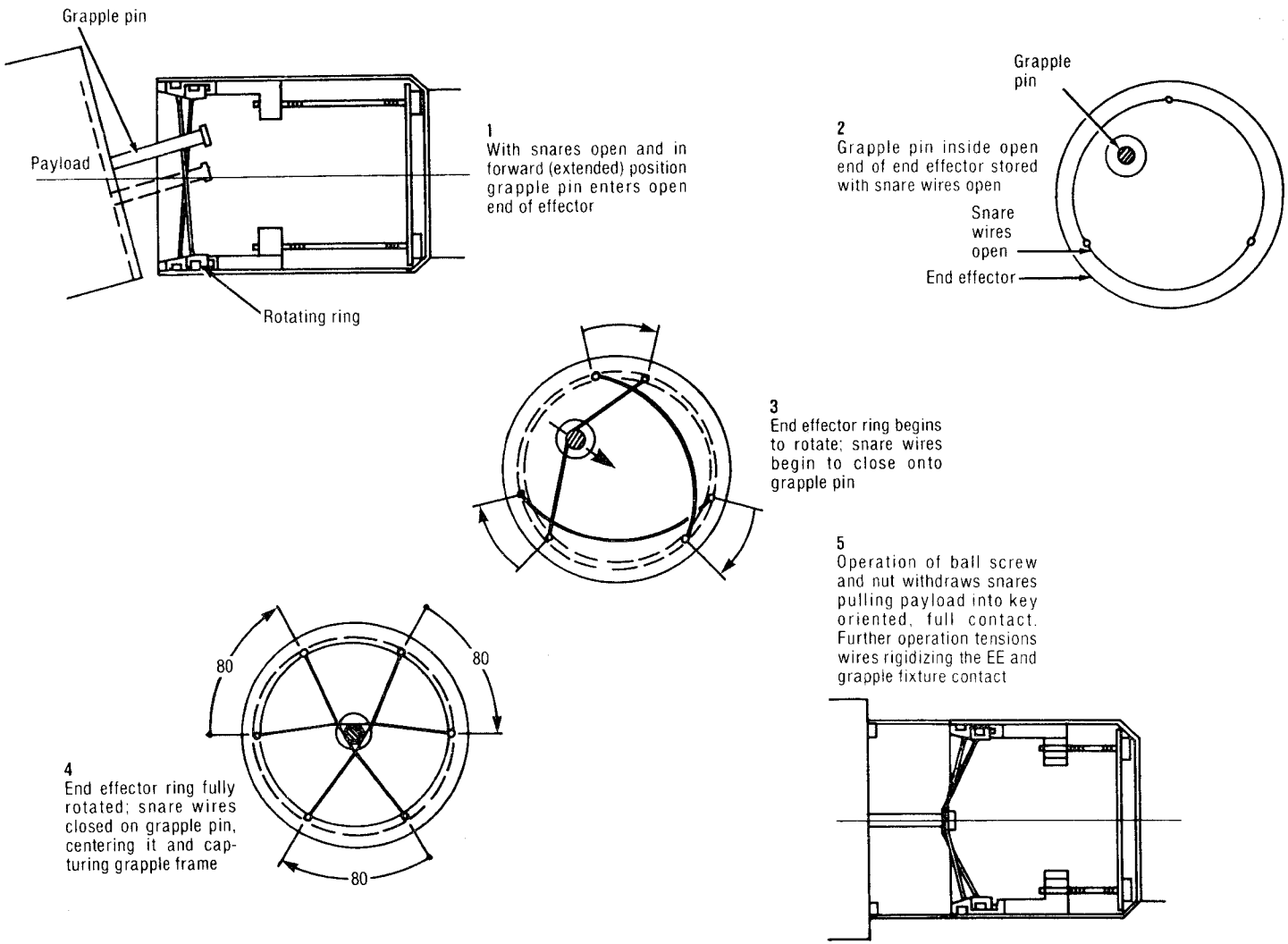


Figure 2-14.– Standard end effector capture and rigidize sequence.

End Effector Microswitches. There are seven microswitches (figure 2-15) to provide the operator with the EE status.

The seven microswitches are located as follows:

1. Open - At the beginning of rotating snare ring travel
2. Close - At the end of rotating snare ring travel
3. Capture - Two microswitches wired in series at the end of two snare cables. A capture signal is generated if tension is applied on either cable. The capture signal is lost when tension is lost on both cables.
4. Extend - At beginning of rigidization carriage travel
5. Derigid - At point of zero tension in rigidization carriage travel
6. Rigid - At the end of rigidization carriage travel.

These six states are fed into the end effector electronics unit (EEEU) and result in six status signals to the D&C panel.

Standard End Effector Performance. The capture and rigidization time varies depending on the initial misalignments of the grapple fixture within the EE and on the forces associated with centralizing and aligning the EE and payload interface. Maximum capture time is 3 seconds; maximum rigidization time is 20 seconds.

The rigidization force applied to the grapple fixture is 800 lb.

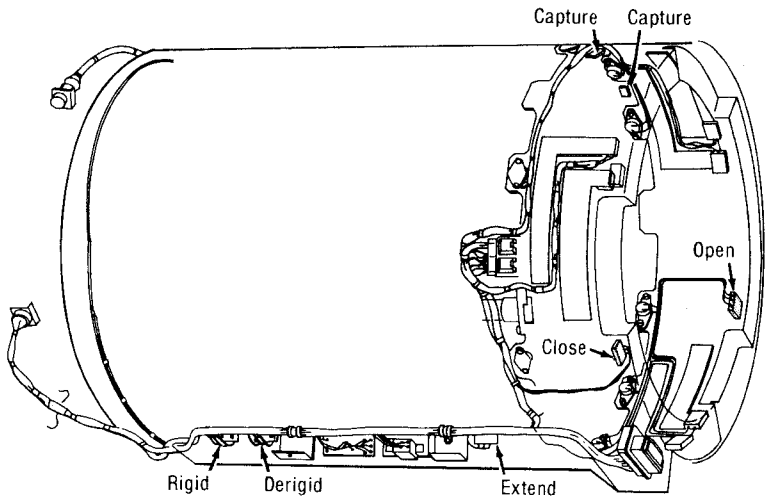


Figure 2-15.– Location of microswitches.

End Effector Operations. In order to fully understand the EE operation, the status of the EE talkbacks, and the sequence of commands to the EE, the following four sequences should be considered. Refer to the appropriate appendix for the detailed steps involved in these sequences.

- Automatic capture and rigidization (appendix C)
- Manual capture and rigidization (appendix D)
- Automatic derigidization and release (appendix E)
- Manual derigidization and release (appendix F).

When using the EE auto logic, the operator may at any time switch to manual operation and continue in this mode.

Arm Configuration During Capture/Rigidization. When the capture or rigidize commands are issued, the arm "limps" and enables the joints to backdrive to a configuration consistent with the grapple fixture orientation. Limping, in effect, draws the arm to the payload.

Control over wrist roll is maintained so that the operator may remove any roll misalignment which is introduced during rigidization; however, if no roll command is present, the wrist roll joint also limps to allow the wrist roll joint to backdrive.

Software System

Most of the RMS operations are performed under GPC control. Operator commands are transmitted to the GPC where the RMS software translates these commands into commands required for RMS hardware operation. The software further performs the task of monitoring the hardware and RMS status.

Software Modes

The software modes visible to the arm operator are

- Temperature monitor mode - This is a noncommanding mode wherein MCIU/GPC communication is established, but no arm is selected for operation. Only temperature data is processed.
- Idle mode - This is a rate commanding mode wherein MCIU/GPC communication is established; the port arm is selected for operation, and

  1. The brakes are on

  or

  2. The MODE SELECT rotary switch has been moved to a mode position, but the enter button has not yet been depressed

  or

  3. A joint has encountered a software stop

  or

  4. A form of safing known as MCIU safing is in progress.

  The idle mode commands each joint to have zero angular rates; all arm monitoring functions are performed.

- Manual augmented mode - This is a POR rate-commanding mode wherein joint motors respond in unison to inputs from the hand controllers. The software is in manual mode whenever one of the four manual augmented control modes is selected and accepted by the RMS software. The manual augmented control modes will be discussed in greater detail later in this handbook.
- Auto mode - This is a POR-commanding mode wherein joint motors respond in unison to prestored or operator-designated sets of position and attitude coordinates. Generated rate commands will cause the arm to hold a desired position or to follow a desired trajectory. The RMS software is in the auto mode whenever an operator-commanded mode or one of the four programmed automatic modes is selected and accepted by the RMS software. The auto modes will be discussed in greater detail later in this handbook.

- Single mode - The RMS software is in the single mode whenever the single operating control mode is selected and accepted by the RMS software. It is a joint rate-commanding mode wherein each joint motor may be individually driven forward or backward by the operator. The single mode will be discussed in greater detail later in this handbook.

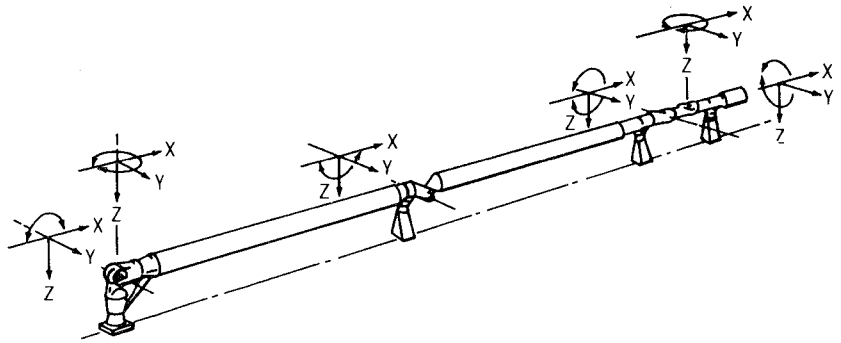
- Test mode - Operationally, test mode is completely equivalent to the manual augmented Orbiter loaded manual mode, except that all the joint current limits are set to maximum attenuation (i.e., zero current, zero joint rate). This mode is used to perform checkout of the translational and rotational hand controllers and to limp the arm.

- Position hold submode - This is a rate-commanding submode of manual augmented modes, auto modes, single mode, and test mode of operation. In this mode each joint is actively commanded to maintain the angular position attained prior to entering the position hold submode; all arm monitoring functions are performed.

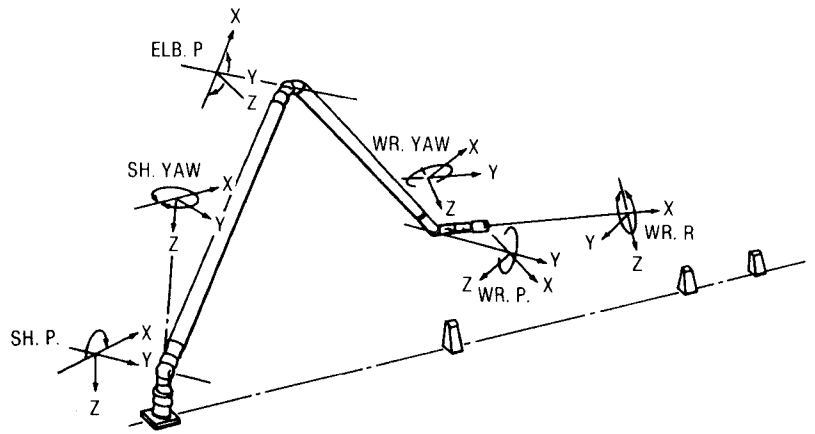
Coordinate Systems

Several different coordinate systems are used as reference frames when relating the RMS to the Orbiter, the RMS to a payload, or a payload to the Orbiter. These coordinate systems are as follows.

Joint Reference System. The joint reference system (figure 2-16 (a)) rotates for each joint to a new orientation with each motion of the attached joint nearest the Orbiter. For each joint except the shoulder joints, the X-axis is along the axis of the part of the arm next to the joint and on the Orbiter side of the joint. The difference in complexity between a stowed position and a random joint orientation is shown in figure 2-16 (b). This reference system is used to measure joint angles in single mode and by the GPC to calculate POR position and attitudes.



(a) Arm cradled position.



(b) Random arm orientation.

Figure 2-16.– Joint reference system.

Orbiter Body Axis Coordinate System. The Orbiter body axis coordinate system (BACS) (figure 2-17) originates 236 inches forward and 400 inches below the nose of the Orbiter. The -X axis points toward the tail of the Orbiter, the + Y axis points toward the starboard wing, and the + Z axis points down to complete the right-handed coordinate system. A positive roll rotates the port wing up, a positive pitch rotates the nose up, and a positive yaw rotates the nose starboard. RMS and payload POR positions (X, Y, and Z) are always given in this coordinate system.

Orbiter Rotation Axis Coordinate System. The Orbiter rotation axis coordinate system (RACS) (figure 2-18) originates 236 inches forward and 400 inches below the nose of the Orbiter. The + X axis points toward the tail of the Orbiter, the + Y axis points toward the port wing, and + Z axis points down to complete the right-handed coordinate system. A positive roll rotates the port wing down, a positive pitch rotates the tail up, and a positive yaw rotates the nose starboard. RMS and payload POR attitudes (pitch, yaw, and roll) are given in this coordinate system.

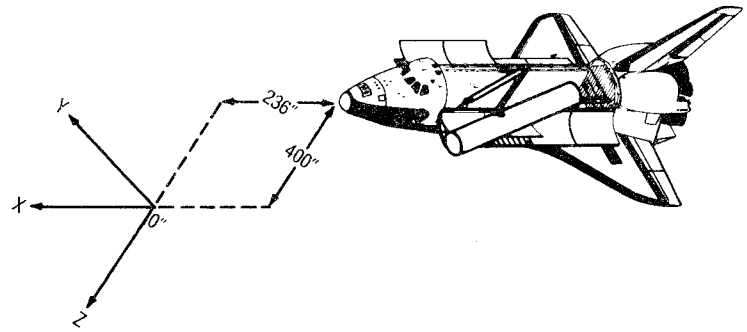


Figure 2-17.– Orbiter body axis system.

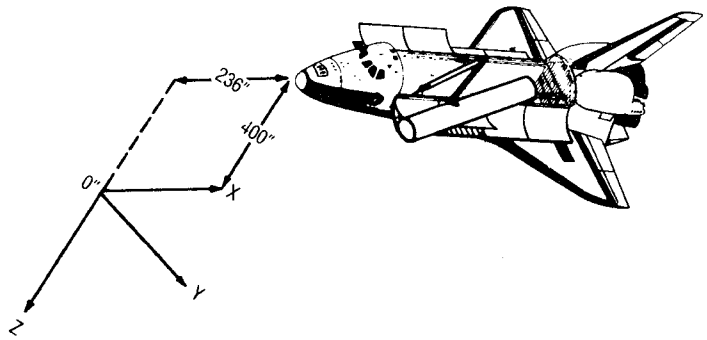


Figure 2-18.– Orbiter rotation axis system.

End Effector Operating System. The end effector operating system (EEOS) (figure 2-19) is fixed with respect to the EE. When the arm is cradled and latched and the MPM is deployed, the EEOS axes are parallel to those of the Orbiter RACS. The EEOS defines the axes along which the EE will move in response to RHC and THC inputs when the RMS is in the EE manual augmented mode.

This mode will be discussed in greater detail later in this workbook.

Payload Coordinate System. The payload coordinate system (PCS) is a right-handed orthogonal coordinate system that defines the axes along which the payload translates and rotates when the RMS is in the manual augmented payload mode. The origin is chosen to be some fixed point on or in the payload (i.e., its center of mass or a specific instrument on the payload surface).

The manual augmented payload mode will be discussed in greater detail later in this workbook.

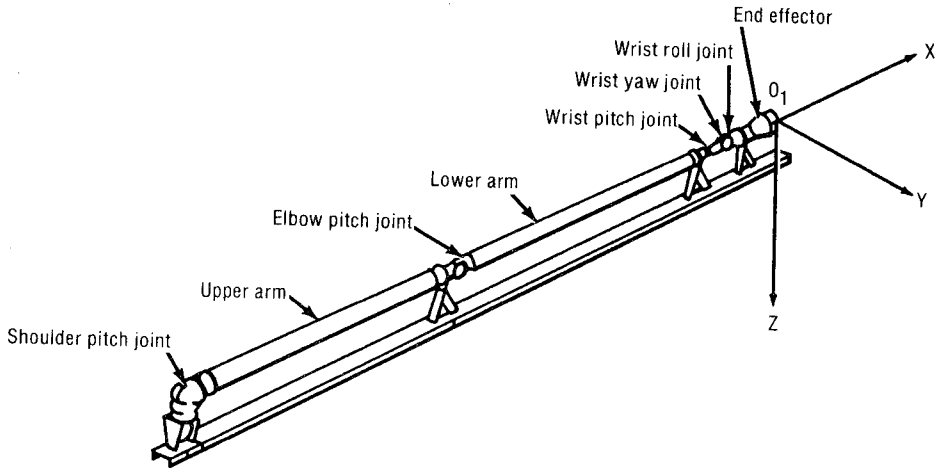


Figure 2-19.– End effector operational system.

Reach Limits

The software also has the capability to warn the operator that the arm is about to reach the end of travel for a particular joint. When a joint has reached its reach limit, the software sets the REACH LIMIT annunciator on the D&C panel and identifies the joint on the cathode ray tube (CRT) display. When a joint crosses a previously defined soft stop limit in forward or backdriving conditions, the arm is brought to rest. The software is capable of bringing the joint to rest before its absolute travel limit, the mechanism stop (hard stop), is reached. The joint travel limits are shown in figure 2-20.

Once a joint has been brought to rest in a soft stop limit, single, direct, or backup mode must be used to drive it out of the soft stop limit. Soft stops are disabled when the arm is in a soft stop and the single mode of operation is selected. If single mode drives the joint into a soft stop, the software will drop into idle mode, and single mode must be entered again to drive the joint out of the soft stop.

Joint	Reach limit	Soft stop	Mechanical stop
Shoulder yaw	+175.4°	+177.4°	+180°
	-175.4°	-177.4°	-180°
Shoulder pitch	+2.6°	+0.6°	+2°
	+140.4°	+142.4°	+145°
Elbow pitch	-2.4°	+0.4°	+2.4°
	-155.6°	+157.6°	+161°
Wrist pitch	-114.4°	-116.4°	-121.4°
	+114.4°	+116.4°	+121.4°
Wrist yaw	-114.6°	-116.6°	-121.6°
	+114.6°	+116.6°	+121.6°
Wrist roll	-440.0°	-442°	-447°
	+440.0°	+442°	+447°

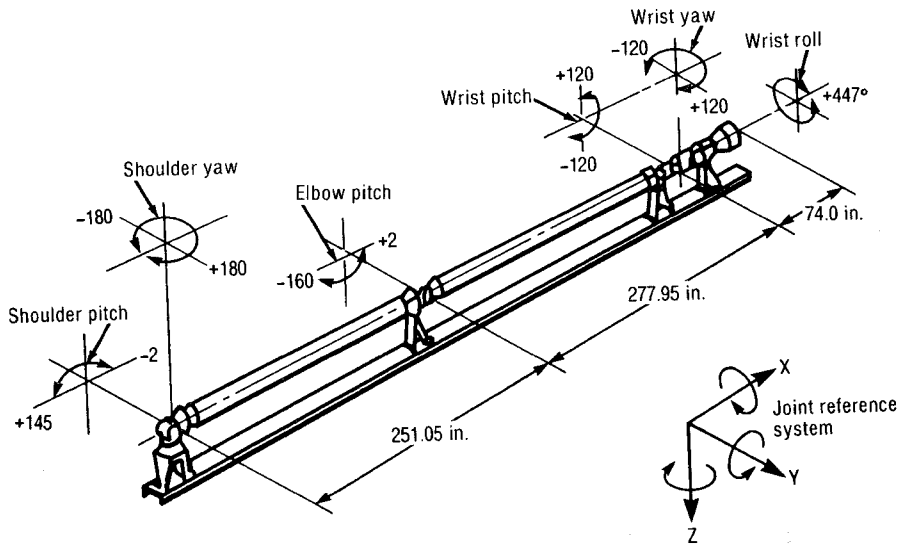


Figure 2-20.–Joint travel limits.

RMS Singularities

The RMS can be driven into a configuration where one or more DOFs of the arm are lost. This condition is referred to as a singularity. The singularities are

- Wrist gimbal lock singularity - This singularity occurs when the wrist yaw joint is at plus or minus 90° (figure 2-21 (a)). A rotational DOF is lost.
- Shoulder yaw singularity - This singularity occurs when the wrist yaw joint is directly over the shoulder yaw axis (figure 2-21 (b)). The DOF lost is the ability to translate perpendicular to the plane containing the booms of the arm.
- Planer pitch joint singularity - This singularity occurs when the wrist pitch, elbow pitch, and shoulder pitch joints are colinear (figure 2-21 (c)). The DOF lost is the ability to translate away from the shoulder joints.

The RMS software is designed to manage these singularities by reconfiguring the joints while driving the arm through them. The arm will reconfigure itself in response to RMS software commands in such a manner as to return the DOF that had been lost. In the course of the arm reconfiguration, the POR's position and attitude remain stationary while the joints move to return the lost DOF.

When the software algorithm detects a singularity, the operator is provided with a caution light on the D&C panel. In response, the operator should monitor the arm for potentially large amounts of movement for collision avoidance reasons.

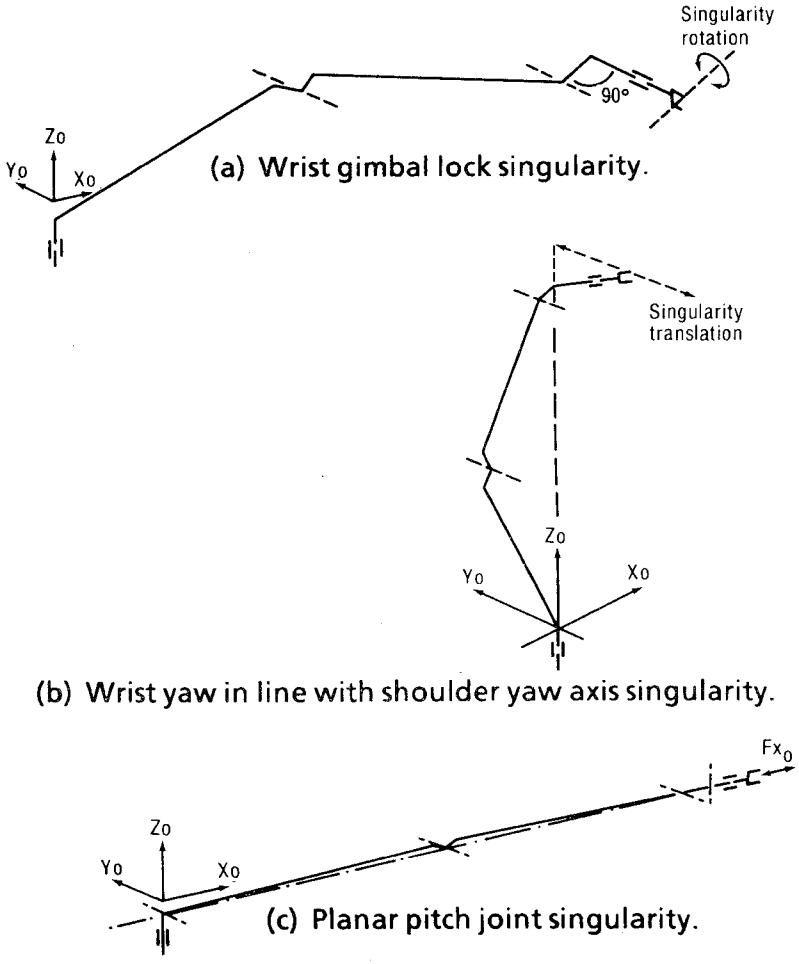


Figure 2-21.– Singularity conditions.

The wrist singularity is annunciated when the wrist yaw is within 15° of the wrist singularity position. Shoulder yaw singularity is annunciated when the wrist yaw joint is within 3 ft of a line drawn through the shoulder yaw axis (vertical). Elbow singularity is annunciated when the elbow is within 5° of the planar pitch singularity position.

Display Singularity

When the arm is being operated in a manual augmented mode, a display singularity exists when the yaw attitude is at 90° or 270°. The display singularity manifests itself by the pitch and roll attitude displays' becoming erratic (often referred to as "dancing"). The digital information is considered to be unreliable when the display singularity is encountered.

Control Modes

The RMS has the following control modes available.

Manual Augmented Control Modes

Manual augmented control modes enable the operator to direct the POR using two hand controllers with three DOFs to provide translation and rotation rate commands. The GPC control algorithms process the hand controller signals into a rate command to each joint of the arm. The operator can carry out manual augmented control of the arm using one of the following control modes:

Orbiter Unloaded. When the Orbiter unloaded mode (figure 2-22) is selected, the POR is defined to be the tip of the EE. Rate commands through the THC will result in motions of the POR that are parallel to the Orbiter body axis coordinate system and compatible with the up/down, left/right, in/out direction of the THC. Commands from the RHC will result in rotation of the POR about the Orbiter rotational axis coordinate system.

The Orbiter unloaded mode is usually used to move the arm when the arm is unloaded (i.e., is not grappled to a payload).

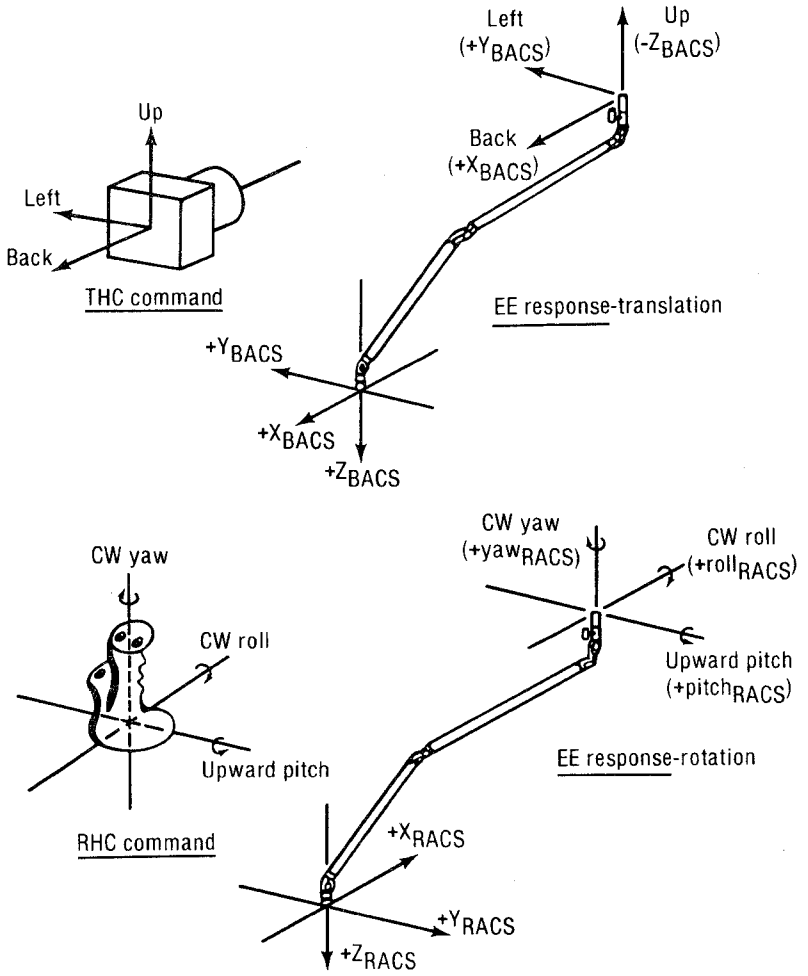


Figure 2-22.– Orbiter unloaded control mode.

End Effector. When the manual EE mode (figure 2-23) is selected, the POR is defined to be the tip of the EE. Commands from the THC will result in motions of the POR that are parallel to the axis of the EE with origin located at the POR. Commands from the RHC will result in rotations of the POR about the axes located at the POR. The EE mode is used primarily for grappling operations. The EE mode is used in conjunction with a wrist-mounted CCTV camera which is oriented with the EE coordinates and rolls with the EE. The scene from the TV camera, presented on a CCTV monitor, will have viewing axes that are oriented with the EE coordinate frame. This orientation results in compatible motion between the rate commands applied at the hand controllers and the movement of the POR in the image presented on the monitor.

Up/down, left/right, in/out motions of the THC will result in the same direction of motion of the EE as seen on the TV monitor, except that the background will move in the opposite direction. The arm operator, therefore, must remember to use a "fly-to" control strategy and apply commands to the THC and RHC that are toward the target area in the CCTV scene.

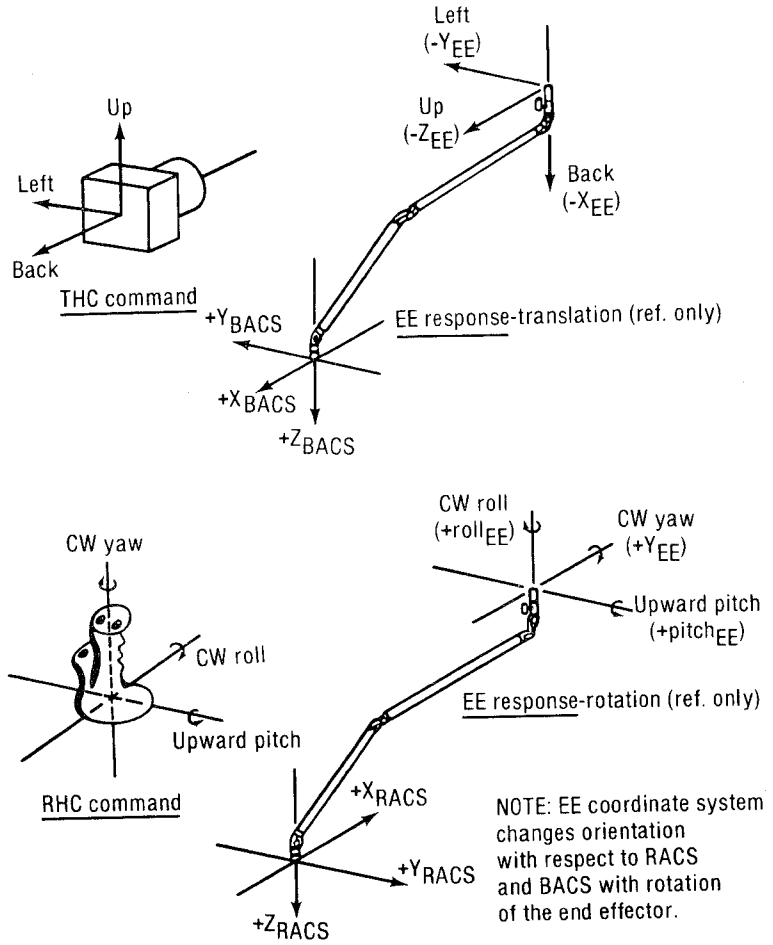


Figure 2-23.– End effector control mode.

Payload. When the manual payload mode is selected, the POR is defined to be a point in space. This point is typically a point within a payload, but it is not restricted to such a constraint. Commands from the THC will result in motions at the POR that are parallel to the coordinate system associated with the POR. Commands from the RHC will result in rotations of the payload about the coordinate system associated with the payload (figure 2-24).

The payload mode is intended to enable the operator to translate and rotate the payload in directions that correspond to the orientation of the payload.

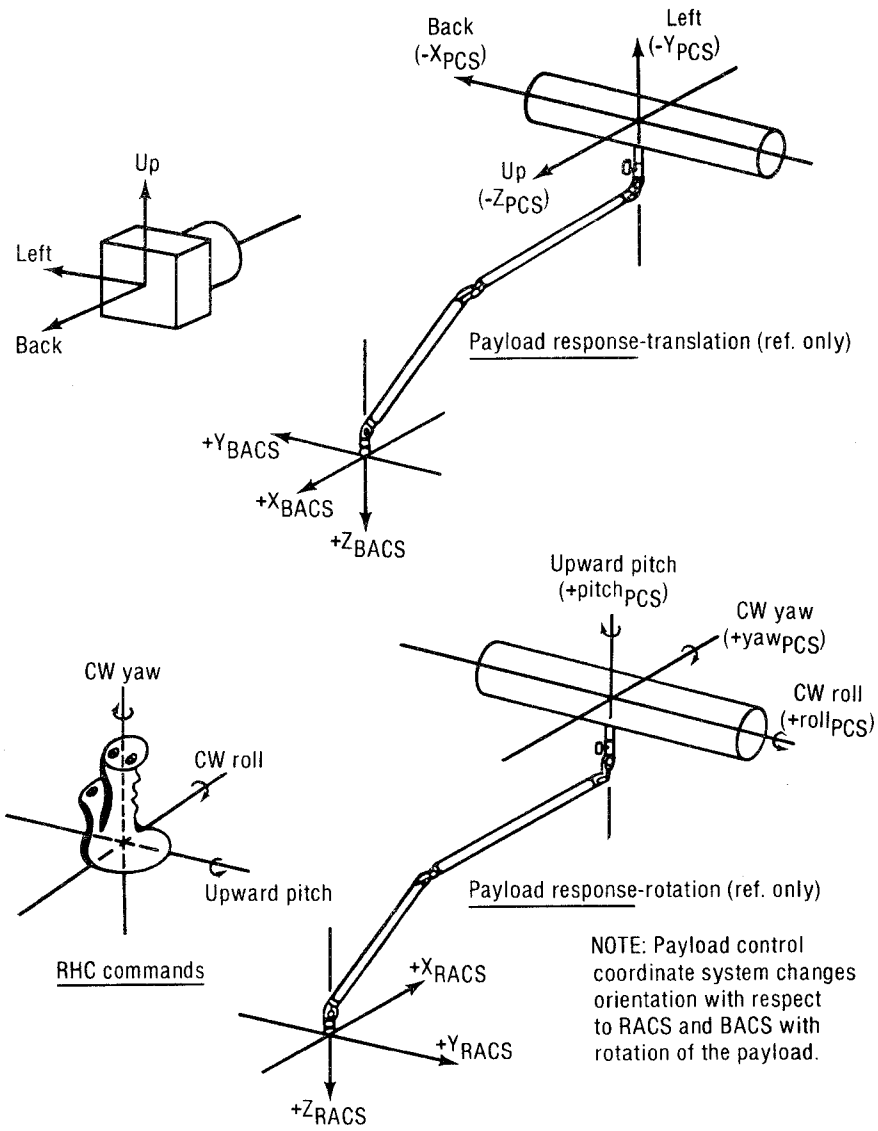


Figure 2-24.– Payload control mode.

Orbiter Loaded. When the Orbiter loaded mode (figure 2-25) is selected, the POR is defined to be a point in space. This point is typically a point within a payload, but it is not restricted to this constraint. Commands from the THC will result in motions at the POR that are parallel to the Orbiter body axis coordinate system. Commands from the RHC will result in rotations at the POR that are about the Orbiter body axis coordinate system.

The Orbiter loaded mode is intended to allow motions of the payload in relation to the Orbiter. This mode is especially useful for berthing and unberthing operations.

Rate Hold. The manual control modes have a rate hold function associated with them. The rate hold function gives the operator the capability to maintain a desired rate command without maintaining inputs from the hand controllers. The rate hold function is accomplished by a pushbutton switch located on the RHC. Some of the features of rate hold are

- Once rate hold has been implemented, additional rate bias can be superimposed by the hand controllers.
- Rate hold is available for both vernier and coarse rates.

The annunciation of rate hold is provided by a flag on the D&C panel.

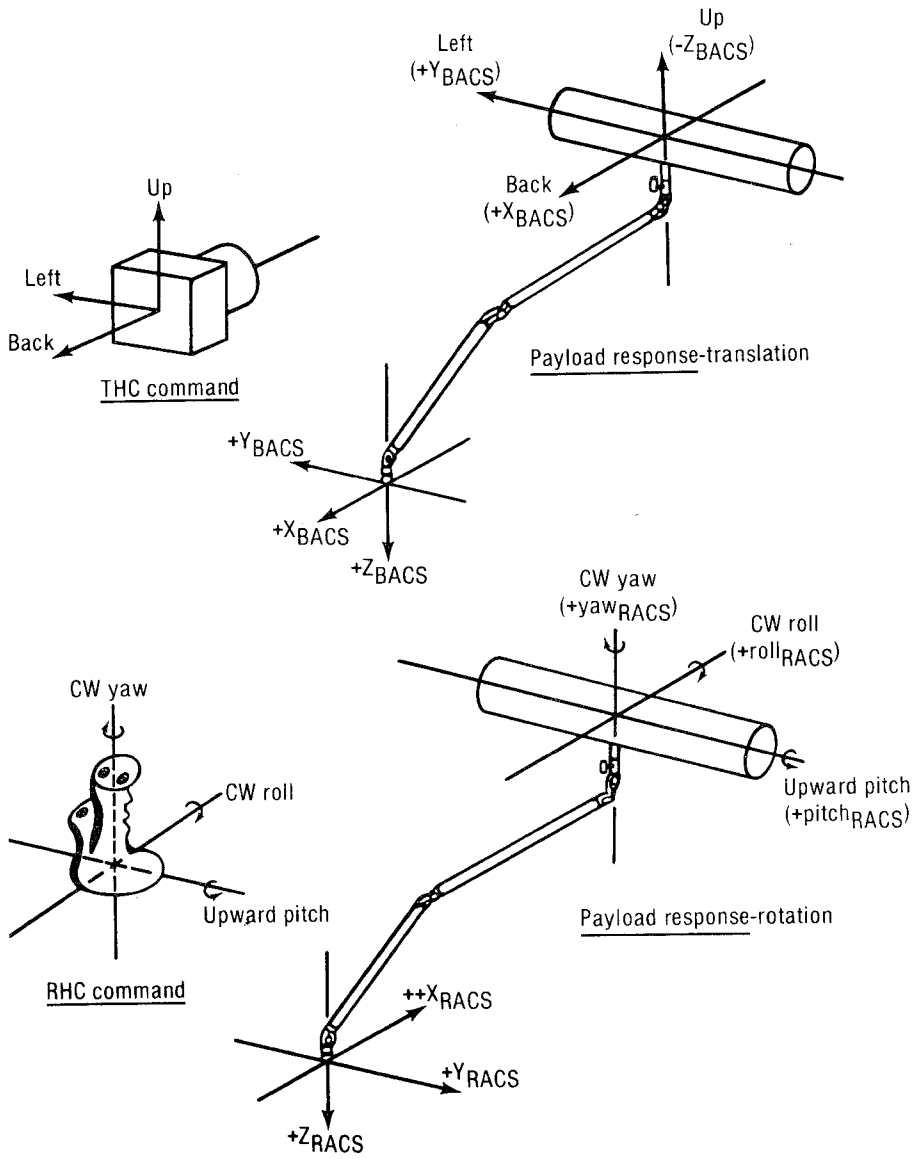


Figure 2-25.– Orbiter loaded control mode.

Automatic Control Modes

There are two types of automatic modes, preprogrammed and operator commanded.

Preprogrammed Mode. The preprogrammed auto mode provides the capability for storing as many as 20 automatic sequences in the GPC. Four of these sequences can be assigned at any one time for selection on the RMS D&C panel. The four sequences assigned to the D&C panel are selected by using a GPC keyboard and the RMS CRT display. Each sequence is given an identification (ID) which is associated with the auto 1, 2, 3, and 4 selections available on the mode switch on the D&C panel.

Each automatic sequence consists of a series of POR positions and attitudes that define a trajectory of motion. The 20 possible sequences may consist of a maximum of 200 points to define the trajectories. Programmed pauses automatically cause the arm to come to rest. Automatic sequences are commanded to start or proceed through the auto sequence PROCEED/STOP switch located on the D&C panel. Likewise, the operator can stop the automatic sequence by placing the PROCEED/STOP switch to STOP. This setting will result in the arm's being brought to rest. The auto sequence may be resumed by placing the auto sequence PROCEED/STOP switch to PROCEED. When the last point in a sequence is reached, the GPC will terminate the movement of the arm. The speed of POR movement between points in a sequence is governed by the limits I-loaded with the auto sequence trajectory and the vernier/coarse select switch.

Operator Commanded Auto Sequence. Operator-commanded auto sequence (OCAS) moves the POR from its present position and attitude to a new position and attitude. The operator defines the new position and attitude to the GPC via the keyboard and RMS CRT display. After the data is keyed in, the operator commands the RMS software to perform a check to verify that the required position and attitude are legal with respect to possible arm configuration and reach envelope. The outcome of the check is displayed on the RMS CRT display. After the check, the operator command mode can be entered and the READY light will be displayed. The operator can execute the auto sequence by placing the auto sequence PROCEED/STOP switch to PROCEED.

The arm operator should be aware that the automatic modes do not check for collision avoidance. Constant visual monitoring of an auto sequence must be maintained. The POR should move in a straight line; however, arm dynamics prevent perfect straight line motion. Any major deviation from a straight line or any potential collision is reason for the operator to terminate the auto sequence. The operator has the capability of stopping and starting an auto sequence through use of the auto sequence PROCEED/ STOP switch.

The following are examples of automatic mode use

- Maneuvering a payload from a location outside the payload bay to its deployment position
- Maneuvering a payload from the capture location to a location just above the payload bay
- Maneuvering a payload to a different location for data taking
- Maneuvering the unloaded arm to the precradle position.

Single-Joint Drive Control Mode

The single-joint drive mode enables the operator to move the arm on a joint-by-joint basis with full GPC support. This mode enables full use of joint drive characteristics on a joint-by-joint basis. The operator supplies a fixed drive signal via a toggle switch on the D&C panel. The GPC then supplies commands to drive the selected joint.

Single mode is used to perform such tasks as

- Stowing and unstowing the arm
- Driving a joint out of a reach limit
- Perigee kick motor (PKM) monitor survey.

Direct Drive Control Mode

Direct drive is a contingency drive mode. The drive commands bypass the MCIU, GPC, and data buses. It provides a direct drive command to the motor drive amplifier (MDA) via hardwires. Since this mode bypasses the GPC, the performance characteristics of the joints are different than for single and manual augmented modes of operation.

Direct drive mode is used when the MCIU or GPC has a problem that requires arm control by the direct drive mode. Direct drive can be used to maneuver a loaded arm to a safe payload release position or to restow an unloaded arm.

Backup Drive Control Mode

The backup drive mode is a contingency mode that is used when the other modes of operation are not available.

The backup drive system is a degraded joint-by-joint drive system designed to meet the fail-safe design requirement.

Backup drive would typically be used to maneuver a loaded arm to a safe payload release position or to restow an unloaded arm.

Vernier/Coarse Rates

The computer supported modes have the capability of selecting two POR velocity ranges, coarse and vernier. Vernier rates allow greater control sensitivity over the movement of the POR. The vernier/coarse selection is accomplished by a two-position thumb switch located on the RHC. The annunciation of vernier select is provided by the MIN rate talkback on panel A8U.

POR State

The state of the POR is available for display on panel A8U and on SPEC 96 when computer supported modes are being used. The POR state consists of position, attitude, translational rates, and rotational rates. This information is dependent upon a reference coordinate system and GPC computations which utilize actual arm joint angles and rates. The relationship of the computer supported modes and reference coordinate systems to the displays is shown in figure 2-26.

Mode	Displayed data			
	POR position (X, Y, Z)	POR attitude (P,Y,R)	POR translation rates	POR rotation rates
Single	BACS	RACS	BACS	RACS
ORB UNL	BACS	RACS	BACS	RACS
ORB LD	BACS	RACS	BACS	RACS
EE	BACS	RACS	EEOS	EEOS
PL	BACS	RACS	PCS	PCS
OPR CMD	BACS	RACS	BACS	RACS
Pre-prog.	BACS	RACS	BACS	RACS
Idle	BACS	RACS	BACS	RACS

Figure 2-26.– Summary of displays used from coordinate systems.

Safing

The arm can be brought to rest by the safing function. Safing can be accomplished by the operator from the D&C panel or by the MCIU upon receipt of certain failure indications.

The two types of safing are MCIU and hardwire. The operator can initiate both types and the MCIU can initiate both types. The GPC is notified of the existence of MCIU safing, but is not aware of hardwire safing.

The MCIU implements safing in response to detected failure conditions. This method is known as auto safing. Both types of safing are maintained until cancelled by the operator; if the condition that initiated safing is still present, of course, safing will again be effected.

Braking

The arm can be brought to rest by using the brakes, a mechanical means of stopping the arm. Braking can be accomplished by the operator from the D&C panel or by the MCIU upon receipt of certain failure indications.

The brakes are manually disengaged by moving the brake switch on the D&C panel to the OFF position. This setting sends a hardwired signal to the brake logic function in the MCIU. The MCIU then commands the brakes to be lifted or removed from restraining the joints on the arm. The operator may reapply the brakes by placing the brake switch in the ON position.

When the brakes are set by the MCIU in response to failure conditions, this form of braking is known as autobraking. The autobraking function may be cleared by cycling the brake switch from off to on and then back to off. However, if the condition causing the autobrakes to trip has not been removed, then the autobrakes will be reset.

Displays: SPEC 94 and SPEC 96

The SM computer contains two PDRS displays. These displays are discussed in the following paragraphs.

SPEC 94

SPEC 94 is a specialist function available in OPS 2 and 4 used to initialize arm operations, provide automatic mode control, and provide a status on the MPM and MRL positions. SPEC 94 is shown in figure 2-27. The functions of the items on the SPEC are discussed in the following paragraphs.

- **RMS SEL** - The manipulator arm that the operator selected for use by the RMS select switch on panel A8L is displayed as either PORT, STBD, or OFF. A blank may also appear. A blank indicates that the RMS software is in suspend mode. This mode occurs when input/output (I/O) has not been established between the GPC and MCIU.

- **PORT - item 1**
  STBD - item 2 - Selects which RMS arm is to be initialized in software and identifies it with an asterisk. When the display is first called, the PORT arm will be selected.

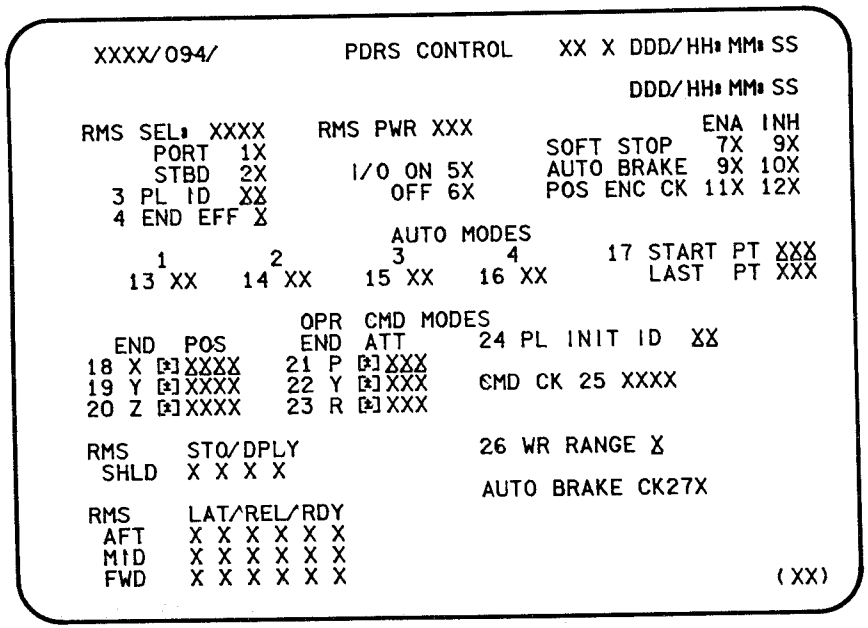


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Figure 2-27.– PDRS CONTROL display.

- **RMS PWR** - The position of the RMS POWER switch on panel A8L is displayed as either PRIMARY, OFF, or BACKUP.

- **PL ID - item 3** - Provides the capability to select the POR to be used during subsequent arm operations. The PORs are identified as 0 through 5. A value of 0 corresponds to an unloaded arm; values of 1 through 5 usually correspond to a POR associated with a given payload. The PL ID will be 0 when the display is first called.

- **END EFF - item 4** - Provides the capability to select the identification number of the EE to be used. Special purpose EEs may be required for specific payloads. The standard EE ID is "1." A special purpose EE is identified as "2." The EE ID will be "1" when the display is first called.

- **I/O - item 5**
  OFF - item 6 - Provides the capability to activate or terminate communications (input/output) between the GPC and MCIU. An asterisk will be displayed to indicate the selection. When the display is first called, I/O will be OFF.

- **SOFT STOP ENA - item 7**
  INH - item 8 - Provides the capability to enable or inhibit the soft stop limit logic. An asterisk identifies the enable or inhibit status of the soft stop limit logic. If the operator is using a computer augmented mode, the soft stop is enabled, and a joint reaches its soft stop limit, the software will drop the arm out of mode, and motion will be discontinued. At this point the joint can only be driven in single, direct, or backup modes. The soft stop limits are identified in figure 2-16. When the display is first called up the soft stop will be enabled.

- **AUTO BRAKE ENA - item 9**
  INH - item 10 - Provides the capability to enable or inhibit the autobrake function. An asterisk identifies the status of the function. Autobraking results from failure of a GPC-conducted test known as the consistency check. The consistency check monitors each joint to assure that the actual joint rate does not exceed the GPC-commanded rates for that joint. The autobrake function was designed to stop arm motion in the event of some dynamic malfunctions of the joint motors. The autobrake function will be enabled when the display is first called.

- **POS ENC CK ENA - item 11**
  INH - item 12 - Provides the capability to enable or inhibit the position encoder check. An asterisk identifies the status of the check. The position encorder check monitors each joint to provide assurance that the measured angular displacement of the joints corresponds to the GPC-calculated understanding of what the joint angular displacement should be. The position encoder check was designed to check the accuracy of each joint position encoder. The position encoder check is enabled when the display is first called.

- **AUTO MODE 1 - item 13**
  AUTO MODE 2 - item 14
  AUTO MODE 3 - item 15
  AUTO MODE 4 - item 16 - These item entries provide the capability to select 4 out of the 20 auto sequences stored in main memory and assign them to AUTO 1 through AUTO 4. The desired sequence is then selected with the MODE switch on panel A8U. When the display is first called items 13, 14, 15, and 16 are defined as 1, 2, 3, and 4, respectively.

- **START PT - item 17** - This provides the capability to select any prestored point in the selected auto sequence to be used as the starting point. Any point (1-199) in the auto sequence may be selected. A blank appears when the display is first called.

- **LAST PT** - Identifies the most recent point reached or passed in an auto sequence as the arm flies the sequence of points. A blank appears when the display is first called.

- **OPR CMD END POS X - item 18**
  OPR CMD END POS Y - item 19
  OPR CMD END POS Z - item 20 - These items allow selection for the final position of the POR when an OCAS is executed. The position is measured in inches in relation to the Orbiter body axis coordinate system. These items will be blank when the display is first called.

- **OPR CMD END ATT P - item 21**
  OPR CMD END ATT Y - item 22
  OPR CMD END ATT R - item 23 - These items allow selection of the final attitude (pitch, yaw, roll) of the POR when the operator-commanded auto sequence is executed. The attitude is measured in degrees in relation to the Orbiter body axis coordinate system in a Euler (pitch, yaw, roll) sequence.

  The item entries must be with the following ranges

  a. Item 21 - Pitch (0° to 359°)

  b. Item 22 - Yaw (0° to 90° or 270° to 359°)

  c. Item23 - Pitch (0° to 359°)

  The item entries are blank when the display is first called up or when an arm is selected.

- **PL INIT ID - item 24** - This item entry allows the selection of the POR to be used by the GPC software for the item 25 command check. A value of 0 corresponds to an unloaded arm; a value of 1 through 5 usually corresponds to a POR associated with a given payload. The item is 0 when the display is first called up. Item 24 must match item 3 for valid entry into the OCAS mode.

- **CMD CK - item 25** - Provides a check that there are valid joint angles available when the POR specified by item 24 is placed in the position and attitude specified by items 18 through 23. When item 25 is executed and if valid joint angles exist then GOOD will be displayed; if valid joint angles do not exist then FAIL will be displayed. Item 25 must display GOOD for entry into the OCAS mode. Item 25 is blank when the display is called for the first time, an arm is selected, or when any of items 18 to 23 are changed. The operator must also be aware that a GOOD indication does not verify a safe trajectory. Collision avoidance is the responsibility of the operator.

- **WR RANGE - item 26** - The wrist has the capability to roll two and one-half full revolutions. This item provides the capability to correct the value of the wrist roll range in the event the GPC software should lose the correct value; this could happen if the wrist joint is rolled 360° while in backup mode. The following are the quadrants associated with each number 1 through 6:

Quadrant WR range ID	WR angle (degrees)
1	-450 to - 360
2	-360 to - 180
3	-180 to - 0
4	0 to + 180
5	+180 to + 260
6	+360 to + 450

The wrist roll range value is 4 when the display is first called up.

- **AUTO BRAKE CK - item 27** - Execution of this item verifies that the autobrake circuitry will apply the brakes. It does not verify the consistency check which is used as the criterion to initiate auto braking. An asterisk indicates selection. To reset the autobrakes, the brake switch on panel A8U must be cycled ON and OFF. The brake switch should be OFF while performing this check.

- **RMS SHLD STO/DPLY** - Identifies the stowage/ deployment status of the shoulder MPM. These items will be discussed in section 3 of this manual.

- **RMS LAT/REL/RDY: AFT, MID, FWD** - Identifies the latch/release /ready for latch status of the MRL's. These items will be discussed in section 3 of this manual.

SPEC 96

The PDRS STATUS display, SPEC 96, is a display available in SM OPS 2 and 4. This display provides information on the POR commanded and actual rates, position, attitudes, and RMS faults. SPEC 96 is shown in figure 2-28. The data presented on the SPEC are discussed in the following paragraphs.

- **RMS SEL** - The manipulator arm that the operator selected for use by the RMS select switch on panel A8L is displayed as either PORT, STBD, or OFF. A blank may also appear. A blank indicates that the RMS software is in suspend mode. This mode occurs when I/O has not been established between the GPC and MCIU.

- **TRANS RATES ACT**
  TRANS RATES CMD - Displays the actual and commanded translational rates of the POR. The rates are resolved into components along the X-, Y-, and Z-axis. The translational rates are given in feet per second with respect to the coordinate system applicable to the control mode selected. The status column after the actual rates will display an M to indicate missing data, as when the arm is not selected or I/O is off.

- **ROT RAT ACT**
  ROT RATES CMD - Displays the actual and commanded pitch, yaw, and roll rates of the POR in degrees per second. These rotational rates are shown with respect to the applicable coordinate system for the control mode selected. The status column after the actual rates will display an M to indicate missing data.

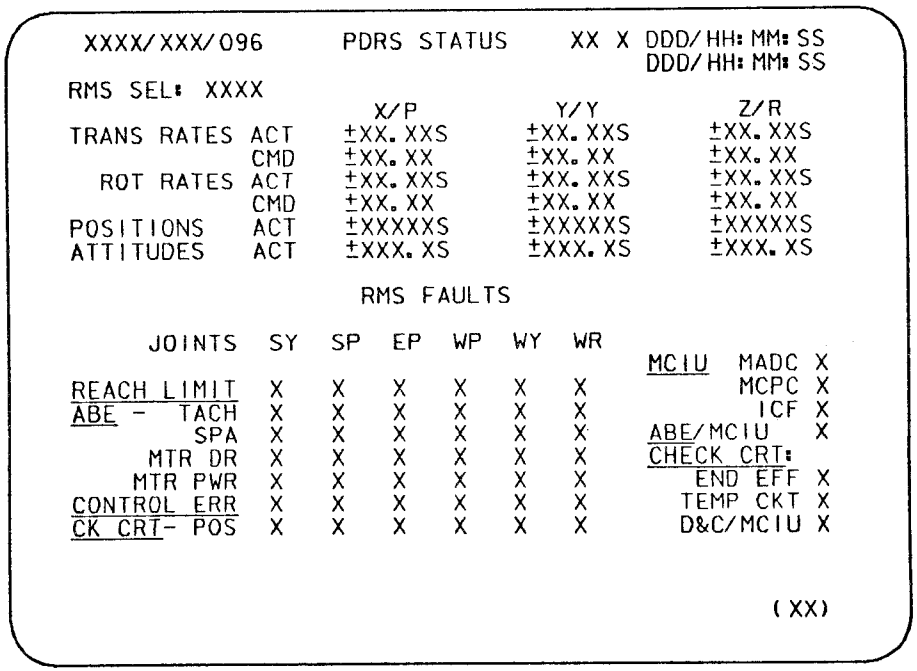

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Figure 2-28.– PDRS STATUS display.

- **POSITIONS ACT**
  ATTITUDES ACT - Displays the actual position and rotational attitudes of the POR, resolving these into components with respect to the Orbiter body axis coordinate system for translations and rotations in inches and degrees, respectively. The status columns display an M to indicate missing data.

- **REACH LIMIT SY, SP, EP, WP, WY, WR** - Identifies by a " + " or "-" the joint that is reaching its travel limit. To avoid continuing in the soft stop, the operator drives the joint in the direction opposite the direction that is indicated. When none of the joints have reached their limits, the status is blank.

- **ABE - TACH SY, SP, EP, WP, WY, WR** - Identifies a joint tachometer failure. A down arrow will be displayed under the affected joint.

- **SPA SY, SP, EP, WP, WY, WR** - Identifies a joint SPA failure. A down arrow will be displayed under the affected joint.

- **MTR DR SY, SP, EP, WP, WY, WR** - Identifies a joint motor drive failure. A down arrow will be displayed under the affected joint.

- **MTR PWR SY, WP** - Identifies a joint power controller failure. A down arrow will be displayed under the affected joint. Only the SY and WP joints can be affected as these joints are the locations for the JPCs.

- **CONTROL ERR SY, SP, EP, WP, WY, WR** - Identifies which joint has a control error. A control error is usually associated with a joint runaway. A down arrow will be displayed under the affected joint.

- **CK CRT - POS SY, SP, EP, WP, WY, WR** - Identifies which joint has an encoder error. A down arrow will be displayed under the affected joint.

Section 2: Review Questions

1. How is the RMS structurally attached to the Orbiter port longeron?

2. How is the RMS deployed and released from the Orbiter?

3. What modes of operation are available?

4. What safety features are available?

5. Suppose the arm has been found to be inoperative during in-flight operations. Subsequent troubleshooting isolates the problem to a faulty MCIU. Would this problem preclude future arm operations?

6. What is the maximum time for an auto capture and rigidization sequence to occur?

7. The arm will be used to unberth a payload. Would the operator normally select vernier or coarse rate to execute this maneuver?

8. An automatic sequence is being executed by the arm and suddenly begins to deviate from the expected trajectory. Should the operator respond?

Section 2: Answers

1. The arm shoulder is attached to an MPM which in turn attaches to the Orbiter. When the arm is cradled, it rests on three MPM pedestals that contain MRLs to secure the arm for launch and entry mission phases.

2. The MPMs are used to roll the arm to and from the deployed position. The MRL's are used to release the arm from the MPMs.

3. The following modes of operation are available:

   a. Automatic modes (operator commanded and preprogrammed)

   b. Manual augmented mode (Orbiter unloaded, end effector, Orbiter loaded, and payload)

   c. Single joint drive mode

   d. Direct drive mode

   e. Backup drive mode

4. The following safety features are available:

   a. Backup modes of operation

   b. Built-in test equipment

   c. Brakes (operator initiated and auto braking)

   d. Safing (operator initated and auto safing)

   e. Jettison system

5. Based upon the information presented so far, the answer to this question is no. The faulty MCIU can be replaced by the spare MCIU. Futhermore, limited operations with the arm would be possible using direct and backup modes of operation. These limited operations would, in general, be controlled by the flight rules.

6. Maximum capture time = 3 seconds
   Maximum rigidization time = 20 seconds

   Total = 23 seconds

7. The operator normally would select vernier rates because the operator has greater control sensitivity over the movement of the POR.

8. Yes, the operator should respond because the deviation represents an unexpected motion and is indicative of a potential failure or problem within the RMS. The motion may be stopped by any of several possible means which include:

   a. Depressing the AUTO SEQ switch to STOP

   b. Moving the SAFING switch to SAFE

   c. Putting the brakes ON

   d. Deselecting the arm and removing power

These have not been listed in any prescribed order of preference. In general, the preferred order of stopping the arm is controlled by the flight rules.

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Section 3: Manipulator Positioning/Retention Mechanism

Introduction

The MPM is the device that rotates the RMS from its stowed position to its operational position outside the payload bay. The rollout moves the stowed arm out of the deployment envelope of a full-sized payload. Prior to closing the payload bay doors, the manipulator arm must be repositioned to its stowed position, or else it interferes with the closing of the payload bay doors (figure 3-1).

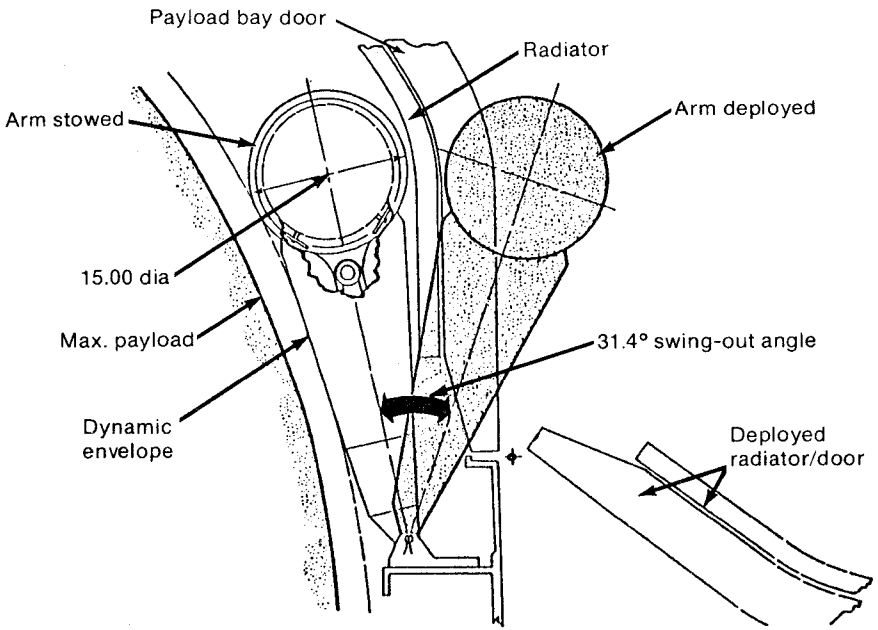

Figure 3-1. – RMS/MPM envelope.

The MRLs secure the arm to the MPM to take the launch and entry loads. If the arm cannot be restowed, a jettison system can be used to separate the arm from the MPM.

Performance data and limitations associated with the MPM/MRLs are contained in appendix B.

Systems Description

The manipulator positioning/retention mechanism is composed of the following major system components.

Support Assembly

The support assembly is the cradling unit upon which the arm rests in the stowed position and that provides housing for the separation system. There are four support assemblies as shown in figure 3-2.

- The shoulder attach point located at an Orbiter X-value of 679.5. The support assembly at the shoulder attach point is unique. Since the RMS is attached to the Orbiter at this point, it does not contain an MRL but does contain a separation system that is part of the MPM.

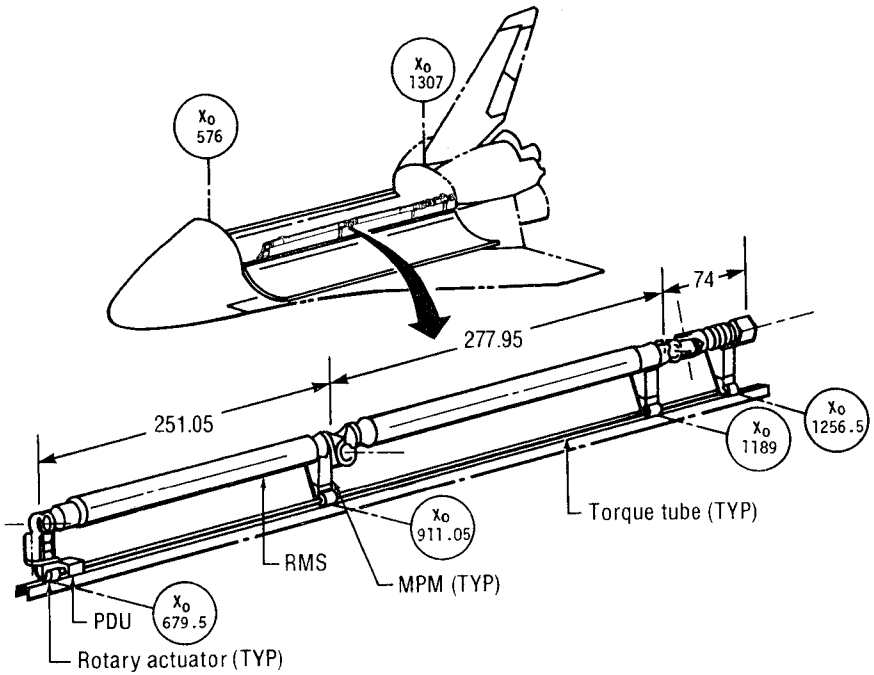

Figure 3-2. – RMS support assemblies.

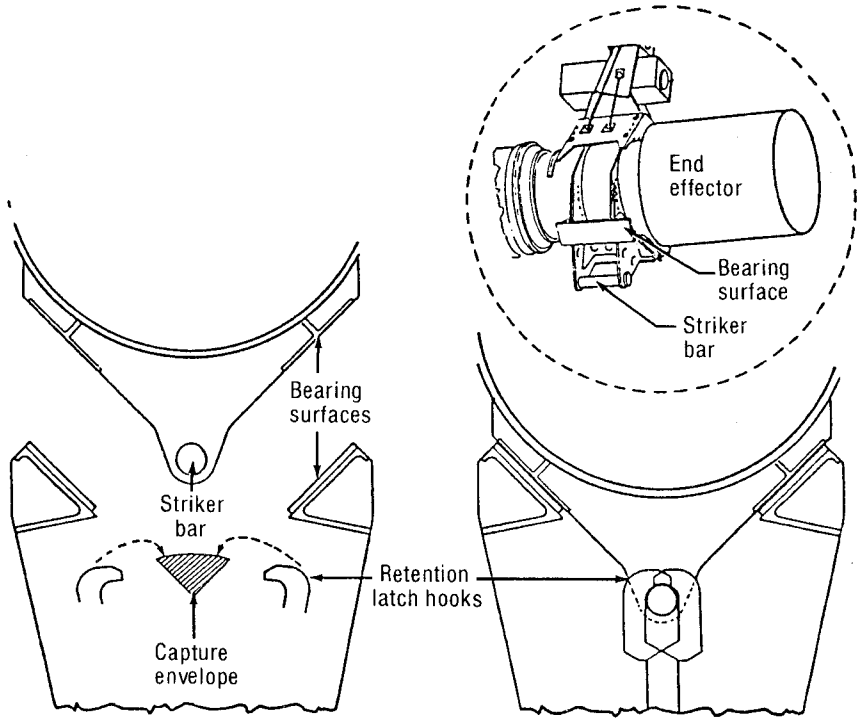

Figure 3-3. – RMS retention mechanism.

- Three retention supports are located at X-values of 911.05, 1189, and 1256.5. The three arm support assemblies are similar. Each retention support contains two 45° saddle interfaces for cradling the arm and a retention latch to lock the arm in place. (Refer to figure 3-3.) The mating hardware for the arm consists of two 45° mating plates to rest on the support saddle and a latch striker which is held by the retention latch.

The support assembly also contains redundant sensors to indicate ready-to-latch and latched/release conditions.

MPM Drive System

The MPM drive system rotates the arm outboard from its stowed position. The drive system consists of dual redundant motors rotating a torque tube that in turn drives the rotary actuators that move the RMS pedestals. The drive mechanism is an overcenter device that is overcenter locked when the arm is in either the stowed or deployed positions. The drive system contains sensors needed for stow/deploy indications.

MRL System

The manipulator arm is latched in three locations (aft, mid, and forward) along the Orbiter longeron to secure it for launch and entry loads. The retention latches are dual rotating surfaces that are driven by redundant motors. When the three ready-to-latch indications are received, the operator commands LATCH and the retention hooks catch the latch strikers on the RMS and secure it firmly in place. The three latches are controlled by one switch. The MRL system contains sensors which are needed for ready-for-latch, latched, and released indications.

Jettison System

If the manipulator arm cannot be restowed for any reason, it can be jettisoned so that the payload bay doors can be closed. There are four separation points: one at the shoulder and one at each of the three retention supports. Each of the separation points is individually actuated.

The shoulder attach point has a wire bundle that must be separated prior to the shoulder support's being separated. The wire bundle is severed by a redundant pyro-operated guillotine (see figure 3-4) prior to the activation of the support jettison system.

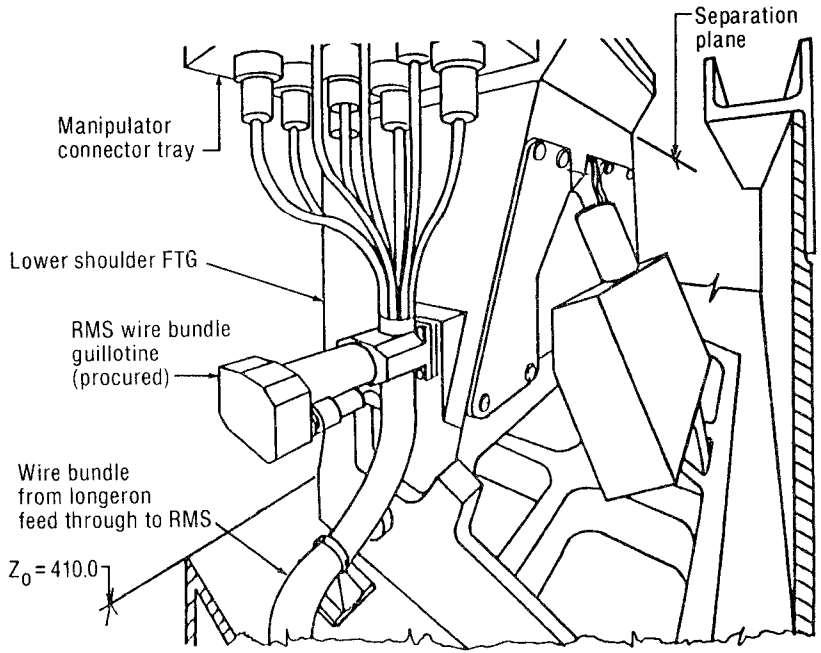

Figure 3-4. – RMS shoulder wire bundle.

The jettison system works by redundant pressure cartridges firing to force down a retractor that pulls back four overcenter tie-down hooks (figure 3-5), releasing the arm at the shoulder joint support or at one of the arm retention supports, depending upon which switch is activated.

The separation system is designed to impart minimum impulse velocity to the RMS.

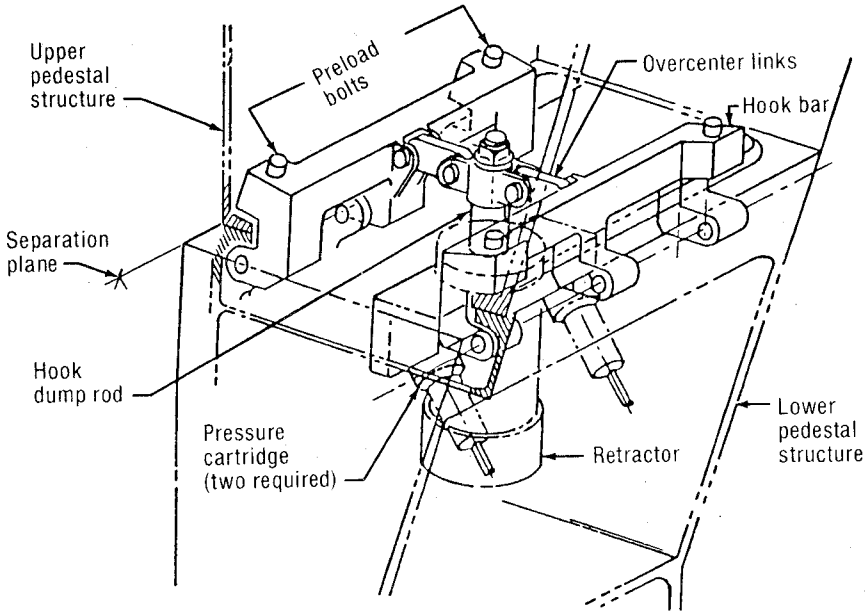

Figure 3-5. – Jettison system.

Displays and Controls

MPM/MRL D&C Panel

The D&Cs associated with the MPM/MRLs are found on panel A8L (refer to figure 3-6). The following paragraphs briefly state the purposes of the MPM/MRL D&Cs.

RMS STOW/DEPLOY Switch and Talkback. The RMS STOW/DEPLOY switch commands the MPMs to roll the RMS into either the deploy position (rolled outboard) or the stowed position (rolled inboard). The talkback indicates the current deploy/stow status of the MPMs as follows:

- STO indicates the MPMs are in the stowed position.
- Barberpole indicates the MPMs are between the stowed and deployed positions.
- DEP indicates that the arm is in the deployed position.

RMS RETENTION LATCHES Switch and Talkback. The RMS RETENTION LATCHES switch releases the MRL's. The talkback indicates the current release/latch status of the MRL's as follows:

- LAT indicates that the MRLs are latched.
- Barberpole indicates that MRLs are between latched and release.
- REL indicates that the MRLs are released.

READY FOR LATCH Talkbacks. These talkbacks indicate that the arm is currently in position for the MRL to latch the arm to the MPM as follows:

- Gray indicates ready for latch.
- Barberpole indicates not ready for latch.

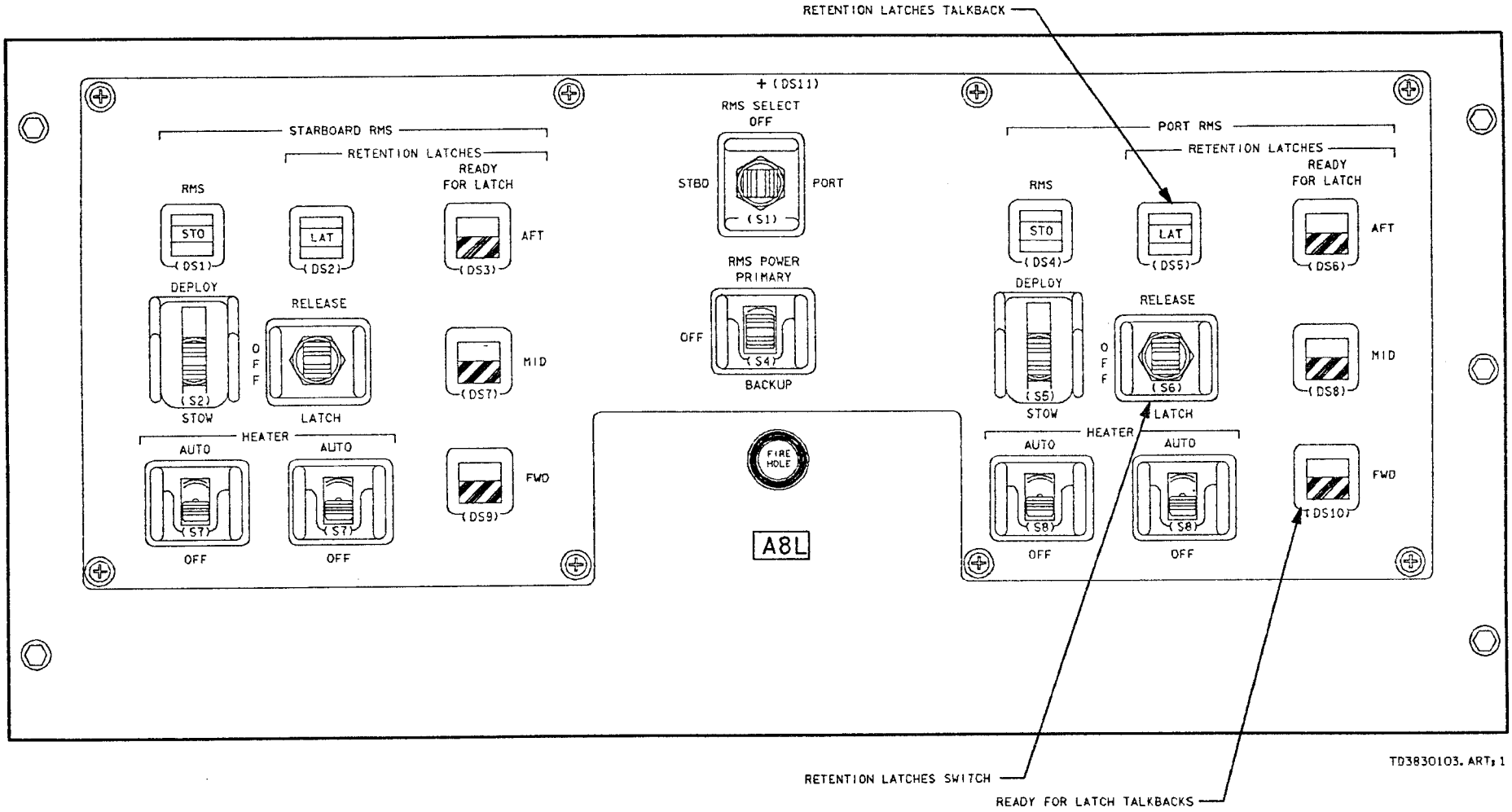

Figure 3-6. – Panel A8L.

Display: SPEC 94

RMS SHLD STO/DPLY - Identifies the stowage/deployment status of the shoulder MPM. The output of four microswitches is displayed; two are redundant stowage indications and the remaining two are redundant deployment indications. A "1" will be displayed for each microswitch that is activated and a "0" for each microswitch that is not activated.

RMS LAT/REL/RDY: AFT, MID, FWD - Indicates that the RMS retention latches are in a latched or released position and if the arm is in a ready-for-latch position. Each of the three latches (aft, mid, and fwd) has redundant microswitches for each of these positions. A "1" will be displayed for each microswitch that is activated and a "0" for each microswitch that is not activated.

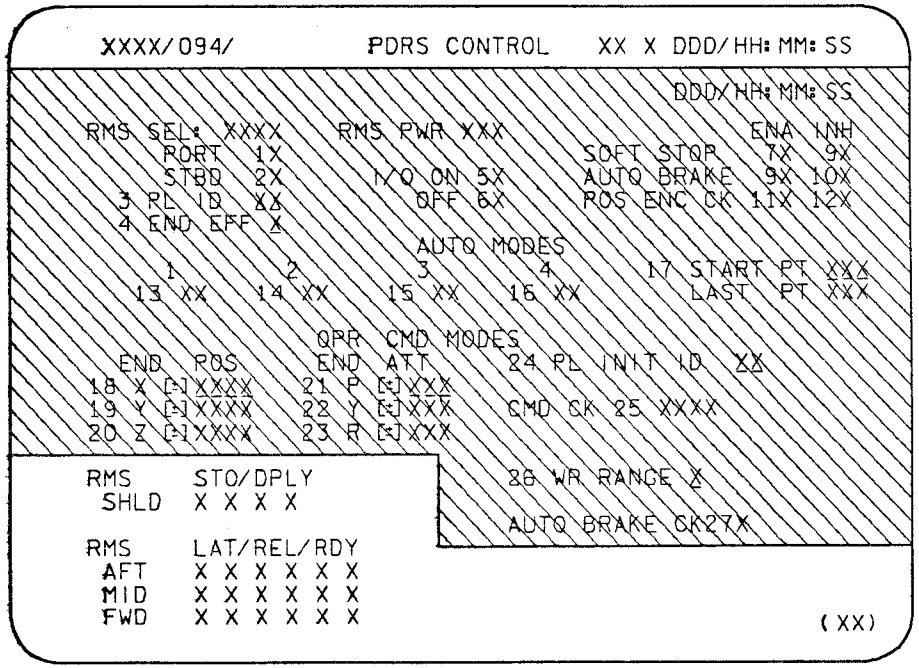

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Figure 3-7. – PDRS CONTROL display.

Jettison System

The D&Cs associated with the jettison system are located on panel A14 (figure 3-8). The following paragraphs briefly discuss the purposes of these D&Cs.

PYRO PORT RMS ARM leverlock switch. This is a three-position switch that performs the following functions:

- JETT - The JETT switch position arms the port RMS jettison circuitry.
- SAFE - The SAFE switch position disables both the guillotine and jettison circuitry.
- GUILLOTINE - The GUILLOTINE switch position arms the port RMS guillotine circuitry.

PYRO PORT RMS SHLDR leverlock switch. This is a three-position switch that performs the following functions:

- JETT - The JETT switch position issues the command to jettison the port RMS shoulder. This command causes the shoulder joint to be mechanically severed from the shoulder MPM. The PYRO PORT RMS ARM switch must be in the JETT position.
- SAFE - The SAFE switch position opens the jettison logic circuitry for the port arm shoulder joint.
- GUILLOTINE - The GUILLOTINE switch position issues the command to guillotine the port arm wire bundles at the shoulder joint. This command causes the wire bundles to be severed. The PYRO PORT RMS ARM switch must be in the GUILLOTINE position.

PYRO PORT RMS LATCHES (FWD, MID, AFT) leverlock switches. These are three-position switches that perform the following functions:

- JETT - The JETT switch position issues the command to jettison the port RMS pedestals. This command causes the latches to be mechanically severed from the MPMs. The PYRO PORT RMS ARM switch must be in the JETT position.
- SAFE - The SAFE switch position opens the jettison logic circuitry for the latches.
- GUILLOTINE - The GUILLOTINE switch position issues the command to guillotine the port arm wire bundles at MPMs. This command causes the wire bundles to be severed. The PYRO PORT RMS ARM switch must be in the GUILLOTINE position.

RMS LATCHES leverlock switch. The RMS LATCHES leverlock switch performs the following functions:

- GND RESET - The GND RESET switch position resets relays in the retention latches. This operation may be performed during ground operations only; the relays cannot be reset in flight.
- SAFE - The SAFE switch position removes power from the ground reset and deadface circuits.
- DEADFACE - The DEADFACE switch position deadfaces the three retention latches electronics. This action removes electrical power from the MRLs.

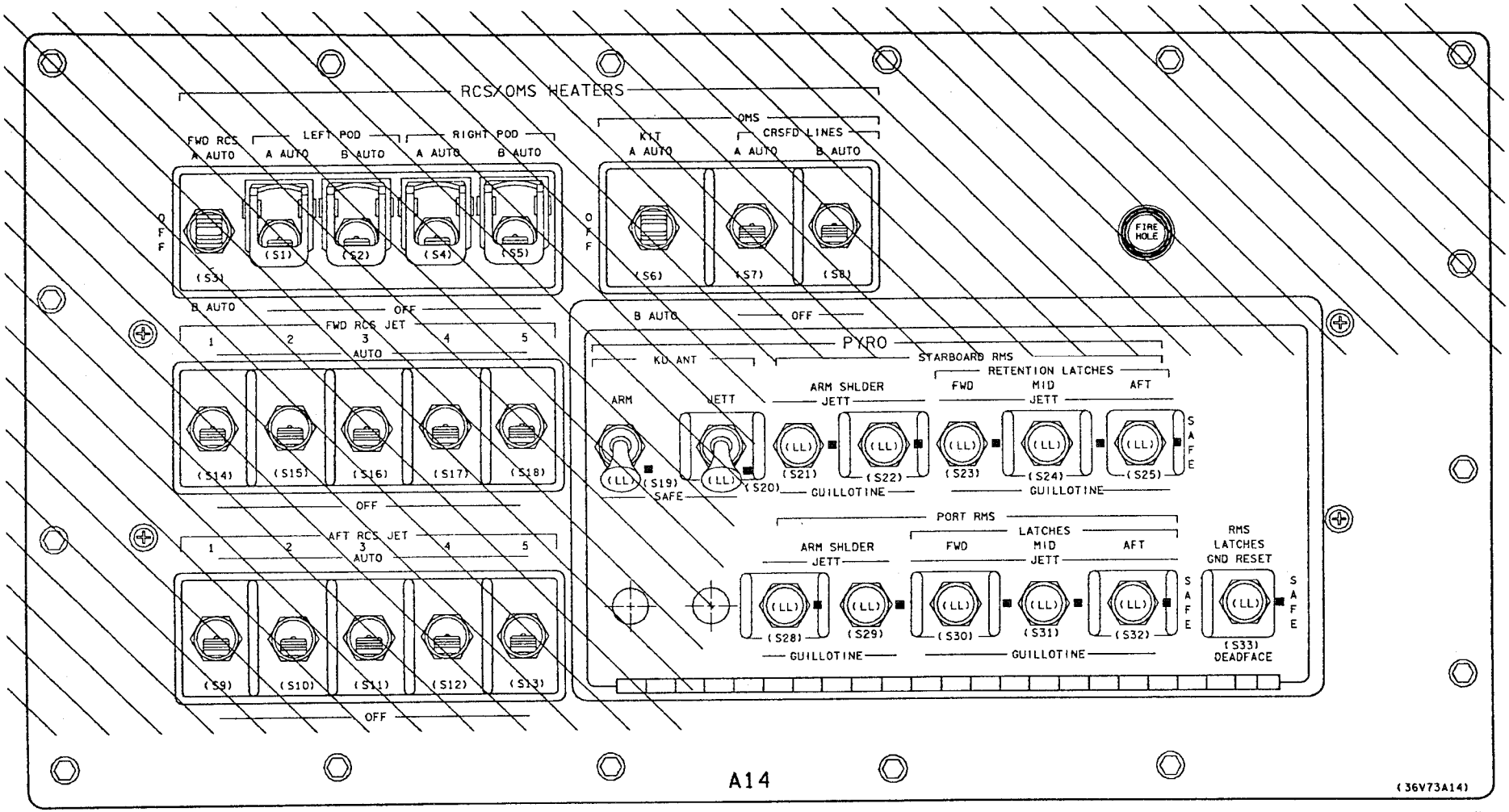

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Figure 3-8. – Panel A14.

Section 3: Review Questions

1. Would the MPMs bind and/or twist the arm if the aft MPM jams during arm rollout operations?

2. What would you expect to do if a captured payload could not be released in EE auto mode, EE manual mode, or backup payload release mode?

Section 3: Answers

1. The arm would not bind and/or twist because all the MPMs are driven by a single torque tube. In the event that one MPM jams, all MPMs will stop moving.

2. Under this set of circumstances, the arm could not be restowed and the payload bay doors closed with the payload still attached. The capability exists for the flight crew to jettison the arm with the payload still attached.

Section 4: Payload Retention Mechanisms

Introduction

Payload retention latches secure the payload in the Orbiter payload bay. Longeron and keel latches are provided by the Orbiter. Special retention devices may be supplied by the customer. Only the Orbiter payload retention system will be discussed here.

Nondeployable payloads are secured by bolted passive retention devices. Deployable payloads are secured by motor-driven active retention devices.

Systems Description

The Orbiter payload retention system uses active latches installed on bridge fittings that, in turn, are attached to the cargo bay frame to secure the payload to the Orbiter (figure 4-1). Switches located on the D&C panel open or close the active latches to secure the payload trunnions.

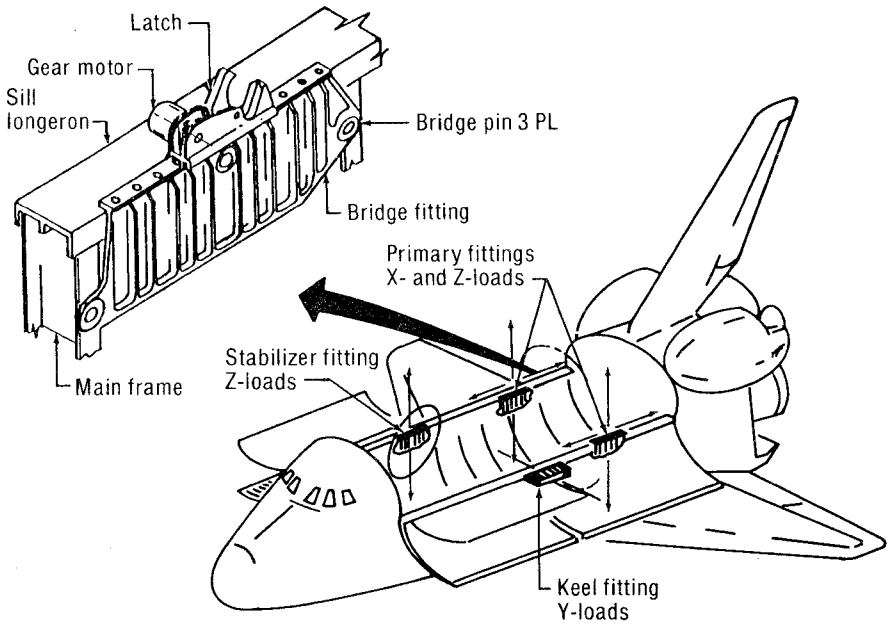


Figure 4-1. – Active payload retention system.

Bridge Fittings

The bridge fittings are the interface between the payload latches and the Orbiter cargo bay frame. There are 13 longeron bridges per side and 12 keel bridges available per flight. Only the bridges required for a particular flight are flown. The bridges are not interchangeable because of main frame spacing, varying load capability, and subframe attachments.

Latches

There are normally three or four longeron latches per payload. Two primary latches are required to take the X- and Z-loads, and one or two stabilizing latches are required to take Z-loads. The stabilizing latches float free in the X-X direction.

The latches are driven by dual redundant electrical motors (figure 4-2). The switches that operate the latches are the maintain type. Each longeron latch has two microswitches which sense the ready-to-latch condition. These microswitches are actuated by the payload trunnion and function so that if either switch works, the ready-to-latch flag for that latch on the D&C panel will function. Microswitches, two to indicate latch and two to indicate release, are associated with each latch. These microswitches are activated by the motor drive mechanism. The latch/release switch on the D&C panel can activate a number of latches, depending upon how they are wired together prior to launch. The latch/release talkback on the D&C panel requires at least one switch indication, of latch or release, from each of the latches that are tied together in order to make the talkback operate.

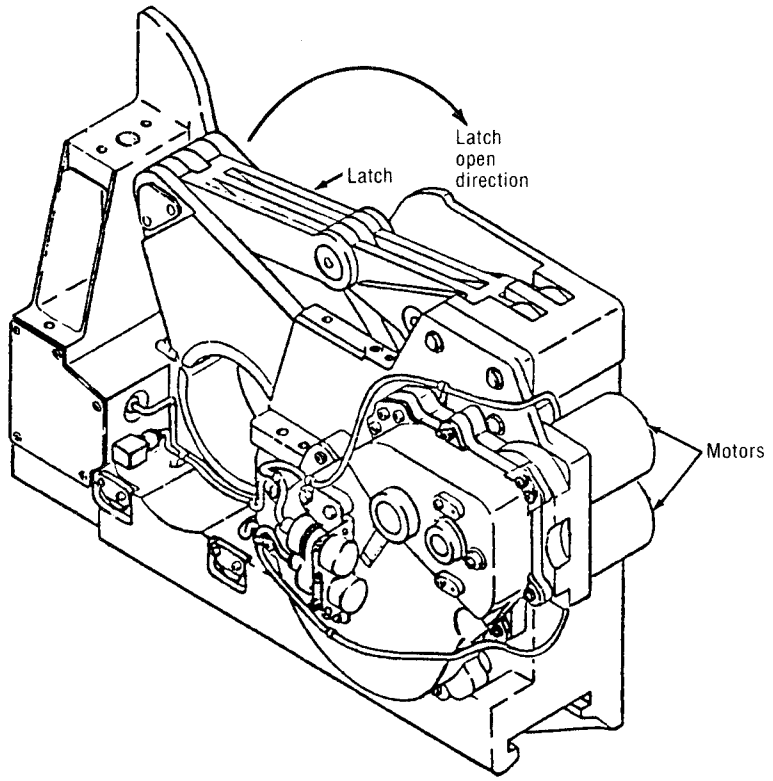


Figure 4-2. – Payload retention latch.

A payload may also require a keel latch that takes the side loads (figure 4-3). The keel latch has two microswitches to indicate whether the latch is open or closed. Either one of these switches can operate the latch/release talkback on the D&C panel. There is also a set of microswitches that senses when the keel latch is closed with a trunnion in it. Either of these switches can operate the talkback on the D&C panel.

The keel latch centers the payload in the cargo bay when it closes; therefore, the keel latch must be closed prior to closing the longeron latches since it does not have the force to overcome the longeron latches.

Trunnions

The payload trunnions are the portion of the payload that interfaces with the Orbiter payload retention system. The longeron trunnion latches are 3.24 in. in diameter and either 7 or 8.75 in. in length, depending upon where they are positioned along the payload bay. The keel trunnions are 3 in. in diameter and can vary from approximately 4 to 11.5 in. in length, depending upon where they will fit in the bay.

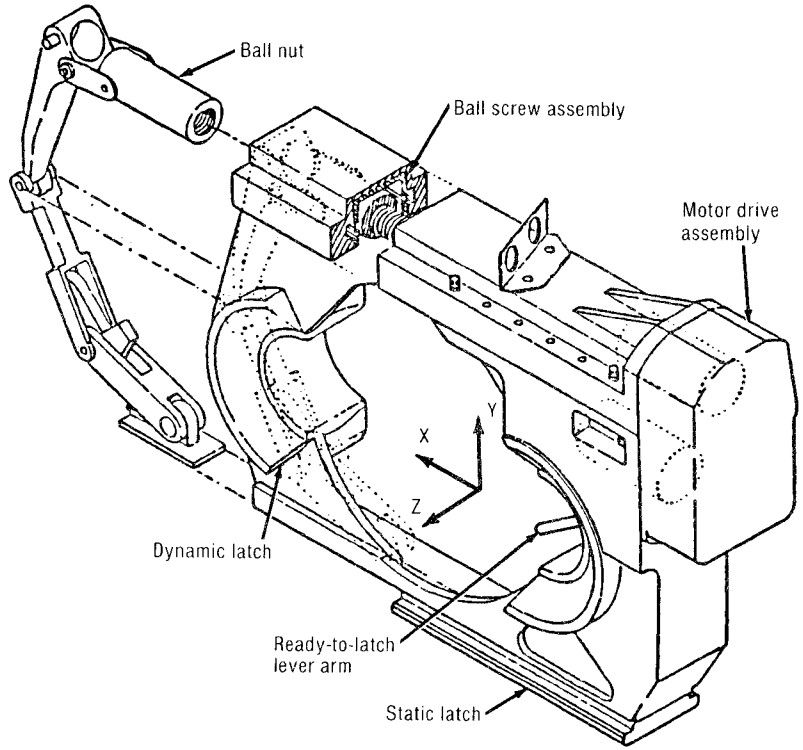


Figure 4-3. – Active keel actuator.

DISPLAYS AND CONTROLS

D&C Control Panel A6

The D&Cs associated with the payload retention system are illustrated in figure 4-4.

PAYLOAD RETENTION LOGIC POWER switch. The PAYLOAD RETENTION LOGIC POWER switch applies power to the retention latch system motors and talkbacks.

PAYLOAD SELECT rotary switch. This switch enables a certain set of latches and sensors to be operated and displayed by the payload retention switches and talkbacks.

PAYLOAD RETENTION LATCHES RELEASE/LATCH switch. This switch commands the payload latches selected by the PAYLOAD SELECT rotary switch to release or latch the payload.

PAYLOAD RETENTION LATCHES talkbacks. These talkbacks indicate the status of the payload latches that are selected to be functional by the PAYLOAD SELECT rotary switch as follows:

- REL indicates that the latches are released or open.
- Barberpole indicates that the latches are between the release and latched positions.
- LAT indicates that the latches are latched or closed.

PAYLOAD RETENTION LATCHES READY FOR LATCH talkbacks. These talkbacks indicate that the ready-to-latch microswitches for a particular latch have been tripped by a payload trunnion.

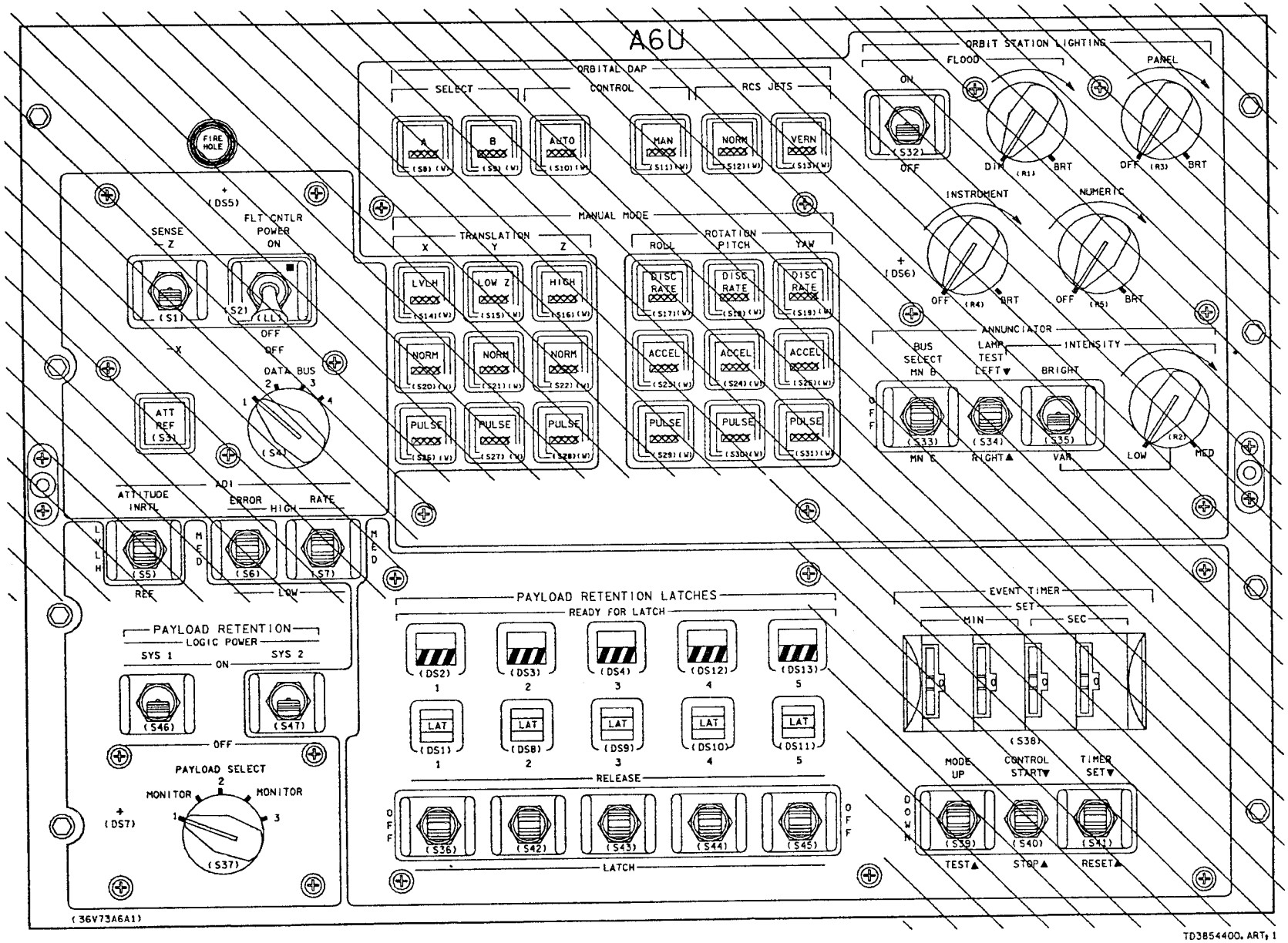


Figure 4-4. – Panel A6.

Display: SPEC 97

The payload retention status display (SPEC 97) is shown in figure 4-5. This SPEC is mission dependent but will use the same format as shown. When the payload is in position to be latched, the RDY fields display "1's"; when the payload is latched, the LAT fields will be "1's" and the REL fields will be "0's." The PL SELECT headings on the display correspond to the talkbacks and PL SELECT switch settings on panel A6.

XXXX/XXX/097 PL RETENTION XX X DDD/MM:MM:SS
DDD/MM:MM:SS

	LATCH 1 AB/AB	LATCH 2 AB/AB	LATCH 3 AB/AB	LATCH 4 AB/AB	LATCH 5 AB/AB
PL SEL 1					
RDY-FOR-LAT	XX	XX	XX	XX	XX
LAT/REL	XX/XX	XX/XX	XX/XX	XX/XX	XX/XX
PL SEL 1					
RDY-FOR-LAT	XX	XX	XX	XX	XX
LAT/REL	XX/XX	XX/XX	XX/XX	XX/XX	XX/XX
PL SEL 1					
RDY-FOR-LAT	XX	XX	XX	XX	XX
LAT/REL	XX/XX	XX/XX	XX/XX	XX/XX	XX/XX

Figure 4-5. – Payload status display.

Section 4: Review Questions

1. What is the minimum number of payload retention latches that would be associated with a deployable payload?

2. Which D&C panel contains the switches that control the active retention system?

Section 4: Answers

1. The minimum number of payload retention latches that are associated with a deployable payload is three. Two primary latches are required to take the X- and Z-loads. A minimum of one stabilizing latch is required to take Z-loads.

2. Panel A6

Section 5: Payload Guides/Scuff Plates

Introduction

The payload guides and scuff plates are used to assist the operator in deploying and berthing payloads in the cargo bay. The payload will be constrained in the X-direction by the guides and in the Y-direction by the scuff plates (figure 5-1).

Interfaces

The payload guides are mounted to the inboard side of the payload latches. The guides interface with the payload trunnions and scuff plates. The scuff plates are attached to the payload trunnions.

Systems Description

The payload guides (figure 5-2) restrain the payload in the X-direction. The guides are V-shaped with one part of the V being 2 in. taller than the other part. This difference in height enables the operator, who is monitoring the berthing or deployment operations through the window views and/or television cameras, to better determine when the payload trunnion has entered the guide. The top of the forward portion of the guide is 24 in. above the center line of the payload trunnion when it is all the way down in the guide. The top of the guide has a 9-in. opening.

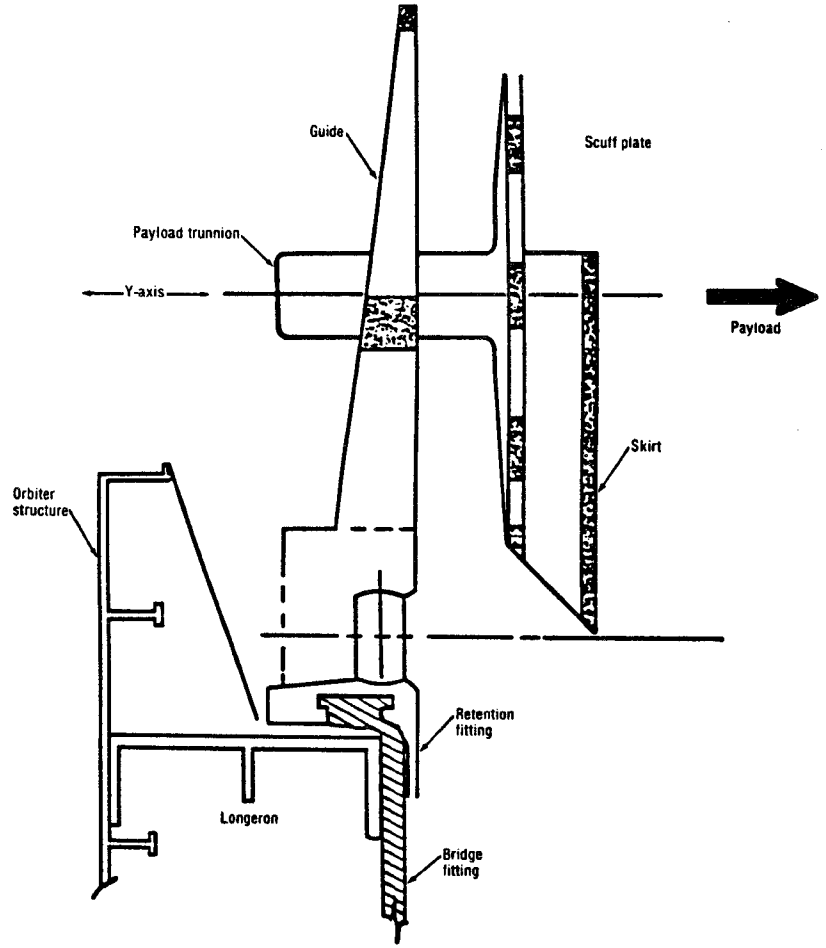


Figure 5-1.– Orbiter payload guide and payload trunnion/scuff plate.

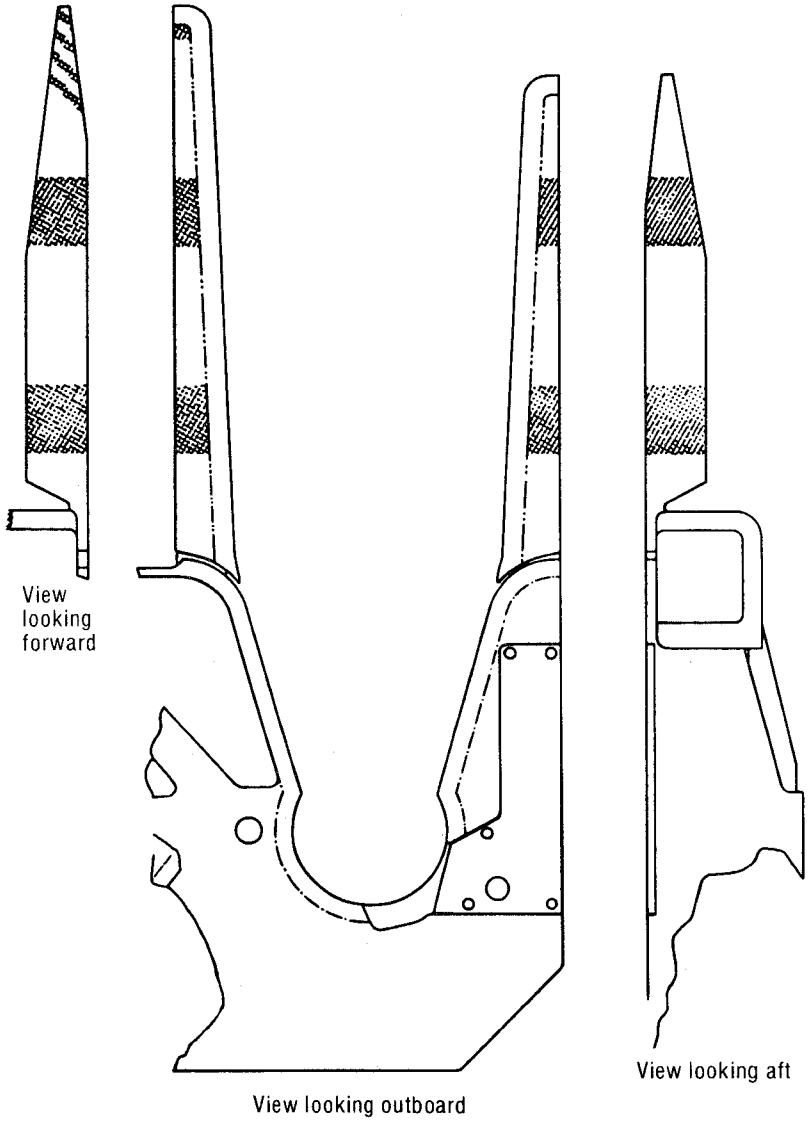


Figure 5-2.– Orbiter active latch guide.

The payload scuff plates restrain the payload in the Y-direction. The scuff plates are mounted to the payload trunnions or to the payload structure. The payload guides and scuff plates interface as shown in figure 5-3.

Displays and Controls

There are no displays and controls associated with the guides and scuff plates.

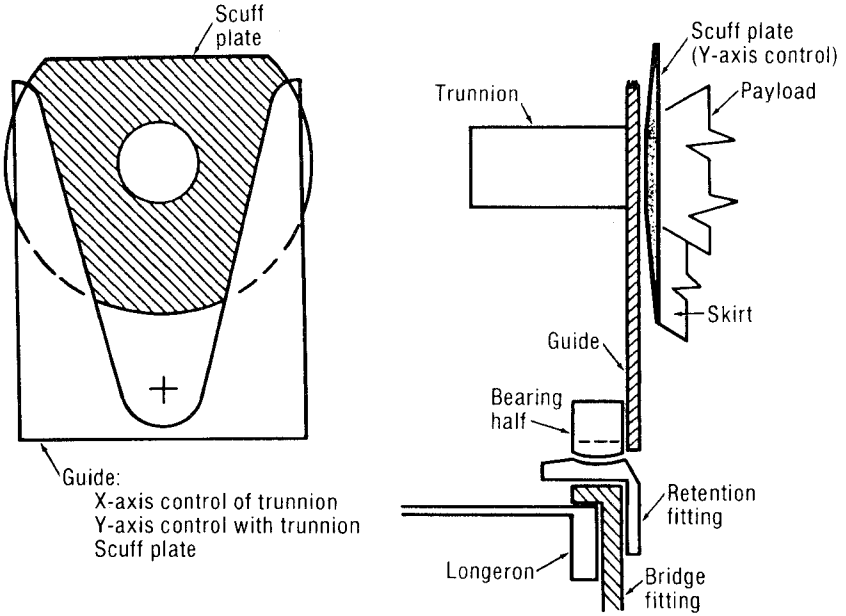


Figure 5-3.– Payload guides, active retention fitting.

Section 5: Review Question

1. The center line of one trunnion of a payload grappled by the RMS is currently at the top of the V-guide . The arm operator is using Orbiter loaded mode. How much freedom is available to move the payload in the Orbiter X-axis?

Section 5: Answer

1. 9 inches - top of V-guide opening

   - 3.24 inches - diameter of trunnion

   5.76 inches - freedom of movement in X-axis

Section 6: Closed Circuit Television System

Introduction

A portion of the CCTV system is used to support PDRS operations. The PDRS operator uses the payload bay TV cameras, arm cameras, TV monitors, video tape recorder (VTR), and TV controls and displays to assist in all phases of the PDRS operations. There are six TV cameras that can be positioned in the following locations, depending upon mission needs, as follows:

- Arm wrist (serial operation with elbow camera)
- Arm elbow (serial operation with wrist camera)
- Forward port bulkhead
- Aft port bulkhead
- Aft starboard bulkhead
- Forward starboard bulkhead
- Keel

Systems Description

The CCTV system supporting PDRS operations is made up of the following equipment:

- TV camera - The cameras used for PDRS operations are black and white cameras. Because of undesirable flicker on the TV monitor, the color cameras normally will not be used.
- Pan/tilt unit - The bulkhead and arm elbow cameras have pan and tilt units.
- All cameras have zoom, iris commands, and gamma stretch capabilities.
- Monitors - There are two black and white TV monitors located on the aft flight deck. The monitors are provided with electronic crosshairs that have both vertical and horizontal components at the electrical center of the image (figure 6-1). The crosshairs are used to align the cameras with targets and sighting aids as well as to align overlays with the monitor image.

The TV monitors are critical in tracking and capturing operations. An overlay (electronic or physical) is used to aid the operator with ranging cues (relative to the EE).

Each monitor is capable of displaying two images simultaneously. The right or left half of the monitor will display the center half of the selected camera scene when the split screen mode is selected on the D&C panel.

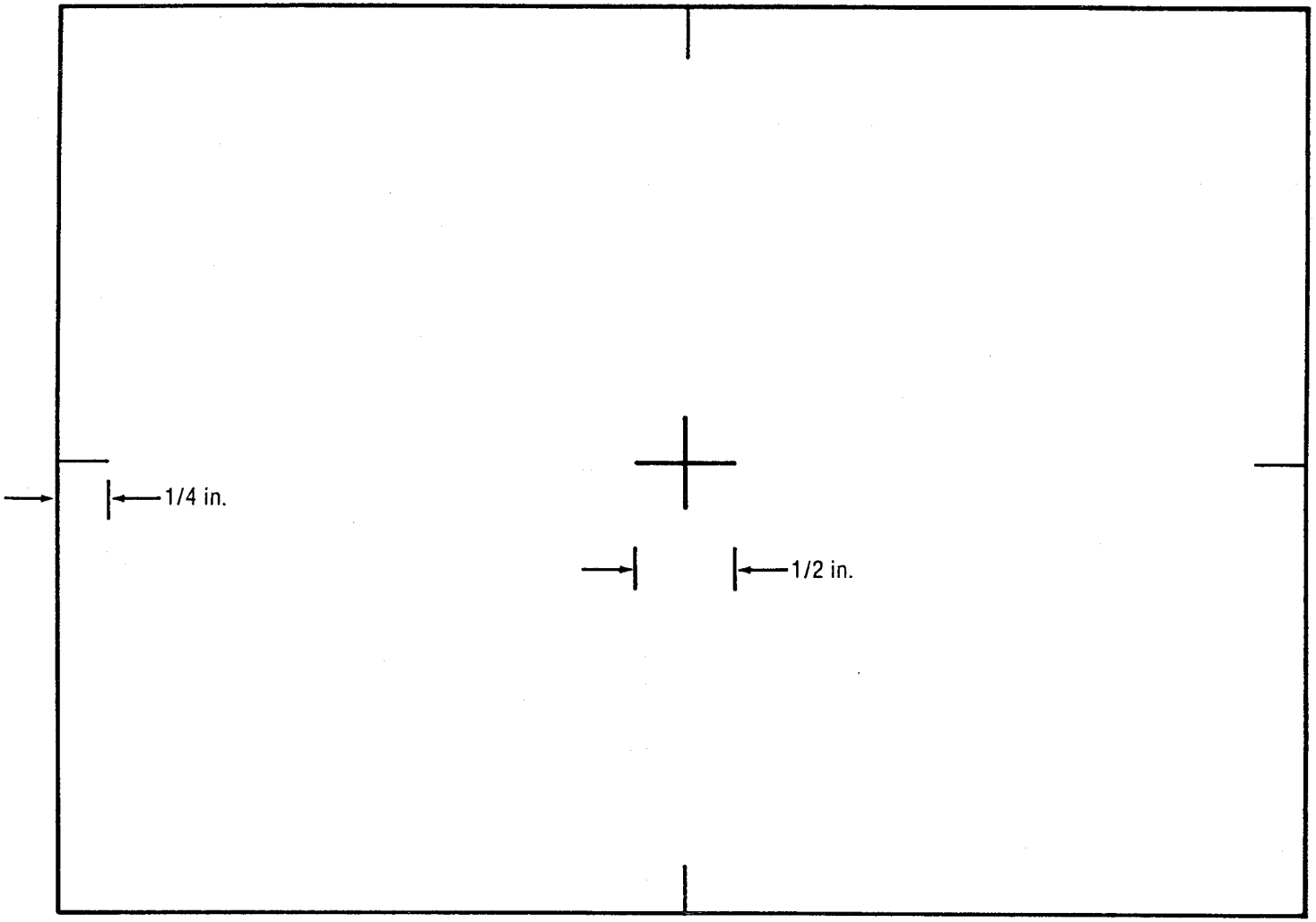


Figure 6-1.- Crosshair pattern.

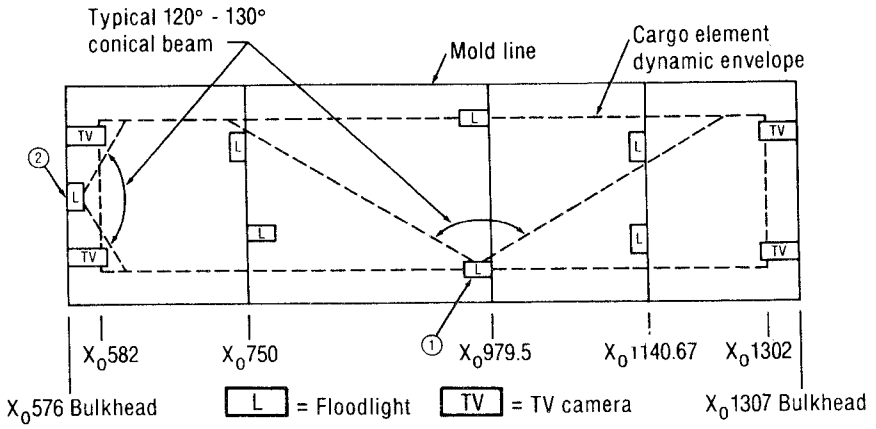
Section 7: Lighting

Introduction

The exterior lighting system is used to provide illumination during PDRS operations. In addition to several cargo bay lights, there is a light attached to the RMS wrist camera assembly.

Systems Description

The position and field of view of the payload bay lights are shown in figure 7-1. The RMS light is shown in figure 7-2. Control of the lights is from panel A7. The forward, mid, and aft (both starboard and port) payload bay floodlights can be individually turned off or on. The docking and forward bulkhead light can be controlled to bright, dim, or off. The RMS wrist light is controlled to ON or OFF.



NOTES

① Six lights mounted outside cargo element dynamic envelope (120° minimum conical beam pointed within approx 5° of normal to cargo bay centerline).

② Forward bulkhead floodlight - 120° conical beam pointed in +X direction penetrates 0.14 by 5.70 diameter into the cargo element dynamic envelope.

Figure 7-1.– Cargo bay light locations.

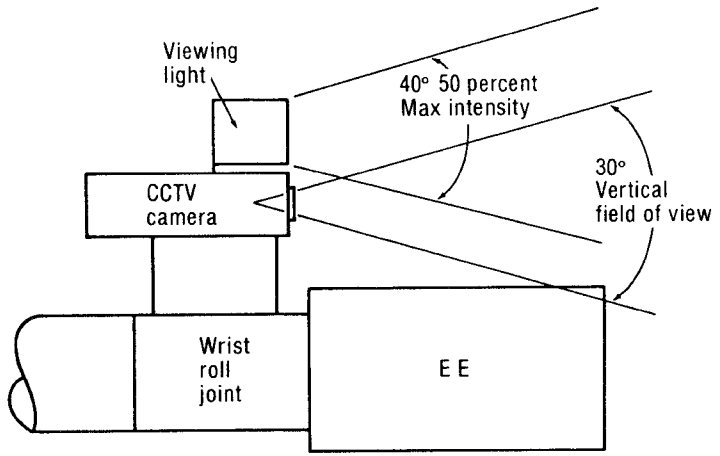


Figure 7-2.– RMS light assembly.

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Appendix A: RMS Component Physical Characteristics

Component	Height, in.	Width, in.	Length, in.	Diameter, in.	Weight, lb	Construction
D&C control panel	19.0	19.22	12.25	-----	54.5	Aluminum panel switches/wiring
MCIU	10.1	7.6	17.7	-----	18.1	Aluminum alloy enclosure
THC	6.5	5.5	9.5	-----	7.0	----------
RHC	7.5	4.0	15.33	-----	9.5	----------
Joint motor modules	-----	-----	6.0	6.4	6.7	Overall metal
SPA	4.8	7	11.2	-----	9.03	Aluminum alloy enclosure
JPC	5.0	5.12	8.93	-----	5.75	Aluminum alloy enclosure
BDA	2.94	8.41	10.88	-----	7.5	Aluminum alloy enclosure
Upper arm boom	-----	-----	251.05	13.5	-----	Graphite/epoxy thin walled tube
Lower arm boom	-----	-----	277.95	13.5	-----	Graphite/epoxy thin walled tube
Thermal blankets	Variable	Variable	Variable	-----	Variable	Beta cloth/Dacron scrim/Kapton
End effector	-----	-----	21.5	13.6	62.24	Light gauge aluminum
EEEU	6.9	5.5	4.6	-----	5.0	Overall metal assembly
Shoulder joint	33.09	13.5	44.9	-----	-----	----------
Elbow joint	21.02	13.51	38.0	-----	127.0	----------
Wrist joint	13.19	19.10	92.47	-----	221.1	----------

System total weight 966 lb

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Appendix B: Systems Performance Data and Limitations

RMS

The RMS is designed to perform in a zero-g environment as outlined below. A more complete listing of RMS performance data and limitations may be found in NSTS 07700, appendix B.

- Deploy or return (without release) up to a 65,000-lb maximum envelope payload from/to payload handling aids.
- Deploy or return (without release) up to a maximum 65,000-lb payload with dimensions (15 ft by 56 ft 10 in.) from/to the payload retention devices that have 24-in. guides.
- Retrieve up to a 32,000-lb maximum envelope payload and place the payload in a position for engaging the payload with payload handling aids.
- Retrieve up to a 32,000-lb payload with dimensions 15 ft by 56 ft 10 in. and place in the payload retention devices that have 24-in. guides.
- With a 32,000-lb payload attached, the maximum driven speed of the EE will not exceed 0.2 ft/sec. At this speed, the RMS can stop the payload within 2 ft.
- The maximum tip speed of the arm is as follows:
  - Unloaded arm, coarse rate - 2 ft/sec
    vernier rate - 0.61 ft/sec
  - Loaded arm, coarse rate - payload less than 32,000 lb - 0.2 ft/sec
    payload greater than 32,000 lb - 0.1 ft/sec
    vernier rate - 0.061 ft/sec
- The maximum rotational rates are as follows:
  - Unloaded arm, coarse rate - 4.76 deg/sec
    vernier rate - 4.76 deg/sec
  - Loaded arm, coarse rate - payload less than 32,000 lb - 0.476 deg/sec
    payload greater than 32,000 lb - 0.238 deg/sec
    vernier rate - 0.0833 deg/sec
- The arm, when fully extended and attached to a payload, will transmit a load not exceeding the following:
  - A combined 12-lb sheer force and 160-ft-lb bending moment at the EE
  - A 230-ft-lb torque about the EE axis
- The EE can entertain a misalignment of ± 15° angular except in roll which is ± 10° and ± 4 in. linear, except in the X-axis which is ± 2 in. with respect to the grapple fixture.
- With the Orbiter reaction control system (RCS) off, the RMS can deploy a 65,000-lb payload with the following accuracy:

- Attitude 5° relative to the RMS shoulder joint
- Angular rate of the payload relative to the Orbiter less than or equal to 0.015 deg/sec

- Position accuracy of an unloaded EE in the auto mode of control is ± 2 in. and ± 1°.
- The maximum allowable deflection between the grapple fixture and the EE when a 32,000-lb payload is being maneuvered at maximum acceleration is ± 15° and ± 0.1 in. in all axes.
- In order to maintain a stopping distance of 2 ft, the relative rates between the grapple fixture on a 32,000-lb payload and the RMS shoulder joint at capture shall not exceed 0.1 ft/sec.

MPM/MRL

The MPM and MRL are designed to perform in a zero-g environment as follows:

- With two motors running, the MPM will go from the stowed position to the deployed position in 34 sec. If only one motor is operating, the task takes 68 sec.
- With two motors running, the MRL operational time is 8 sec. If only one motor is operating, the time is 18 sec.
- The latch envelope for the MRL is 0.875 in. in the Z-axis and ± 1.50 in. in the Y-axis. However, the operational envelope in the Y-axis is only ± 0.74 in. because of the size of the saddle opening.
- The MRL Z-axis loading is approximately 2000 lb, and Y-axis loading during latchup is 150 lb.
- The separation system produces minimum impulse and no debris.
- Prior to RMS/MPM/MRL mechanical separation, the subsystems will be manually deadfaced and guillotined by the operator.

CCTV

The CCTV system is designed to perform in a zero-g environment as follows:

- The design of the pan and tilt unit provides ± 170° in pan and tilt. These angles may be mechanically stopped at any angle within the above limits. For the bulkhead cameras, the stated requirements are 90° inboard, 45° outboard in pan and 90° upward, 70° downward in tilt. For the RMS elbow camera, the stated requirements are ± 170° in pan and ± 70° in tilt.
- The pan and tilt unit has two rates, 1.2 deg/sec and 12 deg/sec.
- The torque required to overcome the pan/tilt unit function is such that an EVA crewman can manually force a failed unit to a position to permit safe closure of the cargo bay doors.
- The camera lens has a 6 to 1 zoom capability going from a focal length of 108 to 18 mm.
- Full rotation rates are as follows:
  - Zoom, 18 to 108 mm, 7.5 sec
  - Focus, 28 in. to 0, 8.4 sec
  - Iris, f 1.6 to closed, 3.46 sec

Lighting System

The illumination characteristics are presented in the following table:

Component performance	Orbiter baseline
Payload bay floodlights	
Watts	200
Lumens/watt	40 minimum
Type	Arc discharge
Beam	135° by 135°
Docking floodlight	
Watts	200
Lumens/watt	40 minimum
Beam	120° by 120°
Overhead/docking light	
Watts	130
Lumens/watt	12 minimum
Beam	120° by 120°
RMS light	
Watts	150
Lumens/watt	12 minimum
Beam	80°

The RMS light brightness is 3 ft-c at 30 feet, diminishing to 0.15 ft-c at 200 feet.

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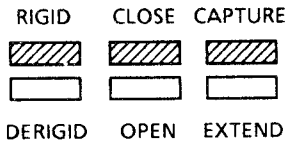
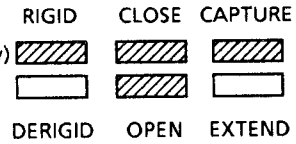
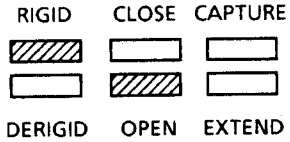
Appendix C: Auto Capture and Rigidization Sequence

The auto capture and rigidization sequence is initiated by selecting auto on the EE mode switch and momentarily depressing the EE capture switch on the RHC.

EE mode SW	EE rigid/ derigid SW	RHC capture SW	EE status talkbacks	EE effect	Time, sec
Auto	Off				0
Auto	Off	Capture (momentary)		Snares begin to close	0
Auto	Off			Snares close and capture sensed	3

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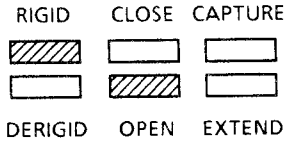
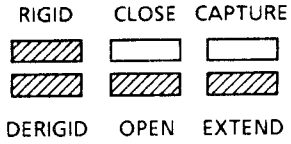
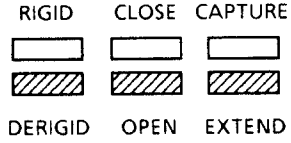
EE mode SW	EE rigid/ derigid SW	RHC capture SW	EE status talkbacks	EE effect	Time, sec
Auto	Off			Carriage begins to draw into EE	3
Auto	Off			Carriage crosses point of zero tension	0
Auto	Off			Carriage reaches end of travel	20

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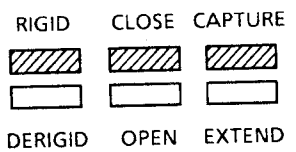
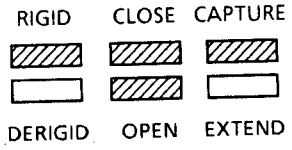
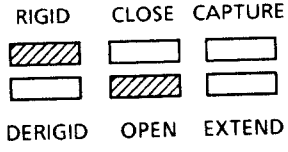
Appendix D: Manual Capture and Rigidization Sequence

The sequence of events is essentially the same as for the auto capture and rigidization sequence detailed in appendix C. The manual sequence is initiated by selecting the manual position on the EE mode switch. The capture operation is performed by actuating the capture switch on the RHC. Operation will be maintained only as long as the switch is held. When the CLOSE talkback indicates the snare ring has fully rotated, the switch may be released.

If the switch is not released, the EE motor will be operating under stall conditions. To achieve the RIGID indication, the manual rigidize switch must be operated and held until the RIGID talkback goes gray.

In general, the manual mode of operation is considered to give the operator more control over the capture/rigidize sequence.

EE mode SW	EE rigid/ derigid SW	RHC capture SW	EE status talkbacks	EE effect	Time, sec
Man	Off	Detent			0
Man	Off	Capture (continous)		Snares begin to close	0
Man	Off	Detent		Snares close	3

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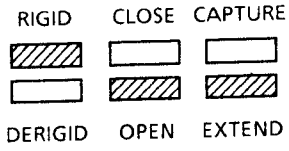
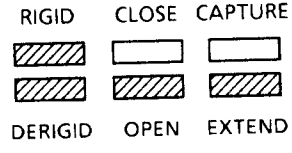
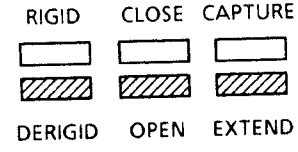
EE mode SW	EE rigid/ derigid SW	RHC capture SW	EE status talkbacks	EE effect	Time, sec
Man	Rigid			Carriage begins to draw into EE	3
Man	Rigid			Carriage crosses point of zero tension	20
Off	Off			Carriage reaches end of travel	23

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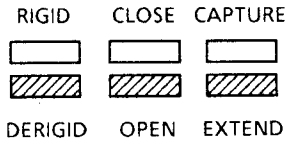
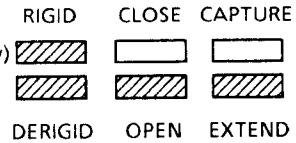
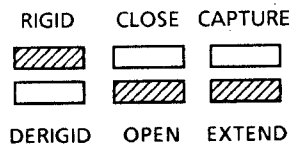
Appendix E: Auto Derigidization and Release Sequence

The auto derigization and release sequence is initiated by selecting auto on the EE mode switch and momentarily depressing the EE release switch on the RHC.

EE mode SW	EE rigid/ derigid SW	RHC capture SW	EE status talkbacks	EE effect	Time, sec
Auto	Off				0
Auto	Off	Release (momentary)		Carriage begins to extend	0
Auto	Off			Carriage reaches point of zero tension	3

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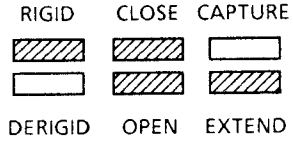
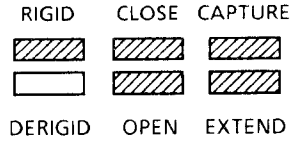
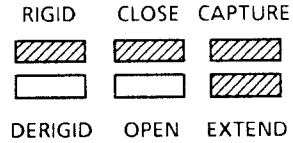
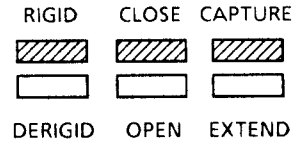
EE mode SW	EE rigid/ derigid SW	RHC capture SW	EE status talkbacks	EE effect	Time, sec
Auto	Off			Snares begin to open	3
Auto	Off			Grapple probe released	3 +
Auto	Off			Snares completely opened	6
Auto	Off			Carriage completely extends	23

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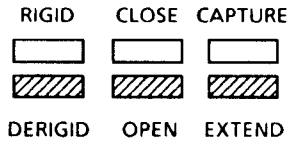
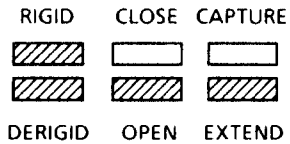
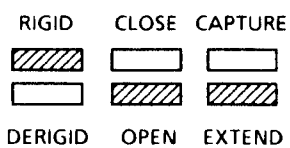
Appendix F: Manual Derigidization and Release Sequence

The sequence of events is essentially the same as for the auto derigidization and release detailed in appendix E, except that the derigidization and release operations are performed independently by use of the manual rigidize/ off/derigidize switch and RHC capture/release switch, respectively.

During the derigidization, the switch must be held in the derigidize position and the DERIGID talkback changes to gray; the release switch must be actuated. To complete release, the switch must be held until the OPEN talkback changes to gray. The derigidization switch must be in the off position during the release operation and to complete the operation, must be reactivated and held until the EXTEND talkback changes to gray.

Upon completion of the sequence, the EE mode switch should be returned to the off position.

EE mode SW	EE rigid/ derigid SW	RHC capture SW	EE status talkbacks	EE effect	Time, sec
Man	Off	Detent			0
Man	Derigid	Detent		Carriage begins to extend	0
Man	Off	Detent		Carriage reaches point of zero tension	3

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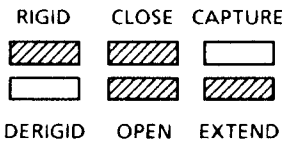
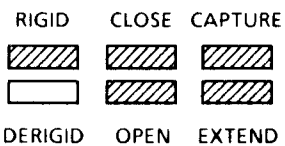
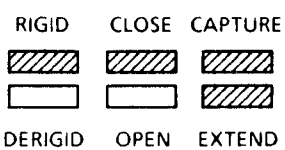
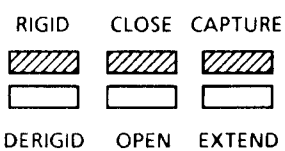
EE mode SW	EE rigid/ derigid SW	RHC capture SW	EE status talkbacks	EE effect	Time, sec
Man	Off	Release (continous)		Snares begin to open	3
Man	Off	Release (continous)		Grapple probe released	3 +
Man	Off	Detent		Snares completely opened	6
Man	Derigid	Detent		Carriage completely extends	23

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Appendix G: Acronyms

BACS	body axis coordinate system
BDA	backup drive amplifier
BITE	built-in test equipment
C&W	caution and warning
CCTV	closed circuit television
CRT	cathode ray tube
CSA	commutation scanner assembly
D&C	display and control
DOF	degree of freedom
EE	end effector
EEEU	end effector electronics unit
EEOS	end effector operating system
EVA	extravehicular activity
GFE	Government-furnished equipment
GPC	general purpose computer
ID	identification
I/F	interface
IFM	in-flight maintenance
I/O	input/output
I-load	initialization load
JPC	joint power conditioner
JSC	Johnson Space Center
KE	kinetic energy
LAT	latch
LED	light emitting diode
LRU	line replaceable unit
MCIU	manipulator controller interface unit
MDA	motor driver amplifier
MOD	Mission Operations Directorate
MPM	manipulator positioning mechanism
MRL	manipulator retention latch
NASA	National Aeronautics and Space Administration
OCAS	operator-commanded auto sequence
OMS	orbital maneuvering system
ORB	orbit
PCS	payload coordinate system
PDRS	payload deployment and retrieval system
PKM	perigee kick motor
PL	payload
POR	point of resolution
PRLA	payload retention latch assembly
PTU	pan/tilt unit
RACS	rotation axis coordinate system
RCS	reaction control system
RDY	ready
REL	release
RHC	rotational hand controller
RMS	remote manipulator system
SM	systems management
SPA	servo power amplifier
SRU	shop replaceable unit
SPEE	special purpose end effector
THC	translational hand controller
TV	television
VTR	video tape recorder

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LESSON CRITIQUE SHEET

LESSON CODE _____ DATE OF MATERIAL _____

Please explain any negative answers to the questions below in questionsbelow in specific terms. Use the back of the sheet if required.

1. Was the lesson material presented in a logical manner?

2. Comments on handout organization:

3. Were the figures and diagrams optimum to understanding the material?

4. Did the lesson start from your entry level?

5.. In your opinion, was the level of detail about right?

6. Additions or deletions from the lesson?

7. Prior knowledge: Considerable _____ Some _____ Very little _____

8. Other comments

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