NSTS 07700, Volume XIV,

Appendix 8

System Description and Design Data

Payload Deployment and Retrieval System

DESCRIPTION OF CHANGES TO

SYSTEM DESCRIPTION AND DESIGN DATA - PAYLOAD DEPLOYMENT AND RETRIEVAL SYSTEM
NSTS 07700, VOLUME XIV, APPENDIX 8

CHANGE NO.	DESCRIPTION/AUTHORITY	DATE	PAGES AFFECTED
REV J	Complete revision; replaces and supersedes PDRS sections to Revision I of NSTS 07700, Volume XIV (reference CR D07700-014-008-00). The following CR's are included: D07700-014-008-01, D07700-014-008-02 D07700-014-008-03, D07700-014-008-04 D07700-014-008-05, D07700-014-008-06 D07700-014-008-07, D07700-014-008-08 D07700-014-008-09, D07700-014-008-10 D07700-014-008-11, D07700-014-008-12 D07700-014-008-13, D07700-014-008-14 D07700-014-008-15, D07700-014-008-16 D07700-014-008-17, D07700-014-008-18 D07700-014-008-19, D07700-014-008-20 D07700-014-008-21, D07700-014-008-22 D07700-014-008-23, D07700-014-008-24 D07700-014-008-25, D07700-014-008-26 D07700-014-008-27, D07700-014-008-30 D07700-014-008-31, D07700-014-008-32 D07700-014-008-33, D07700-014-008-34 D07700-014-008-35.	5/2/88	ALL
1	The following CR is included: D07700-014-008-36.	6/14/89	Figure 1
	Reformat Word for Windows.	7/96	ALL
2	Add Deviations/Waivers section and Deviations and Waivers statement. The following PRCBD is included: S064832	11/24/97	(i), (ii), (1), (2), (3), 3-7, 3-8, 9-3
3	Update table of contents and figure 2-3. The following CR is included: D07700-014-008-37.	11/21/89	ix, 2-3
REV K	The following CR is included: D07700-014-008-45	10/13/00	ALL

DEVIATIONS/WAIVERS AUTHORIZED FOR REQUIREMENTS CONTAINED IN THIS DOCUMENT

This section contains only currently approved Deviations/Waivers to the requirements of NSTS 07700, Volume XIV, Appendix 8

INDEX OF DEVIATIONS/WAIVERS AUTHORIZED FOR REQUIREMENTS CONTAINED IN THIS DOCUMENT

Number	Title	Para. No.	Page
1.	Preplanned Sequences RMS pre-planned sequence (automatic mode) (Reference Space Shuttle PRCBD S064832, dated 11/24/97)	3.3.2.a, Figure 3-8	1
2.	RMS Procedure Constraints (Reference Space Shuttle PRCBD S064832, dated 11/24/97)	9.2.1	2
3.	Auto Trajectory Constraints (Reference Space Shuttle PRCBD S064832, dated 11/24/97	9.2.3	3

DEVIATIONS/WAIVERS AUTHORIZED FOR REQUIREMENTS CONTAINED IN THIS DOCUMENT

1. **REQUIREMENT:** Paragraph 3.2.2.a Preplanned Sequences. Coordinated six-joint arm movement can be controlled automatically along a preflight specified trajectory, or auto sequence, that is comprised of a series of points. Up to 20 sequences can be constructed per flight. Each sequence is designed for a specific flight, arm, EE, and payload. No limit is set on the number of points in a sequence, except that the total number of points in all of the sequences for any flight cannot exceed 200. Each point is defined by the OBAS position (X, Y, and Z) and ORAS attitude (pitch, yaw and roll). Each of the identical points that are to be repeated during a specific sequence requires one of the 200 available slots.

   In order to start an auto sequence, the payload (or EE) POR must be within a specified distance of the first point, Figure 3-8. The distance is specified preflight and is usually 2 inches and 1 degree. The RMS software continuously calculates a straight line from the current POR position to the next point; however, arm dynamics prevents exact straight line motion. Points may be either fly-by or pause points. The arm will drive toward a fly-by point until the POR is within 12 inches (30.5 cm) and 3 degrees (the fly-by sphere) of the point. As soon as the POR is within the fly-by sphere, the arm will move toward the next point. Because of this, the position and attitude specified for fly-by points may not be achieved. When approaching a pause point, the arm will begin to decelerate when the POR reaches the washout sphere (24 inches and 5.5 degrees) around the point. Once stopped, the POR will remain within 2 inches and 1 degree of the pause point until commanded by the operator to move to the next point. Both the initial and last points of every sequence are pause points.

   Auto trajectories will be designed to keep the arm boom and payload at least 5 feet (1.52 m) from any Orbiter or payload structure. The RMS Mission Designer will develop and verify all auto sequences prior to incorporating the sequences into the RMS software. Early discussions with an RMS Mission Designer are suggested for anyone planning to use RMS automatic sequences.

   WAIVER: The above requirement is waived for RMS/payload auto trajectory as violated by the STS-87 (Spartan-201 payload) autosequence maneuver.

   RATIONALE: The VGS auto trajectory (total of 51 points) has been designed such that the first VGS position (auto sequence points 1-4) is the closest position to Orbiter structure (specifically the MPESS) at 49 inches. It is reasonable to allow the auto sequence to start at less than 5 feet from structure because, once the auto trajectory proceeds to VGS position 2 (auto sequence points 5-8) and subsequent positions, clearance between the Spartan and the MPESS will increase and remain at distances greater than 5 feet. In addition, the SRMS will be driven at vernier rates while operating inside of 10 feet of structure, and the crew will be trained to recognize unwanted motion during the auto sequence and to stop the SRMS by turning the brakes on.

   EFFECTIVITY: STS-87

   AUTHORITY: Space Shuttle PRCBD S064832, dated 11/24/97.

DEVIATIONS/WAIVERS AUTHORIZED FOR REQUIREMENTS CONTAINED IN THIS DOCUMENT (Continued)

2. REQUIREMENT: Paragraph 8.2.1 RMS Procedures. Many hazardous conditions, due to failures, can be averted by operating the RMS only within the constraints outlined below. For this reason, waiver requests to violate these constraints become crew safety issues.

- The arm will not be driven unless the crew can observe the arm and payload structure via the window and/or CCTV views.
- Auto modes will not be entered until the operator has verified that there is no obstacle in the path of the sequence. The operator will only enter an auto mode immediately prior to the desired drive time.
- Computer supported modes will not be used if the auto brake or auto safing functions have failed.
- If the brakes are inoperative due to a mechanical failure for primary and backup modes, the RMS will be stowed as soon as possible in single mode.
- Both heater systems A and B will be powered 1 hour before and during all arm operations to provide active redundancy.
- Computer supported modes will not be used within 5 feet (1.5 m) of structure, payload, or an EVA crewmember if the MCIU safing function is lost. Auto trajectories will not be built to pass within 5 feet of structure, etc. While berthing a payload, all modes can be used once the trunnions have entered the "V" guides.
- RMS operations will be at the vernier rate in computer supported modes when the arm and/or payload is within 10 feet (3 m) of structure, a payload, or an EVA crewmember.
- No constant computer command (rate hold) will be used when the arm/payload is moving toward and is within 10 feet (3 m) of structure, a payload, or an EVA crewmember. This constraint does not apply when capturing a free-flying payload.
- The arm will not be maneuvered or parked in regions where it cannot be safely jettisoned.
- During a capture or release of a free flying payload, the EE must be far enough away from structure, payloads, or an EVA crewmember so that no contact can occur regardless of payload rotations.
- The RMS must be latched during OMS firings (section 2.5).

WAIVER: The above requirement is waived for RMS/payload auto trajectory as violated by the STS-87 (Spartan-201 payload) autosequence maneuver.

DEVIATIONS/WAIVERS AUTHORIZED FOR REQUIREMENTS CONTAINED IN THIS DOCUMENT (Concluded)

RATIONALE: The VGS auto trajectory (total of 51 points) has been designed such that the first VGS position (auto sequence points 1-4) is the closest position to Orbiter structure (specifically the MPESS) at 49 inches. It is reasonable to allow the auto sequence to start at less than 5 feet from structure because, once the auto trajectory proceeds to VGS position 2 (auto sequence points 5-8) and subsequent positions, clearance between the Spartan and the MPESS will increase and remain at distances greater than 5 feet. In addition, the SRMS will be driven at vernier rates while operating inside of 10 feet of structure, and the crew will be trained to recognize unwanted motion during the auto sequence and to stop the SRMS by turning the brakes on.

EFFECTIVITY: STS-87

AUTHORITY: Space Shuttle PRCBD S064832, dated 11/24/97

3. REQUIREMENT: Paragraph 8.2.3 Auto Trajectory Constraints

- Auto trajectories must maintain a minimum of 5 feet clearance between the deployed payload and any part of the Orbiter (including payloads fixed in the bay) at all times (section 3.2.2).
- Clearance between the protective RMS boom envelope, and any part of the Orbiter (including payloads fixed in the bay) must be maintained (section 5.1).
- All auto trajectories must be validated by NASA prior to use (section 3.2.2).
- Trajectories will be designed such that the arm or payload will not be placed in any position where the arm or payload cannot be safely jettisoned (section 6.6).

WAIVER: The above requirement is waived for RMS/payload auto trajectory as violated by the STS-87 (Spartan-201 payload) autosequence maneuver.

RATIONALE: The VGS auto trajectory (total of 51 points) has been designed such that the first VGS position (auto sequence points 1-4) is the closest position to Orbiter structure (specifically the MPESS) at 49 inches. It is reasonable to allow the auto sequence to start at less than 5 feet from structure because, once the auto trajectory proceeds to VGS position 2 (auto sequence points 5-8) and subsequent positions, clearance between the Spartan and the MPESS will increase and remain at distances greater than 5 feet. In addition, the SRMS will be driven at vernier rates while operating inside of 10 feet of structure, and the crew will be trained to recognize unwanted motion during the auto sequence and to stop the SRMS by turning the brakes on.

EFFECTIVITY: STS-87

AUTHORITY: Space Shuttle PRCBD S064832, dated 11/24/97

Preface

This document is designed to be used in conjunction with the series of documents illustrated in Figure 1. Information on the Payload Deployment and Retrieval System (PDRS) is presented herein.

Specific agreements for ground services must be specified in the individual payload integration plans.

Effective with the publication of this revision, configuration control of this document will be accomplished through the application of the procedures contained in NSTS 07700, Vol. IV, Configuration Requirements.

Questions and recommendations concerning this document should be addressed to:

Manager, Customer and Flight Integration Office

National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, Texas 77058

Signed by Leonard S. Nicholson
Leonard S. Nicholson
Manager
NSTS Integration and Operations Office

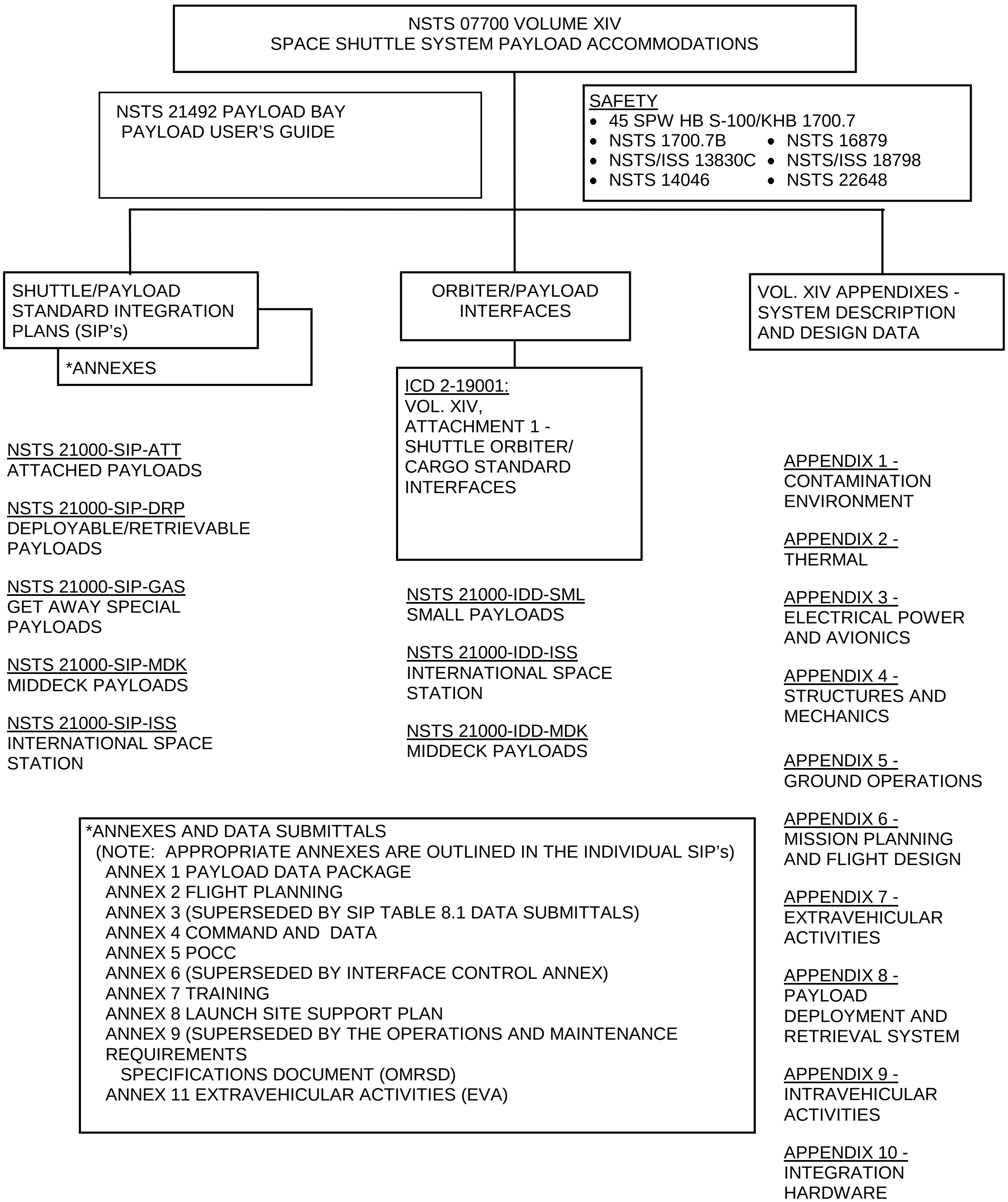

Figure 1.- NSTS customer documentation tree.

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Figures

Introduction

1

This document provides the Space Shuttle community with a comprehensive source of information on the Payload Deployment and Retrieval System (PDRS) and the integration of a payload with the PDRS. This document describes the PDRS system, operations and constraints, payload design considerations, mission definition and design, and real-time operations and capabilities.

In the text, the terms “will” and “must” are used when compliance is mandatory. “May” is used to indicate a choice exists.

This document contains the constraints to be applied to all payloads interfacing with the PDRS. Shuttle Orbiter/Cargo Standard Interfaces, ICD 2-19001, contains the constraints applied to the Orbiter-to-payload interface. International Space Station Interface Definition Document, NSTS-21000-IDD-ISS, contains the constraints applied to the Space Station-to-payload interface. The Integration Plan (IP) and Annexes contain the agreement for services between the National Aeronautics and Space Administration (NASA) and the customer. Any discrepancies noted between this document and individual IP’s should be brought to the attention of the assigned Payload Integration Manager (PIM) for resolution.

The payload designer is cautioned that while this document imposes payload design constraints, it is supplied as an educational tool. Actual mission design will be performed by the Space Shuttle Program (SSP) working with the customer and from the data provided.

Payload Deployment and Retrieval System Description

2

The PDRS, Figure 2-1, consists of those SSP-provided systems which are devoted to payload deployment, retrieval, special handling operations, and other Orbiter servicing. Other Orbiter systems, not considered a part of the PDRS, are required to support the payload deployment and retrieval activities. The remote manipulator system (RMS)

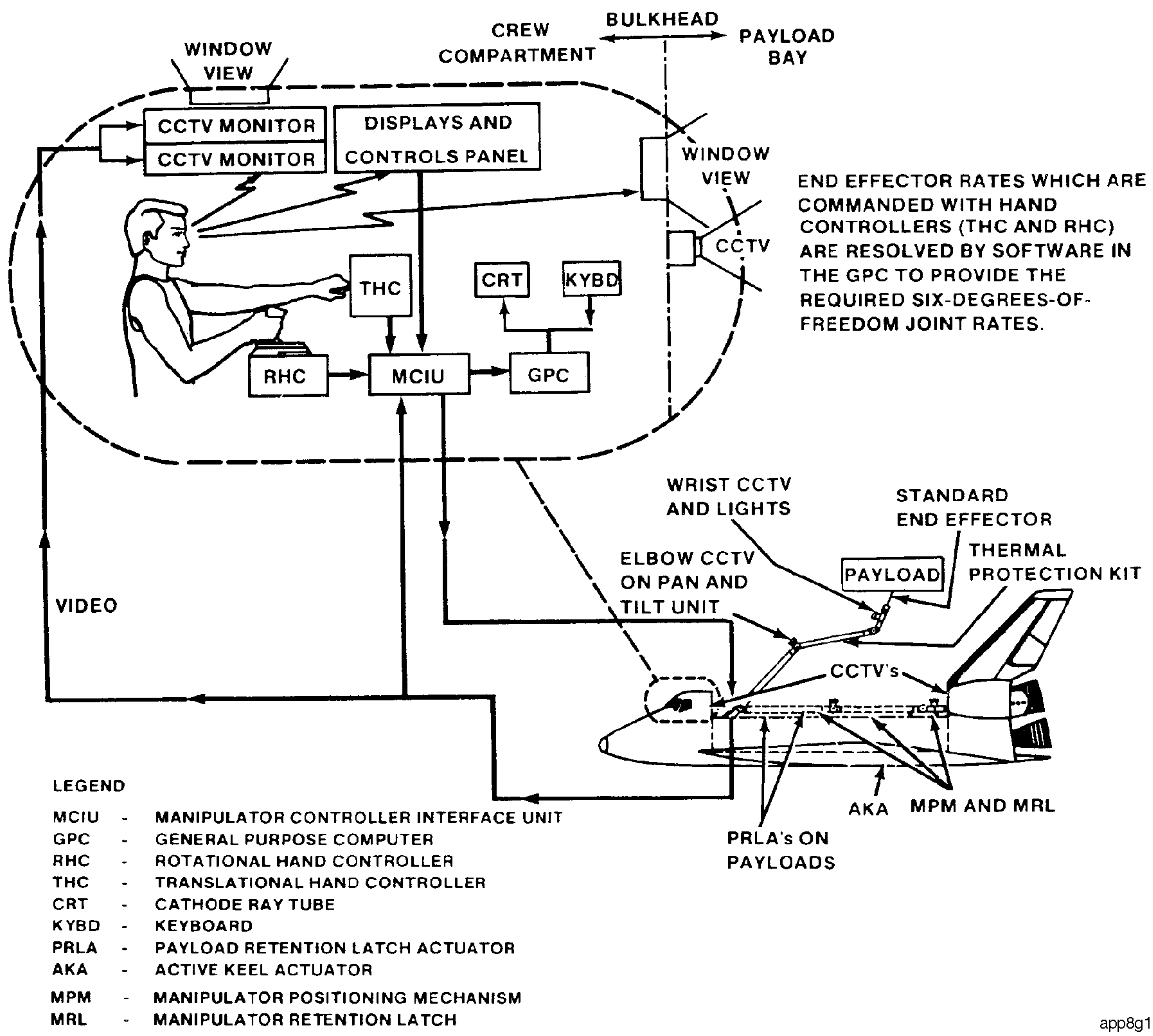


Figure 2-1.- Payload deployment and retrieval system.

software resides in a general purpose computer (GPC). Orbiter attitude and stationkeeping are accomplished by the digital auto pilot (DAP); guidance, navigation, and control (GNC) system; Reaction Control System (RCS) (both primary and vernier); and radar. The electrical power system (EPS) supplies power to the RMS and through an electrical grapple fixture (if installed), to the payload. The closed circuit television (CCTV) system, and the cargo bay lights also support payload operations.

The PDRS consists of:

- The RMS:
  - The manipulator arm:
    - Mechanical Arm Assembly
    - End Effector (EE)
    - Special Purpose EE Connector (optional)
    - Thermal Protection System
    - Shoulder Brace
  - The aft station cabin equipment:
    - Manipulator Controller Interface Unit (MCIU)
    - Displays and Control Panel (D&C Panel A8 Upper)
    - Power Control Panel (D&C Panel A8 Lower)
    - Translational Hand Controller (THC)
    - Rotational Hand Controller (RHC)
  - The software that controls RMS motion:
    - Control loop algorithms
    - System health monitoring routines
    - Data transfer routines
    - Caution and warning alarm generation
  - The MCIU, Servo Power Amplifiers (SPA's) and End Effector Electronics Unit (EEEU) contain Built-inTest Equipment (BITE) that monitors the health of the hardware.
- Manipulator Positioning Mechanism (MPM)
- Manipulator Retention Latches (MRL's)
- Payload Retention Latch Actuator Assemblies (PRLA's)
- Grapple Fixtures (GF's)
- Targets
- CCTV system

2.1 Remote Manipulator System Hardware

2.1.1 Mechanical Arm Assembly

The RMS is anthropomorphic. An upper and a lower arm boom driven by two joints at the shoulder and one joint at the elbow provide mainly translational capability. Three joints form the wrist and provide mainly attitude pointing. Six-joint arm motion is coordinated by an on-board computer from operator inputs or pre-flight-generated automatic point tables. Individual joint control is effected by the operator either through the computer system or through one of two hardwired systems.

The RMS, Figure 2-2, is 50 feet 3 inches (15.32 m) in length and is located on the port side of the vehicle. The RMS is stowed outside the payload dynamic envelope (except that a limitation exists with the elbow camera; see section 2.7.1) and its weight of 966 pounds (438 kg) is chargeable to the Orbiter. Detailed arm dimensions and joint angle limits are shown in Figure 2-3.

2.1.2 Manipulator Controller Interface Unit (MCIU)

The MCIU, which does not have any significant data processing function, performs data communications with the GPC, arm based electronics (ABE), the D&C panel, hand controllers, and arm temperature sensors. The MCIU issues EE drive commands when in the EE auto mode, and conditions power for the MCIU and D&C circuits. The MCIU contains the brake drive control and a hardwired fault detection and annunciation system, including the automatic brakes and automatic safing systems.

Signals from the hand controllers and D&C panel are routed through the MCIU to the Orbiter GPC where the commands are converted into joint motor rate commands. The MCIU then passes joint rate commands and current limits to the appropriate joints. (The direct and back-up drive mode commands are hardwired from the D&C panel to the appropriate motor.)

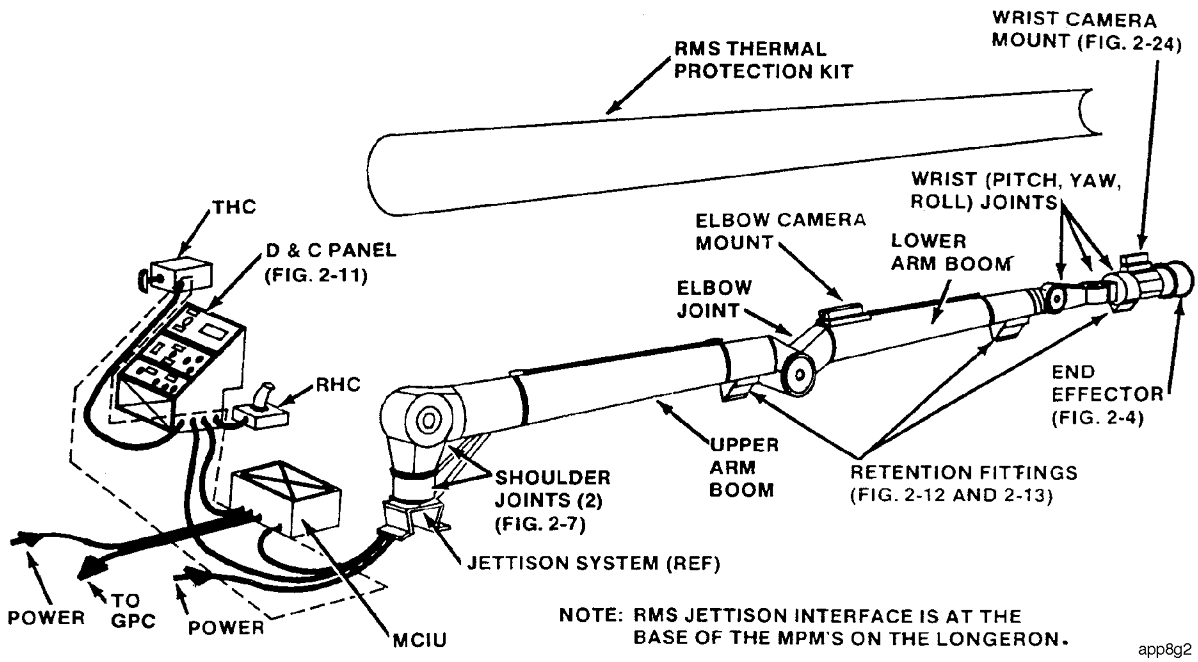


Figure 2-2.- Remote manipulator system.

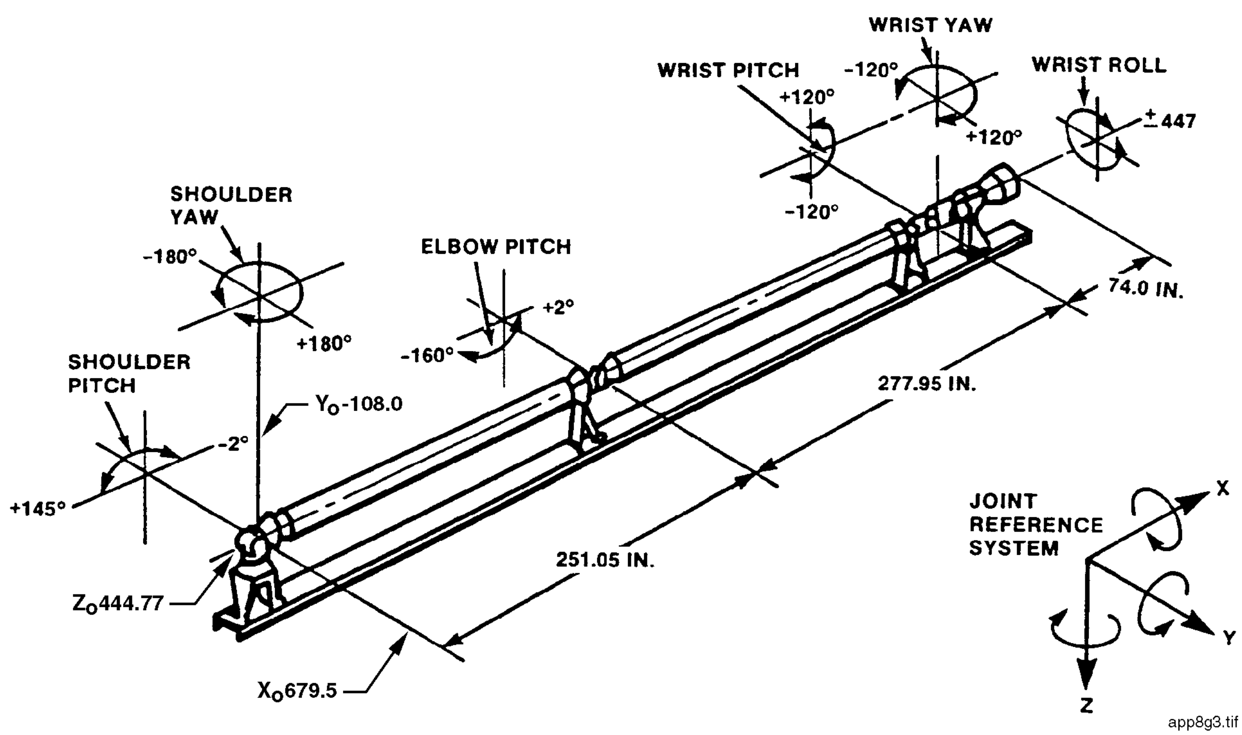


Figure 2-3.- RMS dimensions and joint limits (deployed position).

2.1.3 End Effector (EE)

The EE, Figure 2-4, which connects the arm to the payload GF, is a hollow cylinder 13.6 inches (34.5 cm) in diameter and 21.5 inches (54.6 cm) long. The EE is made primarily of aluminum.

The EE drive system provides two major functions: Capture and release of payloads, and rigidization and derigidization of payloads. During capture (or release), a rotating ring at the end of the EE closes (or opens) three snare cables around the payload-mounted GF. This sequence, Figure 2-5, takes approximately 1 second.

During rigidization, capture misalignments between the payload and EE are taken out as the three location cams seat in the EE, as shown in Figure 2-6. The GF cam pockets in the EE take out the roll misalignment. Pitch and yaw misalignments are taken out by the cam arms during the final 3 inches (7.62 cm) of travel. Splines draw the carriage into the EE in approximately 11 seconds. Between 900 and 1600 pounds force (lbf) (4003-7118 N) of tension is applied to the GF as the snare cables are drawn to the rigid position, as shown in step 5 of Figure 2-5. Tension in the snare cables is relieved prior to release by derigidization of the EE.

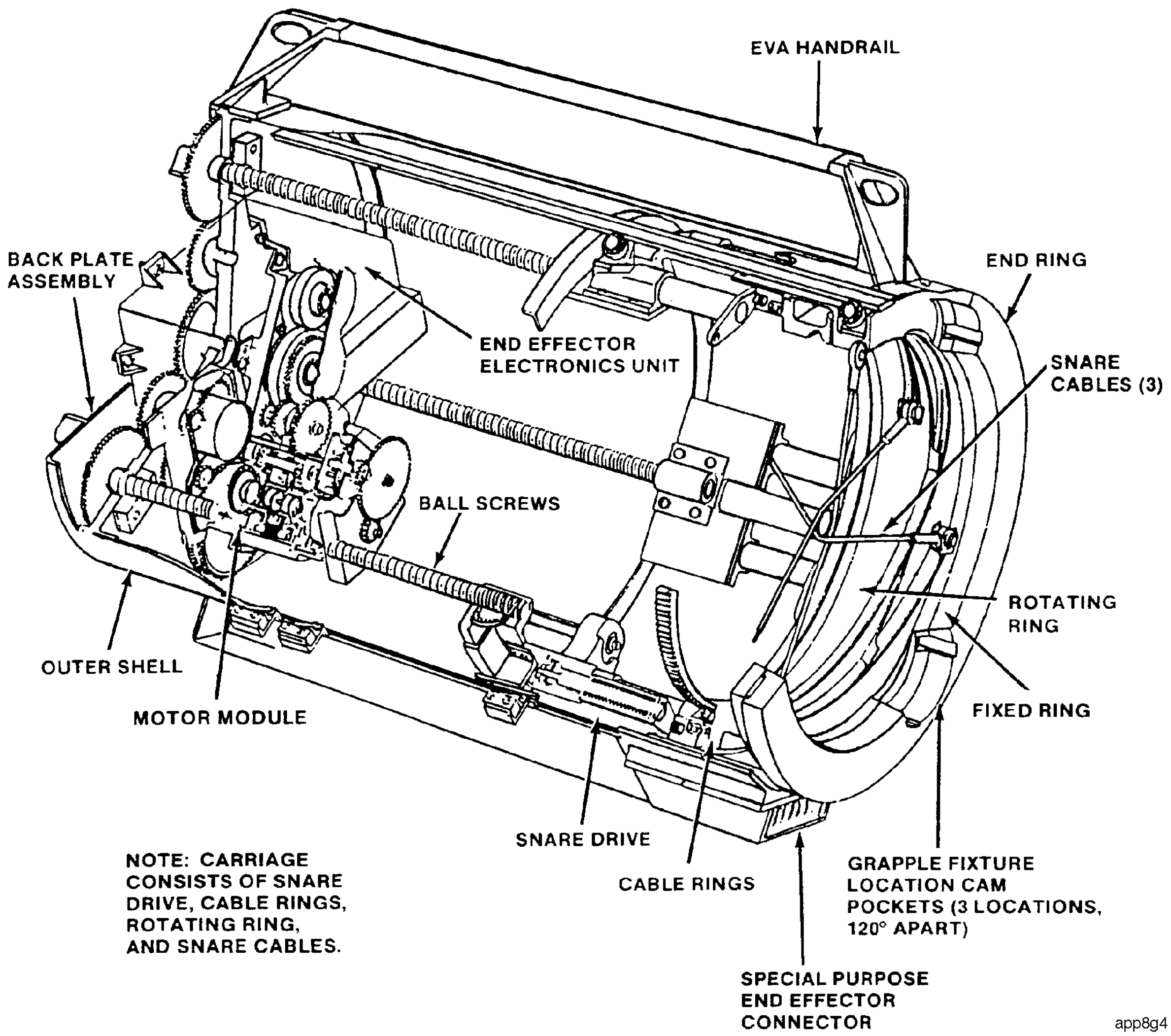


Figure 2-4.- Standard end effector.

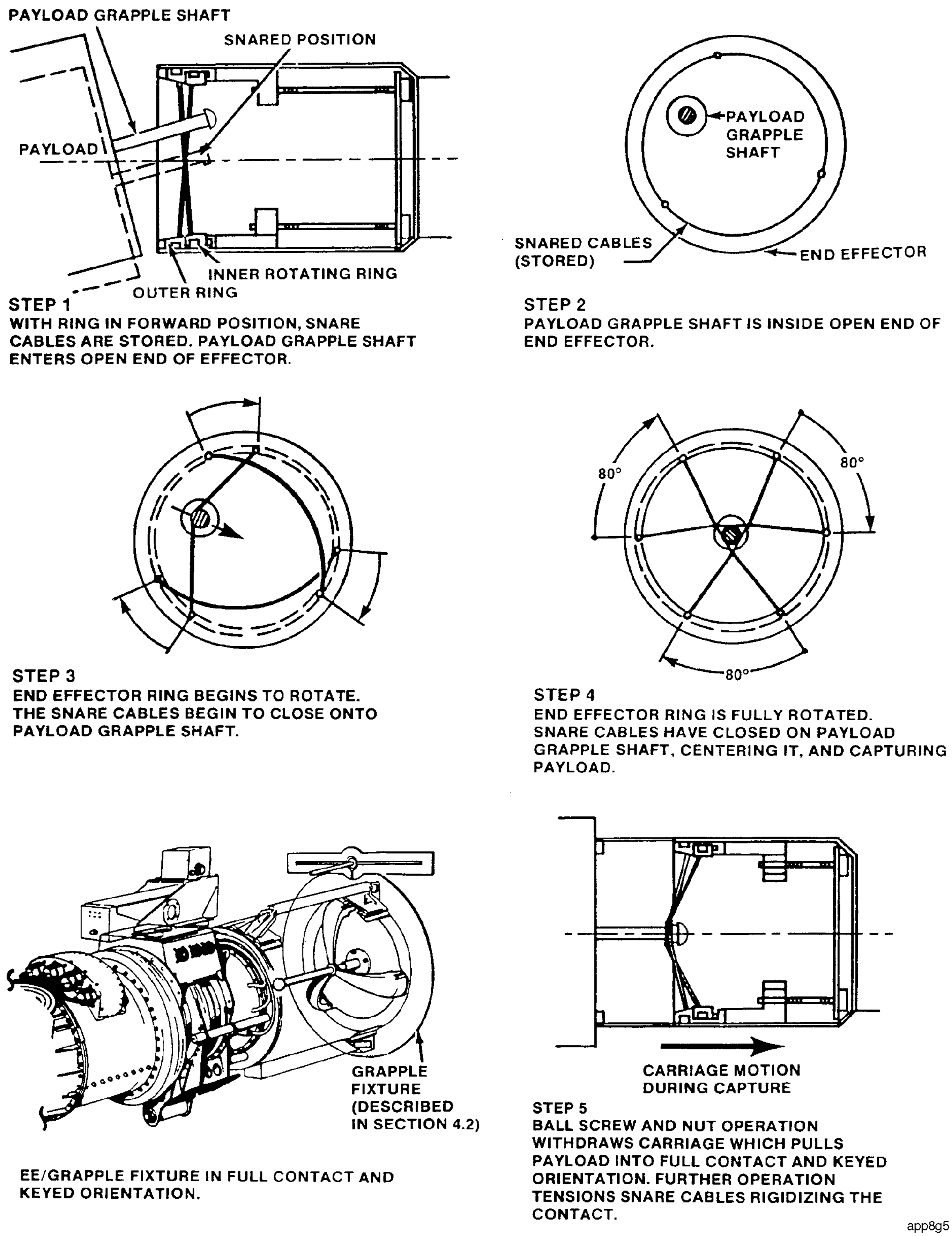


Figure 2-5.- Snare/EE capture and rigidize sequence.

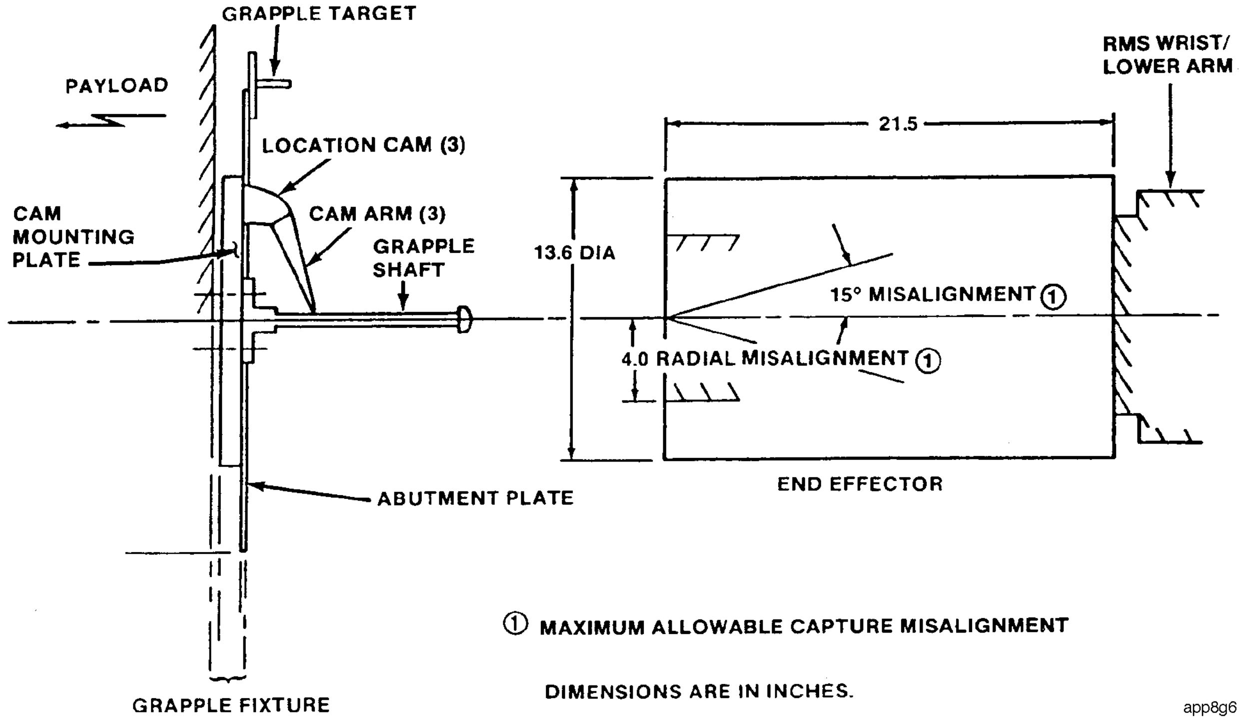


Figure 2-6.- RMS standard EE and grapple fixture envelope.

When fully extended, the open snare ring pushes into the GF cam pockets and causes a 0.5-inch (1.3-cm) separation between the EE and GF. If the EE carriage is extended into the GF when the snare ring is closed, the GF will be pushed 3.0 inches out of the EE. This occurs when the snare cables impact the GF location cams near the grapple shaft. In order to minimize payload tip-off rates, the EE must be withdrawn from the payload before the carriage is fully extended.

Two modes of EE operation are available: automatic and manual. In the EE automatic mode, if a GF is present when the capture switch (on the RHC) is pressed, the EE will continue operating until the payload is fully rigidized. Automatic release derigidizes the payload slightly (releases the tension from the snare cables), opens the snare cables to release the payload, then extends the carriage forward (to prepare for the next capture). In the EE manual mode, only payload capture will occur when the capture switch is pressed; a separate rigidization command must be issued to rigidize the payload. Manual release is usually preceded by a manual derigidization. Commands are present only as long as the capture switch is held.

A back-up release capability exists for contingencies; there is no back-up capture capability. Should a failure cause loss of primary release capability, the back-up clutch can be disengaged to release the payload via a spring mechanism. An isolation clutch prevents the spring from unwinding while the payload is captured. Unless derigidization is performed in the primary EE mode (prior to operating the snare cables), snare cable tension on the payload will not be relieved prior to payload release and a force may be applied to the payload.

2.1.4 Special Purpose End Effector (SPEE) Connector

All EE's are equipped with an electrical (SPEE) connector to provide +28 volts direct current (Vdc) and 16 command, data, or heater power lines to the payload. (The SPEE connector is shown in the lower right hand corner of Figure 2-4.) Two +28-volt lines and two return lines are supplied; however, both power lines are connected together in the EE. Sixteen lines are available to the payload for command signals, data return, low amperage heater circuits, etc. Of these 16, 4 lines are rated for 3.7 amperes (amps) (2 power and 2 return). The remaining 12 are rated for 1.5 amps. Heater circuits may be powered from any of these lines as long as the maximum amp rating is not exceeded. Shuttle Orbiter/Cargo Standard Interfaces, ICD 2-19001, section 14, provides additional details.

The customer is responsible for the interfaces to the SPEE: (1) The payload must be equipped with an electrical GF, as described in section 4.2.3. (2) The Orbiter +28 Vdc must be controlled through a power transfer relay switch from an aft flight deck switch panel. (3) The payload is limited to a maximum current of 2.5 amps per line, for a total of 5.0 amps. Five-amp fuses must be installed in each power line on the payload side to protect the RMS EE electronics unit from excessive current draw. (4) The 16 available command and data lines must be connected to a customer-supplied D&C switch panel, recording device, computer, etc., for use. Telemetry requirements are negotiated with SSP during the IP process.

2.1.5 Thermal Protection System

The thermal protection system is composed of two redundant active heater systems and passive thermal blankets. The system is designed to provide a stable thermal environment for RMS operations. If a system failure results in extreme temperatures, RMS operations will be terminated for readings outside of the -33 to +140 degrees F (-36 to +60 degrees C) range for the ABE, or outside of the - 41 degrees to +204 degrees F (-41 to +96 degrees C) range for other arm components. Once the temperatures are brought back into range, a single joint drive test will be performed to guarantee the arm is still operating within its performance specification.

2.1.6 Shoulder Brace

The shoulder brace, illustrated in Figure 2-7, is installed between the upper arm boom and the shoulder pedestal to carry loads during launch. It must be released to allow arm uncradling, cannot be relatched in orbit, and is not required for entry.

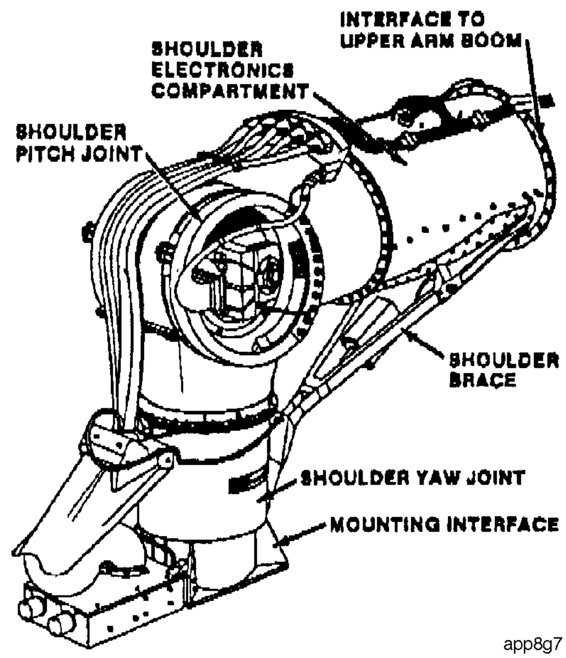


Figure 2-7.- RMS shoulder joint.

2.2 RMS Software

The software that controls most RMS operations resides in one of the five Orbiter GPC's. On orbit, at least one GPC is performing Orbiter guidance, navigation, and control (GNC software); one contains a copy of the software required for entry; one contains a copy of the back-up GNC software; and a fourth performs systems management (SM). The RMS software is contained in the SM GPC and performs the following functions:

a. Translates operator commands into RMS/ payload motion

b. Monitors and displays RMS operational status

c. Generates caution and warning annunciations and safes the system when certain failures are detected

Control algorithms contained in the RMS software convert operator commands into output rates resolved for each joint of the arm. The rates sent to the joint servos are limited by Level C constants, as described in section 6.2.1. These are selected preflight (based on the mass characteristics of the payload) to guarantee the EE can stop within 2 feet. The heavier the payload, the lower the rates and the greater the maneuvering times.

2.3 Aft Flight Deck (AFD) Equipment

The Orbiter AFD contains the stations for payload deployment and retrieval operations. The RMS D&C's, Figure 2-8, are located on panels A8A1 (A8U) and A8A2 (A8L), Figure 2-9. All RMS D&C's, including the hand controllers, are located on the port side of the AFD. Software initialization is performed via CRT keyboard item entry on the starboard side. Messages from the GPC can be displayed on any one of four cathode ray tubes (CRT's) in the cockpit (one on the starboard side of the AFD and three in the forward flight deck). In addition, CCTV monitors are located on the AFD. Orbiter vehicle translation and attitude controls are on the starboard side of the AFD. Two aft windows and two overhead windows provide direct exterior viewing for two operators on the AFD.

On Panel A8U, a rotary switch allows mode selection and monitoring of the automatic (either operator commanded or pre-stored points), manual, single, or direct modes. The automatic modes are started, stopped, and monitored; the EE operations are performed and monitored; brakes and safing are applied and monitored; the shoulder brace is released; and system health is monitored.

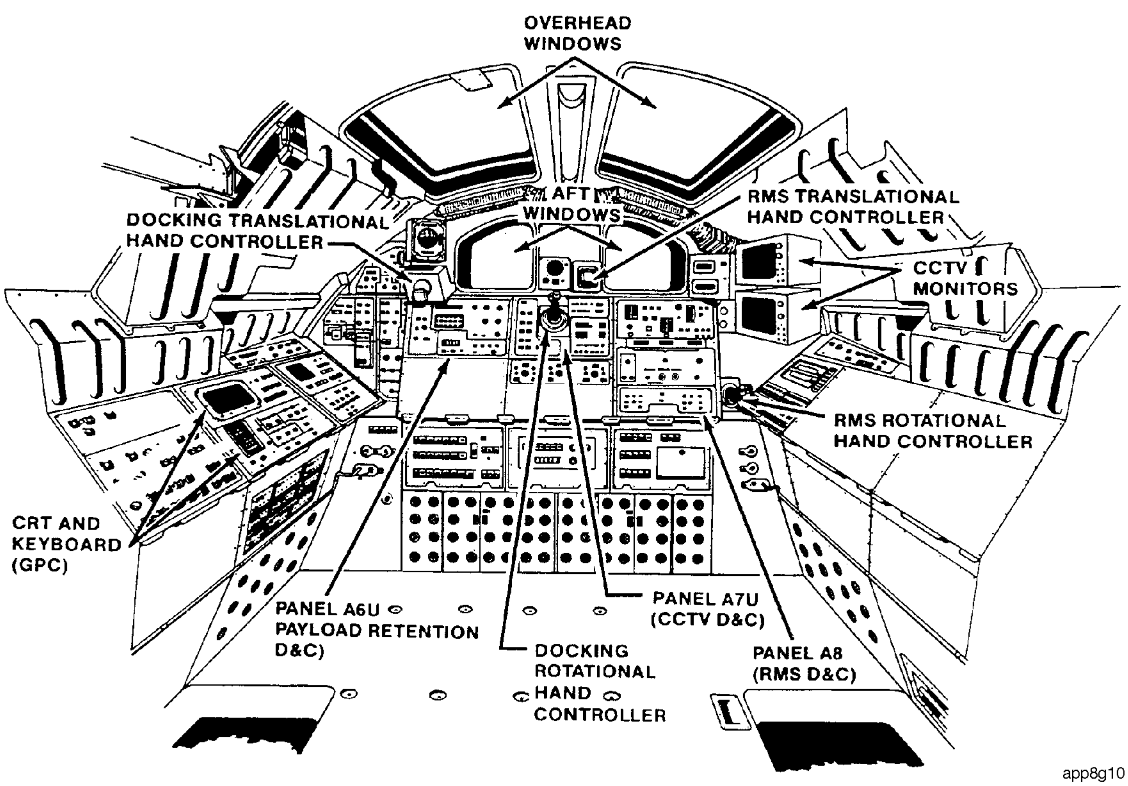
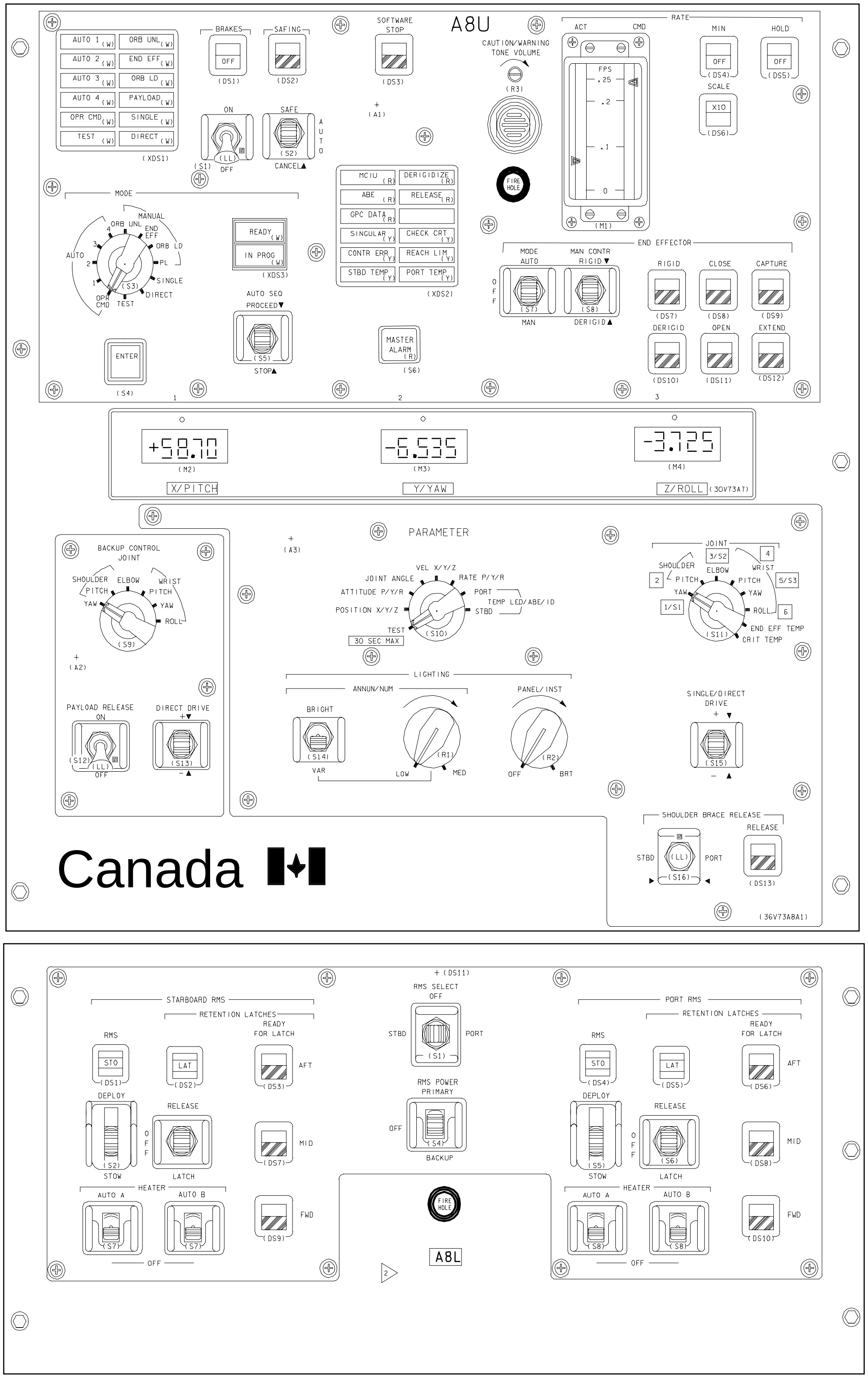


Figure 2-8.- Orbiter aft flight deck.



NOTE: ENGINEERING DRAWINGS REFER TO
- A8U as A8A1
- A8L as A8A2

app8_g11.cgm

Figure 2-9.- RMS displays and controls (Panel A8U and A8L).

Three light-emitting-diode type units display data as selected by two rotary switches on the bottom portion of Panel A8U. Positions, attitudes, joint angles, velocities, rates, and temperatures can be displayed for any joint or the EE. The single mode drive commands are initiated, the RMS shoulder brace is released, and the lighting is controlled from this panel.

Direct drive is a contingency mode; it will only be used for loss of the computer supported modes. If the MCIU is not operational, data will not be available on the display units during direct drive operations.

The back-up control portion of the panel is powered from a different source and consists of individual joint control and a payload release switch. Display data is not available when using the back-up mode (either onboard or on the ground).

Panel A8L contains the RMS power switch, the port or starboard arm select switch, and controls for the MPM, MRL's, and heaters.

2.4 Manipulator Positioning Mechanism

The MPM attaches the RMS to the Orbiter at the sill longeron, Figure 2-10. In the stowed configuration (rotated 11.88 degrees inboard) during launch and entry, the MPM positions the RMS between the payload and payload bay door dynamic envelopes. For RMS/payload operations the MPM's are deployed (rotated 19.48 degrees outboard) so there is adequate clearance for payload unberthing, berthing, and maneuvering.

The MPM must be fully deployed and mechanically locked in order to transfer RMS/payload handling loads to the sill longeron. It may be possible to maneuver a payload with the MPM stowed. However, before doing so, the nonstandard services described in section 8.2.1 must be performed to determine if the payload operation produces excessive sill loads.

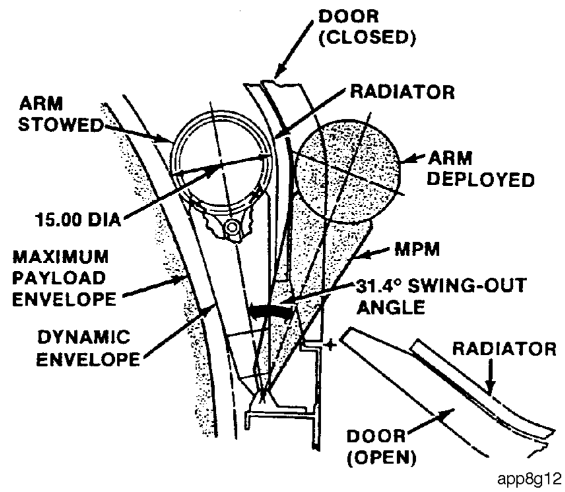


Figure 2-10.- Manipulator positioning mechanism.

2.5 Manipulator Retention Latches

The forward, mid, and aft MPM pedestals contain the MRL's, Figure 2-11, that secure the RMS to the Orbiter. Three MRL's and a shoulder brace fasten the arm boom for launch. The RMS must be latched during ascent, Orbital Maneuvering System (OMS) firings, and entry.

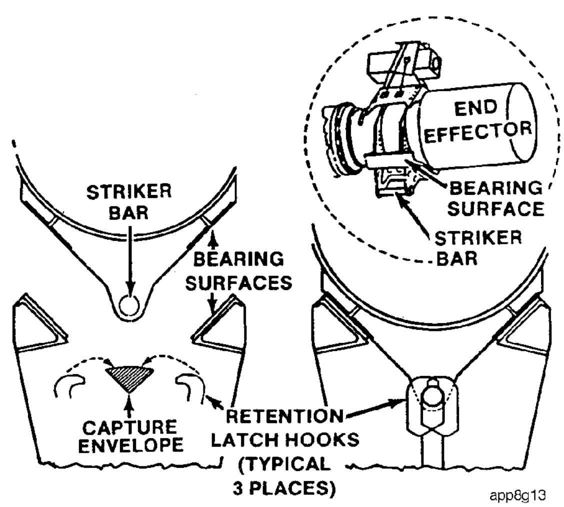


Figure 2-11.- Manipulator retention latch.

2.6 Payload Retention Systems

Two types of retention latches secure deployable and non-deployable payloads in the payload bay: longeron latches and keel latches. These latches are provided by the SSP. Special retention latches may be supplied by the customer, but must comply with Shuttle Orbiter/Cargo Standard Interfaces, ICD 2-19001, which is the controlling document for SSP-supplied hardware.

Detailed design requirements for deployable and non-deployable customer-supplied hardware are contained in ICD-2-19001.

The following sections provide descriptions of both SSP and customer-supplied hardware for deployable payloads. Further details, if required, are available in System Description and Design Data - Structures and Mechanics, NSTS 07700, Volume XIV, Appendix 4.

2.6.1 Hardware Description

The SSP-supplied hardware associated with the payload retention system is as follows:

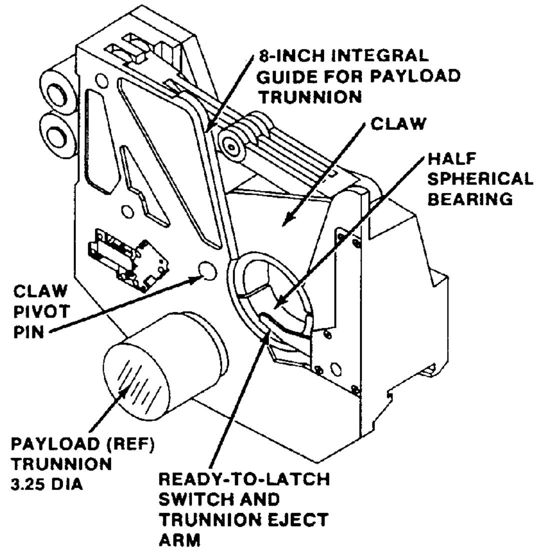
- Standard PRLA
- Lightweight Longeron Latch (LWLL)
- Middleweight Longeron Latch (MWLL)
- Alignment Guides
  - Standard Alignment Guides
  - Lightweight Alignment Guides
- Active Keel Actuator Assembly (AKA)
- Lightweight Keel Latch (LWKL)
- Displays and Controls (Panel A6U)

The customer-supplied hardware includes:

- Longeron trunnions
- Keel trunnions
- Scuff plates

a. Standard PRLA's

The standard PRLA, Figure 2-12, is designed to restrain payloads weighing 65,000 pounds (29,484 kg). The PRLA reacts loads through the Orbiter structure in the X-X, Z-Z, and combined X-Z directions. It is a dual-motor-actuated device. Normal opening or closing time is 30 seconds; with one motor failed, the time increases to 60 seconds. The PRLA has a 3.25-inch (8.26-cm) diameter spherical half bearing attached to the claw and linkage that has a 2.0-inch (5.1-cm) pulldown capability.



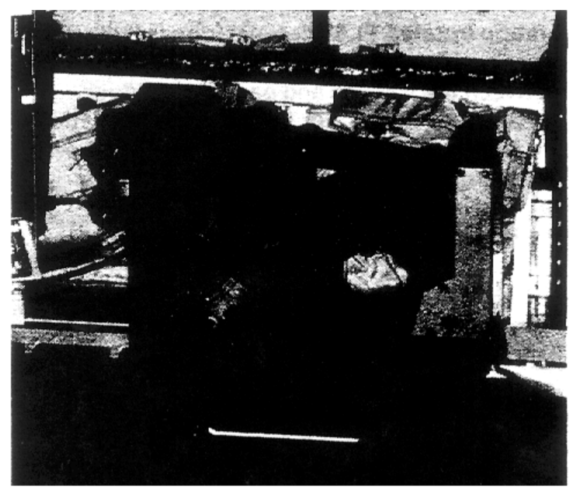


Figure 2-12.- Standard payload retention latch actuator assembly.

Redundant feedback indications are provided to show when the actuator is open, closed, and when the trunnion is present (ready-to-latch). These indications are displayed on Panel A6U. When unlatched, the ready-to-latch/eject arm imparts a small force (12 lbf or 53 N) to start the payload trunnion out of the latch.

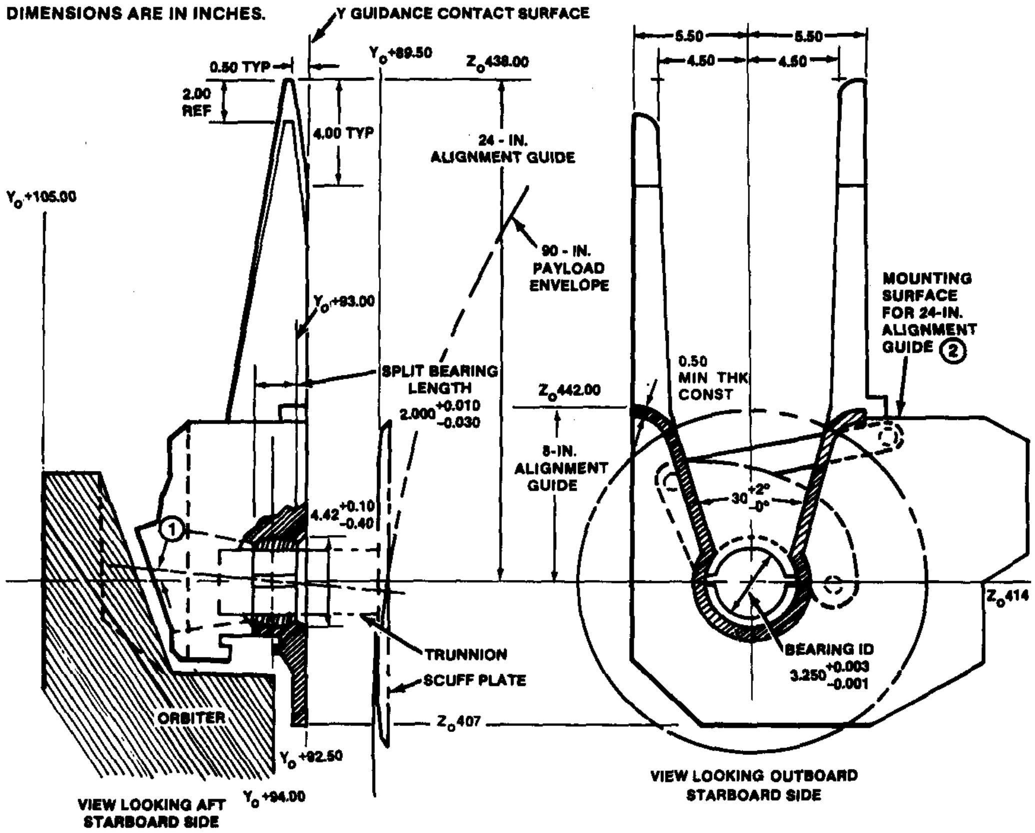
b. Lightweight and Middleweight Longeron Latches

The LWLL and MWLL will have the same basic design as the standard PRLA's but have two unique features: (1) these latches have an extravehicular activity (EVA) disconnect mechanism that provides manual open and close capability in the event of a jammed gear mechanism or motor failure; and (2) these latches are designed to be lighter and thus carry less load.

c. Guides

The standard Orbiter active retention system for deployable payloads will include 8-inch (20-cm) guides integral with the active latches to constrain payload motion in the Orbiter X direction (fore and aft). These integral guides are illustrated in Figure 2-12. The guides will also ensure adequate visibility/motion cues to the operator during deployment or berthing.

Extended alignment guides are auxiliary equipment attached to either standard, lightweight, or middleweight PRLA's to serve as visual cues during payload berthing and unberthing. The extended alignment guides are 20 to 22 inches (50.8 to 55.9 cm) in length with bright yellow and black markings. The extended alignment guides are mounted to the forward and aft 8-inch integral guide surface of either standard or lightweight latches. The resultant length is 22 and 24 inches (55.9 and 61.0 cm) from the trunnion centerline to the top of the guides. The shorter guide is placed closest to the viewing point to provide payload positioning cues. Figure 2-13 is an illustration of a standard extended alignment guide.



NOTES:

① CLEARANCE FOR ANGULAR DEFLECTION OF TRUNNION

② EXTENDED ALIGNMENT GUIDES ARE MOUNTED TO THE BASIC MECHANISM (INCLUDING 8-IN. GUIDE) TO FORM THE 24-IN. ALIGNMENT GUIDE

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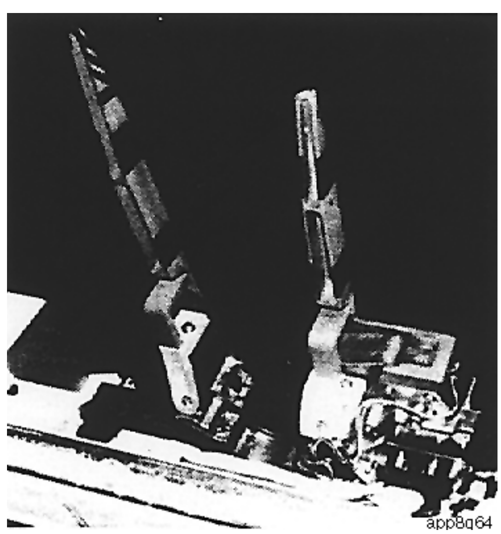


Figure 2-13.- Standard 24-inch extended alignment guide.

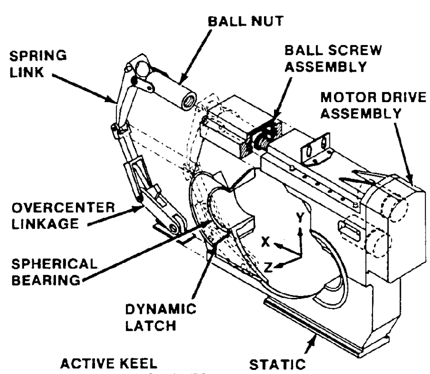
d. Standard AKA

The AKA, Figure 2-14, is the Orbiter Y-direction load-carrying latch. Aside from reacting to Y loads, the AKA also serves as a centering device for both deployable and non-deployable payloads. Although the AKA is called an active keel actuator, it also serves as a passive latch. An active keel latch can be controlled by switches on Panel A6U, and the passive keel latch can only be operated by ground support equipment. No EVA capability exists to open or close any keel actuator.

The standard AKA has a 3-inch (7.6-cm) diameter spherical half bearing that is attached to the static and dynamic halves of the latch. A spring link drives the overcenter links to the locked position. When the AKA is opened, it produces a 9.5-inch (24.1-cm) diameter opening to accommodate keel trunnion motion during berthing and unberthing.

e. Lightweight Keel Latches

The LWKL has the same design as the AKA but weighs less and thus carries less load.



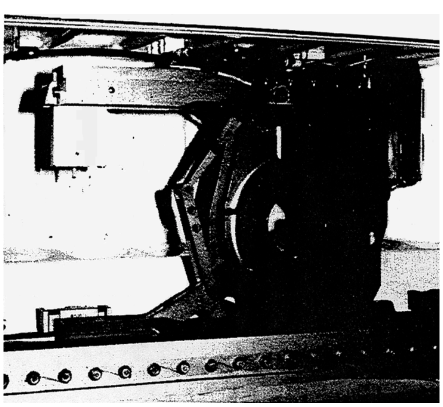


Figure 2-14.- Standard active keel actuator assembly.

f. Panel A6

Panel A6U, Figure 2-15, is in the aft crew station. The bottom portion of the panel contains the retention system latch and release switches as well as the latch status talkbacks.

The Payload Select switch is a five-position rotary switch; three positions govern which set of latches are operated; two positions allow latch monitoring during non-operating mission phases. When payload select position 1, 2, or 3 is chosen, the five latch/release switches and the corresponding talkbacks (above the switches) are activated and/or assigned to the selected position. Each latch switch operates the two motors on the associated PRLA or AKA. Only two latches may be operated simultaneously.

When a payload is selected, the talkback indications correspond only to the payload selected. The release/latch talkback has three indications: REL when the latch is open (released), barberpole (bp) when the latch is in transit, and LAT when the latch is closed (latched).

The monitor position serves two purposes: (1) It allows the operator to monitor every latch during any phase of the mission. (2) It acts as an inhibit to prevent inadvertent latch release. The operator must call up the payload retention display on the CRT display, Figure 2-16, in order to see all of the latch statuses while in the monitoring position.

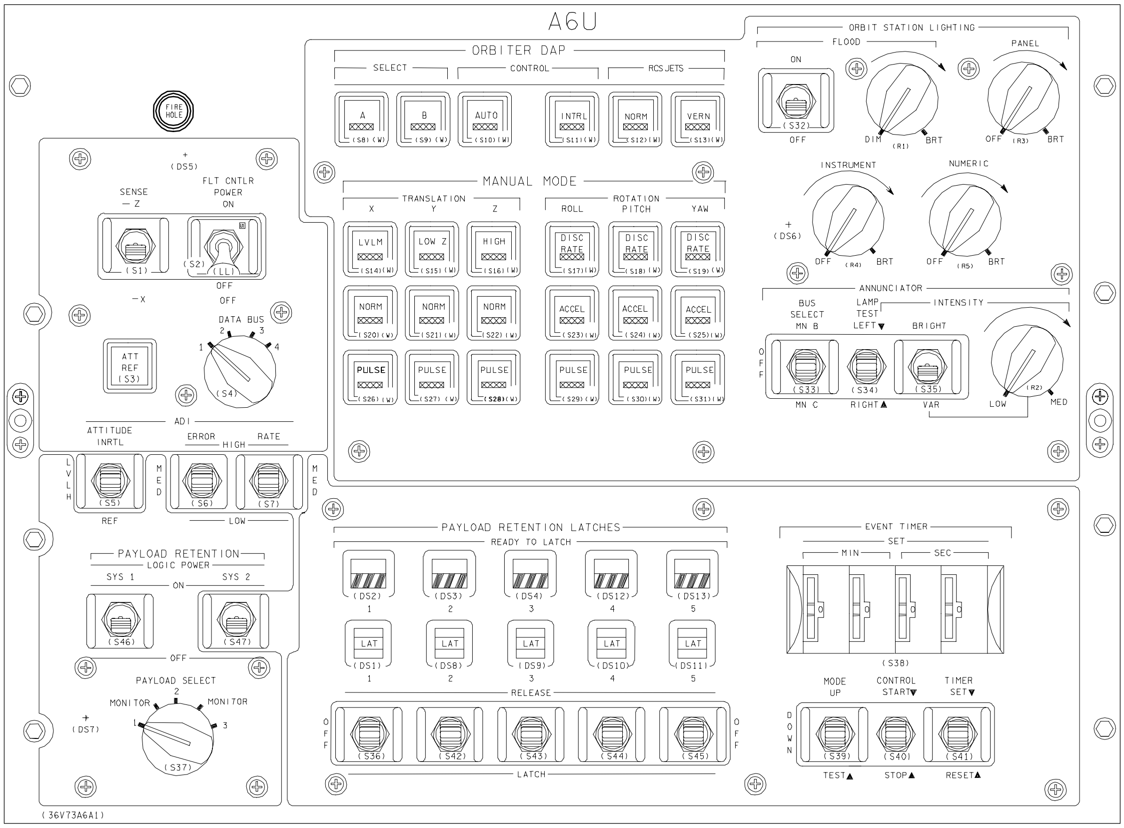


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Figure 2-15.- Payload retention displays and controls (Panel A6U).

Any combination of payload select and latch/release switches may be used for a payload. The actual combination is flight specific depending on the number of payloads manifested and the total number of latches used (up to the maximum of 15).

XXXX/XXX/097 PL RETENTION XX X DDD/HH:MM:SS
DDD/HH: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	11	11	11	11	/
LAT/REL	11/00	11/00	11/00	11/00	
PL SEL 2					
RDY-FOR-LAT	/	11	11	11	/
LAT/REL		00/11	00/11	00/11	
PL SEL 3					
RDY-FOR-LAT	00	00	00	00	00
LAT/REL	00/11	00/11	00/11	00/11	00/11

(XX)

EXAMPLE:

- PAYLOAD 1 HAS 4 LATCHES WHICH ARE LATCHED.
- PAYLOAD 2 HAS 3 LATCHES WHICH ARE RELEASED BUT PAYLOAD 2 IS STILL SEATED IN THE PRLA'S.
- PAYLOAD 3 HAS 5 LATCHES AND HAS BEEN DEPLOYED.

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Figure 2-16.- Typical Payload retention display (SPEC 97)

g. Trunnions

The customer provides longeron trunnions on the payload as shown in Figure 2-17. Keel trunnions, Figure 2-18, are also provided by the customer. Maximum and minimum longeron trunnion lengths will be limited by Orbiter structure and by combined deflections of the Orbiter and the payload. To prevent excessive deflections in the Y direction from contacting the Orbiter, the payload designer/manufacturer will incorporate scuff plates (as described in Figure 2-17 and section 2.6.1.h).

Minimum allowable longeron trunnion spacing for vertical installation and removal of the payload is shown in Figure 2-19. For more information about ground handling of payloads refer to System Description and Design Data - Ground Operations, NSTS 07700, Volume XIV, Appendix 5.

The force required to pull down the trunnions will be combined with the flight loads and assessed against the strength capability of the Orbiter structure as defined in Appendix I of Shuttle Orbiter/Cargo Standard Interfaces, ICD 2-19001, and System Description and Design Data - Structures and Mechanics, NSTS 07700, Volume XIV, Appendix 4.

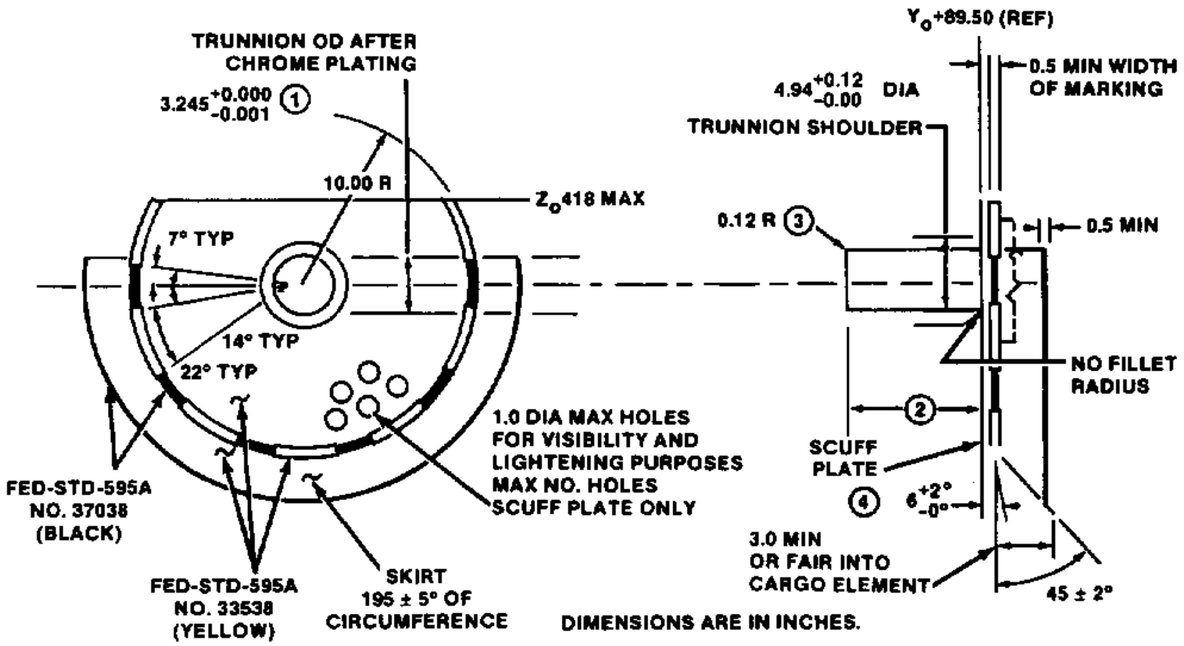
Certain design requirements must also be considered. The design of trunnion and bridge interfaces shall use the coefficient of friction defined in ICD 2-19001. The chrome electro-deposition standards must be followed as cited in Figures 2-17 and 2-18.

h. Scuff Plates

To prevent undesired contact between the payload and the Orbiter during the initial phase of deployment or the final stages of berthing, the payload must have a surface (i.e., scuff plate) on each trunnion that is perpendicular to the axis of the trunnion, as shown previously in Figure 2-17. The scuff plates and trunnions will interface with the “V” guides to prevent free motion in the Y and X directions. The scuff plate and skirt, with dimensions and markings, will be attached to the trunnion or the basic payload structure.

2.6.2 Latch Configurations

The design concept for payload retention at the longeron will permit stabilizing fittings to carry only Z-Z loads by sliding fore and aft on the longeron bridge cap relieving X-X loads. At the same time, the payload trunnion is free to slide through the bearing relieving Y-Y loads. Insertion of shear pins between a longeron retention fitting and the bridge converts the fitting to a primary fitting, which will carry X-X loads in addition to Z-Z loads.



NOTES:

① TRUNNION SURFACE MATERIAL:
ON NICKEL-BASED ALLOYS (e.g., INCONEL 718): ELECTRO-DEPOSITED CHROME (PER FED SPEC QQ-C-320B, CLASS 2); THICKNESS 0.0003 IN. (0.008MM) MINIMUM.

ON TITANIUM ELECTRO-DEPOSITED CHROME (PER ROCKWELL SPEC MA0109-318); THICKNESS 0.002 IN. (0.05MM) MININUM. TRUNNION SURFACE FINISH AFTER CHROME PLATING 8 (8 RHR, MEASURED IN MICROINCHES-EQUIVALENT TO 0.2 MICRON). SUBSEQUENT TO GRINDING, THE FINAL SURFACE FINISH SHALL BE OBTAINED BY POLISHING, LAPPING, BUFFING, OR SIMILAR METHODS.

② TRUNNION LENGTH SHALL BE IN ACCORDANCE WITH THE FOLLOWING:

FOR TRUNNION SPACING IN THE X_0 DIRECTION OF 100 INCHES OR LESS - LENGTH IS 7.00 IN.

FOR TRUNNION SPACING GREATER THAN 100 IN. - LENGTH IS 8.25 IN.

③ THIS RADIUS FAIRED WITH NO MISMATCH TO CYLINDRICAL SURFACE.

④ AT SUPPLIER'S OPTION, SCUFF PLATE MAY BE SEPARATE PIECE ATTACHED TO TRUNNION OR MAY BE INTEGRAL PART OF TRUNNION OR CARGO ELEMENT.

5 SCUFF PLATE IMPACT REQUIREMENT:
ENERGY EQUIVALENT TO CARGO ELEMENT MASS MOVING AT 0.11 FT/SEC (32K CARGO ELEMENT MAX).

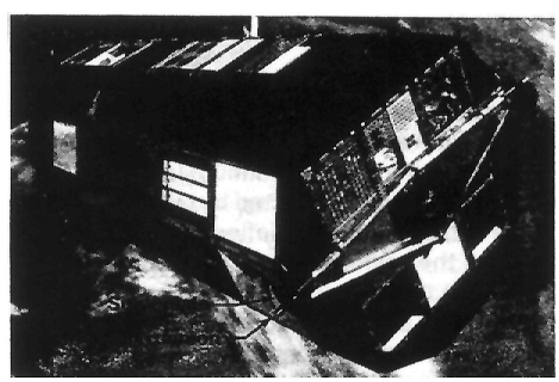


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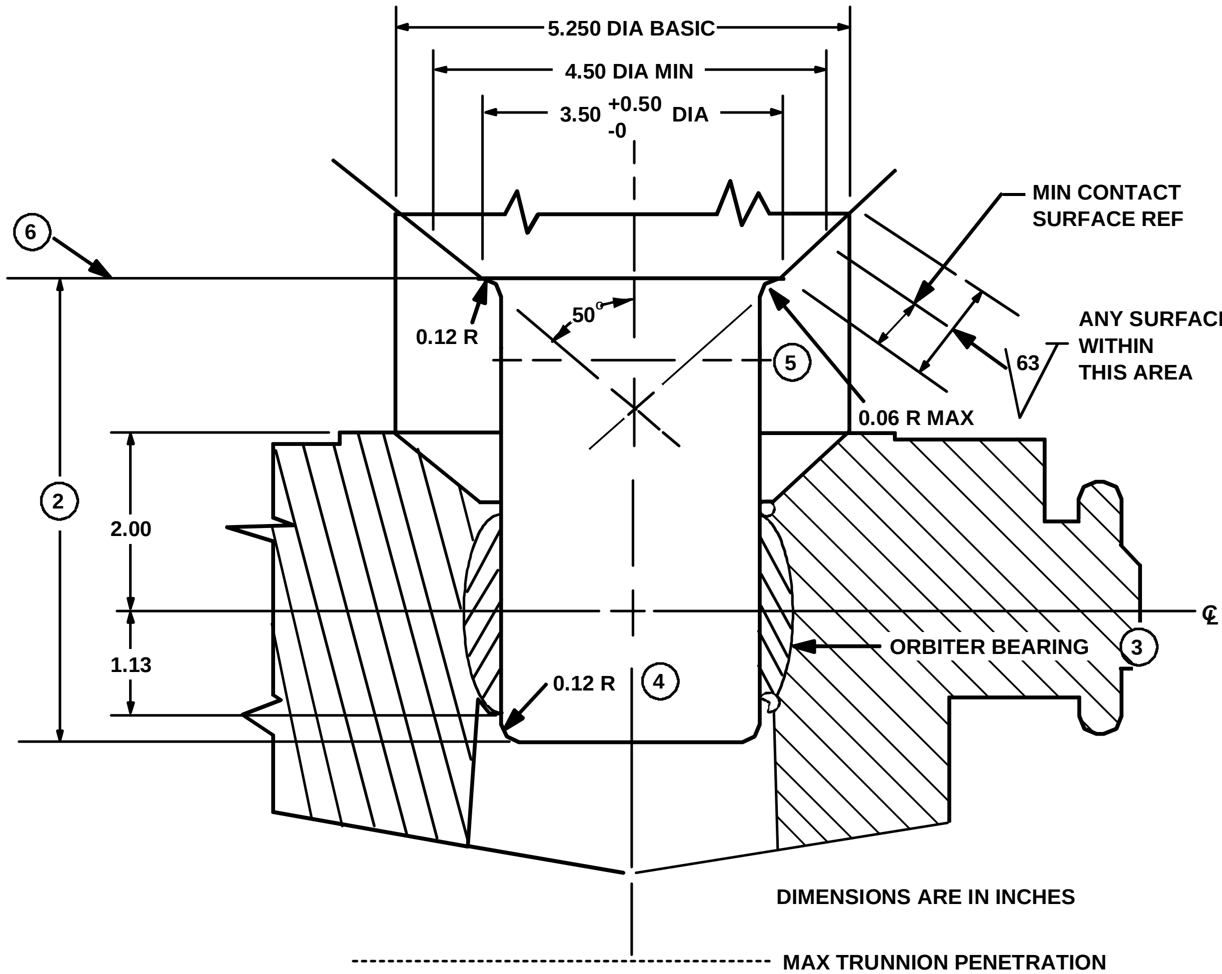
Figure 2-17.- Longeron trunnion and scuff plate.



NOTES:

1 TRUNNION CYLINDRICAL SURFACE MATERIAL: HARD, DENSE, FINE-GRAINED, ELECTRO-DEPOSITED CHROME TO WITHIN 0.15 IN. OF ROOT. *NICKEL-BASED ALLOYS* ARE TO BE PLATED PER FED SPEC QQ-C-320B, CLASS 2; THICKNESS SHALL BE 0.0003 IN. MIN.

TITANIUM IS TO BE PLATED PER ROCKWELL SPEC MA0109-318; THICKNESS SHALL BE 0.002 IN. MIN. TRUNNION FINISH AFTER PLATING SHAL BE $\sqrt{8}$ (8 RHR, MEASURED IN MICROINCHES).

(2) TRUNNION LENGHT SHALL BE IN ACCORDANCE WITH THE FOLLOWING:
FORWARD OF X_o1191.00 - LENGHT IS 8.00 IN.
AFT OF X_o1191.00 - LENGHT IS 4.82 IN.

(3) SELF-ALIGNING SPLIT BEARING, INSIDE DIAMETER 3.0000 + 0.0010, -0.0000. BEARING CENTER-LINE AT Z_o305.025 FORWARD OF X_o1191, AT Zo308.40 AFT OF X_o1191.

(4) BLEND WITHOUT MISMATCH WITH CYLINDRICAL OD

(5) TRUNNION OD AFTER CHROME PLATING IS: 2.9960 $^{+0.0000}_{-0.0010}$

(6) TRUNNION STATIC OCATION AT Z_o309.50 FORWARD OF X_o1191, AT Z_o311.10 AFT OF X_o1191

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Figure 2-18.- Keel trunnion.

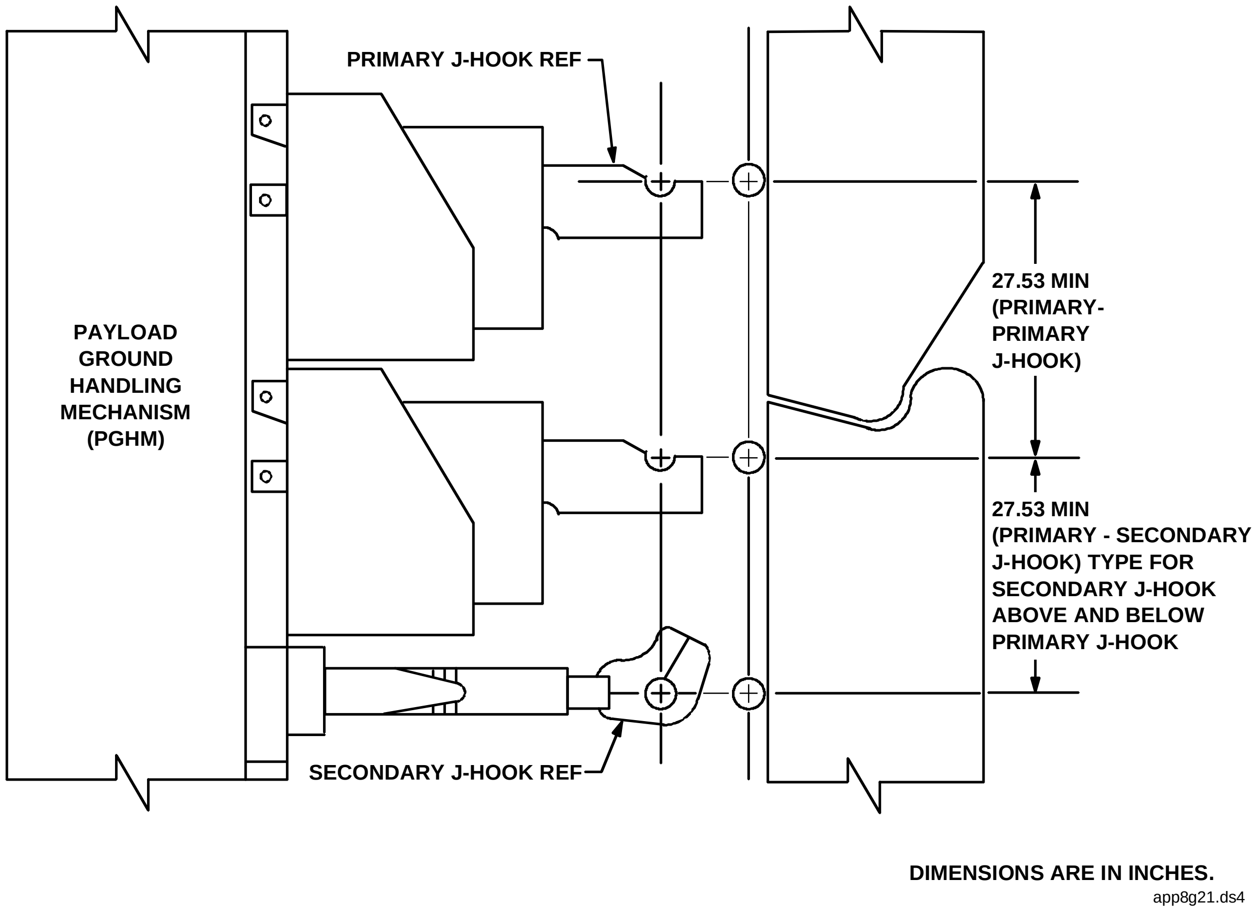


Figure 2-19.- Minimum longeron trunnion spacing (vertical processing).

The keel fitting will carry Y-Y loads from the payload keel trunnion (the keel trunnion is free to slide in the bearing, thus relieving Z-Z loads). The keel fitting is free to slide in the keel bridge in the X direction, thus relieving X-X loads, or can be pinned to the keel bridge to carry X-X loads.

Three installation schemes are used (Figure 2-20), depending on the load relief requirements of the payload. The most common arrangements are the three-point and five-point designs. If a five-point (or more) latch system is chosen and a latch fails, it will not be possible to determine the loads applied to the remaining latches during entry. Under worst-case circumstances, it may be necessary to leave the payload in orbit rather than land with it. Detailed payload attachment and installation schemes are contained in System Description and Design Data - Structures and Mechanics, NSTS 07700, Volume XIV, Appendix 4.

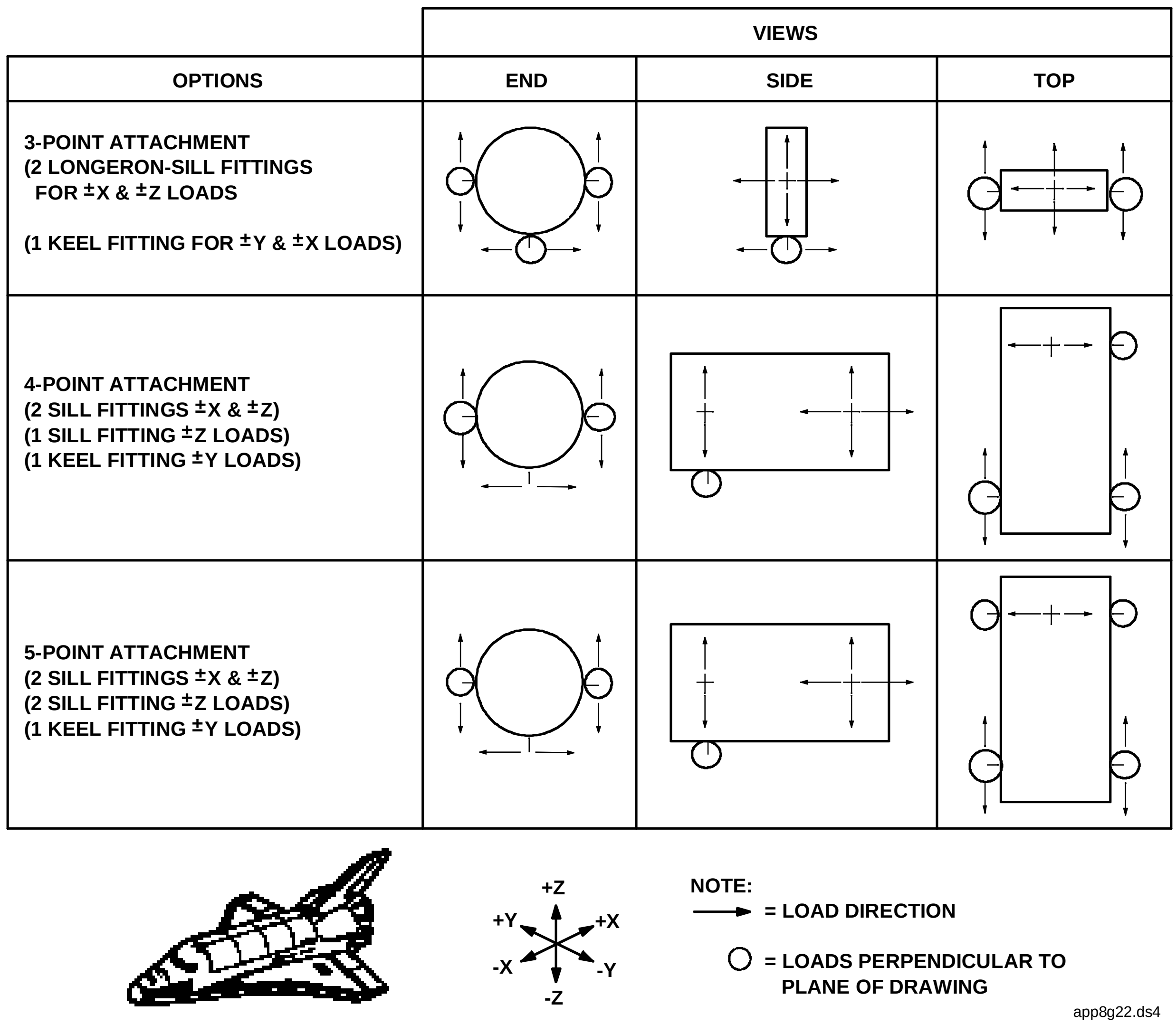


Figure 2-20.- Orbiter/payload retention system options.

2.7 CCTV System

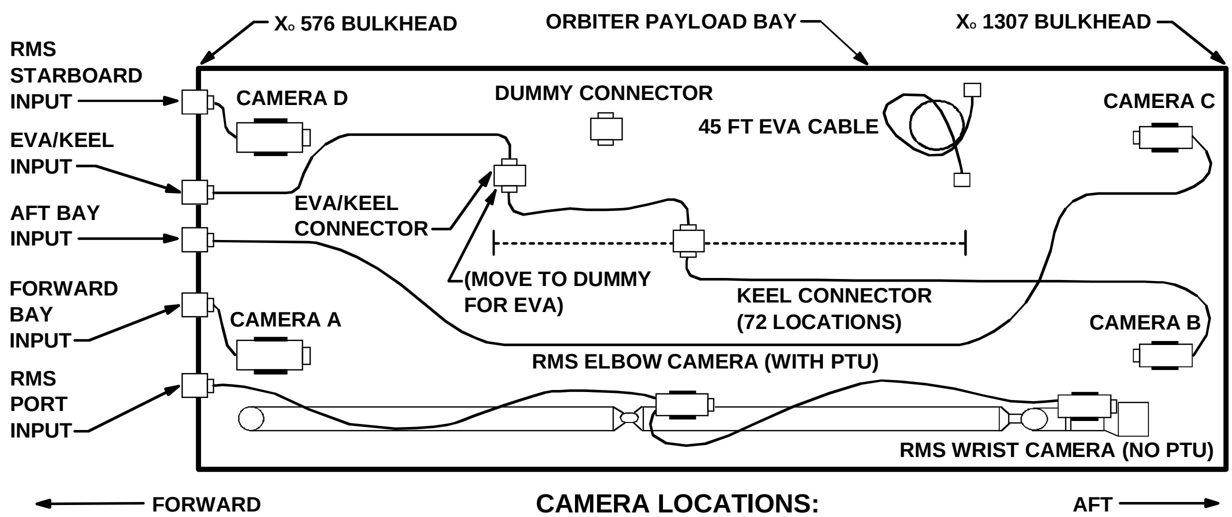
CCTV cameras in the payload bay, on payload support structures, and on the RMS augment the operator's window views. Lights in the bay and on the RMS provide illumination as required. There is no automatic collision avoidance system associated with the RMS; therefore, the operator must have adequate visual cues to monitor the RMS/payload motion. Where direct cues are obscured by payload bay configuration, etc., the customer must provide visual aids to meet this requirement.

2.7.1 Standard Configurations

The Orbiter has five inputs for CCTV cameras, Figure 2-21. The standard configuration is: Camera A connected to forward bay input, Camera B connected to keel/EVA input, Camera C connected to the aft bay input, Camera D connected to the starboard RMS input, and the RMS cameras connected (serially) to the port RMS input. CCTV cameras are generally considered as configurable with any mix of up to five cameras to support mission requirements. Nonstandard configurations may be negotiated during the PIP process.

Installations may include cameras mounted on payload-provided cradles or hardware to support viewing requirements for the payload deployment or berthing operation. A keel-mounted camera view is required to assist payload unberthing and berthing. A keel position will be negotiated and documented in the payload-unique Interface Control Document (ICD). With acceptable justification, an exception to the keel camera requirement may be negotiated and documented in the Integration Plan (IP). Keel camera/target alignment is addressed in section 4.3.1.

All exterior CCTV cameras are controlled at the AFD D&C panel. All cameras have zoom and iris control. Bulkhead cameras and the RMS elbow camera have pan and tilt controls, with relative pan and tilt angles displayable on the CCTV monitors. The television (TV) cameras can be configured preflight to accommodate a range of lenses for special payload applications. The standard lens



CAMERA LOCATIONS:

BULKHEAD CAMERA	ATTACHMENT TO BULKHEAD Xo	LENS EXTREME POSITION* Xo	CAMERA CENTERLINE Yo	CAMERA CENTERLINE Zo	KEEL CAMERA CENTERLINE AT ATTACHMENT PLANE Xo	Yo	Zo
D	576	598	71.5	446	789.73	-1.4	316.14
A	576	598	-71.5	446	TO	. . .	. . .
C	1307	1285	87	446	1124.07	-1.4	316.14
B	1307	1285	-87	446			

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Figure 2-21.- CCTV camera locations.

field of view ranges from approximately 46 degrees diagonal to 8.5 degrees diagonal (full-zoom range) when focused at infinity. A wide angle lens with a field of view range from 102 degrees to 36.5 degrees (full-zoom range) can replace the standard lens as required. The standard lens can be either monochromatic or color; the wide angle lens is color. Because the onboard CCTV monitors are monochromatic, CCTV display of signals from cameras with color lenses flicker. For nominal PDRS/RMS operations monochromatic lenses are desirable.

RMS elbow and wrist cameras can only be controlled and viewed one at a time. Using split screen capabilities of the TV monitors, up to four TV camera signals may be simultaneously viewed.

A limitation exists when a large diameter payload is manifested next to the RMS elbow camera. The elbow camera is mounted to the arm with a 25-degree wedge which will allow the port payload bay door to be closed if a pan-tilt unit (PTU) fails (preventing camera stowage). However, with this wedge installed, the elbow camera can intrude into the 15-foot diameter payload envelope. If the RMS operator needs the elbow camera to satisfy visual cue requirements during unberthing and berthing, camera operational constraints may be imposed. For more information about intrusions into the payload envelope, refer to ICD 2-19001.

CCTV coverage can be recorded on the video tape recorder (VTR) and/or downlinked for ground monitoring. Downlinked video may be available immediately or played back later, depending on Orbiter/data link/ground configuration.

All video requirements will be negotiated with SSP during the PIP process.

2.7.2 Flight-Support-Structure-Mounted Cameras

A Flight-Support-Structure-(FSS)-mounted camera view is required to assist the operator in payload docking to the FSS. A standard CCTV camera is mounted horizontially in the FSS with a prism that simulates a vertical camera view. The standard Airborne Support Equipment (ASE) mounting is described in section 4.3.2, along with the payload target alignment requirements.

2.8 Orbiter/RMS Lighting

The Orbiter exterior lighting in the vicinity of the payload bay is used to provide illumination to aid direct and indirect (CCTV) viewing of payload handling and proximity operations. In addition to the payload bay, bulkhead, and overhead lights, a light is located on the wrist segment of the RMS arm to provide illumination for RMS operations or for Orbiter/payload inspection. The RMS light, along with a CCTV camera, is mounted to and rolls with the wrist roll joint, Figure 2-22. The RMS light uses an incandescent filament lamp (rated at 130 watts) and a parabolic reflector. Most of the heat generated by the light is transmitted through the sapphire window and is radiated in the direct beam of light. The RMS light brightness is 3 foot-candles (32 lumens/m^2) at 30 feet (9.1 m), diminishing to 0.15 foot-candle (l.6 lumens/m^2) at 200 feet (61 m).

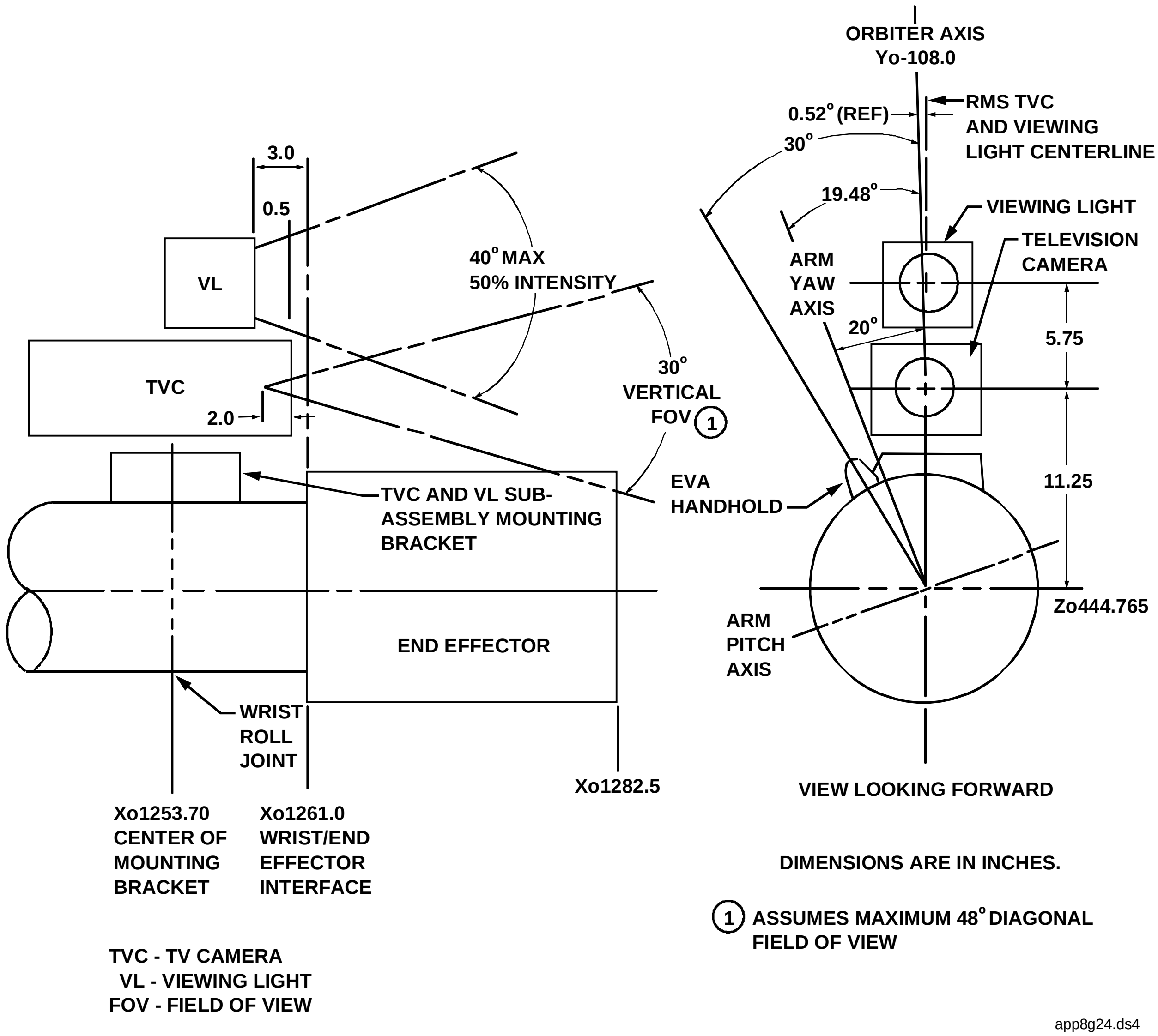


Figure 2-22.- Wrist camera and light subassembly configuration.

2.9 Manipulator Foot Restraint

The manipulator foot restraint (MFR) is a special purpose attachment for the EE that provides a platform for an EVA crewmember to accomplish payload servicing, repair, etc. Refer to System Description and Design Data- Extravehicular Activities, NSTS 07700, Volume XIV, Appendix 7, for more information on the MFR.

The MFR is certified for the following load carrying capabilities and RMS velocities. The tables are based on the MFR carrying a 486-pound (220-kg) suited crewmember. Table 2-I assumes a 500-pound (225-kg) payload is attached with the center of mass (c.m.) of the payload no more than 12 inches (30.5 cm) from the centerline of the stanchion. Table 2-II velocities are for unloaded operations (no payload attached).

TABLE 2-I.- RMS VELOCITIES FOR MFR WITH PAYLOAD ATTACHED

	Translation	Rotation
Vernier	0.25 ft/sec (0.076 m/sec)	0.59 deg/sec
Coarse	0.44 ft/sec (0.134 m/sec)	1.49 deg/sec

TABLE 2-II.- RMS VELOCITIES FOR MFR WITHOUT PAYLOAD ATTACHED

	Translation	Rotation
Vernier	0.26 ft/sec (0.079 m/sec)	0.61 deg/sec
Coarse	0.77 ft/sec (0.235 m/sec)	2.79 deg/sec

The crewmember should not apply more than 100 lbf (460 N) to the MFR structure. The foot restraint is designed for a ±140-lbf (640-N) load applied by each foot.

The RMS-applied constrained motion load limit is a force of 300 lbf (1380 N) applied to the MFR on the foot-restraint-to-GF structure. The 300-lbf limit is an ultimate load limit, and the MFR will not fail in any manner which would separate the crewmember from the RMS. The EVA crewmember's space suit is limited to this same load. The RMS position must be chosen to limit the constrained loads to less than 300 lbf. The family of curves that define the allowable RMS positions is used by NASA in the design process.

2.10 RMS Safety Features

Due to the large number of components and the single string design of the RMS, every effort has been made to include safety features as an integral part of the arm. When a failure occurs, the GPC and MCIU display the appropriate caution or warning to the operator on the D&C panel or CRT. Data is downlisted to provide system status to the ground flight controllers. Payload-dependent joint rate limits are used by the RMS software to guarantee undesired motion does not exceed 2 feet (0.61 m) when any of the following features are used.

2.10.1 Safing Function

MCIU safing is initiated when the MCIU is first powered up or when the MCIU software detects loss of GPC communications. Safing stops arm motion by zeroing the joint rate commands and maximizing the current available to dynamically stop the motors.

2.10.2 Automatic Braking Function

The automatic braking safety feature was developed to stop individual joint runaways. Joint angle and rate data (derived from the encoders and tachometers, respectively) are compared in the GPC RMS software. If actual joint rates are faster than commanded rates over a period of time, or if the angles and rates are not consistent, the software engages the brakes and drops the system out of any computer-supported mode. (Joints that are frozen or cannot move are not detected by this method.) Trajectory Tracking Error Detection (TTED) is implemented in the GPC software and will also apply automatic brakes.

2.10.3 Brakes

The operator can stop undesired arm motion by applying the brakes through the "Brake" switch on Panel A8U. The torque applied by the brakes to the joints is usually not as high as the torque that is applied to the joint by safing (i.e., zero rate commands with maximum motor current to the motors).

2.10.4 RMS Built-in Test Equipment

Built-in test equipment (BITE) in the RMS generates flags that alert the RMS operator and ground flight controllers when hardware failures occur. Certain flags will initiate the automatic braking or safing functions described above. The operator is trained to respond to these flags and to perform malfunction procedures in order to determine what capabilities remain.

2.11 Contingencies

Certain backup procedures for RMS failures have been prepared and are listed below.

a. The shoulder brace can be released by an EVA crewmember.

b. The MPM can be deployed and stowed by an EVA crewmember. The MRL's cannot be latched via EVA. However, the capability does exist to strap the RMS to the MPM for entry.

c. Inflight maintenance repairs for some D&C failures can be performed with a pin kit or D&C panel break-out box.

d. The arm assembly can be jettisoned with or without a payload attached.

e. EVA techniques have been developed to cradle the RMS in the event of a joint failure.

f. An EVA crewmember can disconnect the payload GF from a failed EE.

g. A failed MCIU can be replaced by a spare MCIU (stored in a middeck locker).

Refer to System Description and Design Data - Extravehicular Activities, NSTS 07700, Volume XIV, Appendix 7, for a more complete description of the EVA capabilities and hardware available.

System Operational Description

3

3.1 Coordinate Systems/Points of Resolution

The RMS software is capable of controlling rotation about a point -- internal or external to the payload -- within the hardware travel limits of the joints. A total of six points of resolution (POR) are available during a flight. One is always reserved for the EE, and the other five must be shared by the payload(s) requiring RMS handling (i.e., five payloads can have one each or one payload can have five). An item entry on Spec 94 (section 2.2) tells the software which POR to use. Translation of the payload and rotation about the POR is done in one of several different coordinate systems, depending on which RMS mode is being used.

Nine different coordinate systems are used as reference frames when relating the RMS to the Orbiter, the RMS to the payload, or the payload to the Orbiter. All are right-handed systems. It should be noted that all payload positions and attitudes are displayed in the Orbiter body axis system and Orbiter rotation axis system, respectively. Rotation rates are displayed in different coordinates, depending on which operational mode is being used. For each axis, positive roll is around the +X axis, positive pitch is around the +Y axis, and positive yaw is around the +Z axis.

A description of those coordinate systems of interest to the RMS payload user is given below:

3.1.1 Orbiter Coordinate System (Orbiter Structural Reference System)

The Orbiter coordinate system (OCS), also referred to as the Orbiter structural reference system (OSRS), Figure 3-1, originates 236 inches (6 m) forward of the nose and 400 inches (10.2 m) below the centerline of the Orbiter. The +X axis points toward the Orbiter's tail, the +Y axis points toward the starboard wing, and the +Z axis points "up" to complete the right-handed coordinate system. Payload manifest location coordinates (X_o, Y_o, and Z_o) are given in this system.

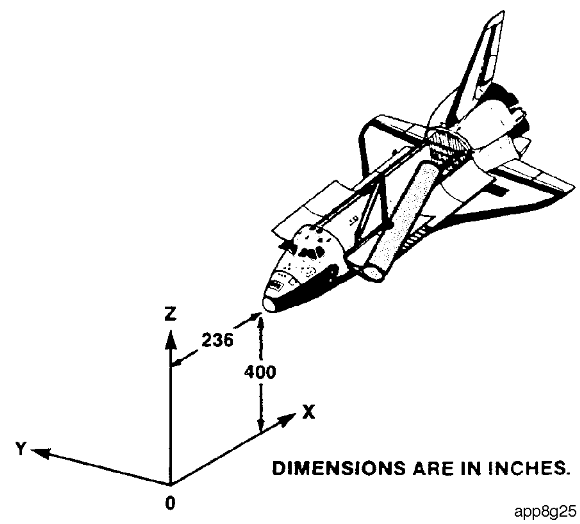


Figure 3-1.- Orbiter coordinate system.

3.1.2 Orbiter Body Axis System (OBAS)

The OBAS, Figure 3-2, originates 236 inches forward of the nose and 400 inches below the centerline of the Orbiter. The -X axis points toward the Orbiter's tail, 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.

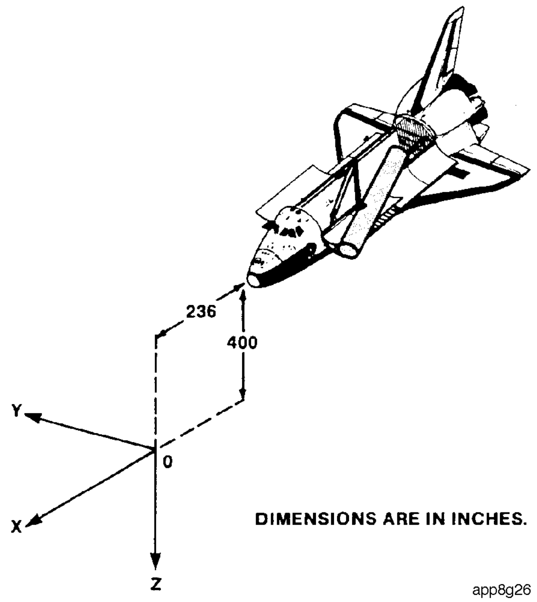


Figure 3-2.- Orbiter body axis system.

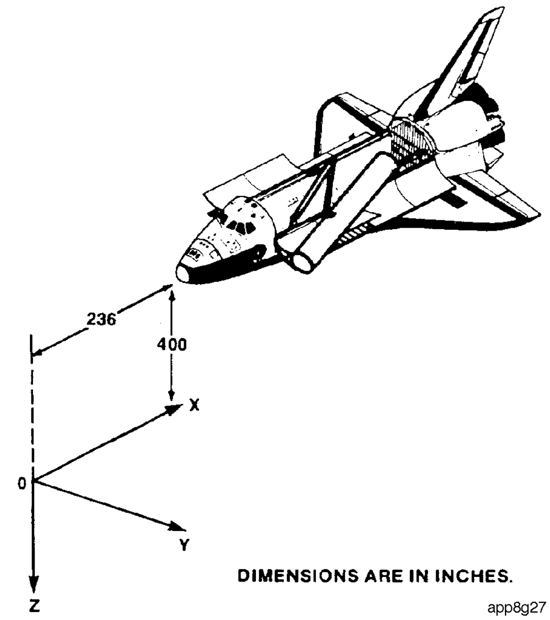


Figure 3-3.- Orbiter rotation axis system.

3.1.3 Orbiter Rotation Axis System (ORAS)

The ORAS, Figure 3-3, originates 236 inches forward of the nose and 400 inches below the centerline 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.

3.1.4 End Effector Operating System (EEOS)

The EEOS, Figure 3-4, 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 ORAS. 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 mode.

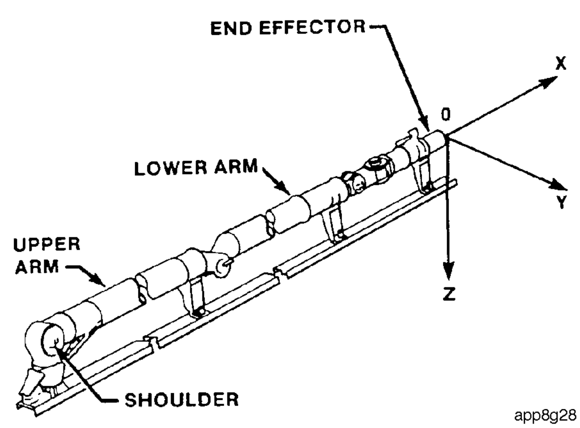


Figure 3-4.- End effector operating system.

3.1.5 Payload Axis System (PAS)

The PAS is defined by the payload designer and is used as the spacecraft's reference system just as the Orbiter coordinate system is used to define Shuttle stations. The PAS must be a right-handed, orthogonal coordinate system for ease of transposing into the other right-handed, orthogonal coordinate systems of the RMS. The PAS is usually chosen so that its axes are parallel or orthogonal to those of the Orbiter coordinate system when the payload is berthed. The origin is usually located at or near the payload's geometric center or the c.m.

3.1.6 Grapple Fixture Axis System (GFAS)

The GFAS, Figure 3-5, is the standard coordinate system which defines the position and orientation of GF's mounted to the payload structure. The origin of the GFAS is located at the base of the grapple shaft. Positive X is out the grapple shaft, positive Z is up through the grapple target, and positive Y completes the right-handed coordinate system. GFAS information is required for each GF, if more than one are employed. The location and orientation of each payload GFAS is defined with respect to the PAS.

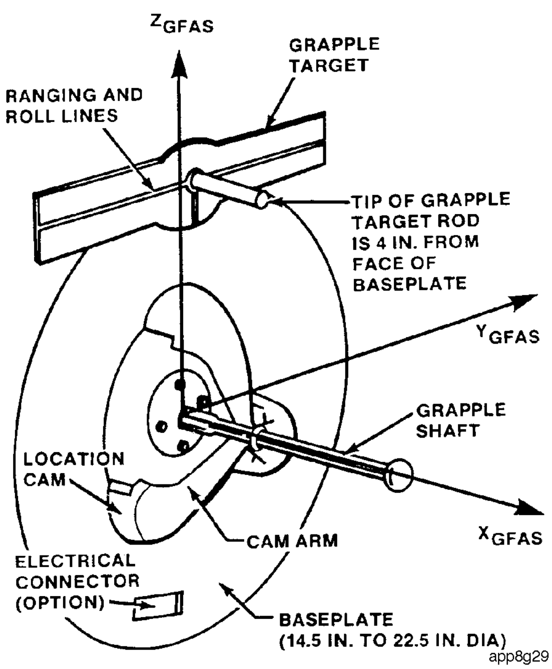


Figure 3-5.- Grapple fixture axis system.

3.1.7 Payload Operating System (PLOP)

The PLOP is defined by NASA. The PLOP 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 payload mode. The PLOP's origin and orientation need not bear any resemblance to the PAS. The origin is chosen to be some fixed point on or in the payload (i.e., its c.m. or a specific instrument on the payload's surface). It is often given as a transpose of the PAS axes with its axes parallel to those of the ORAS when the payload is berthed.

3.1.8 Local Vertical/Local Horizontal (LVLH)

LVLH, Figure 3-6, is a reference frame used to describe the location and orientation of the Orbiter in orbit. An LVLH +Z axis vector points from the Orbiter's c.m. to the center of the Earth. The +Y axis points in the direction opposite to the Orbiter angular momentum vector. The +X axis lies in the orbit plane in the direction of the velocity vector, but is only identical to the velocity vector for perfectly circular orbits. When the Orbiter is in an LVLH attitude with pitch, yaw, and roll all equal to zero, the belly points to the center of the Earth (i.e., the open payload bay points away from the Earth) and the nose points in the direction of the velocity vector. LVLH is an Earth-relative reference frame. When the Orbiter is maintaining a fixed LVLH attitude, it will remain in the same Earth-facing orientation as it orbits.

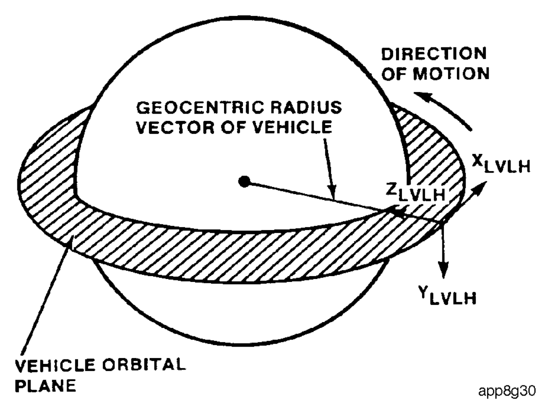


Figure 3-6.- Local vertical/local horizontal reference system.

3.1.9 Inertial

An inertial reference frame describes the location and orientation of the Orbiter in space. It is fixed relative to the stars and has its axis origin at the center of the Earth. Various inertial reference frames exist, each defining the direction of the X, Y, and Z axes in relation to different star references.

3.2 Operating Modes

The RMS is controlled by the operator from the RMS D&C panel in the AFD. Four primary control modes (manual, automatic, single, and direct drive) with varying degrees of software support are available, as well as a contingency back-up mode. Combined six-joint operation of the arm, through either the manual or automatic control modes, enables the operator to move the EE in six degrees of freedom (three degrees of motion in translation, three in rotation). A summary of the coordinate systems used during RMS operations is given in Table 3-I. The control modes that can be selected by the operator are in the following sections. Position Orientation Hold Submode (POHS) is used to control unwanted POR motion during manual augmented mode operation. POHS controls the unwanted motion by creating a feedback loop that compensates for POR position and orientation error.

3.2.1 Manual Modes

There are four manual modes: Orbiter unloaded, Orbiter loaded, EE, and payload. In manual modes, the operator issues commands through two three-degree-of-freedom hand controllers. The RHC provides for pitch, yaw, and roll about the POR. The THC provides for resolved up/down, left/right, fore/aft translation. Cross-coupling (that varies with payload mass and POR velocity) and drifting in uncommanded directions can be expected in this mode during arm operations. However, once stationary, the arm will maintain its position to within ± 2 inches (5 cm) and ± 1 degree.

a. Orbiter Unloaded Mode

This mode uses the tip of the EE as the POR, Figure 3-7a. Translation commands are in the OBAS (reference section 3.1.2) and rotation commands are in the ORAS (reference section 3.1.3).

b. Orbiter Loaded Mode

This mode uses a predetermined point within the payload (or the tip of the EE) as the POR, Figure 3-7b. The POR does not have to be at the c.m. or center of geometry. Translation commands are in the OBAS (reference section 3.1.2) and rotation commands are in the ORAS (reference section 3.1.3).

TABLE 3-I.- SUMMARY OF RMS OPERATING MODES AND COORDINATE SYSTEMS USED FOR DISPLAY

Operating Mode		Coordinate System Used for Display (Point of Resolution) Position (X, Y, Z)	Attitude (P, Y, R)	Translation rates	Rotation rates
Manual Modes	Orbiter Unloaded	OBAS	ORAS	OBAS	ORAS
	Orbiter Loaded	OBAS	ORAS	OBAS	ORAS
	End Effector	OBAS	ORAS	EEOS	EEOS
	Payload	OBAS	ORAS	PLOP	PLOP
Automatic Modes	Preplanned Sequence	OBAS	ORAS	OBAS	ORAS
	Operator Commanded	OBAS	ORAS	OBAS	ORAS
Single Joint Drive Mode		OBAS	ORAS	OBAS	ORAS
Direct Drive Mode (when available)		OBAS	ORAS	OBAS	ORAS
Back-up Drive Mode		Display of Data Not Available			

c. EE Mode

This mode uses the tip of EE as the POR, Figure 3-7c. Translation and rotation commands are in the EEOS (reference section 3.1.5).

d. Payload Mode

This mode uses a predetermined point within the payload (or the tip of the EE) as the POR, Figure 3-7d. The POR does not have to be at the c.m. or geometric center. Translation and rotation commands are in the PLOP system (reference section 3.1.8).

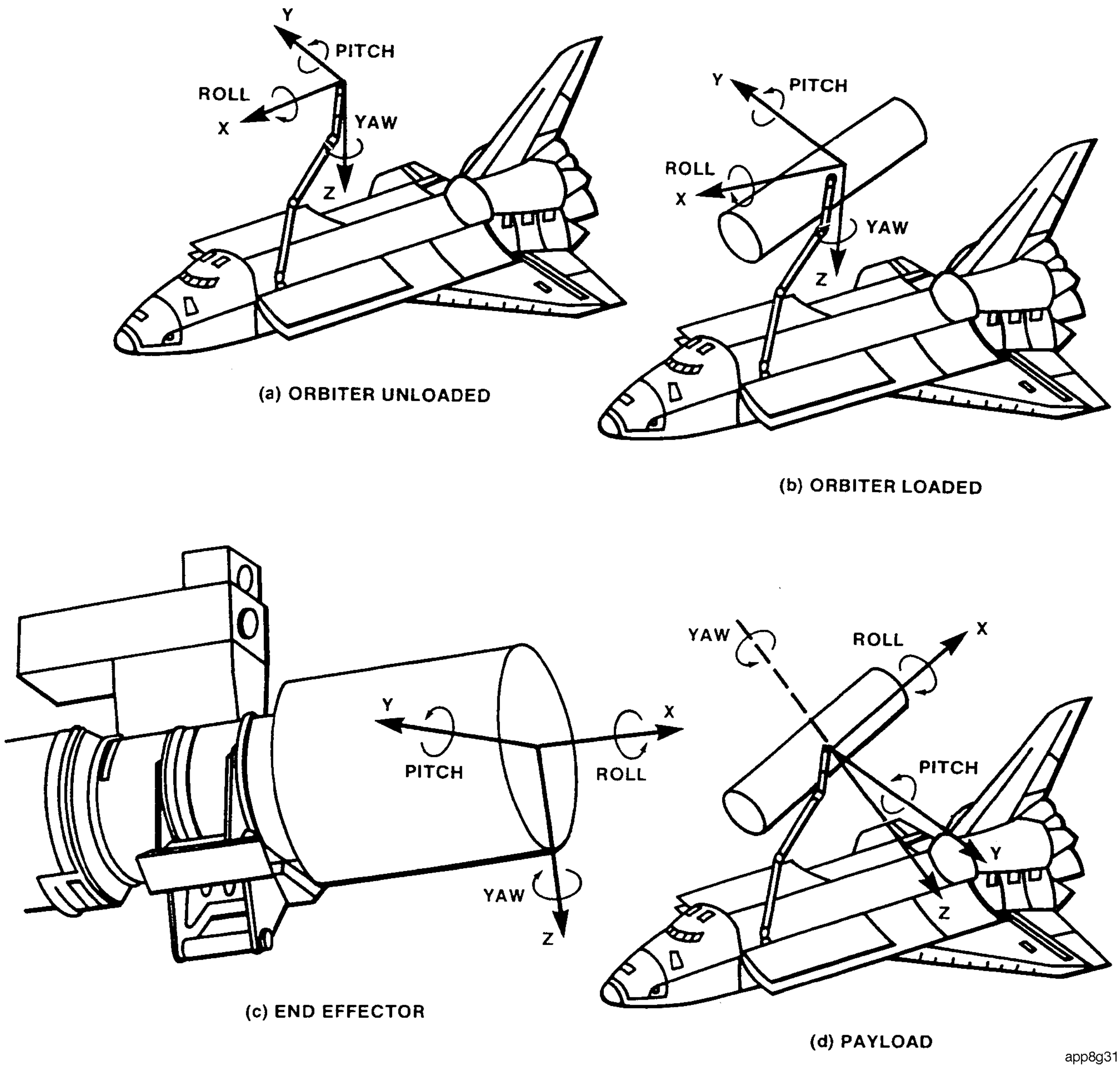


Figure 3-7.- RMS manual operating modes.

3.2.2 Automatic Modes

a. Preplanned Sequences

Coordinated six-joint arm movement can be controlled automatically along a preflight specified trajectory, or auto sequence, that is comprised of a series of points. Up to 20 sequences can be constructed per flight. Each sequence is designed for a specific flight, arm, EE, and payload. No limit is set on the number of points in a sequence, except that the total number of points in all of the sequences for any flight cannot exceed 200. Each point is defined by the OBAS position (X, Y, and Z) and ORAS attitude (pitch, yaw and roll). Each of the identical points that are to be repeated during a specific sequence requires one of the 200 available slots.

In order to start an auto sequence, the payload (or EE) POR must be within a specified distance of the first point, Figure 3-8. The distance is specified preflight and is usually 2 inches and 1

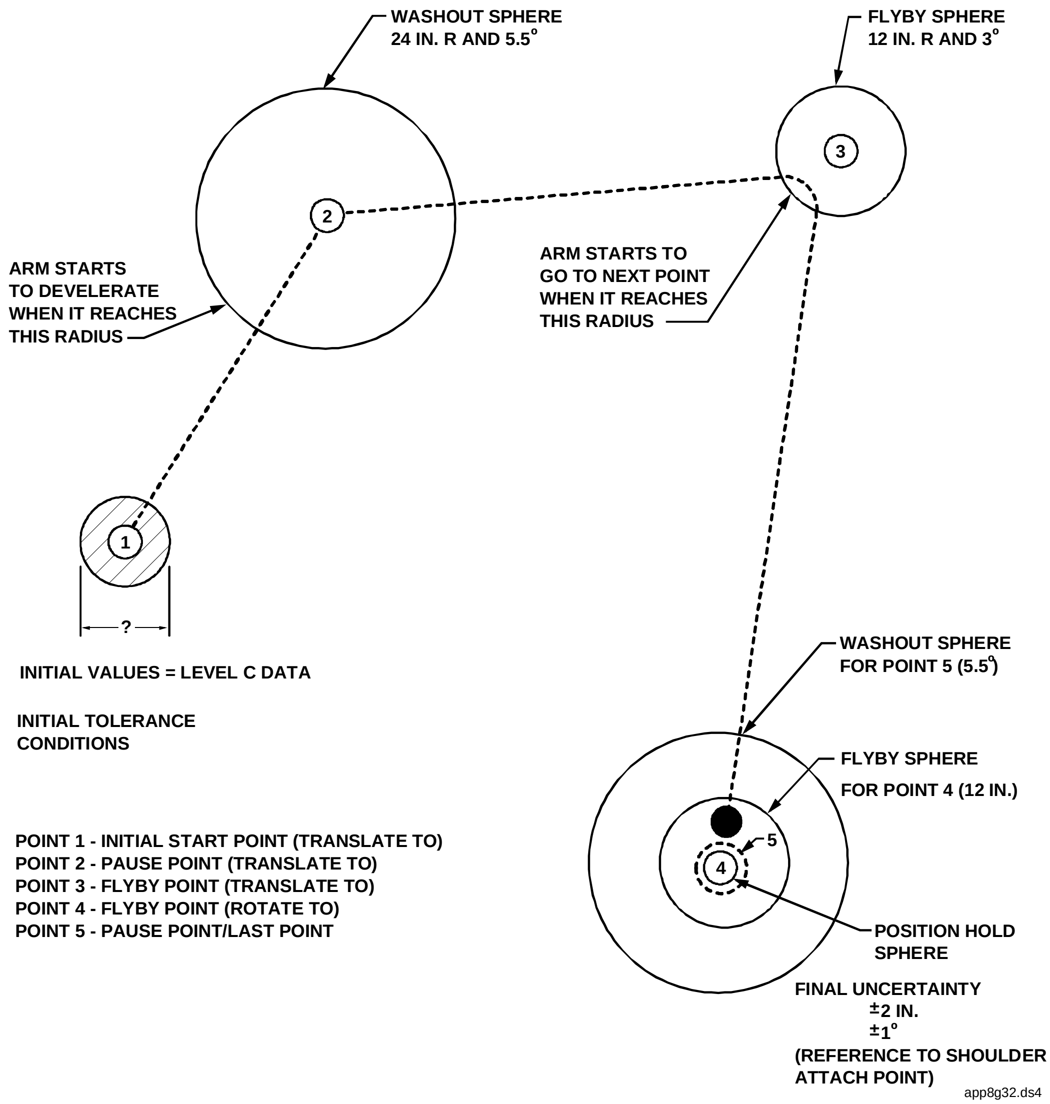


Figure 3-8.- RMS pre-planned sequence (automatic mode).

Deviation/Waiver 1 is applicable to Figure 3-8.
Refer to the Deviations/Waivers Section in front of the document.

degree. The RMS software continuously calculates a straight line from the current POR position to the next point; however, arm dynamics prevents exact straight line motion. Points may be either fly-by or pause points. The arm will drive toward a fly-by point until the POR is within 12 inches (30.5 cm) and 3 degrees (the fly-by sphere) of the point. As soon as the POR is within the fly-by sphere, the arm will move toward the next point. Because of this, the position and attitude specified for fly-by points may not be achieved. When approaching a pause point, the arm will begin to decelerate when the POR reaches the washout sphere (24 inches and 5.5 degrees) around the point. Once stopped, the POR will remain within 2 inches and 1 degree of the pause point until commanded by the operator to move to the next point. Both the initial and last points of every sequence are pause points.

Auto trajectories will be designed to keep the arm boom and payload at least 5 feet (1.52 m) from any Orbiter or payload structure. The RMS Mission Designer will develop and verify all auto sequences prior to incorporating the sequences into the RMS software. Early discussions with an RMS Mission Designer are suggested for anyone planning to use RMS automatic sequences.

Deviation/Waiver 1 is applicable to Paragraph 3.2.2.a.
Refer to the Deviations/Waivers Section in front of the document.

b. Operator Command Mode

A second type of automatic trajectory is under direct control of the RMS operator. The operator commanded auto sequence (OCAS) mode is initiated by entering the desired position and attitude of the POR into the GPC via the keyboard. After a check to determine whether a set of joint angles exists that can produce the desired point, the RMS software calculates a straight line from the current POR to the desired point. Arm dynamics prevent perfectly straight line motion. No collision detection or avoidance system prevents an incorrect command from causing the arm/payload to hit the Orbiter. Therefore, each OCAS command must be verified as safe prior to its use. This can be accomplished preflight through procedure testing, or in-flight through visual inspection by the crew or by flight controllers in mission control.

3.2.3 Single Joint Drive Mode

Individual arm joints are driven by operator command through the D&C panel. These commands are routed through the RMS software, which (1) controls the position of all joints, (2) limits drive speeds, (3) provides joint position displays, and (4) indicates when joint-angle-reach limits are encountered. When not being commanded to drive, the joints are maintained (via software command) at their current positions.

3.2.4 Direct Drive Mode

Direct drive uses hardwired commands from the D&C panel to the individual joints; it is a contingency mode which bypasses the software. The brakes must be engaged to enter direct drive. When a joint is selected to drive, that joint's brake is released; the other brakes remain engaged. When the drive command is taken off, the brake is reapplied and higher-than-normal joint rate oscillations occur. Current supplied to the motors in this mode is lower than in the other primary modes; therefore, torque available is lower. No current ramping is applied during joint start-up and as a result start-up is usually not as smooth as in other primary modes. System display data may not be available in this mode since it is used only in contingencies.

3.2.5 Back-up Drive Mode

Back-up drive is only used during contingencies when no primary mode is available. It operates like direct drive except that display data and ground downlist are never available.

3.3 Noncommanded Operations

When not being commanded to move, the joints are held in position in one of three ways: (1) position hold, (2) zero rate command hold, or (3) brakes on. The software controls arm motion when driving through singularities and stops arm motion when software stops are encountered.

3.3.1 Position Hold Submode

In position hold, the computer generates rate commands to drive each joint back to the desired angle. The further away from the desired angle, the greater the rate command. Externally applied torques will meet with resistance. The arm may move in response to the torque; however, as soon as the application of the torque stops, the joint will return to its previous position. This is the control process that holds the nonmoving joints during single mode operations.

3.3.2 Zero Rate Command Submode

In the zero rate command submode, joint rate commands are set to zero in the RMS software. The arm electronics feedback loop generates commands to stop joint motion. The higher an externally applied torque or residual joint rate, the greater the response in the opposite direction to stop the motion. Once the arm has stopped, externally applied torques will meet with resistance. The arm may move in response to the torque; however, unlike position hold, when the application of the torque stops, the arm will stop where it is. This is the control process that holds the nonmoving joints during manual mode operations. Some drift in the position of the noncommanded joints is expected.

3.3.3 Brakes-On

With brakes on, a brake pad is held in contact with the brake shaft surface on each joint. (The brake pad is disengaged from the shaft when 28 Vdc is applied to the brake coil.) When the brakes are engaged, no software-generated rate commands are acted on in the arm based electronics. The brakes can oppose externally applied torques only until the brake static friction (stiction) is overcome. The brakes are applied to the nonoperating joints during direct drive and back-up drive operations.

3.3.4 Singularity Handling

Certain arm configurations cause mathematical and operational singularities. Defined mathematically, a singularity occurs when the determinant of the Jacobian transformation matrix that converts joint angle rates to POR translation and rotation rates is zero. When this occurs, no inverse transformation matrix is available to convert desired operator commands into the motor commands for the joints.

Operationally, singularities occur when one or more controlled degrees of freedom of the arm are lost. The three sets of these configurations are shown in Figure 3-9. With the wrist yaw joint above the shoulder joints, Figure 3-9a, ± Y translation commands cannot be accomplished. With the arm straight out, Figure 3-9b, commands in the +X direction in the EE mode are not possible. With the wrist yaw joint 90 degrees from the arm pitch plane, Figure 3-9c, some roll commands are not possible.

When degrees of freedom are lost, loads induced in the arm by external forces (i.e., Reaction Control System (RCS) jets and payloads) are not transferred to the Orbiter longeron as expected. This may cause shortened arm lifetime or structural failure. For this reason, RCS firings and payload captures are not allowed when the arm is in a singularity.

The singularities are managed within the RMS software algorithms. The arm is driven through the singularity by the software in the automatic and manual modes. The operator is advised via a caution light on the D&C panel when a singularity is approached or encountered. During software handling, the arm may deviate slightly from its commanded trajectory. Every effort is made to avoid singularities when developing procedures.

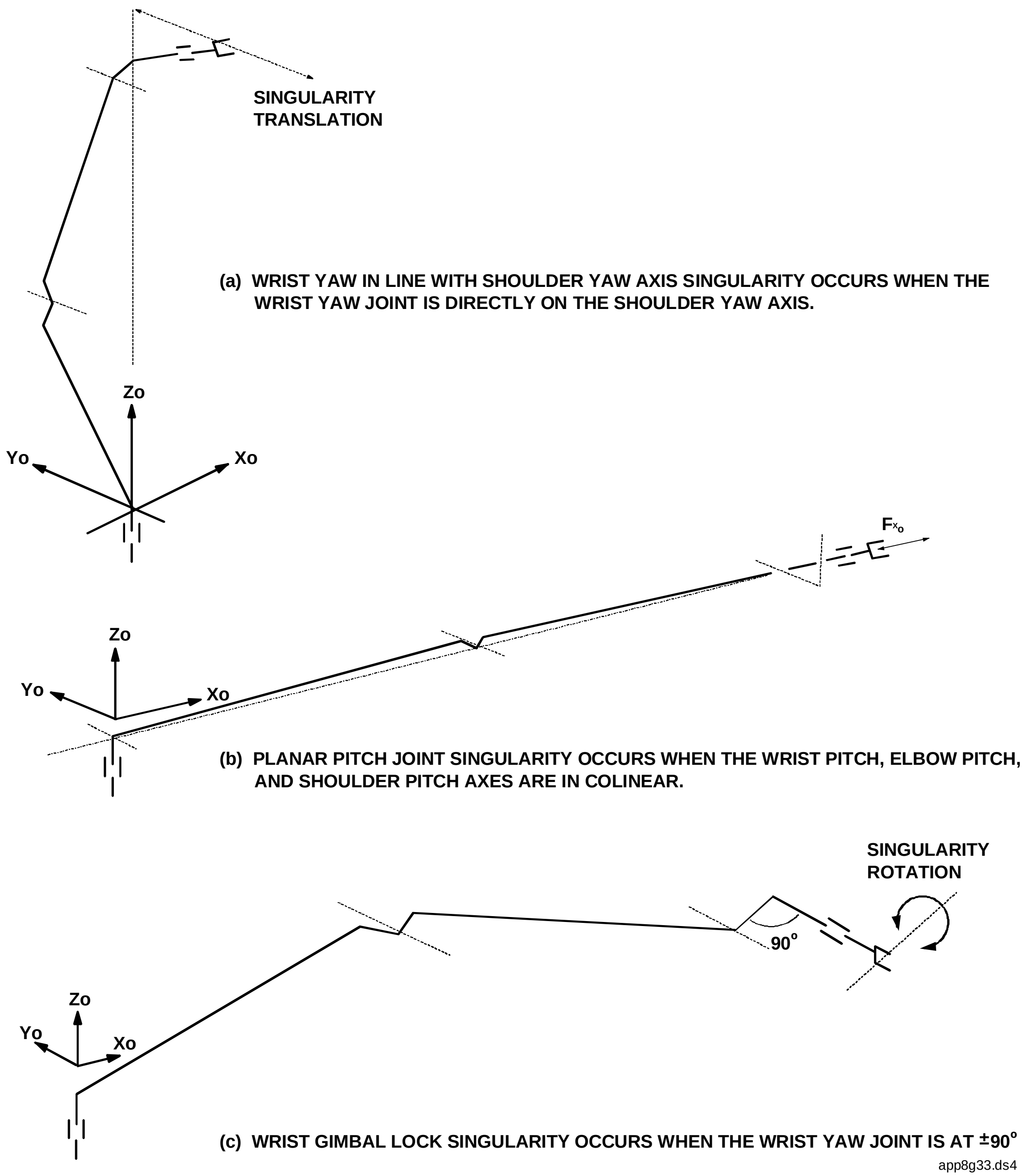


Figure 3-9.- RMS singularity configurations.

3.3.5 Software Stop and Reach Limits

The RMS software prevents joints from driving into their hardstops. Table 3-II lists the location of the reach limits, software stop limits, and hardstop limits. A reach limit caution is issued to the operator when a joint is approaching its software-stop limit. When a joint reaches its software-stop limit, the software drops out of any computer-supported mode and brings the arm to rest. Operations can continue only after the joint is driven out of its software-stop limit by one of the single-joint modes. This software protection is not available in direct drive or back-up drive modes.

3.4 RCS and Digital Auto Pilot Descriptions

3.4.1 RCS Description

Two different systems of jets are used for Orbiter translation and rotation maneuvers, the primary reaction control system (PRCS) and the vernier reaction control system (VRCS). Each PRCS jet produces 870 lbf (3975 N) of thrust; each VRCS jet produces 24 lbf (110 N) of thrust. Only the PRCS can be used for Orbiter translations, including payload rendezvous and proximity operations. The VRCS is normally used for Orbiter attitude maintenance. Using the VRCS to achieve Orbiter attitude for payload deployment ensures the greatest possible attitude accuracy at payload release. Because the VRCS is only zero-fault tolerant, contingency operations may be planned using the PRCS if analyses indicate no structural load limits are exceeded and that no DAP instability will occur. Release attitude and rate accuracy will probably decrease under PRCS control.

TABLE 3-II.- RMS JOINT TRAVEL LIMITS

Joint	Specification Travel, deg	Reach Limit Location, deg	Soft Stop Location, deg	Mechanical Stop Location, deg
Shoulder Yaw	+180 -180	+175.4 -175.4	+177.4 -177.4	+180 -180
Shoulder Pitch	-2 +145	+2.6 +140.4	+0.6 +142.4	-2 +145
Elbow Pitch	+2 -145	-2.4 -155.6	-0.4 -157.6	+2.4 -161
Wrist Pitch	-120 +120	-114.4 +114.4	-116.4 +116.4	-121.4 +121.4
Wrist Yaw	-120 +120	-114.6 +114.6	-116.6 +116.6	-121.3 +121.3
Wrist Roll	-447 +447	-440.0 +440.0	-442 +442	-447 +447

Jet firings produce plumes that can impact the RMS or payload. Table 3-III shows the RCS plume-avoidance zones for the RMS hardware. The plume effects (force and torque) on the payload can be determined when payload surface area is known.

3.4.2 Digital Auto Pilot Description

The digital auto pilot (DAP) consists of several software algorithms which provide attitude maintenance and control of the Orbiter. The DAP operates in both open and closed loop rotational modes.

The open-loop modes are MANUAL ACCEL (ACCEL) and PULSE. When in the ACCEL mode, the DAP will command the appropriate jets ON as long as the Orbiter RHC is out of detent. Once the RHC is returned to detent, the Orbiter will be in free drift. When in the PULSE mode, the DAP will command the appropriate jets ON to achieve the crew entered rotational rate. Once this rate is achieved, jets are commanded OFF and the Orbiter will be in free drift. There is no Inertial Measurement Unit (IMU) rate feedback to ensure the desired rate was indeed achieved.

The closed loop modes are MANUAL DISC RATE, AUTO, and MANUAL LVLH. These modes use IMU data to automatically command jets ON to achieve the desired rate/attitude.

The rate and attitude will be controlled to within the deadbands specified by the crew on the DAP Configuration Spec. The minimum jet firing time is 80 milliseconds.

An example: If the DAP receives a request to maneuver at 0.5 deg/sec with a rate deadband of 0.02 deg/sec and attitude deadband of 1.0 degree, it will turn jets on and off to maintain an Orbiter rate of 0.5 (± 0.02) deg/sec and an Orbiter attitude to within 1.0 degree of desired.

3.5 Allowable Maneuvering Zones

DAP stability is achieved during closed-loop operations when the Orbiter/payload c.m. and RMS/payload dynamic flexibility characteristics stay within the operational envelope where the jets can maintain an attitude without divergent oscillations and with minimum jet firings. In order to determine whether a proposed Orbiter maneuver will result in a stable DAP, mission-specific analyses are performed for each payload.

TABLE 3-III.- RCS PLUME STAY-OUT ZONES FOR RMS

(a) PRIMARY RCS STAY-OUT ZONES

Firing Rate	Stay-out-Zones*			
Continuous	X = 0, R = 200	X = 425, R = 150	X = 500, R = 100	X = 600, R = 0
6 sec	X = 0, R = 200	X = 200, R = 100	X = 340, R = 0	
80 msec	X = 0, R = 40	X = 130, R = 40	X = 160, R = 30	X = 180, R = 0

(b) VERNIER RCS STAY-OUT ZONES

Firing Rate	Stay-out-Zones*			
Continuous	X = 0, R = 18	X = 50, R = 18	X = 70, R = 10	X = 80, R = 0
80 msec	X = 0, R = 5	X = 30, R = 0		

*X = Distance in inches from thruster in direction of thruster plume.
R = Lateral distance in inches from center of thruster.

3.5.1 PRCS Operations

PRCS use cannot be planned during RMS operations unless optional service analyses indicate structural load limits are not exceeded. If these analyses are not performed preflight, the PRCS will not be used if the VRCS fails. With no RCS control, the Orbiter attitude will drift (free drift) until the payload is berthed or released.

3.5.2 VRCS Operations

Tables 3-IV and 3-V are used by the RMS Mission Designer as a guide to position the c.m. of a payload during VRCS closed-loop operations. If the VRCS DAP deadbands, payload weight, and interface frequency fall within the envelopes shown in the tables, NASA will perform the analyses required. Otherwise, the analysis will negotiated as part of the IP process.

Table 3-IV defines the DAP stability envelopes with the payload position being maintained by the RMS brakes. Table 3-V defines the envelopes with the payload held in the RMS-position-hold submode or while the RMS is moving the payload. To use either table, choose the row that describes the payload as designed -- payload weight and interface frequency. If the desired DAP deadband is known, select the corresponding payload position envelope from the last column. If the desired payload position is known, select the corresponding DAP deadband. If the interface frequency as designed does not allow the desired

deadband or position envelope, select the desired envelopes and determine what the interface frequency must be. If no combination satisfies the customer's requirements, the customer must fund the optional service analysis to determine if there is a combination that will guarantee a stable DAP.

Table 3-IV is valid from OCS Y = +75 to -75 inches, and for all payloads with interface frequencies ≥ 0.2 Hz. Abbreviations used are: (1) RL - rate limit deadband, (2) DB - attitude deadband, (3) x, y, z - X, Y, Z position of payload c.m. in OCS.

Table 3-V is valid for RMS operations in position hold or with commanded motion, with the DAP as specified in the Minimum Deadzone Size column. Abbreviations are the same as for Table 3-IV, except that PH refers to position hold and M refers to RMS in motion.

TABLE 3-IV.- GENERIC VRCS DAP STABILITY ENVELOPES FOR BRAKES ON

Payload Weight (K Pound)	Minimum Deadzone Size	Envelope Size (Inches, OCS)
0 < w ≤ 1	RL ≥ 0.01 deg/sec DB = Normal unloaded RMS restrictions without attached payload	Normal unloaded RMS restrictions
1 < w ≤ 8	RL ≥ 0.02 deg/sec DB ≥ 2 deg	490 ≤ x ≤ 1040 -75 ≤ y ≤ 75 Z ≤ 610
1 < w ≤ 8	RL ≥ 0.04 deg/sec DB ≥ 2 deg	490 ≤ x ≤ G1 -75 ≤ y ≤ 75 Z ≤ H1
8 < w ≤ 25	RL ≥ 0.02 deg/sec DB ≥ 2 deg	F2 ≤ x ≤ G2 -75 ≤ y ≤ 75 Z ≤ H2
8 < w ≤ 25	RL ≥ 0.04 deg/sec DB ≥ 2 deg	F3 ≤ x ≤ G3 -75 ≤ y ≤ 75 Z ≤ H3
25 < w ≤ 65	Payload specific assessment will be performed as a standard service.	

NOTE: Table valid for all payloads with grapple fixture/payload interface frequencies ≥ 0.2 Hz.

RL denotes rate limit deadband.

DB denotes attitude deadband.

Envelope limits are parameterized by payload weight w (in klb) and payload X-Z c. m. position in OCS, Figure 3-1.

G1 = 1347.8 + 0.456Z
H1 = The least of 895 and (2957.8 – 2.194×)

F2 = 467 + 3.33w
G2 = 1200 – 20w
H2 = 650 – 5w

F3 = 467 + 3.33w

$$G3 = \frac{W+10}{W-47.5} Z - \frac{10w^2 - 1175w + 62000}{W-47.5}$$

H3 = The least of (975 - 10w) and

$$\frac{W-47.5}{W+10} X + \frac{10w^2 - 1175w + 62000}{W+10}$$

TABLE 3-V.- GENERIC VRCS DAP STABILITY ENVELOPES FOR POSITION HOLD AND RMS MOTION

Payload Weight (K Pound)	RMS Mode	Grapple Fixture Interface Frequency (HZ EE_OP)	Minimum Deadzone Size	Envelope Size (Inches, OCS)
$0 < w \le 1$	PH or M	≥ 0.2	RL $\ge$ 0.01 deg/sec for PH or without attached payload RL $\ge$ 0.2 deg/sec for M with payload attached DB $\ge$ Normal unloaded RMS restrictions for PH or without attached payload $\ge$ 3 deg for M with payload attached	Normal unloaded RMS restrictions
$1 < w \le 8$	PH or M	≥ 0.2	RL $\ge$ 0.01 deg/sec for PH $\ge$ 0.2 deg/sec for M DB $\ge$ 0.5 deg for PH $\ge$ 3.0 deg for M	$400 \le x \le 1300$ $-90 \le y \le 90$
$8 < w \le 35$	PH only	≥ 0.2	RL $\ge$ 0.02 deg/sec DB $\ge$ 1.0 deg	$A1 \le x \le B1$ $C1 \le y \le D1$ $z \le E1$
$8 < w \le 35$	PH only	≥ 0.5	RL $\ge$ 0.01 deg/sec DB $\ge$ 0.5 deg	$A2 \le x \le B2$ $C2 \le y \le D2$ $z \le E2$
$8 < w \le 35$	PH only	≥ 0.5	RL $\ge$ 0.02 deg/sec DB $\ge$ 1.0 deg	$A3 \le x \le B3$ $C3 \le y \le D3$ $z \le E3$
$35 < w \le 65$		≥ 0.5	Payload specific assessment will be performed as a standard service.	

NOTE: PH denotes position hold.
M denotes RMS motion allowed.
RL denotes rate limit deadband.
DB denotes attitude deadband.

Envelope limits are parameterized by payload weight W (in K pounds) and payload X-Z c. m. position in OCS, Figure 3-1.

A1 = The greatest of 400 and 10W + 300
B1 = The least of 1200 and 1557.0 - 0.857 Z -5.0 W
C1 = The greatest of -90 and 3W - 150
D1 = The least of +90 and 150 - 3W
E1 = The least of 900 and 1817.0 - 1.167X - 5.833 W

A2 = The greatest of 400 and 10W + 300
B2 = The least of 1200 and 1557.0 - 0.857 Z - 5.0 W
C2 = The greatest of -90 and 3W - 150
D2 = The least of +90 and 150 - 3W
E2 = The least of 900 and 1817.0 - 1.167 X - 5.833 W

A3 = The greatest of 400 and 10W + 300
B3 = The least of 1200 and 1657.0 - 0.857 Z - 5.0 W
C3 = The greatest of -90 and 3W - 150
D3 = The least of +90 and 150 - 3W
E3 = The least of 950 and 1933.0 - 1.167X - 5.833 W

Example 1, Figure 3-10, shows the envelope for a 10,000-pound (4530-kg) payload with a rate limit of 0.02 deg/sec for both position hold and brakes on. The figure indicates it may not be possible to position a 10,000-pound payload at X = 700 inches and Z = 700 inches with brakes on, since it falls outside the brakes-on envelope. Example 2, Figure 3-11, shows the same envelope for a 20,000-pound (9060-kg) payload. Examples 3 and 4, Figures 3-12 and 3-13, show the brakes-on envelopes for 10,000-pound and 20,000-pound payloads, respectively, for a rate limit of 0.04 deg/sec.

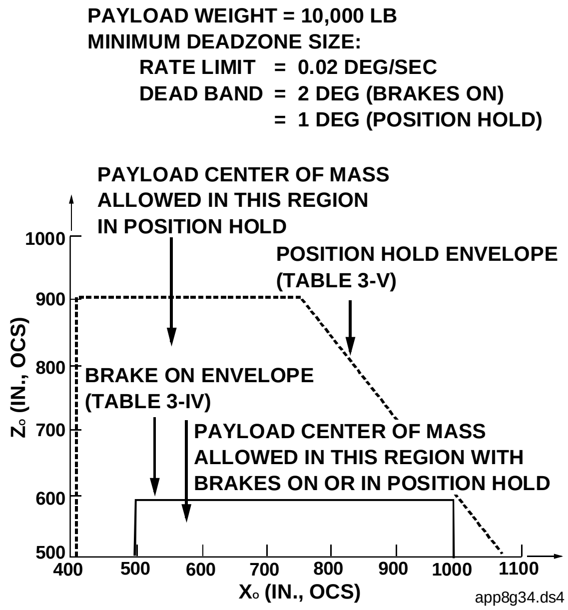


Figure 3-10.- VRCS DAP stability envelope, example 1.

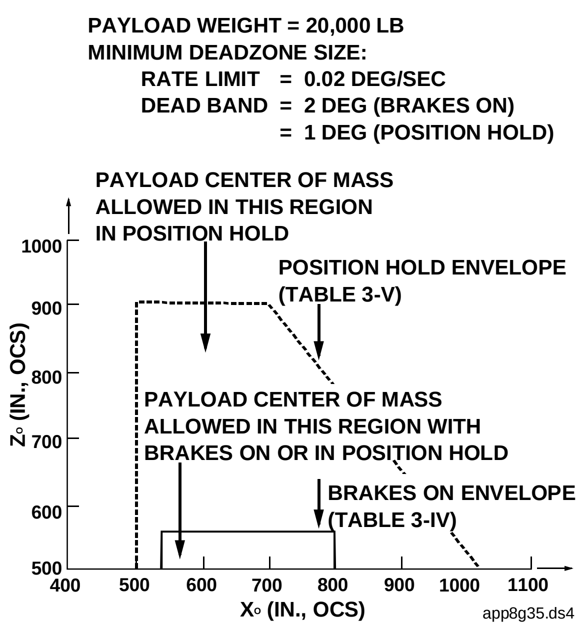


Figure 3-11.- VRCS DAP stability envelope, example 2.

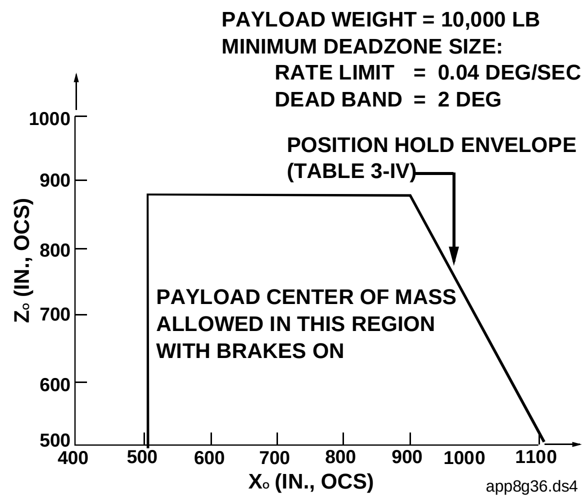


Figure 3-12.- VRCS DAP stability envelope, example 3.

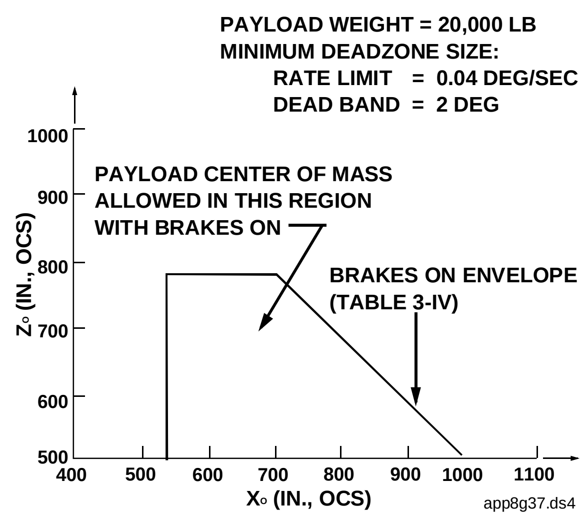


Figure 3-13.- VRCS DAP stability envelope, example 4.

3.5.3 Operational Considerations

During payload deployment, the brakes are usually turned on while the crew performs check-outs, verifies positions, etc. It is required that the brakes be on whenever the operator is not visually monitoring the RMS and payload. Because the operator may not be able to monitor the payload at all times during a deployment, all payload positions that require VRCS DAP attitude control must be chosen within the brakes-on DAP stability envelope as defined in Table 3-IV or from a payload-specific assessment.

Payload Design Requirements and Recommendations

4

4.1 Design Case Payload

Three different criteria have been established to define the maximum envelope for payloads located within the payload bay:

a. A payload can be 15 feet (4.57 m) in diameter and 53 feet 3 inches (16.3 m) in length. This gives a 2-foot (0.61-m) clearance from forward and aft bulkhead CCTV cameras, as illustrated in Figure 4-1.

b. A payload can be 12 feet (3.7 m) in diameter and 54 feet 10 inches (16.7 m) in length. This gives a 4-foot (1.2-m) clearance from the forward bulkhead for EVA clearance and a 2-foot (0.61-m) clearance from the aft bulkhead and aft CCTV cameras, as illustrated in Figure 4-2.

c. A payload can be 9 feet 7 inches (2.97 m) in forward diameter, 12 feet (3.7 m) in aft diameter, and 56 feet (17.1 m) in length. The forward diameter is based on a 2-foot (0.61-m) clearance from forward bulkhead CCTV cameras; the aft diameter is based on a 2-foot (0.61-m) clearance from the aft bulkhead CCTV cameras; and the length is based on a 2-foot clearance with the bulkhead, as illustrated in Figure 4-3. The 4-foot (1.2-m) EVA envelope is violated; therefore, the payload must be removable or jettisonable.

Payloads will be manifested so that 2 feet (0.61 m) of clearance is maintained with any other payload, payload cargo element (other structure on the same pallet), or Orbiter structure until the trunnions enter the guides. The clearance can be decreased uniformly to a minimum of 6 inches (15 cm) when the trunnions are fully seated in the latches. For more information about intrusions into the payload envelope, refer to ICD 2-19001.

A pallet with RMS deployable payloads must: (1) provide either the clearances as above, or (2) be designed so the pallet elements within 2 feet of the payload during operations can safely withstand 1.1 ft/sec (0.34 m/sec) contact velocities.

Bump protection must be provided for critical payload items, such as hydrazine storage tanks, attitude control systems, cryogenic tanks, and pyrotechnic devices.

Standard RMS services are based on a 32,000-pound (14,515-kg), rigid, homogeneous, 60-foot-long, 15-foot-diameter payload with moments of inertia as follows:

I_{xx} = 27,973 slug-ft^2 (37,903 kg-m^2)
I_{yy} = 312,112 slug-ft^2 (422,921 kg-m^2)
I_{zz} = 312,112 slug-ft^2 (422,921 kg-m^2)

The capability does exist for the RMS to deploy and retrieve payloads of a mass greater than 32,000 pounds (14,514 kg) in a non-time-constrained operation. An analysis will be required to confirm RMS and Orbiter capabilities for any payload weighing more than 32,000 pounds (14,515 kg).

All payloads must have visual cues to aid the operator during RMS operations. The visual cues include, but are not limited to: (1) out-the-window direct-line-of-sight viewing of the payload structure of interest during operations; (2) Orbiter bulkhead CCTV views; (3) keel or FSS-mounted CCTV views; (4) payload-unique physical cues to be used in conjunction with (1), (2), and (3); i.e., “feelers” or “whiskers” mounted to the Orbiter or payload latch guides. The exact nature of the cues must be negotiated during the IP process. (Reference sections 2.8, 4.2.4, 4.3, and 5.3.)

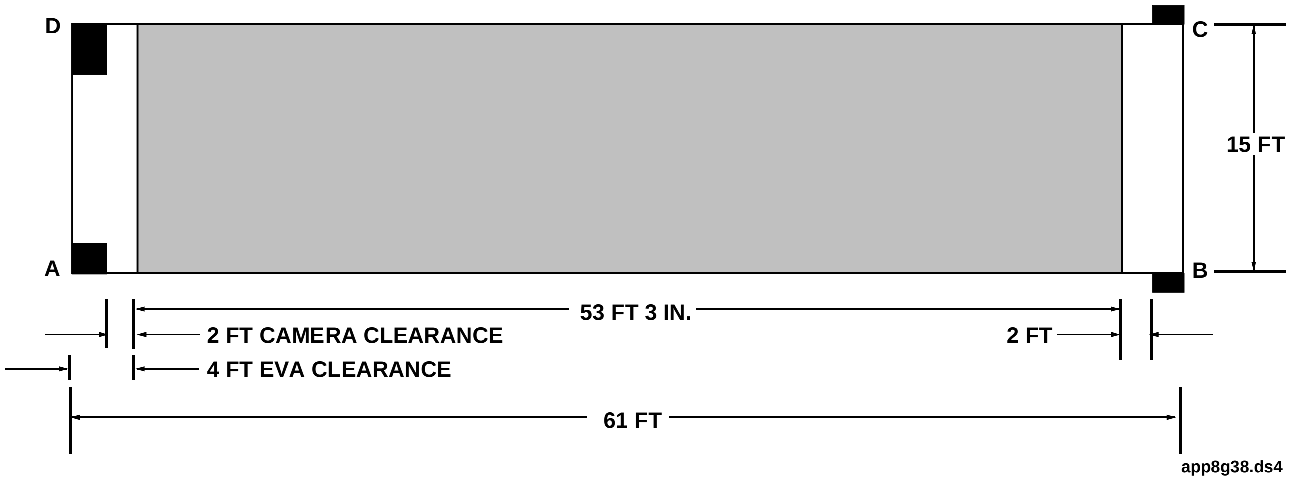


Figure 4-1.- Diameter and length for design case payload.

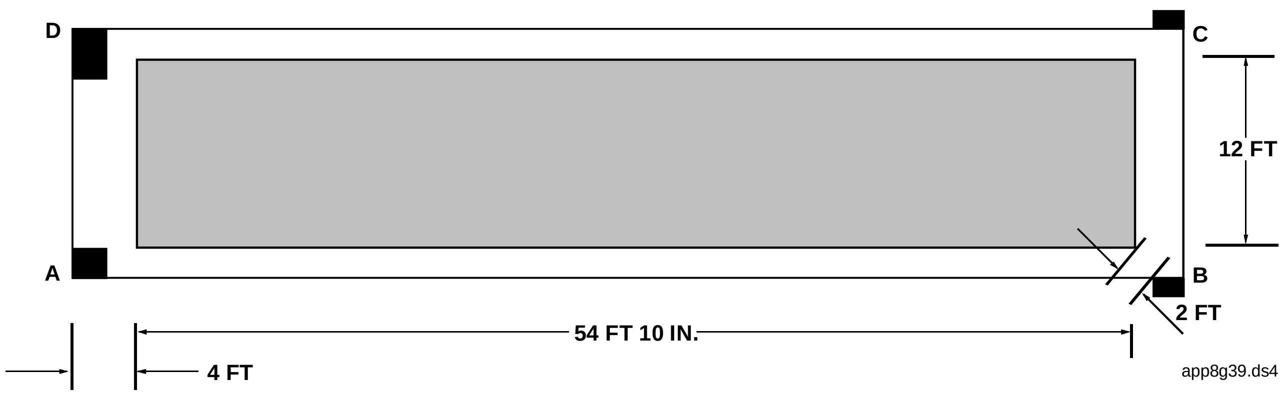


Figure 4-2.- Diameter and length for design case payload.

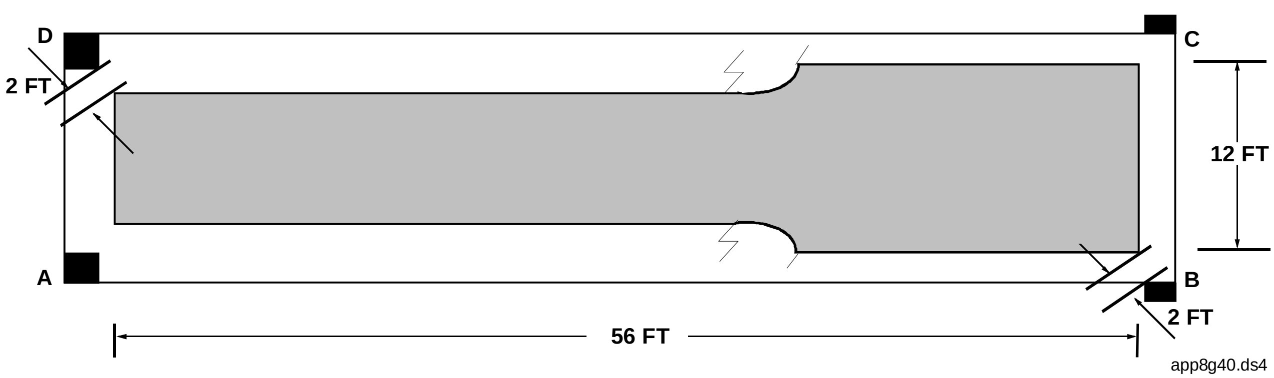


Figure 4-3.- Diameter and length for design case payload.

4.2 Payload Grapple Fixtures (GF's)

There are three types of GF's: (1) the standard GF, (2) the rigidize-sensing GF, and (3) the electrical GF. The following describes the characteristics common to all three. Differences are described in sections 4.2.1 through 4.2.3.

Each GF has crew-operated EVA release bolts which are flight critical components. The EVA release bolts are properly torqued when delivered. Operation of the bolts by the payload organization is strictly prohibited. Torque striping material is applied to the EVA release bolts to permit preflight inspection and verification. The GF will not be flown if there is any indication that the EVA bolt has been moved.

Payload design requirements will determine whether a standard, a rigidize-sensing, or an electrical GF is required. GF's are leased or purchased from Lyndon B. Johnson Space Center (JSC).

The GF will be located such that the perpendicular distance from the GF centerline to the payload c.m. is ≤ 11.0 feet (3.4 m) and the total distance from the payload c.m. to GF base is ≤ 13 feet (4.0 m), as illustrated in Figure 4-4. If the GF centerline passes within 1 foot (0.30 m) of the payload c.m., the total distance can be increased to 20.0 feet (6.1 m), as illustrated in Figure 4-5.

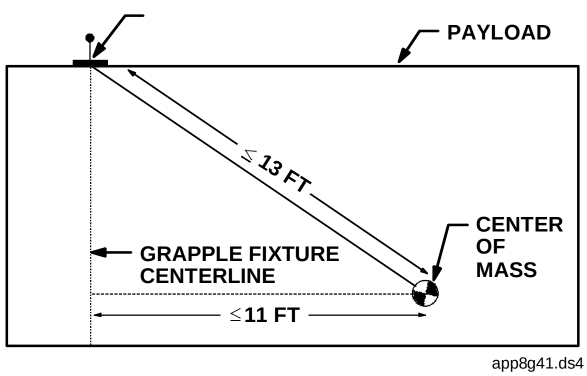


Figure 4-4.- Grapple fixture location.

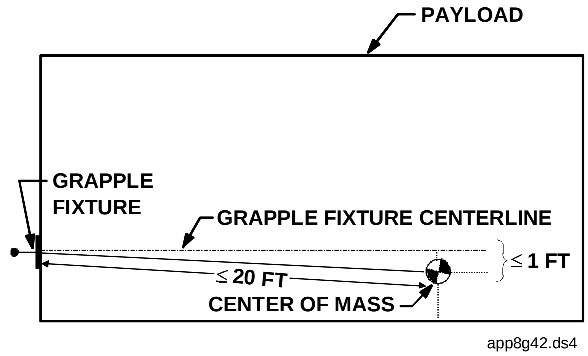


Figure 4-5.- Alternate grapple fixture location.

It is recommended that the GF be installed with the grapple shaft parallel to the Orbiter Z axis for most manifested locations. However, for forward and aft locations, a GF placement analysis will have to be performed. The location of the GF's on payloads with appendages will be determined by mutual agreement.

Following rigidization, the tensile force exerted by the EE on the GF is 740 - 820 lbf (3292 - 3647 N) in the EE auto mode and 740 - 1300 lbf (3292 - 5782 N) in EE manual mode. The GF will distribute the reaction force between the EE end ring and GF baseplate uniformly over the annular contact area.

The GF will be able to transmit the following loads, Table 4-I, between the EE and the standard 32,000-pound (14,515-kg) payload (as described in section 4.1). Case 1 shows the maximum torsional moment expected (700 ft-lb) with its associated bending moment and shear force. Case 2 shows the maximum bending moment expected (1200 ft-lb) with its associated torsional moment and shear force.

TABLE 4-I.- GRAPPLE FIXTURE LOADS

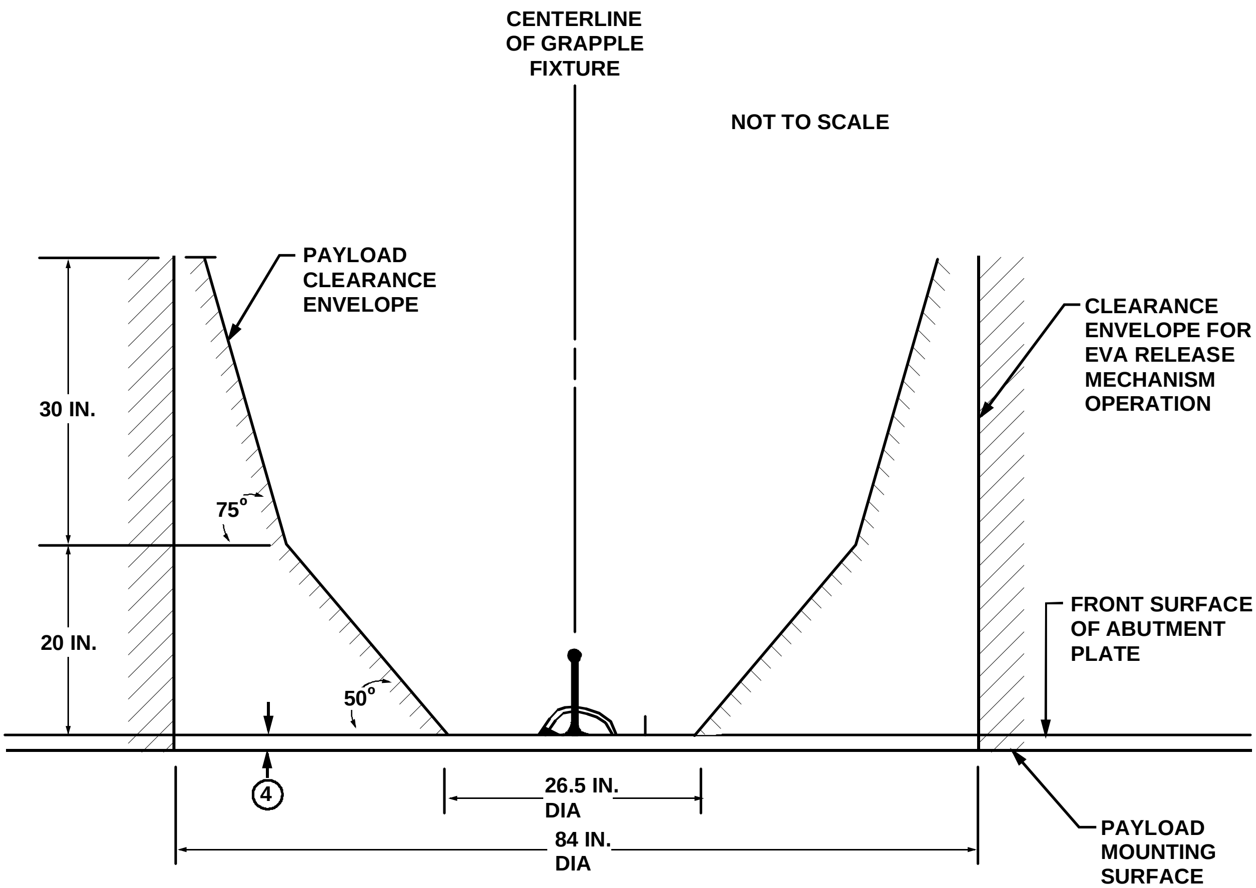
	Case 1	Case 2
a. Torsional moment about the longitudinal axis of the EE	700 ft-lb (949 N-m)	450 ft-lb (610 N-m)
b. Bending moment to EE	900 ft-lb (1220 N-m)	1200 ft-lb (1627 N-m)
c. Shear force associated with the bending moment of (b) above	40 lbf (178 N)	50 lbf (222 N)

The torsional moment and bending moment for either case will be applied simultaneously. Note that the load cases should not be combined. The payload must be designed to withstand both cases, one case at a time.

The maximum bending moment without EE/GF separation is approximately 350 ft-lbf (474 N-m). Separation will not exceed 3 degrees during the loading conditions given above. Moments and shear forces shown will be transferred at the 3-degrees angular separation. The tensile load in the grapple shaft is 2215 lbf (9852 N) when the Case 2 bending moment is applied.

Following installation of the GF on the payload, the alignment between the GF-to-EE-interface plane and the payload reference axes must be supplied in Annex 1 of the PIP to within ± 0.15 degrees in pitch, yaw, and roll and to within ± 0.25 inch (0.63 cm) in X, Y, and Z.

The GF capture envelope (shown previously in Figure 2-6) and the payload clearance envelope (Figure 4-6) are designed to support RMS



NOTES:
1 CLEARANCE VOLUME CENTERED ON CENTERLINE OF GRAPPLE FIXTURE.

2 CLEARANCES REQUIRED BEYOND 50 INCHES FROM THE ATTACHMENT PLANE WILL BE DEPENDENT ON THE PAYLOAD AND THE REQUIRED ARM CONFIGURATION.

3 THE GRAPPLE FIXTURE/TARGET MOUNTING ORIENTATION ON THE PAYLOAD WILL BE DETERMINED BY THE OPERATIONAL TASK AND THE REQUIRED VIEWING REFERENCE FOR THE OPERATOR.

(4) DIMENSION DEPENDENT ON TYPE OF GRAPPLE FIXTURE INSTALLED.

app8g43.ds4

Figure 4-6.- Clearance envelopes for RMS operations.

operations. A maximum pitch and yaw misalignment of ± 15 degrees and a maximum roll misalignment of ± 10 degrees between the EE and GF is allowed at capture. Greater misalignments may preclude SPEE connector mating and proper seating of the location cams in the EE, or may cause premature activation of a rigidize-sensing GF.

Figure 4-6 also illustrates the volume around the GF that must be kept clear of all structure (primary structure or appendages) to ensure an EVA release capability.

All GF's, the area around the GF, and all surfaces the crew will touch during an EVA to release a GF must be built according to the EVA specification described in System Description and Design Data - Extravehicular Activities, NSTS 07700, Volume XIV, Appendix 7.

Thermal Considerations - The heat transfer rate between the GF and the EE must not exceed 1.5 BTU/hr deg F. For use in calculations, the worst case hot temperature for the EE is 65 degrees C, the worst case cold temperature for the EE is -10 degrees C. The allowable payload structure to GF thermal conductance for various payload temperatures is shown in Figure 4-7.

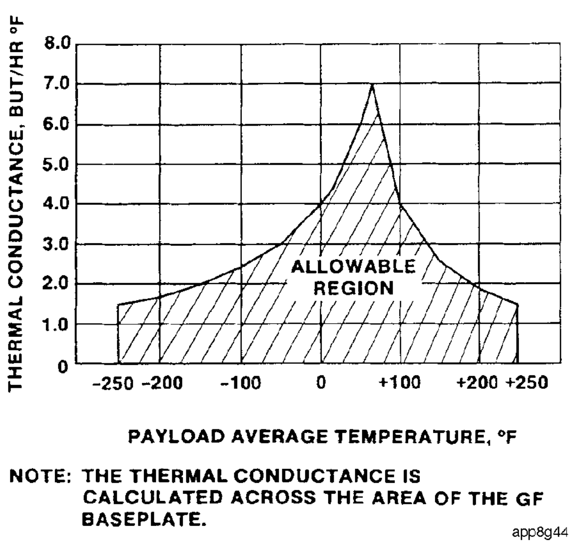


Figure 4-7.- Allowable payload structure to grapple fixture heat transfer rate.

The GF-to-payload bonding will be as specified in Shuttle Orbiter/Cargo Standard Interfaces, ICD 2-19001. A resistive element in the ground path will provide static charge protection for the RMS electronics. Figure 4-8 illustrates the bonding method for a typical GF installation.

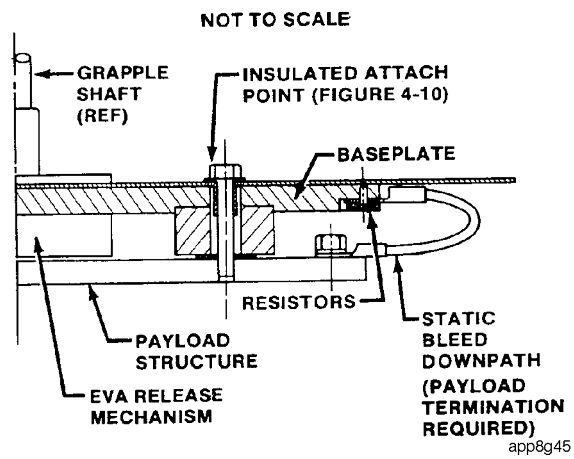


Figure 4-8.- Grapple fixture electrical bonding.

Grapple Shaft Stiffness - The grapple shaft will have the following stiffness characteristics:

a. Axial direction (along the axis of the shaft) 175,000 lb/inch minimum

b. Transverse direction (perpendicular to the axis of the shaft):
100 lb/inch minimum
725 lb/inch maximum

The stiffness defined above is with respect to the contact surface of the EE/GF interface. Only the contact surface is assumed fixed.

Natural Frequency Vibration - The major structural vibration frequencies of a payload and its GF interface, when cantilevered from the GF, will be greater than or equal to that found in Table 3-IV or Table 3-V.

Number of GF's Available - The RMS software limits the total number of GF's available per flight to five. Some payloads will require more than one GF for deploying, berthing, or handling.

4.2.1 Flight-Releasable Grapple Fixture

The standard grapple fixture is a flight releasable grapple fixture (FRGF). It includes a camera grapple fixture target used by the RMS operator to align the EE with the GF before initiating the payload capture sequence. The FRGF to cargo element interface will be as defined in Figures 4-9 and 4-10.

The central grapple shaft of the FRGF is releasable during an EVA by a suited crewmember. A spare shaft may be inserted and locked in place for subsequent handling by the RMS. System Description and Design Data - Extravehicular Activities, NSTS 07700, Volume XIV, Appendix 7, contains information about EVA releasing of the GF's.

The FRGF is designed to withstand operational temperatures between -105 to +154 degrees F (-76 to +68 degrees C). It will survive and function after exposure to average structural temperatures between ±250 degrees F (-156 to +121 degrees C).

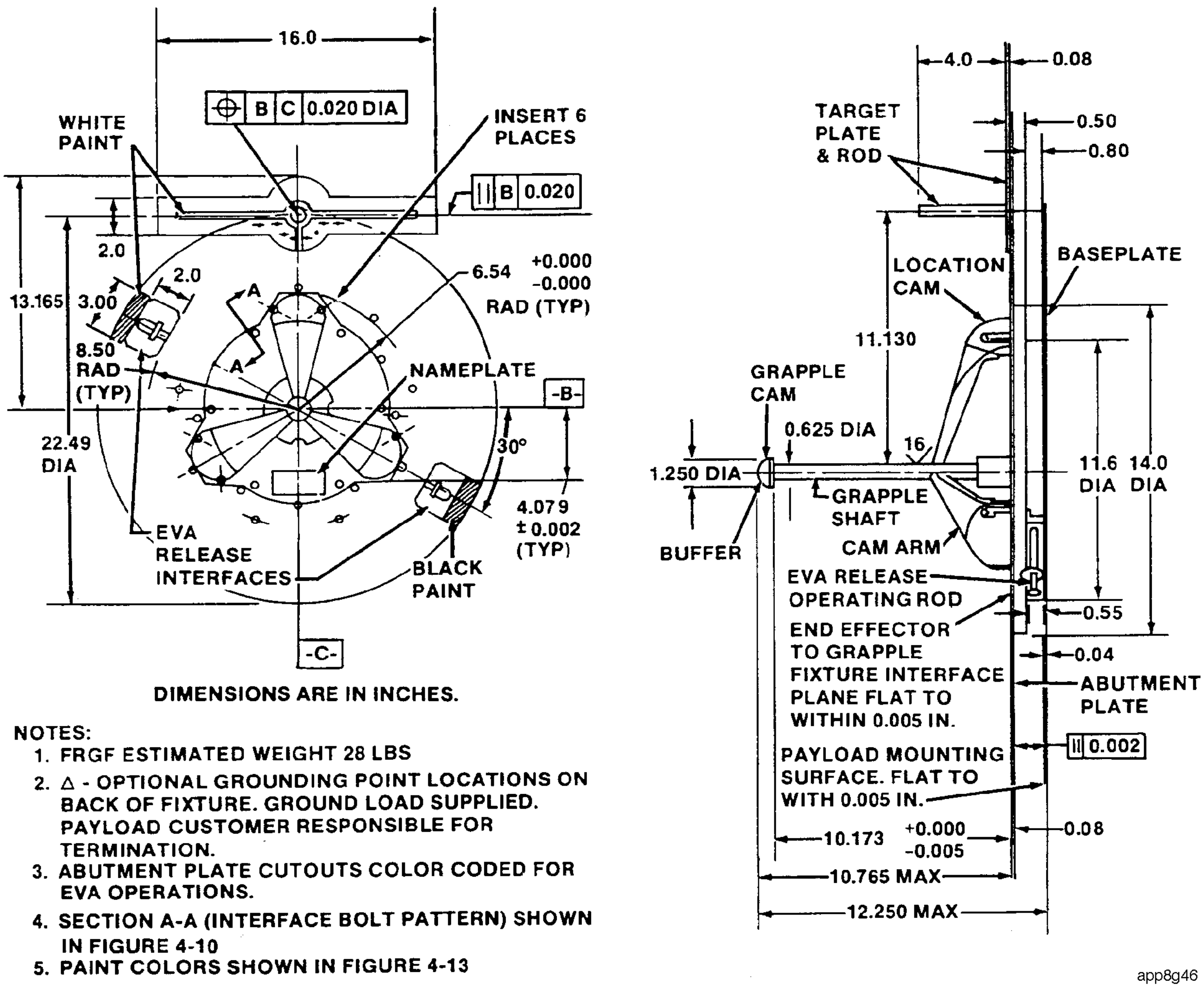


Figure 4-9.- Flight-releasable grapple fixture.

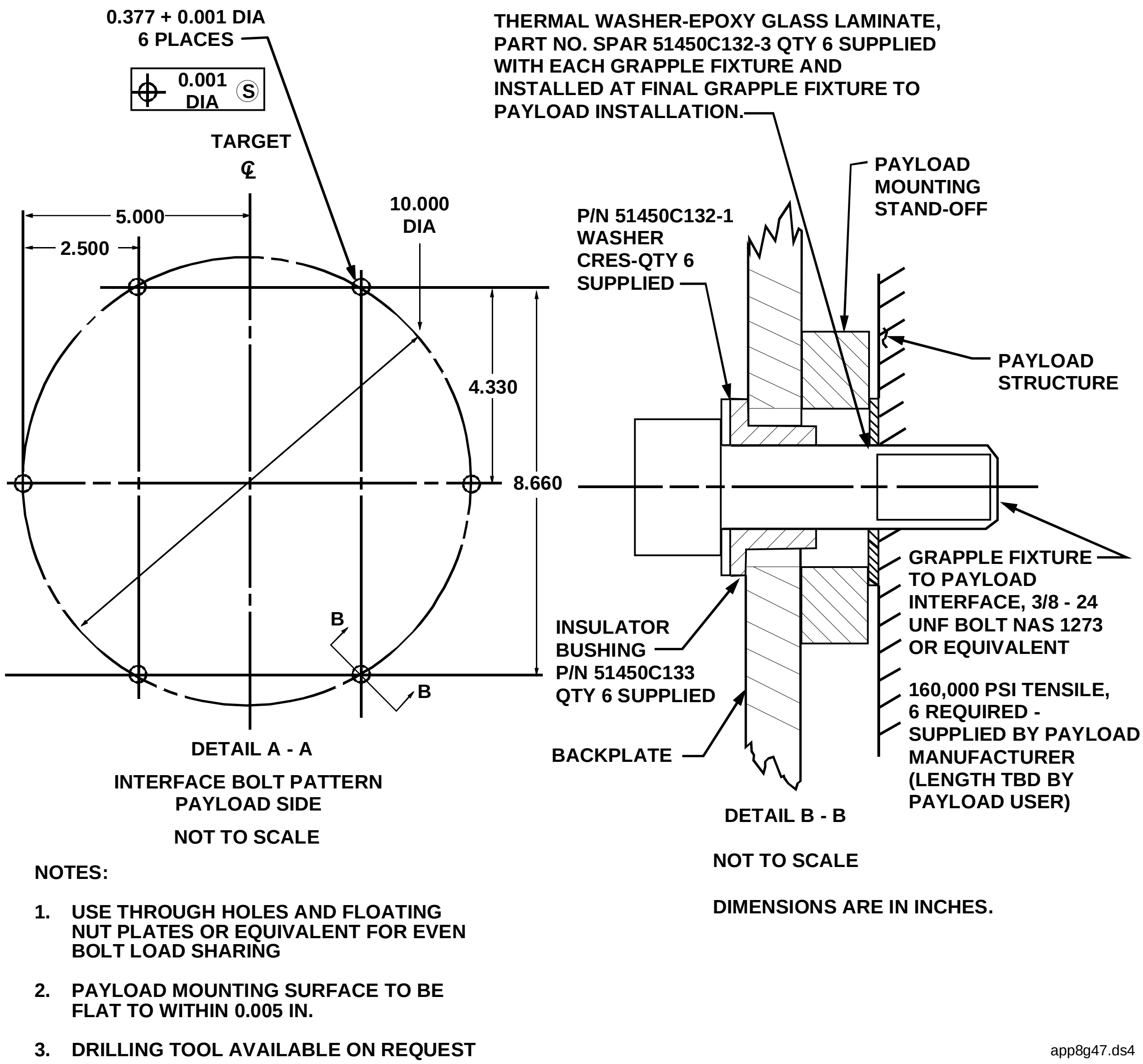


Figure 4-10.- GF/payload interface bolt pattern.

4.2.2 Rigidize-Sensing Grapple Fixture

The rigidize-sensing grapple fixture (RSGF) is an adaptation of an FRGF that incorporates a movable grapple shaft which extends under EE rigidization loads and retracts during derigidization. One-half inch (1.27 cm) of grapple shaft motion is available behind the backplate for activation of microswitches. The RSGF capability must never be used to activate payload functions that can be hazardous to the Orbiter.

EVA release of the center portion of the RSGF is provided. The RSGF to cargo element interface will be as defined in Figure 4-11.

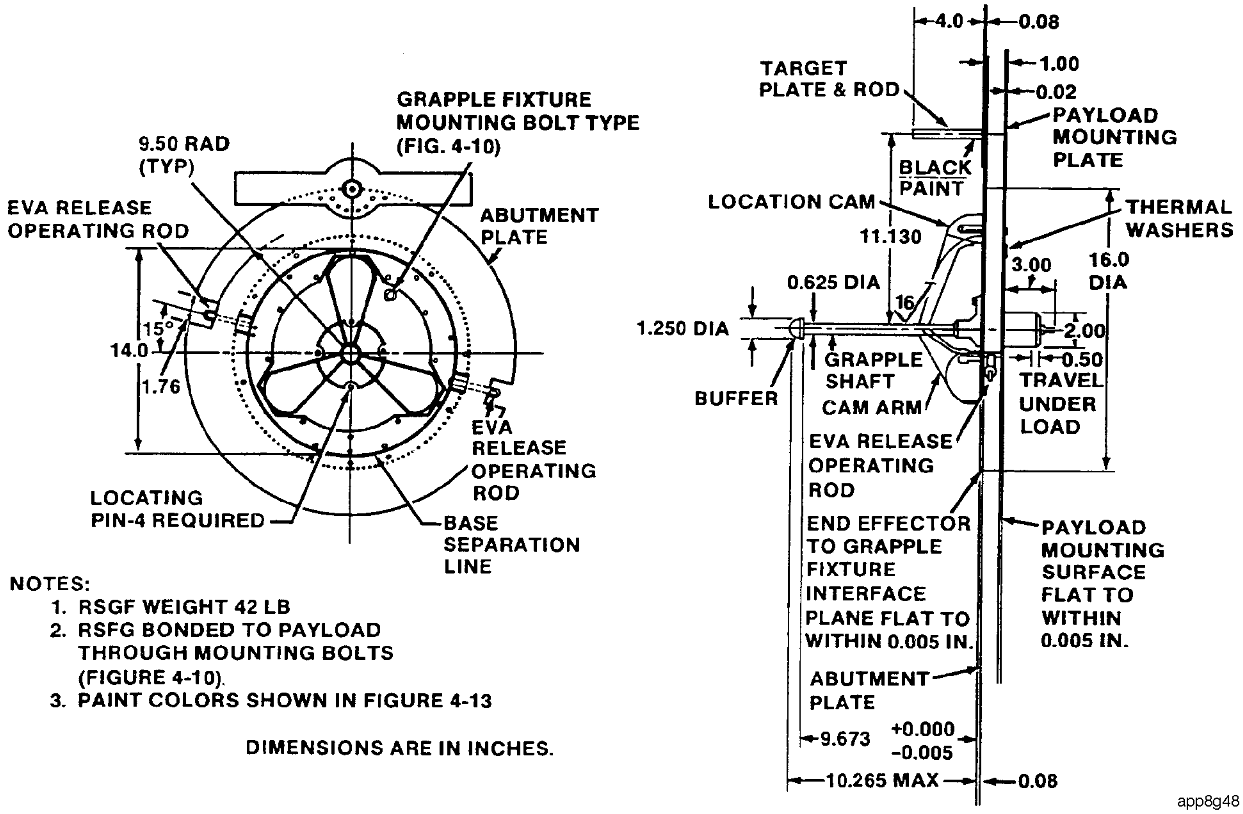


Figure 4-11.- Rigidize-sensing grapple fixture.

The RSGF grapple shaft mechanism will function as designed within an operational temperature range of -70 to +190 degrees F (-57 to +88 degrees C). The EVA release mechanism and EE/GF interface will function within an operational temperature range of -105 to +154 degrees F (-76 to +68 degrees C). The GF will survive and function as designed after exposure to an average structural temperature between ± 250 degrees F (-156 to +121 degrees C). The GF must not be exposed to temperatures outside this structural temperature range at any time prior to intended use.

4.2.3 Electrical Flight Grapple Fixture

The electrical flight grapple fixture (EFGF) is an adaptation of an RSGF which uses the movable grapple shaft to extend and retract an electrical connector. The GF connector mates with the SPEE electrical connector on the standard RMS EE. The location and orientation of the connector will be as defined in Figure 4-12. The EFGF is also EVA releasable. The EFGF is payload unique and requirements must be negotiated with NASA.

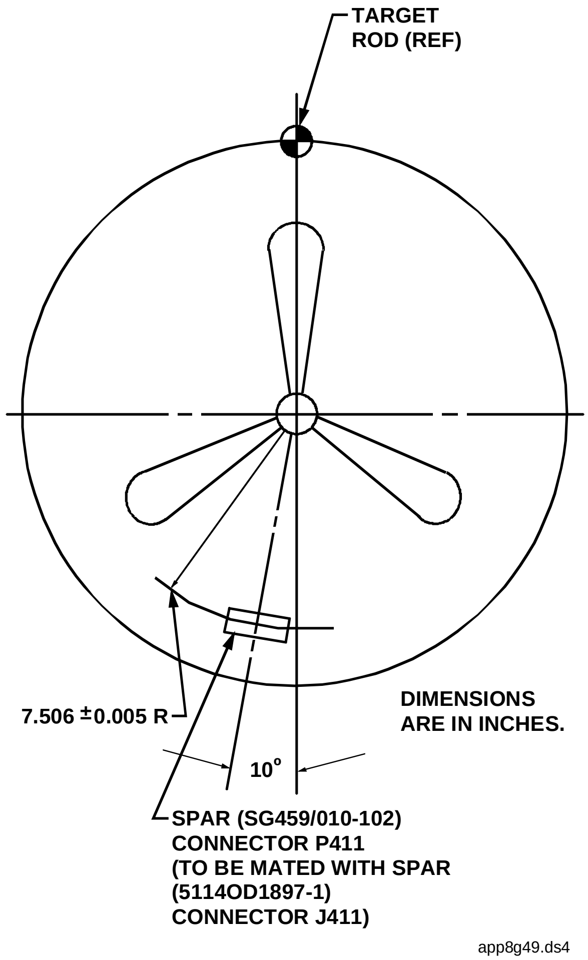
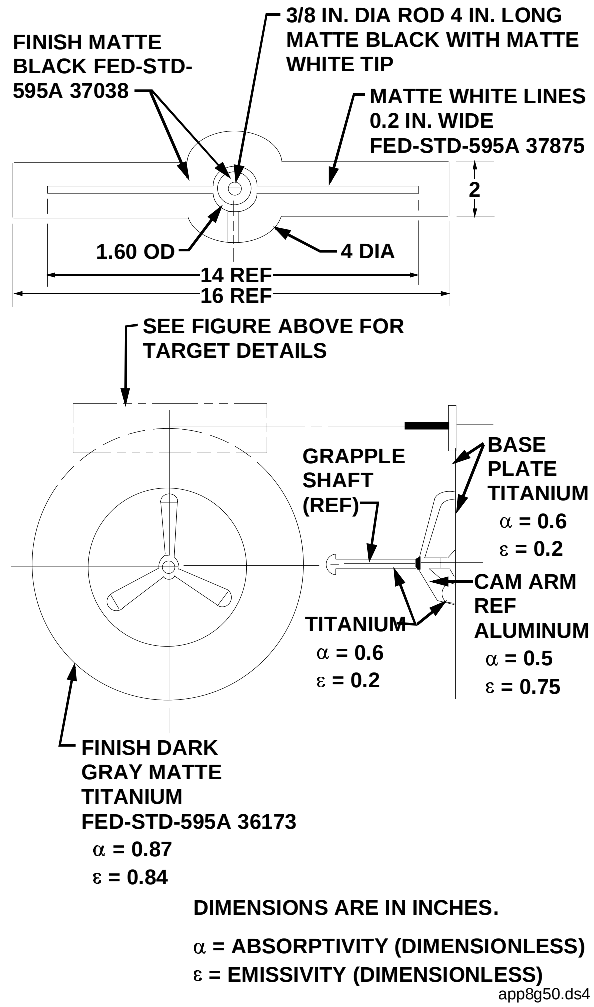


Figure 4-12.- Grapple fixture electrical connector alignment.



4.2.4 Payload Grapple Fixture Target

A grapple fixture target, Figure 4-13, is used in conjunction with the wrist CCTV to align the EE to the GF during payload capture. The standard GF requires a grapple fixture target.

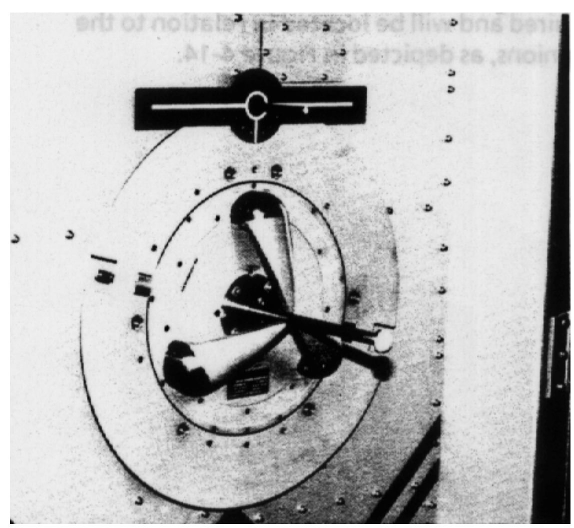


Figure 4-13.- Grapple fixture target.

4.3 Camera Targets Used as Alignment Aids

Camera targets must be placed on the payload when visual alignment cues are required in conjunction with CCTV's. The standard target is a payload GF target (without the GF), but the use of cloth or decal visual targets will be considered upon receipt of acceptable justification.

The target alignment pin must face downward in the payload bay (parallel with the Orbiter Z axis), with the target "wings" (or arms) parallel to the Orbiter Y axis when berthed. The target must be mounted within ± 0.1 inches and ± 0.15 degrees of the location provided by NASA.

4.3.1 Keel Camera Targets

A keel camera view is required and a keel camera target must be installed on the payload to align with the available keel camera when berthed. The X- and Y-coordinate location of the target is a function of manifest location, and must be negotiated on an individual payload basis. With acceptable justification, an exception to the keel camera and target requirement may be negotiated and documented in the IP.

4.3.2 Airborne Support Equipment Camera Targets

If ASE docking is required, an ASE target may be required and will be located in relation to the trunnions, as depicted in Figure 4-14.

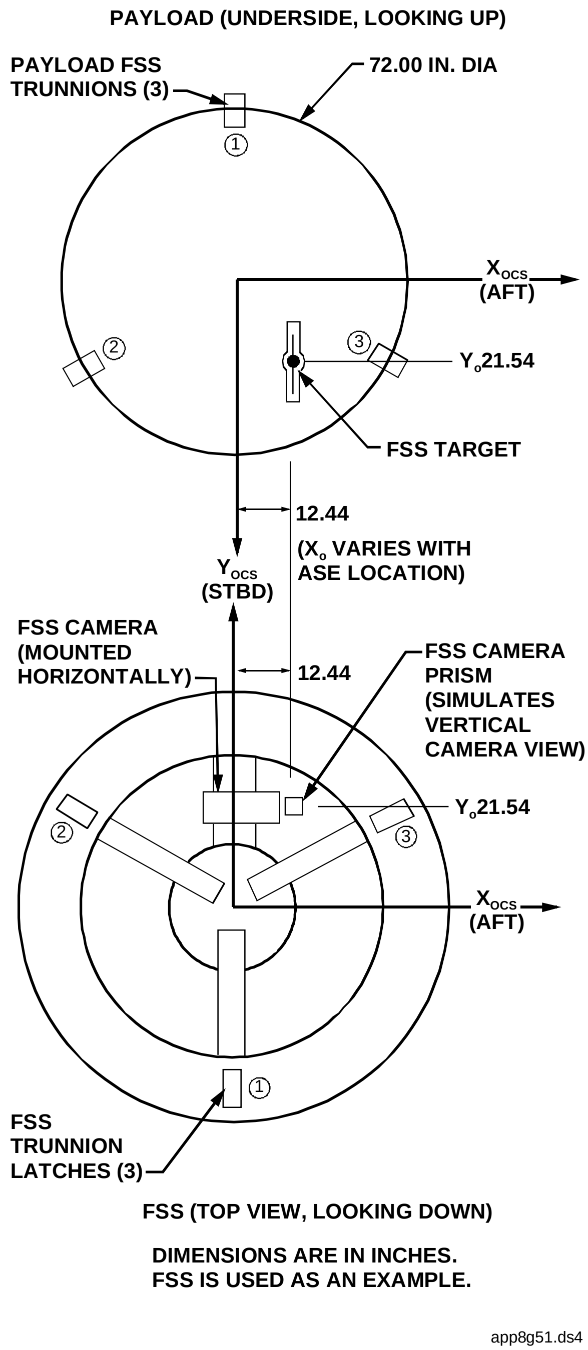


Figure 4-14.- Example of standard payload/ASE camera-target relationship.

PDRS System Capabilities and Services

5

5.1 PDRS Capabilities

The PDRS is designed to deploy and retrieve payloads as described in section 6.1.1. Orbiter payload weight limitations are specified in Space Shuttle System Payload Accommodations, NSTS 07700, Volume XIV.

RMS operations will not be scheduled prior to 3 hours after launch (to guarantee the payload bay doors are open), or later than 1 day prior to deorbit (to guarantee an EVA required to stow or latch the RMS for entry does not cause a deorbit delay). Normally, RMS operations will be scheduled during daylight.

When fully extended and attached to a payload, the RMS has the capability of generating control forces of at least the following:

a. A combined 12 lbf (53.4 N) shear force and 160 ft-lbf (217 N-m) bending moment about any axis in the EE Y-Z plane (i.e., GF/EE plane).

b. A 230 ft-lbf (312 N-m) torque about the EE X-axis (i.e., longitudinal axis).

When the arm is not fully extended, significantly higher forces and moments may be applied to the payload. The actual forces and moments applied depend on arm configuration, the maneuver being performed, the rate of motion, and the arm control mode.

The RMS has a maximum reach capability that is dependent on location and EE orientations. The full arm torque/force capability and DAP stability do not exist for every position the RMS can reach.

Figures 5-1 through 5-5 indicate the wrist pitch joint reach limitations. (Each figure is discussed below.) The limits shown are contours along an axis parallel to the OCS but located at the arm attach point (X, Y, and Z = 0 where the arm is attached to the port longeron). Where there are two contours shown for the same station, the one with the greater radius shows the maximum reach of the arm; the one with the least radius shows the area the arm cannot reach. The envelopes do not account for Orbiter/RMS/payload structural interference. Total reach accessibility within the contour envelopes may, therefore, not be available. The actual reach capability for a flight or payload task must be analyzed on an individual basis prior to flight.

Figure 5-1 shows the reach envelope in the X-axis direction as viewed from the Orbiter tail looking forward. To read the figure, select the X station of interest and locate the contour(s) for that station. The reach capabilities in the Y and Z directions are then read from the Y and Z axes.

For example: For X = 0, and Y = 90 inches, the wrist pitch joint can reach from approximately 140 inches to 580 inches above the attach point in Z. It cannot reach X = 0, Y = 90, and Z = 0 inches.

Figures 5-2 and 5-3 show the wrist pitch reach envelopes for $Z \geq 0$ (above the bay) and $Z < 0$ (toward the belly), respectively. Read these figures as described above.

For example: To determine the reach capability for Z = 100 inches, choose the contours for Z = 100 then read the X and Y reach envelopes on the axes given. For Z = 100 and X = 0 inches, going starboard the wrist pitch joint can reach

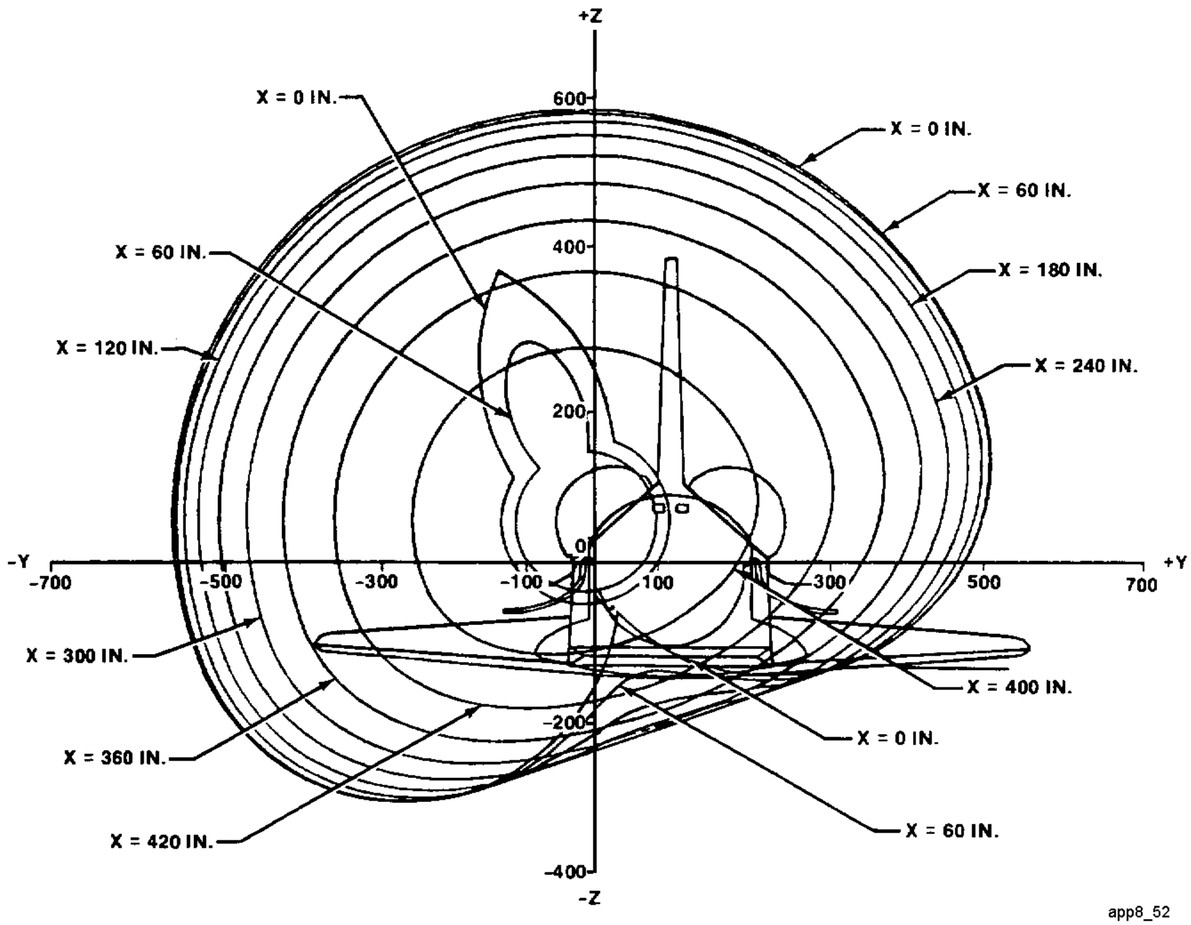


Figure 5-1.- X-contour of the reach envelope.

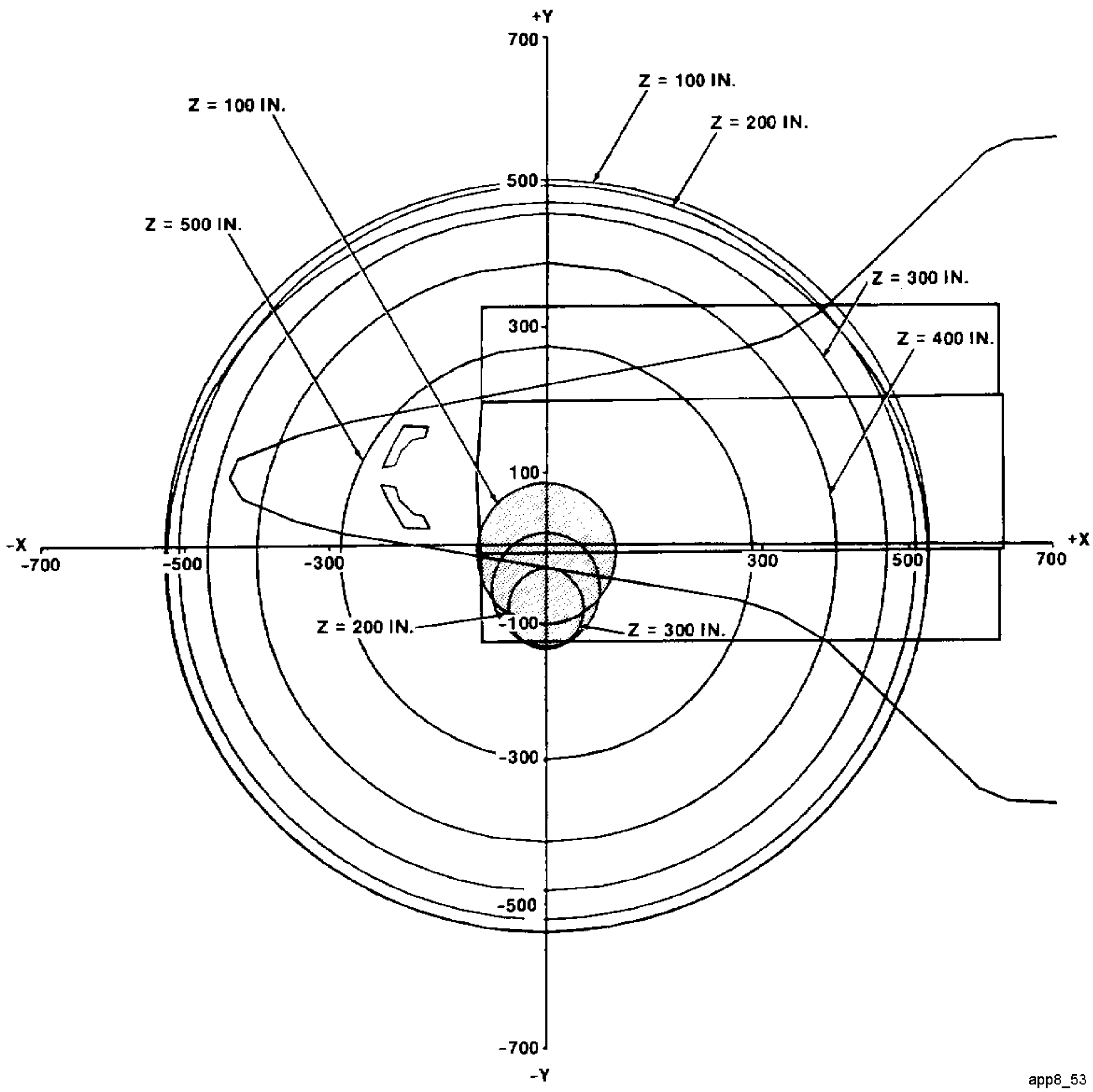


Figure 5-2.- Z-contour of the reach envelope (Z > 0)

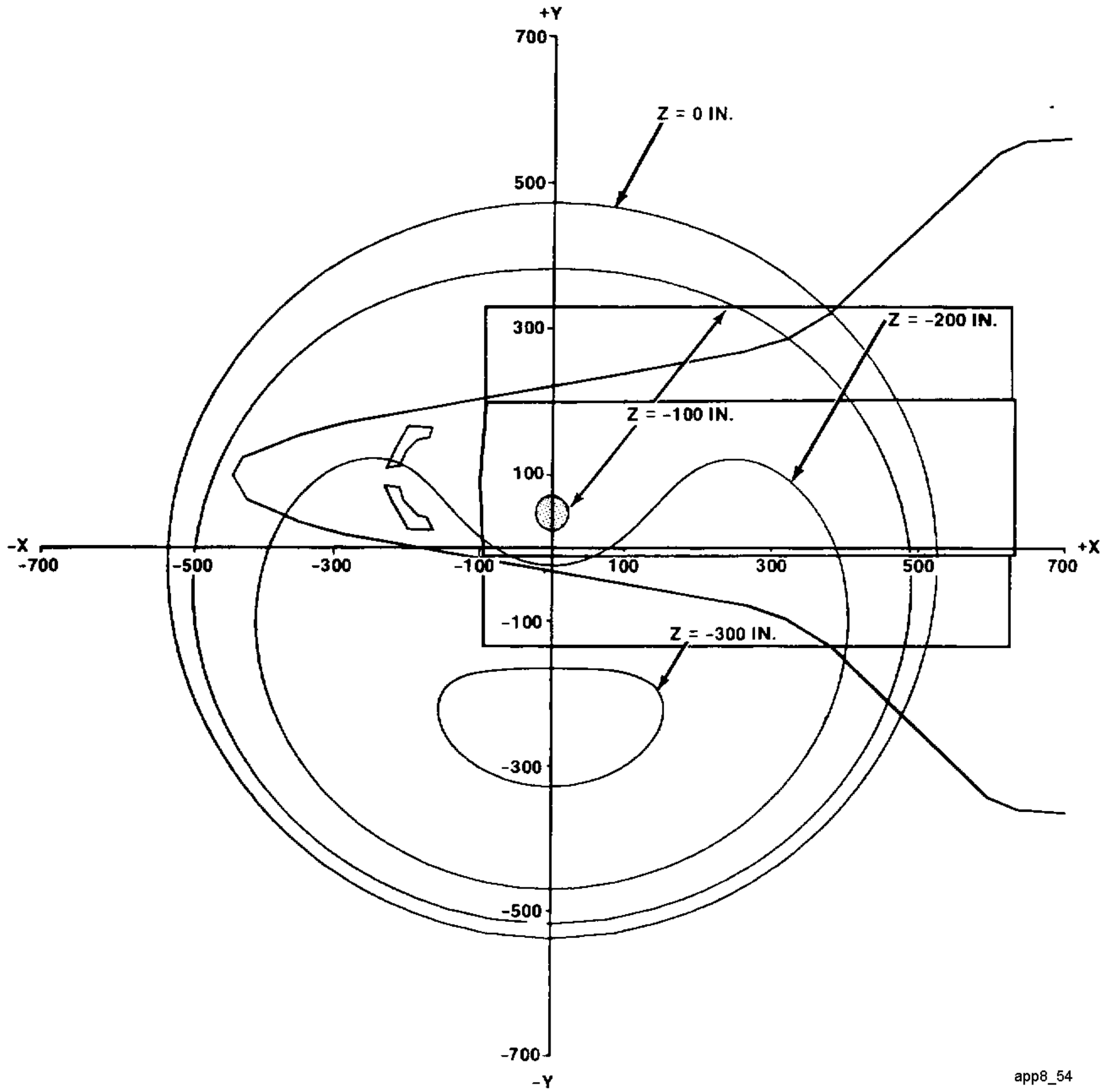


Figure 5-3.- Z-contour of the reach envelope (Z ≤ 0)

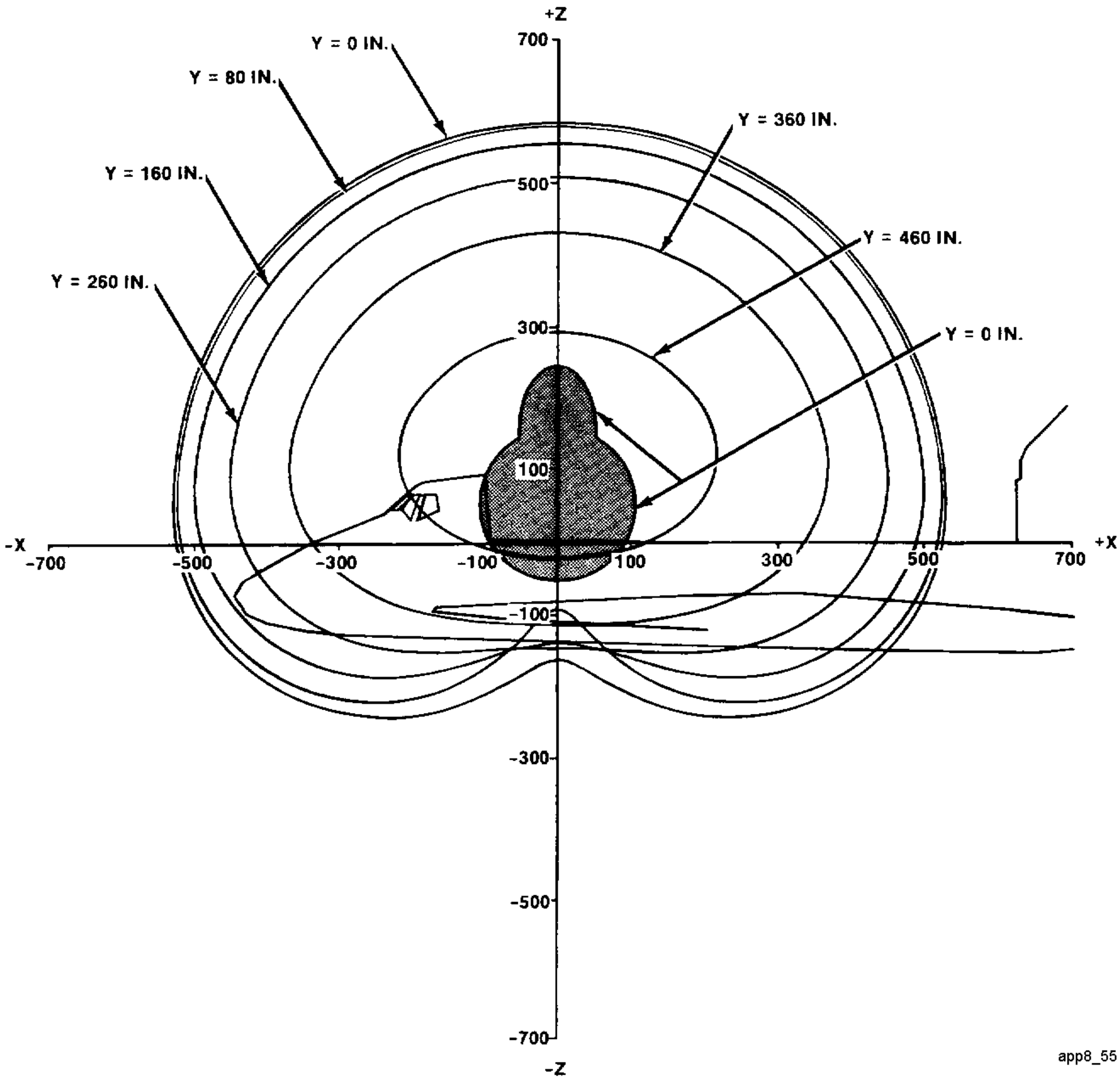


Figure 5-4.- Y-contour of the reach envelope (Y ≥ 0)

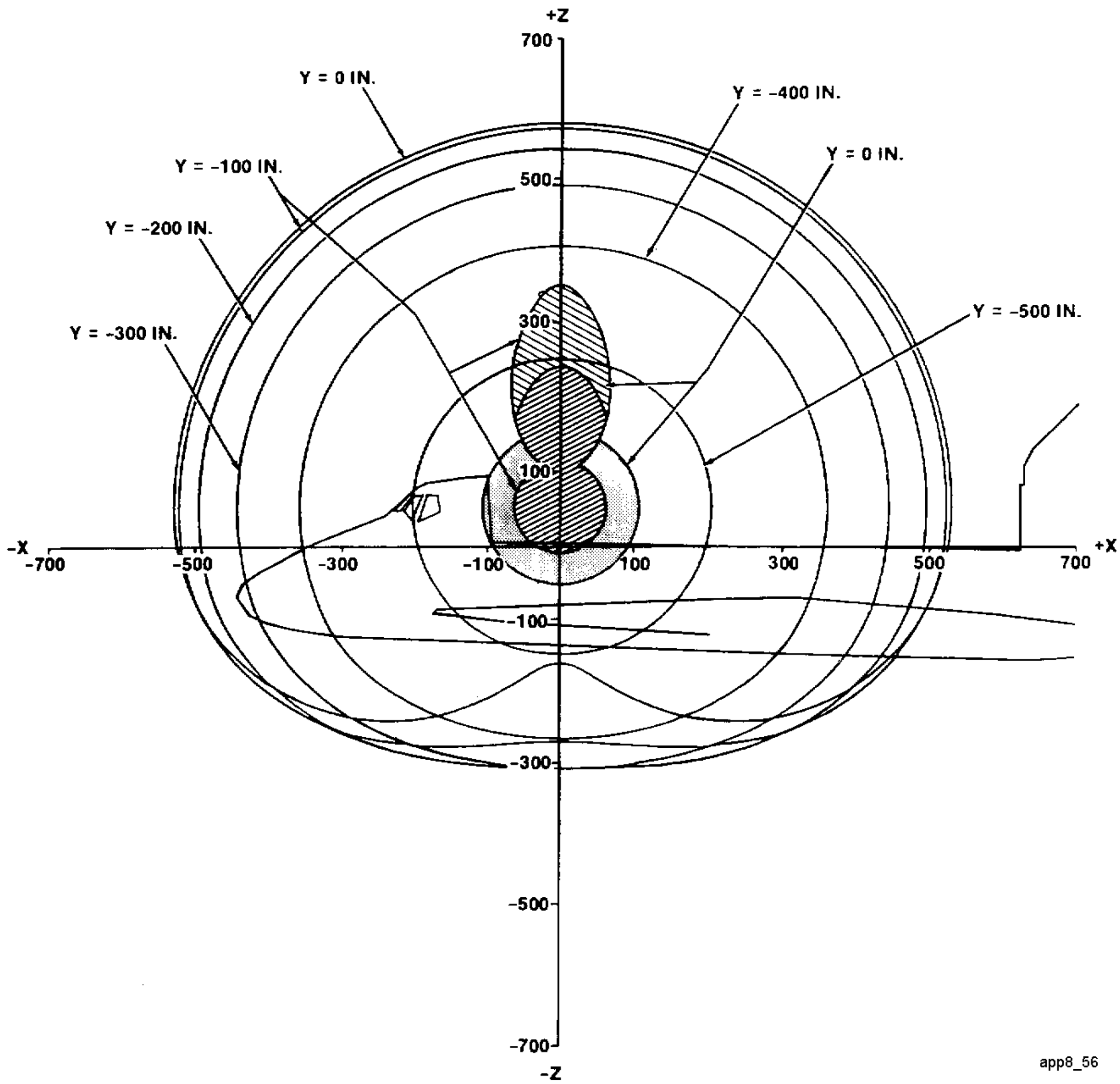


Figure 5-5.- Y-contour of the reach envelope (Y ≤ 0)

from approximately Y = 90 inches to Y = 500 inches.

Figures 5-4 and 5-5 show the wrist pitch reach envelopes for Y ≥ 0 (or on the starboard side of the attach point) and Y < 0 (or on the port side of the attach point), respectively. The wrist pitch reach envelopes are interpreted as previously described.

Although the arm can reach within the contours shown, it will not be placed where it cannot be safely jettisoned. RMS procedures will ensure the arm booms do not come closer to the Orbiter or payload structure than the limits shown in Figure 5-6.

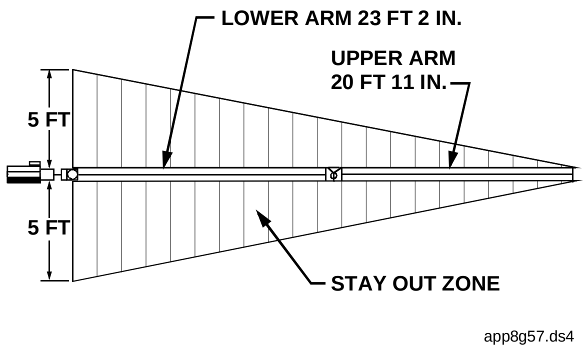


Figure 5-6.- RMS boom envelope.

The EE can be positioned to within ± 2 inches (5.1 cm) and ± 1 degree with respect to the shoulder attach point. The actual uncertainty in position is a function of arm geometry. Section 5.2.2 discusses the payload deployment accuracies.

5.2 Payload Unberth and Deployment

5.2.1 Standard Unberth and Transition to Deployment Position

The capability exists to unberth and move payloads weighing up to 65,000 pounds (29,484 kg), maximum volume payload, to a desired position with respect to the Orbiter, and then to move both the Orbiter/payload to a desired inertial or LVLH attitude for payload release. The actual release position chosen is subject to constraints on the payload position relative to the Orbiter, payload GF stiffness, DAP deadband parameters, and DAP I-Loads. These constraints are designed to minimize the likelihood of sustained dynamic oscillations between the Orbiter and the payload during closed-loop (auto, manual discrete rate, or manual LVLH) flight control operations. These interactions tend to sharply increase fuel usage and jet pulsing activity, and can create undesirable dynamic loads in the payload.

The amount of time required from payload trunnion unlatching to release from the RMS is payload dependent. Payload checkout tests to be performed, payload volume and mass (maximum joint rate limits affected), appendage deployment, and visibility will affect this time.

While the RMS is moving to the deployment position, Orbiter attitude can be simultaneously maintained using the VRCS for payloads weighing up to 8000 pounds (3630 kg) providing the DAP attitude deadband is set to ≥3 degrees, and the DAP rate deadband is set to ≥0.2 deg/sec. Orbiter free drift is required for payloads weighing more than 8000 pounds while the RMS is moving.

Once the payload is held stationary with respect to the Orbiter by the RMS position hold mode (brakes off), Orbiter attitude can be changed or maintained using the VRCS. The PRCS may be used as a contingency to achieve deployment attitude if an analysis is performed to determine if there are rates and deadbands that will minimize loads to an acceptable level.

5.2.2 Payload Deployment/Release Accuracy

A payload can be stabilized prerelease with the following accuracy.

a. Attitude uncertainty of no more than a total of 5 degrees, root-sum-square (RSS) for all three axes, between the payload and the desired inertial/LVLH reference due to RMS flexure, Orbiter drift, gravity gradient torques, aerodynamic drag, and measurement inaccuracies. (This is approximately 3 degrees per axis.)

b. Angular rate uncertainty of 0.1 deg/sec, RSS for all three axes, between the payload and LVLH or inertial reference.

c. Additional uncertainties can be introduced during mechanical release due to tip-off/ separation dynamics. The payload designer may compute the effects of this by assuming a worst case impulse of 1.5 lbf-sec (6.7 N-sec) applied to the GF in any one direction. Normally, the effects are significantly less than 1.5 lbf-sec.

To ensure the accuracies shown above, an Orbiter DAP free drift period prior to release between 15 and 120 seconds must occur to allow RMS oscillation damping. Propellant usage and jet duty cycles increase as the prerelease accuracy requirements are tightened. Payloads requiring more precise stabilization, or having lower interface frequencies than allowed by Table 3-IV can be accommodated to a certain extent, but a payload specific assessment will be required.

If the PRCS must be used as a contingency to establish the prerelease attitude, the attitude and angular rate errors may be greater than described above.

5.3 Payload Retrieval and Berthing

All payload retrieval activity (all analyses, procedure development, crew training, mission control staff, etc.) are nonstandard services.

The following applies to payloads not exceeding the maximum payload envelope. Payloads with appendages or protuberances beyond the 15 × 60 foot (4.6 × 18.3 m) envelope must be evaluated on a case-by-case basis.

The DAP constraints listed in section 5.2.1 also apply to retrieval activities.

5.3.1 Payload Capture

To capture a free-flying payload, a station-keeping period is required to ensure the payload is within RMS capture constraints. The time required for stationkeeping will vary with payload stability; i.e., for payloads rotating at the capture limit, a longer period may be required.

Prior to initiation of the capture and grapple procedure, the Orbiter RCS will be configured to free drift and the payload attitude control system will be deactivated. The RMS operator acquires and tracks the payload and moves the EE towards the GF.

The expected payload attitude at capture (relative to an inertial or LVLH reference frame) must be computed preflight. The actual attitude (relative to the same reference frame) of the payload at capture cannot be greater than ± 20 degrees total in all axes from the expected attitude.

At capture, the roll alignment error between the payload grapple target and the EE CCTV (or more specifically, between the GF location cams and the EE location cam pockets) must be no greater than ± 10 degrees.

During capture, the payload translational rate relative to the shoulder attach point is limited to ± 0.1 ft/sec (0.031 m/sec) per axis. The payload rotational rate relative to the stationary EE is limited to ± 0.1 deg/sec per axis. These constraints are based on the RMS design strength capturing a full volume, 32,000-pound, homogeneous payload. The rotational rate limit for specific payloads is a function of the mass properties and based on equivalent energy relative to the design case. Simulations show it may be possible, in a contingency, to capture a payload rotating at 0.3 deg/sec about all three axes, combined with the relative translation rate of 0.1 ft/sec in all three axes. Cases where ± 0.1 deg/sec is exceeded must be evaluated by the SSP.

When the GF is within the capture envelope, the operator initiates the capture command and the EE snare cables are closed. The operator may then command rigidization. Maximum time for capture (snare cable closure) is 3.0 seconds and for rigidization is 20.0 seconds.

5.3.2 Payload Berthing

As defined in paragraph 4.1, payloads can be maneuvered from either the deployment position or the post capture position into the latched position. The time to accomplish this task will vary with payload volume and mass (which affect maximum joint rates), visibility, and RMS mode.

At very low rates, the RMS produces large cross-coupling.

For example: A very low rate command to translate the payload straight into the guides will result in motion toward the port or starboard wing as well as forward or aft. The exact motion is payload mass and arm configuration dependent. The RMS mission designer will provide, upon request from the payload designer, the minimum rate possible for berthing a specific payload.

5.4 Other Servicing and Experiments

5.4.1 Deployed Payload Monitoring

The RMS cameras can be used to monitor deployed payload events.

5.4.2 Off-Nominal Payload Capture

The RMS can be used in tandem with the MFR and an EVA crewmember to retrieve small payloads that could not be captured with the RMS EE alone. Factors such as low payload weight (on the order of 5,000 pounds), mass distribution, volume, and stability will determine whether or not an EVA capture is feasible. This will be negotiated as a nonstandard service.

5.4.3 EVA Assistance

In addition to its capabilities for payload operations prior to or subsequent to an EVA, the RMS may perform one or more of the following functions to assist the EVA crewmembers: (1) multiple transfers of equipment between the EVA work area and the replacement equipment stowage area; (2) transfers via MFR of EVA crew members to remote areas on the payload or Orbiter; (3) additional lighting provided at the work area, and monitoring of the EVA work area.

5.4.4 Orbital Replacement Unit Changeout

With proper design, an orbital replacement unit (ORU) can be changed out using the RMS. ORU's must be designed to meet RMS design and operational constraints as summarized in section 9 (i.e., the ORU's must be able to tolerate an uncertainty in positioning of $\pm$ 2 inches (0.61 m), and withstand an impact with the host payload of 1.1 ft/sec (0.34 m/sec)). Early assessment by NASA of the ORU/payload design is recommended.

5.4.5 Miscellaneous

A few of the additional ways the RMS can be used include: payload servicing through remote connection of umbilicals, stabilization of a payload during EVA crewmember servicing, and payload instrument surveys of the Orbiter environment. Section 11 lists a sampling of the types of RMS missions flown.

Mission Design Activities

6

The PDRS related activities that must be completed prior to flight require that discussions among the various organizations be initiated as soon as possible in order to ensure completion of the milestones in a timely manner.

6.1 Payload Data Required

To generate the payload dependent RMS software parameters, the following payload characteristics must be provided according to the schedule contained in the IP. If special simulations (to support analyses defined in this document) will be required, these payload characteristics must be provided as soon as the simulation requirement is identified. In all cases, the data are required no later than 18 months prior to flight. Section 10 describes the requirements in more detail, as well as the formats to be used by customers when submitting their data to the IP Annex 1 for baselining. The characteristics are:

a. Payload mass to ± 10 percent. If the mass will vary during the mission (e.g., payload refueling on-orbit), payload mass for each configuration must be supplied.

b. Payload c.m. to ± 6 inches (15.3 cm), defined in PAS coordinates. Anticipated variations in the c.m. must also be supplied.

c. Moments and products of inertia about PAS to approximately ± 10 percent. (Mathematically, the moment of inertia is known to less certainty than the mass is known.) Indication must be given whether products of inertia were calculated with positive or negative integrals. If these values change during the mission (e.g., during appendage deployment), moments and products of inertia must be supplied for every configuration. Any change in these values should be reported as the changes occur. New analyses, software parameters, etc., will be required if the moments of inertia about the payload principal axis change by more than ± 10 percent of the values most recently reported.

d. GF location(s) and installation orientation, in payload axis system coordinates. SSP will assist the payload designer in selecting GF position and attitude.

e. Payload stiffness matrix and interface frequencies calculated about each GF node (if more than one). The calculation will not include the GF or base plate stiffness. Stiffness matrices may be required for deployed appendages (e.g., solar arrays and high-gain antennas). For payloads with significant distributed flexibility, a modal model of payload flexibility that is compatible with the RMS dynamic simulators used by the SSP must be supplied.

f. Auto mode sequence requirements. The SSP will provide assistance to define the actual auto sequence points that will accomplish the task described.

The payload manifest location will be supplied in the Flight Requirements Document (FRD). An unofficial, preliminary manifest location may be used to perform early assessment analyses. Location changes will require a reassessment. The SSP will calculate the PAS-to-payload operating system transformation matrix. The customer will supply the coordinates of the origin of the PAS with respect to the payload structure in Annex 1 of the IP.

6.2 RMS Software Initialization

6.2.1 Level C Data Generation

When the payload data are received, the SSP generates a set of parameters, called Level C data, to be used by the RMS software.

Examples of the Level C data: Payload coordinate systems, POR, auto sequence points, and payload-dependent RMS joint rate limits.

Typical payload-dependent parameters for a 32,000-pound (14,515-kg) payload are given below. These rates are chosen to ensure the EE will come to rest within 2 feet when commanded to stop:

TABLE 6-I.- TYPICAL PAYLOAD DEPENDENT PARAMETERS

32K Payload Rate Limits	Coarse	Vernier
Payload Translational Velocity Total in ft/sec (m/sec)	0.2 (0.061)	0.1 (0.030)
Payload Translational Velocity in Any One Axis in ft/sec (m/sec)	0.2 (0.061)	0.1 (0.030)
Payload Rotational Velocity Total in deg/sec	0.476	0.25
Payload Rotational Velocity in Any One Axis in deg/sec	0.476	0.25
Shoulder Yaw and Pitch in deg/sec	0.229	0.115
Elbow Pitch in deg/sec	0.321	0.160
Wrist Pitch, Yaw, and Roll in deg/sec	0.476	0.238

Section 10 lists all of the parameters calculated by NASA from the data furnished by the customer. Inputs to these parameters must be supplied no later than launch minus 10 months. Level C parameters are baselined approximately 8 months prior to flight. Only those changes required to complete the mission will be made after this time. The last opportunity to modify the Level C parameters is 4 months prior to launch when a 10 percent update package is approved.

6.2.2 DAP I-Load Generation

The DAP software controls the PRCS and VRCS jets in response to Orbiter pilot inputs. Each jet makes a different contribution to the angular acceleration (and over a period of time to the rotation rate) of the Orbiter/payload around the actual c.m. As the actual c.m. of the Orbiter/payload changes, the effect of each jet changes. Significant changes in the c.m. will result in significant changes in jet effects. Because it is not possible to compute the actual c.m. of the Orbiter/RMS/payload system as RMS position and Orbiter mass change, a set of numbers for each significant configuration expected is produced preflight for VRCS DAP software use.

The RMS, payload configuration, and expected Orbiter mass properties (including the fuel and consumables remaining) are used to compute the composite Orbiter/payload inertia matrix. Using the torque equation for each jet, the angular acceleration contributed by each jet is computed. These acceleration numbers are multiplied by 80 milliseconds and the resultant angular rate estimates are compiled into a control acceleration table. Up to five different configurations are computed and are available per flight. Before using the VRCS, the crew selects via keyboard item entry, the set of control acceleration numbers to be used based on the current Orbiter/payload configuration. When a rotation is commanded, the DAP software determines which jets to fire and how long to fire the jets based on which set of accelerations was selected.

Since only five sets of control accelerations are loaded per flight, care must be taken preflight to determine which Orbiter/payload configurations will require changes to the DAP tables. A configuration is considered for a table entry when it is determined by the SSP that the VRCS will be required for attitude maintenance and an undesirably high fuel usage will result if a new set of control accelerations is not available for use during that time. Each planned configuration which requires closed-loop attitude control will have a specific set of control accelerations loaded.

The PRCS jet selection is performed via a fixed table.

6.3 Simulations/Analyses

There are non-real-time models and real-time (man-in-the-loop) facilities used for simulating RMS activities and for training RMS operators.

6.3.1 Non-Real-Time Models

a. “All Singing All Dancing” (ASAD)

ASAD (All Singing, All Dancing) is a high fidelity, PC-based simulation of the SRMS. It is validated simulator for the SRMS with digital Servo Power Amplifiers and the only simulator validated for loads. It is used for control system development and verification, arm motion analysis, arm loads analysis, and as a 'truth' model for other SRMS simulators. The ASAD program is based on a detailed RMS dynamics model. The arm structural flexibility is represented by torsional springs at each joint about nondrive axes, and by seven flexible beams with three bending modes per beam per direction (and with torsion as well). The Orbiter RCS effects can be simulated using the time histories of jet firings. The program is used to evaluate the arm/payload dynamics, as well as the joint servo responses. ASAD is capable of simulating flexible payloads.

b. Draper RMS Simulation (DRS)

The DRS has a mathematical formulation similar to that of ASAD. The DRS program was developed and implemented at C. S. Draper Laboratory, Cambridge, Mass., as an independent RMS simulation. The customary DRS configuration is one with 25 degrees of freedom, which include freeplays at the attach point and at the grapple point, torsion in each of the long booms, and two bending modes in each of the transverse directions in each of the long booms.

The DRS has available: (1) a nonlinear EE stiffness model, (2) a flexible payload model, and (3) a detailed model of the snare/rigidize process.

The DRS can also be coupled with a validated version of on-orbit FCS software to provide closed-loop Orbiter/DAP/RMS/payload integrated simulations.

c. PDRS Simulation (PDRSS)

The PDRSS is a dynamic simulation derived from the Shuttle Vehicle Dynamics Simulator (SVDS). It is run on the UNIVAC computer at JSC. This model has reduced RMS flexibility models (as compared to ASAD) but higher fidelity Orbiter FCS models. It is used to analyze the RMS and payload loads environment.

d. RMS Planning System (RPS)

The RPS is a kinematic and graphics model used at JSC for reach, lift, and clearance evaluation; preliminary flight procedures development; Level C data generation used by the onboard RMS software; and during flights by the RMS console operators. It is run on the HP 9000 computer.

6.3.2 Real-Time Models

a. Shuttle Mission Simulator (SMS)

The SMS is located in Building 5 at JSC. It is a secure crew training facility that uses actual RMS flight software in an Orbiter GPC. The AFD is a high fidelity mockup. No RMS flexibility model is available. The visuals are out-the-window type solid-body. Malfunctions are inserted by training personnel during crew training. This facility is used during integrated crew/mission control simulations. RMS procedures can be validated on this simulator prior to final version publication.

b. Shuttle Engineering Simulator (SES)

The SES is located in Building 16 at JSC. It is used for crew training, proximity operations, rendezvous, and RMS procedures development and verification. It has a flexible RMS model, color graphic visuals, and the ability to incorporate RMS malfunctions. The SES has Orbiter dynamics and an FCS model. It can simulate three body orbital (i.e., Orbiter, payload, and manned maneuvering unit) dynamics in the visual displays. It generates equations of motion, including plume impingement and relative motion between the Orbiter and payload.

c. Shuttle Avionics Integration Laboratory (SAIL)

The SAIL is located in Building 16 at JSC. It is a verification and validation tool for Orbiter avionics, and is the only simulator with both flight hardware and software. It is used for RMS flight software verification, hardware/software compatability analyses, and PDRS mission verification. The SAIL has a high fidelity forward and aft flight deck, excellent visuals, and an arm flexibility model comparable to SES.

d. Manipulator Development Facility (MDF)

The MDF is a full scale electrohydraulic model of the RMS located in Building 9A at JSC. The joint motive forces are hydraulic; however, the control algorithms have been designed to simulate as closely as possible the motor responses to control inputs. The MDF has direct visuals, full CCTV and split screen monitoring capability, the capability to handle full volume payload mock-ups (helium filled balloons), and the capability to simulate some malfunctions. The MDF is used to evaluate operator field of view for payload designs and cargo manifests. Some crew training is accomplished in the MDF.

e. Sonny Carter Training Facility Neutral Buoyancy Lab (NBL)

The NBL is a full scale payload bay water tank used to integrate EVA and RMS mission activities and develop and verify timelines. The RMS model is used to position the EE/crewmember/ MFR.

6.4 Telemetry Requirement Definition

Payload customers may require RMS data during the flight to determine payload attitude versus time, etc. Section 11 lists the RMS parameters available to the flight controllers via telemetry and the data recorded for postflight analyses. Parameters required by customers for real-time monitoring must be negotiated with the SSP and will be included in Annex 4 (the Command and Data Annex) of the IP.

6.5 Flight Data File Procedures Development

Approximately 1 year prior to launch, the SSP develops a preliminary version of the RMS procedures required to complete the payload mission. These procedures, the Flight Supplement to the PDRS Operations Checklist, take into account the results of the loads analyses performed (if any), previous experience, flight rules, RMS operational constraints, etc. The preliminary procedures are not under configuration control.

After a review by the customer and crew, updates and corrections are made and tested through simulations, and the basic version is published and placed under configuration control. Any changes made to it must be approved by the Crew Procedures and Configuration Board (CPCB). The customer may initiate change requests through the book manager. Any changes made by the procedures writer are coordinated with the customer, crew, and those in other affected disciplines (e.g., proximity operations and EVA).

Several months prior to flight, a final version containing all of the approved changes is developed. Once procedures validation is performed by the book manager, the procedures are published. Additional changes may be made; however, each must be validated. No changes are allowed after 6 weeks prior to launch unless safety of flight is involved. Adequate crew training is difficult to achieve when changes are made close to flight.

6.6 Flight Rules

In addition to the generic flight rules, flight rules are written for each flight to define payload-unique constraints. These rules are approved by SSP management and provide guidelines for decisions made during flight when contingencies/anomalies occur. Customer support during flight rule development is required to ensure correct interpretation of constraints.

6.7 Training Required

The Orbiter crew, flight controllers, and customer representatives require preflight training on flight requirements and procedures to develop coordination and workaround skills. Simulations are coordinated by the Training Division; the number and duration of simulations are determined by the complexity of the mission being flown. Procedures must be completed early enough to support simulation training for all those involved.

Flight Activities

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7.1 Console Operations

The RMS position in the Flight Control Room (FCR) and the RMS Systems position in the Multi-purpose Support Room (MPSR) of the Mission Control Center (MCC) are responsible for RMS procedures and system health monitoring. During flight, the payload customer will have access to the RMS flight controllers through the Payload Officer. Mission Control protocol requires all requests made for RMS operations by the customer to be routed through the Payload Officer; all Payload Officer-generated requests will be coordinated with the RMS console operator.

The RMS console operator will provide a detailed log of flight events, if requested, for use post-flight.

7.2 Real-Time Changes to Procedures

Although great effort is made to validate and verify RMS procedures preflight, changes may be allowed during the flight to accommodate unforseen events or to take advantage of an unanticipated opportunity. All changes to pre-flight-approved procedures will be validated by the RMS flight controllers prior to use. Changes will require coordination among all of the disciplines involved.

Summary of Constraints and Recommendations

8

Hardware and operational constraints have been imposed on the PDRS in order to ensure the safety of the crew, Orbiter, and payload. These constraints can only be waived by the SSP Program Requirements Control Board (PRCB), or the Payload Safety Review Panel. The following is a brief compilation of the constraints. For a more detailed description, see the referenced sections.

8.1 Hardware Constraints

8.1.1 Payload Characteristics

Payload characteristics are fully explained in section 6.1. The following characteristics must be provided:

- ± 10 percent for payload mass
- ± 6 inches (15 cm) for payload c.m. (in PAS)
- ± 10 percent for moments of inertia

8.1.2 Visual Cues

Visual cues must be provided on payloads to aid the operator in berthing, deploying, and proximity operations (sections 4.1 and 5.3).

- When a CCTV view is required for operations (i.e., keel or FSS camera/target), the target associated with it must be aligned per standard RMS orientations (sections 2.7, 4.2.4, and 4.3).

8.1.3 Payloads on the Same Pallet

Payloads on the same pallet manifested within 2 feet of pallet structure (or each other) must be built to withstand 1.1 ft/sec (0.33 m/s) contact velocities between its components (section 4.1).

8.1.4 Grapple Fixture (GF's)

- All must be EVA releasable, placed to be compatible with RMS reach capabilities, installed in an area easily accessible to an EVA crewmember, and built to EVA specifications. (Refer to Systems Description and Design Data - Extravehicular Activities, NSTS 07700, Volume XIV, Appendix 7, and section 4.2 of this document.)
- The GF location must be known in the PAS to within ± 0.15 degree in pitch, yaw, and roll, and ± 0.25 inch (0.63 cm) in X, Y, and Z (section 4.2).
- The GF will be located so the perpendicular distance from GF centerline to payload c.m. is ≤ 11 feet (3.35 m) and a total distance from payload c.m. to GF is ≤ 13 feet (3.96 m) -- or if GF centerline passes through the payload c.m. (within 1.0 foot (0.3 m)), the total distance can be up to 20 feet (6.1 m) (section 4.2).
- Fuses, each rated at no more than 5 amps, are required on the payload side of the electrical GF wiring (section 2.1.4).

8.1.5 Structural Vibrational Frequencies

The structural vibrational frequencies are fully explained in sections 3.5.2 and 4.2.

- The major structural vibration frequencies of a payload and its GF interface, when cantilevered from the GF, will be greater than or equal to that found in Tables 3-IV and 3-V.
- Computation of the frequencies will exclude the GF (both GF and abutment plate).

- Simulation will be required for payloads with frequencies lower than allowed by Tables 3-IV and 3-V.

8.1.6 Payload Flexibility and Thermal

Payload flexibility and thermal distortions must allow compliance during latching. Distortions must be small enough so that no trunnion is out of the latch capture envelope with all other trunnions in the “ready-to-latch” position (section 2.6).

8.1.7 Payload Unique Berthing/ Latching Systems

The payload unique berthing/latching systems are fully explained in section 2.6.

- The system must accommodate payload/RMS motion without contact of Orbiter or payload critical surfaces.
- All latches require redundant ready-to-latch cues and must allow for the RMS positioning uncertainty of ± 2 inches (5.1 cm) and ± 1 degree EE (not POR).
- The total force required to remove a payload from (or place it into) the retention system must be ≤ 12 lbf (53 N).

8.1.8 Berthing Guides

Berthing guides are fully explained in section 2.6.

- Guides will be provided to constrain payload motion in fore/aft directions during berthing and unberthing.
- Scuff plates on trunnions (or equivalent) must be provided to constrain port/starboard motion.
- Extention guides will be installed on the latches so that the longer side is the farthest from the viewing position.

8.1.9 Lighting and Crew Viewing

Lighting and crew viewing of critical payload structure is required. Laboratory tests may be required to verify glare will not reduce visibility (sections 2.8, 4.3, and 5.3.1).

8.1.10 Electromagnetic Interference EMI)

EMI characteristics and shielding must comply with the requirements shown in Shuttle Orbiter/Cargo Standard Interfaces, ICD 2-19001, section 10.

8.1.11 Bump Protection

Bump protection must be provided for critical payload items (such as hydrazine storage tanks, etc.) (section 4.1).

8.2 Operational Constraints

8.2.1 RMS Procedure Constraints

- The arm will not be driven unless the crew can observe the arm and payload structure via the window and/or CCTV views.
- Auto modes will not be entered until the operator has verified that there is no obstacle in the path of the sequence. The operator will only enter an auto mode immediately prior to the desired drive time.
- Computer supported modes will not be used if the auto brake or MCIU safing functions have failed.
- If the brakes are inoperative due to a mechanical failure for primary and backup modes, the RMS will be stowed as soon as possible in single mode.
- Both heater systems A and B will be powered 1 hour before and during all arm operations to provide active redundancy.
- Computer supported modes will not be used within 5 feet (1.5 m) of structure, payload, or an EVA crewmember if the MCIU safing function is lost. Auto trajectories will not be built to pass within 5 feet of structure, etc. While berthing a payload, all modes can be used once the trunnions have entered the “V” guides.
- RMS operations will be at the vernier rate in computer supported modes when the arm and/or payload is within 10 feet (3 m) of structure, a payload, or an EVA crewmember.

- No constant computer command (rate hold) will be used when the arm/payload is moving toward and is within 10 feet (3 m) of structure, a payload, or an EVA crewmember. This constraint does not apply when capturing a free-flying payload.

- The arm will not be maneuvered or parked in regions where it cannot be safely jettisoned.

- During a capture or release of a free flying payload, the EE must be far enough away from structure, payloads, or an EVA crewmember so that no contact can occur regardless of payload rotations.

- The RMS must be latched during OMS firings (section 2.5).

Deviation/Wavier 2 is applicable to Paragraph 8.2.1
Refer to the Deviations/Waviers Section in front of the document.

8.2.2 Scheduling of RMS Operations

Scheduling of RMS operations cannot occur prior to 3 hours after launch or later than 1 flight day prior to deorbit. When possible, the RMS operations will be scheduled to take advantage of daylight operations (section 5.1).

8.2.3 Auto Trajectory Constraints

- Auto trajectories must maintain a minimum of 5 feet clearance between the deployed payload and any part of the Orbiter (including payloads fixed in the bay) at all times (section 3.2.2).

- Clearance between the protective RMS boom envelope, and any part of the Orbiter (including payloads fixed in the bay) must be maintained (section 5.1).

- All auto trajectories must be validated by the SSP prior to use (section 3.2.2).

- Trajectories will be designed such that the arm or payload will not be placed in any position where the arm or payload cannot be safely jettisoned (section 6.6).

Deviation/Wavier 3 is applicable to Paragraph 8.2.3.
Refer to the Deviations/Waiviers Section in front of the document.

8.2.4 Rate Limits

Joint rate and payload translation and rotation rate limits will be established for each payload so that the EE will come to rest within 2 feet of its position when commanded to stop by either the software, the brakes, or the MCIU (safing) (sections 2.10 and 6.2.1).

8.2.5 Payload Deployment

- To ensure the payload tip-off rates are as low as possible, the EE must be withdrawn from the GF before the carriage is extended (section 2.1.3).

- Closed-loop (auto, manual discrete rate, or manual LVLH) flight control constraints are: (section 3.4)

    - For payloads weighing up to 1000 pounds (454 kg), no operational constraints exist, except that if the payload is kept out of the deployment envelope longer than 1 hour, an appropriate control acceleration value must be used.

    - For payloads weighing between 1000 pounds (454 kg) and 8000 pounds (3629 kg), the RMS can maneuver the payload while the VRCS maintains attitude.

    - For payloads weighing over 8000 pounds (3629 kg), DAP free drift is required while the RMS is maneuvering the payload.

    - For a moving arm, the payload constraints for payloads weighing between 1000 and 8000 pounds are based on using an Orbiter DAP attitude deadband $\geq$ 3 degrees, a rate deadband of $\geq$ 0.2 deg/sec and a maneuver rate of $\leq$ 0.02 deg/sec.

    - For all stationary payloads, the DAP maneuver rate must be $\leq$ 0.2 deg/sec if the rate deadband is $\geq$ 0.02 deg/sec and $\leq$ 0.1 deg/ sec if the rate deadband is $<$ 0.02 deg/sec.

- VRCS can be used in all cases where the RMS is stationary within the valid DAP stability envelopes shown in Tables 3-IV and 3-V.

- Payload c.m. must remain within the valid DAP stability envelopes shown in Tables 3-IV and 3-V. An analysis must be performed for deployment positions outside of these envelopes.

- Release accuracies during deployment: (section 3.3.2)

  - Total attitude uncertainty ≤ 5 degrees, RSS for all three axes, between the payload and the desired reference (inertial or LVLH).

  - Total angular rate uncertainty ≤ 0.1 deg/sec RSS for all three axes, between payload and desired reference.

  - Linear motion ≤ 0.1 feet/sec (0.03 m/sec) relative to RMS attach point.

  - The payload may experience up to 1.5 lbf-sec (6.67 N-second) impulse applied in any direction during EE withdrawal from GF.

  - The DAP must be in free drift prior to payload release for 15 to 120 seconds (optimum 80 seconds) to ensure release accuracies.

  - Greater inaccuracies may occur when the Orbiter attitude for release is established using the PRCS.

8.2.6 Payload Capture

Payload capture is fully explained in section 5.3.1.

- The DAP must be in free drift during capture.

- The payload attitude control system (ACS) and any system used for translating the payload must be deactivated prior to capture. Payloads will not be under active control (except for small momentum wheels or cold gas reaction control, when approved by SSP) (section 9.3.6).

- Attitude error between the payload and the preplanned capture orientation must be ≤ 20 degrees total in all axes.

- Rotational rate relative to the stationary EE must be ≤ 0.1 deg/sec per axis.

- Translation rate between the GF and the RMS shoulder joint must be ≤ 0.1 ft/sec (0.031 m/sec) per axis.

- The GF location must allow easy access to EE during capture. (Protuberances are not allowed within 3 feet (0.9 m) of the planned EE approach corridor.)

- The payload must be visible by two methods (e.g., CCTV, unaided eye, rendezvous radar, and crew optical alignment sight (COAS)) during approach and stationkeeping.

- Roll alignment errors between the GF and EE must be ≤ 10 degrees at capture.

8.2.7 RMS Reach Capability

RMS reach capability for each payload or flight task must be individually analyzed (section 5.1).

8.3 Manifesting Constraints

8.3.1 Berthed Payloads 2 Feet from Structure

Payloads must be manifested so at least 2 feet (0.61 m) clearance of Orbiter structure, payload cargo elements, or other payloads is maintained until the trunnions enter the guides. This clearance can be decreased uniformly to 6 inches (15 cm) when the trunnions are fully seated in the payload retention latches (section 4.1).

8.3.2 Payloads on the Same Pallet

Payloads on the same pallet which are manifested within 2 feet of pallet structure (or each other) must be constructed to withstand 1.1 ft/sec (0.33 m/sec) contact velocities between components (section 4.1).

8.4 Design Recommendations

8.4.1 The PAS Orientation

The PAS should be chosen to be parallel or orthogonal to the OCS (OSRS) when the payload is berthed for ease of computation and flight planning (sections 3.1.5 and 9.1.1).

8.4.2 Keel Camera Target

A keel camera may be recommended to enhance mission success should other required CCTV's fail. If a keel camera is used, the payload should incorporate a keel camera target aligned to the keel camera. Misalignment may preclude mission success (section 4.3).

8.4.3 Grapple Fixtures (GF's)

GF's should be installed (if at all possible) with the GF shaft parallel to the Orbiter Z axis. When a payload is located far forward or far aft, this may not be possible (section 4.2).

PDRS Payload Data Requirements

9

Payload and mission design information must be available to the PDRS/Orbiter community far enough in advance of launch to ensure adequate time for planning, nominal and off-nominal analyses, simulation model development, software development and approval, procedures development and verification, and crew and flight controller training.

Early feasibility assessment analyses may be performed whenever requested by the customer or the PIM. The customer can request aid in payload design if the request is made early enough in the template. RMS analyses done early can prevent costly design changes later in the payload development process.

This section contains data which are required for payloads that are handled by the PDRS. The data are required to perform preflight procedures development, reach/clearance analyses, and loads and stability analyses. RMS flight software is also generated with the data. The data will be input to Annex 1 of the applicable IP. All tables except Table 9-IV represent the format in which SSP would like the information presented.

9.1 Reference Frames

All reference frames are assumed to be right-handed Cartesian coordinate systems. A typical coordinate system relationship is depicted in Figure 9-1.

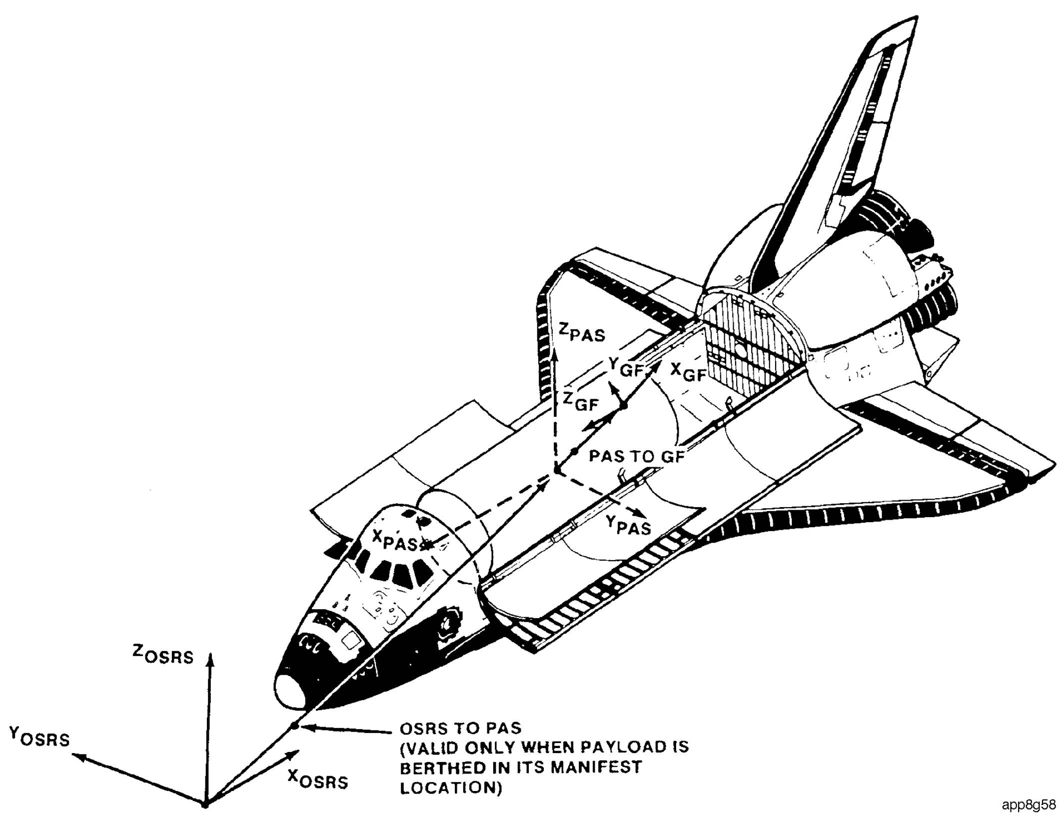

Figure 9-1.- Typical relationship of Orbiter/payload coordinate systems.

9.1.1 PAS

The PAS is the standard coordinate system, usually defined by the payload manufacturer, by which all structural characteristics of the payload are referenced. The origin of the PAS is normally located centrally within the payload structure. The orientation of the PAS is normally parallel or orthogonal to the OSRS when berthed. OSRS is synonymous with OCS. The PAS is also known as spacecraft coordinate system, payload coordinate system, and mass property coordinate system.

Dimensional drawings of the payload which clearly define the PAS origin location and the axes orientation with respect to the payload structure are required (see Figure 9-2). These drawings

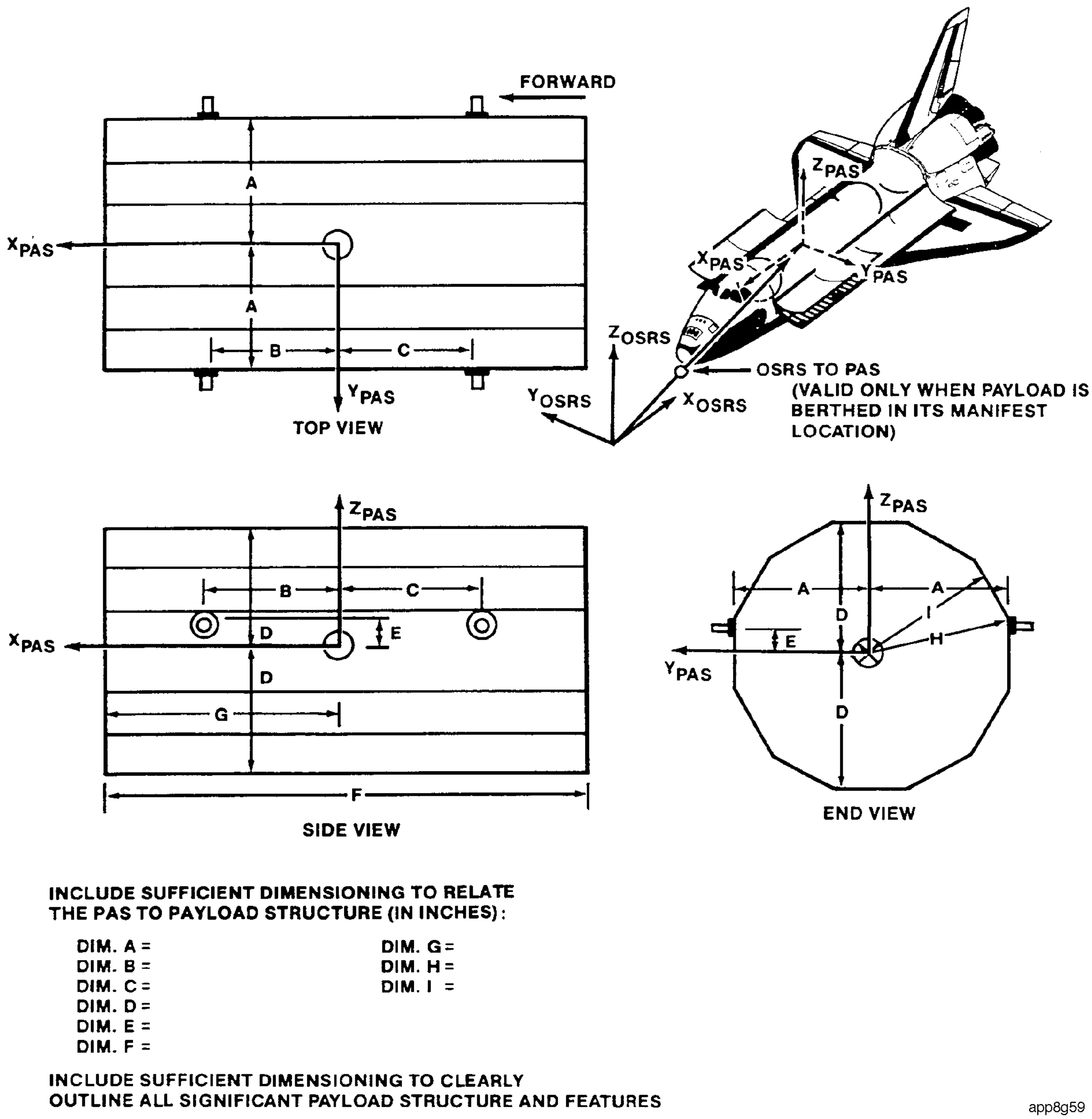

Figure 9-2.- Payload axis system definition.

are used to help visualize the payload structure as well as generate analytical and simulation models. The drawings should include physical dimensions of the major structural components and their connection points.

The position and orientation of the PAS in the payload bay is defined with respect to the OSRS. The vector from the OSRS origin to the origin of the PAS expressed in OSRS coordinates is:

$$\begin{Bmatrix} X \\ Y \\ Z \end{Bmatrix}_{PAS} = \begin{Bmatrix} \_\ \text{inches} \\ \_\ \text{inches} \\ \_\ \text{inches} \end{Bmatrix}_{OSRS(OCS)}$$

The transformation matrix defining the orientation of the PAS with respect to the OSRS is:

$$\begin{Bmatrix} X \\ Y \\ Z \end{Bmatrix}_{PAS} = \begin{bmatrix} \_\_ & \_\_ & \_\_ \\ \_\_ & \_\_ & \_\_ \\ \_\_ & \_\_ & \_\_ \end{bmatrix} \begin{Bmatrix} X \\ Y \\ Z \end{Bmatrix}_{OSRS\ (OCS)}$$

9.1.2 GFAS

The GFAS is the standard coordinate system which defines the position and orientation of GF's mounted to the payload structure. The origin of the GFAS is located at the base of the grapple shaft as depicted in Figure 3-5.

GFAS information is required for each GF, if more than one are employed. The location and orientation of each payload GFAS is defined with respect to the PAS and the payload structure as dimensionally depicted in Figure 9-3. The vector

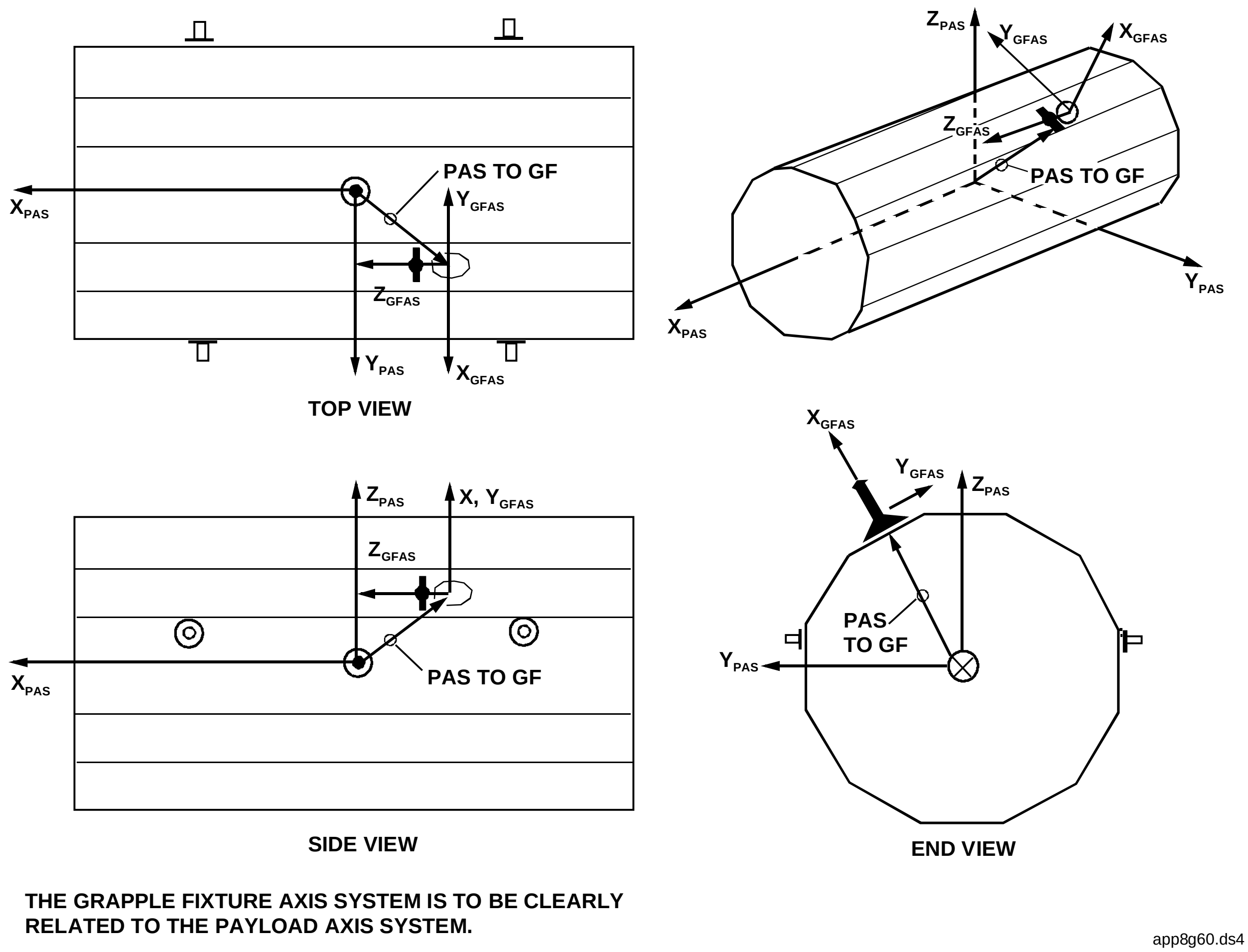

Figure 9-3.- PAS to GFAS definition.

from the PAS origin to the origin of the GFAS expressed in PAS coordinates is:

$$\begin{Bmatrix} X \\ Y \\ Z \end{Bmatrix}_{GFAS} = \begin{Bmatrix} \_\text{inches} \\ \_\text{inches} \\ \_\text{inches} \end{Bmatrix}_{PAS}$$

The transformation matrix defining the orientation of the GFAS with respect to the PAS is:

$$\begin{Bmatrix} X \\ Y \\ Z \end{Bmatrix}_{GFAS} = \begin{bmatrix} \_ & \_ & \_ \\ \_ & \_ & \_ \\ \_ & \_ & \_ \end{bmatrix} \begin{Bmatrix} X \\ Y \\ Z \end{Bmatrix}_{PAS}$$

9.2 Mass Properties

The following mass property data are required for each composite payload (lumped mass) configuration where mass properties change and for each major appendage (element), if applicable. An example of payload/element structural configurations corresponding to each mass property data set is depicted in Figure 9-4.

Mass, c.m., and inertia may be presented in table form (if more convenient) as long as the Products of Inertia explicitly indicate whether the positive integral has been negated (see Table 9-I). Principal Axes (PA) to PAS transformation matrices are still required for each configuration/element.

9.2.1 Mass

The mass for each configuration/element is in slugs.

9.2.2 Center of Mass

The vector from the PAS Origin to the c.m. for each configuration/element expressed in PAS coordinates is:

$$\begin{Bmatrix} X \\ Y \\ Z \end{Bmatrix}_{c.m.} = \begin{Bmatrix} \_\text{inches} \\ \_\text{inches} \\ \_\text{inches} \end{Bmatrix}_{PAS}$$

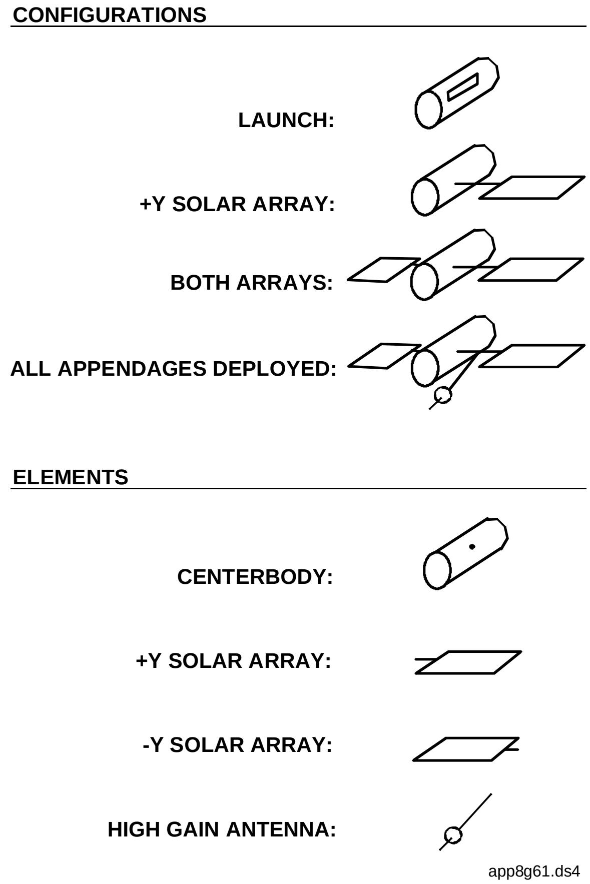

Figure 9-4.- Payload configuration/element definitions.

TABLE 9-I.- PAYLOAD CONFIGURATION/ ELEMENT MASS PROPERTIES (OPTIONAL)

Payload Config/ Element	Mass (slugs)	Center of Mass from PAS Origin (in) X Y Z	Moments of Inertia about c.m. ($slug\text{-}ft_2$) Ixx Iyy Izz	Products of Inertia about c.m. ($slug\text{-}ft_2$) Ixy Ixz Iyz

Notes:

(1) Inertias are defined with respect to the PAS, about the c.m. corresponding to the composite payload configuration/ element.

(2) Products of inertia must indicate whether defined as positive or negative integrals (e.g., $Ixy = + \int xydm$).

9.2.3 Moments/Products of Inertia

Inertia terms for each configuration/element defined about the payload/element c.m. with respect to the PAS is:

$$
\begin{aligned}
I_{xx} &= \_\ \text{slug-ft}^2 & I_{xy} &= \_\ \text{slug-ft}^2 \\
I_{yy} &= \_\ \text{slug-ft}^2 & I_{xz} &= \_\ \text{slug-ft}^2 \\
I_{zz} &= \_\ \text{slug-ft}^2 & I_{yz} &= \_\ \text{slug-ft}^2
\end{aligned}
$$

Products of inertia must indicate whether defined as positive or negative integrals (e.g., $I_{xy} = + \int xydm$).

9.2.4 Principal Axes

The transformation matrix defining the orientation of the PAS with respect to the the payload/element PA is:

$$
\begin{Bmatrix} X \\ Y \\ Z \end{Bmatrix}_{PAS} = \begin{bmatrix} \_ & \_ & \_ \\ \_ & \_ & \_ \\ \_ & \_ & \_ \end{bmatrix} \begin{Bmatrix} X \\ Y \\ Z \end{Bmatrix}_{PA}
$$

9.3 Structural Characteristics

9.3.1 Grapple Fixtures

Specification of which type of grapple fixture is required.

9.3.2 Keel Camera Target

The vector from the PAS Origin to the keel camera target (see Figure 9-5) expressed in PAS coordinates is:

$$
\begin{Bmatrix} X \\ Y \\ Z \end{Bmatrix}_{KEEL\ TARG} = \begin{Bmatrix} \_\ \text{inches} \\ \_\ \text{inches} \\ \_\ \text{inches} \end{Bmatrix}_{PAS}
$$

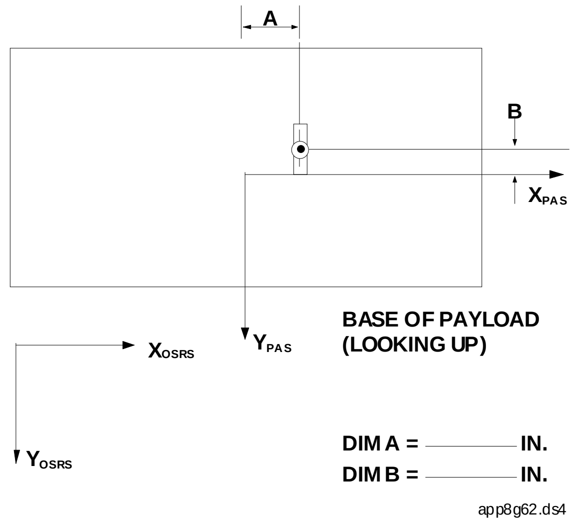

Figure 9-5.- Typical keel-mounted camera target location.

9.3.3 FSS Camera Target

The vector from the PAS Origin to the FSS camera target (see Figure 9-6) expressed in PAS coordinates is:

$$
\begin{Bmatrix} X \\ Y \\ Z \end{Bmatrix}_{FSS\ TARG} = \begin{Bmatrix} \_\ \text{inches} \\ \_\ \text{inches} \\ \_\ \text{inches} \end{Bmatrix}_{PAS}
$$

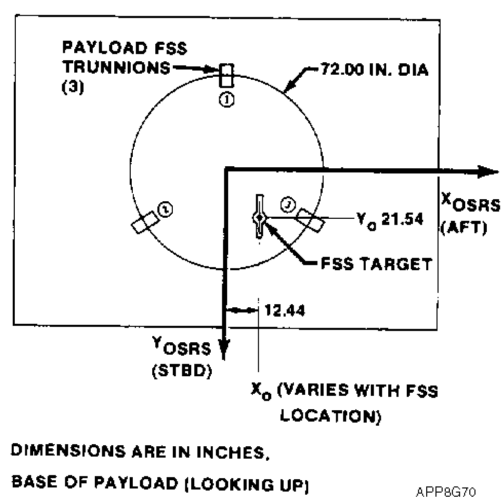

Figure 9-6.- Typical FSS-mounted camera target location.

9.3.4 Natural Frequencies

The structural vibration frequencies of the payload-GF as a system when the payload is cantilevered from the GF are required. Payload and GF attachment stiffnesses must be accounted for.

All frequencies below 0.5 Hz, or if none, the lowest natural frequency, should be reported:

Mode	Freq. (Hz)	Description
1	______	______________
2	______	______________
3	______	______________

9.3.5 Rigid-Body Stiffness Matrix

For payloads with major structural vibration frequencies below 0.5 Hz, the payload designer should provide to SSP a rigid-body stiffness coefficient matrix that is compatible with the simulation capabilities at SSP's disposal. Customers whose payloads have multiple GF's should provide a stiffness matrix for each GF.

a. Model Assumptions

In order to be compatible with SSP's simulation capability, the rigid-body (lumped mass) payload model should include six degrees of freedom at the payload c.m., defined with respect to PAS. The payload model should be cantilevered from the base of the grapple shaft and include the GF attachment stiffness.

The equations of motion for this rigid-body system are defined by the equation:

$$[M]\{\ddot{x}\}+[C]\{\dot{x}\}+[K]\{x\}=\{F\}$$

where

$\{\ddot{x}\},\{\dot{x}\},\{x\}$ are the six-dimensional vectors of accelerations, velocities, and displacement/rotations of the payload c.m. in PAS coordinates.

[M] is the 6 x 6 rigid-body mass matrix about the c.m. with respect to the PAS. This matrix can be constructed from the mass property data provided in section 9.2.

[C] is a 6 x 6 rigid-body damping matrix with respect to the PAS. For analyses, one-half of a percent viscous damping (ζ = 0.005) will be assumed unless the payload designer indicates that there are compelling reasons to apply another value or another form of damping.

[K] is the 6 x 6 rigid-body stiffness matrix which defines the stiffness characteristics between the GF and the payload c.m. This matrix should account for GF attachment stiffness and payload structural stiffness. Terms should be defined with respect to PAS.

{F} is a six-dimensional vector of external forces and torques (Fx, Fy, Fz, Mx, My, Mz) applied at and about the c.m.

b. Data Requirements

The stiffness matrix [K] should be provided in the format:

$$[K]\{x\}=\begin{bmatrix} Kxx & Kxy & Kxz & Kx\theta x & Kx\theta y & Kx\theta z \\ Kyx & Kyy & Kyz & Ky\theta x & Ky\theta y & Ky\theta z \\ Kzx & Kzy & Kzz & Kz\theta x & Kz\theta y & Kz\theta z \\ K\theta xx & K\theta xy & K\theta xz & K\theta x\theta x & K\theta x\theta y & K\theta x\theta z \\ K\theta yx & K\theta yy & K\theta yz & K\theta y\theta x & K\theta y\theta y & K\theta y\theta z \\ K\theta zx & K\theta zy & K\theta zz & K\theta z\theta x & K\theta z\theta y & K\theta z\theta z \end{bmatrix}\begin{Bmatrix} X \\ Y \\ Z \\ \theta x \\ \theta y \\ \theta z \end{Bmatrix}_{c.m.}$$

Units for linear and torsional stiffnesses should be lbf/in. and in.-lbf/rad, respectively. Cross-coupled (off-diagonal) terms in the matrix should be included.

Stiffness matrices may also be requested by NASA to model flexibility between the centerbody c.m. (mass of payload minus appendage mass) and an external appendage c.m. In this case, six degrees of freedom exist at the appendage c.m. such that {x} now defines the displacements and rotations of the appendage c.m. relative to the "fixed" centerbody c.m. (in PAS coordinates). The stiffness matrix, which defines the centerbody-to-appendage stiffness, should be modeled with the appendage c.m. cantilevered from the centerbody c.m. In addition, individual mass property information for the centerbody and the appendage and the appendage attachment location will also be required.

9.3.6 Payload Forces Imparted to the RMS

All forces imparted to the RMS by the payload must be defined.

9.4 PDRS Automatic Trajectories

Automatic trajectories are defined by a sequence of points (maximum 200) which specifies the position and orientation of the payload with respect to the Orbiter, while attached to the RMS. The following data are required to define the RMS automatic trajectory capabilities required by the payload.

9.4.1 Number of Automatic Trajectories

The designer should provide the number of automatic trajectories required by the payload (with a maximum of 20 to be shared by all payloads on a single flight).

9.4.2 POR

The designer should supply the Points of Resolution (POR) required by the payload (with a maximum of five to be shared by all payloads on a single flight). The POR defines a reference location on the payload by which the payload is positioned and about which rotations are performed. Payload POR requirements are defined in Table 9-II.

TABLE 9-II.- AUTO TRAJECTORY POINTS OF RESOLUTION

POR No.	PAS to POR (inches)		
	X	Y	Z
1			

9.4.3 Automatic Trajectory Points

Automatic trajectory points are defined by the position and orientation of the payload with respect to the Orbiter. The position of each trajectory point is defined by the position of the appropriate POR with respect to the OBAS (see Figure 3-2). Payload attitude at each automatic trajectory point is defined with respect to the ORAS (see Figure 3-3). Automatic trajectory points are defined in Table 9-III.

TABLE 9-III.- PAYLOAD/PDRS AUTOMATIC TRAJECTORIES

Sequence No.__ POR No.__							
Point No.	OBAS to POR (in.) X	Y	Z	Attitude in ORAS (deg) P	Y	R	Pause (0/1)
1							

Notes:

(1) X, Y, Z is the vector from the OBAS origin to the POR.

(2) P, Y, R is the Pitch, Yaw, and Roll Euler sequence which defines the payload attitude with respect to ORAS. When berthed, attitude is 0,0,0.

(3) Pause points are indicated by a 1, otherwise 0 indicates fly-by.

9.5 Flexible Payload Model

For some payloads, the rigid-body stiffness matrix does not adequately represent the flexible characteristics of the payload under dynamic conditions. For these payloads, SSP requires a modal representation of the payload in order to accurately analyze “load sensitive” areas (e.g., appendage attach points) and dynamic interactions with the Orbiter RMS and FCS. The requirement for a modal representation may be identified during development of the IP baseline, or may be identified once RMS mission-design analyses are begun.

For payloads for which it is not adequate to lump all payload flexibility at the grapple point, the payload designer should provide to SSP a modal representation of the payload that is compatible with the simulation capabilities at SSP's disposal. Payloads with multiple GF’s should provide a modal model for each GF.

The data required for flexible payload simulation will generally be the output of a finite element analysis of the payload. The required data includes:

- Finite element model reference frame definition (Payload Interface Axis System to GFAS transformation matrix)
- Number of modes
- Modal frequencies (eigenvalues)
- Generalized mass matrix
- Displacement transformation matrix
  - Number of grid points of interest
  - Rigid-body (grid points, nodal coordinates)
  - Elastic (mode shapes, normalized eigenvectors)

The data should be provided via magnetic tape (in standard ASCII format) along with a paper printout.

9.5.1 Reference Frame

The flexible payload model should be constructed in a clearly defined payload fixed frame where the origin is at the EE/GF interface point (i.e., at the base of the grapple shaft). This coordinate system will be referred to as the Payload Interface Axis System (PIAS). It is preferable that the PIAS be aligned with the GFAS. The transformation matrix defining the orientation of the GFAS with respect to the PIAS is:

$$\begin{Bmatrix} X \\ Y \\ Z \end{Bmatrix}_{GFAS} = \begin{bmatrix} — & — & — \\ — & — & — \\ — & — & — \end{bmatrix} \begin{Bmatrix} X \\ Y \\ Z \end{Bmatrix}_{PIAS}$$

9.5.2 Units

Data for flexible payload models should be submitted in consistent units to allow simulators to be unit-independent. The units employed by the payload designer should be clearly identified and conform to one of the columns in Table 9-IV.

TABLE 9-IV.- FLEXIBLE PAYLOAD MODEL UNITS

Parameter	Units		
Length	inches	feet	meters
Linear Acceleration	in./sec^2	ft/sec^2	m/sec^2
Angle	radians	radians	radians
Angular Acceleration	rad/sec^2	rad/sec^2	rad/sec^2
Mass	lbf-sec^2/in.	slugs	kg
Moments of Inertia	lb-in.-sec^2	slug-ft^2	kg-m^2
Force	lbs	lbs	N
Linear Stiffness	lbs/in.	lbs/ft	N/m
Torque	in.-lbs	ft-lbs	N-m
Torsional Stiffness	in.-lbs/rad	ft-lbs/rad	N-m/rad

9.5.3 Model Assumptions

In order to be compatible with SSP's simulation capability, the flexible payload model should include six degrees of freedom at the GF interface, with additional grid points defined with respect to PIAS. For natural vibration analysis, however, the payload is considered to be cantilevered (constrained) at the GF interface (i.e., the base of the grapple shaft). The GF attachment stiffness should be included in the payload model.

The equations of motion for a flexible payload model may be expressed in the form shown in Equation 9-A, which is further detailed in Equations 9-B and 9-C,

and where

$\{x_I\}$ is a six-dimensional vector of the (inertial) accelerations $(\ddot{x}, \ddot{y}, \ddot{z}, \ddot{\theta}x, \ddot{\theta}y, \ddot{\theta}z)$ of the interface point in PIAS coordinates.

{q} is an n dimensional vector of modal amplitudes.

$[M_{II}]$ is the 6 x 6 rigid-body mass matrix as seen at the interface point in PIAS coordinates. This matrix can be divided into the submatrices shown in Equation 9-D. In this equation, m is the mass of the payload, and the upper right hand 3 x 3 submatrix is the cross product operator matrix for the vector $\bar{r}$ from the GF base to the payload c.m. expressed in PIAS coordinates. The lower right hand 3 x 3 submatrix is the inertia matrix of the payload as seen at the interface point in PIAS coordinates.

[B] is an n x 6 matrix of modal integrals where n is the number of modes supplied by the payload designer.

$[F_I]$ is a six-dimensional vector of external forces and torques (Fx,Fy,Fz,Mx,My, Mz) applied at the interface point.

$\{F_k\}$ is a six-dimensional vector of external forces and torques applied at grid point k.

$\phi c(k)$ is a 6 x 6 rigid-body displacement transformation matrix relating displacements of the interface point to displacements at grid point k. This matrix is shown in Equation 9-E. In this equation, $\bar{r}_k$ is the vector from the interface point to grid point k in PIAS coordinates.

$\phi e(k)$ is a 6 x n elastic displacement transformation matrix relating the generalized coordinates (q) to the real displacements at grid point k. The columns of this matrix are the mode shapes at grid point k.

$$\begin{bmatrix} [M_{II}] & [B]^T \\ [B] & [I] \end{bmatrix} \begin{Bmatrix} \ddot{x}_I \\ q \end{Bmatrix} + \begin{bmatrix} [0] & [0] \\ [0] & [C] \end{bmatrix} \begin{Bmatrix} \dot{x}_I \\ q \end{Bmatrix} + \begin{bmatrix} [0] & [0] \\ [0] & [w^2] \end{bmatrix} \begin{Bmatrix} x_I \\ q \end{Bmatrix} = \begin{bmatrix} [I] & [\phi c]^T \\ [0] & [\phi e]^T \end{bmatrix} \begin{Bmatrix} F_I \\ F_k \end{Bmatrix}$$

Equation 9-A

$$[M_{II}]\{\ddot{x}_I\}[B]^T\{\ddot{q}\} = \{F_I\} + \sum_k \phi c^T(k)\{F_k\}$$

Equation 9-B

$$[B]\{\ddot{x}_I\} + \begin{bmatrix} 1 & & & & \\ & 1 & & & \\ & & \cdot & & \\ & & & \cdot & \\ & & & & \cdot \\ & & & & & 1 \end{bmatrix} \{\ddot{q}\} + \begin{bmatrix} 2\zeta w_1 & & & & \\ & 2\zeta w_2 & & & \\ & & \cdot & & \\ & & & \cdot & \\ & & & & \cdot \\ & & & & & 2\zeta w_n \end{bmatrix} \{\dot{q}\} + \begin{bmatrix} w_1^2 & & & & \\ & w_2^2 & & & \\ & & \cdot & & \\ & & & \cdot & \\ & & & & \cdot \\ & & & & & w_n^2 \end{bmatrix} \{q\} = \sum_k \phi e^T(k)\{F_k\}$$

Equation 9-C

w_i are the constrained modal frequencies with the payload cantilevered at the interface point (in rad/sec).

ζ is the damping ratio of the elastic modes (assumed to be the same for all modes).

$$M_{II} = \begin{bmatrix} \begin{bmatrix} m & & \\ & m & \\ & & m \end{bmatrix} & -m\begin{bmatrix} 0 & -r_z & r_y \\ r_z & 0 & -r_x \\ -r_y & r_x & 0 \end{bmatrix} \\ m\begin{bmatrix} 0 & r_z & -r_y \\ -r_z & 0 & r_x \\ r_y & -r_x & 0 \end{bmatrix} & \begin{bmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{xy} & I_{yy} & I_{yz} \\ I_{xz} & I_{yz} & I_{zz} \end{bmatrix} \end{bmatrix}$$

$\bar{r}$ = Interface point to center of mass.

Equation 9-D

$$\phi_c(k) = \begin{bmatrix} \begin{bmatrix} 1 & & \\ & 1 & \\ & & 1 \end{bmatrix} & -\begin{bmatrix} 0 & -r_{kz} & r_{ky} \\ r_{kz} & 0 & -r_{kx} \\ -r_{ky} & r_{kx} & 0 \end{bmatrix} \\ \begin{bmatrix} 0 & & \\ & 0 & \\ & & 0 \end{bmatrix} & \begin{bmatrix} 1 & & \\ & 1 & \\ & & 1 \end{bmatrix} \end{bmatrix}$$

$\bar{r}_k$ = Interface point to grid point k.

Equation 9-E

9.5.4 Data Requirements

The Number of Modes

At present, the simulators are dimensioned to handle up to 10 elastic modes. This number could be increased but with increasing computational expense as the number of modes grows. The judgement of the payload designer will be relied on to supply a sufficient number of modes to adequately represent the payload. It is recommended that more modes than necessary be supplied so that the effect of truncation can be determined.

The Frequencies of the Modes

The payload designer must supply the frequencies of the retained modes (in rad/sec). The payload designer should realize that in addition to being limited as to the number of modes used, the simulations are limited to the frequencies that realistically can be simulated. Frequencies in excess of approximately 10 Hz are impractical to simulate. Moreover, frequencies above 10 Hz are sufficiently above dominant arm natural frequencies that they would not couple with the arm dynamics in any case.

Payload Generalized Mass Matrix

The generalized mass matrix, shown in Equation 9-F, is a (6+n) x (6+n) matrix made up of the rigid-body mass matrix [M_{II}] and the modal integral matrix [B].

$$\begin{bmatrix} 6\overset{6}{\left[M_{II}\right]} & 6\overset{n}{\left[B^T\right]} \\ n\overset{6}{\left[B\right]} & n\begin{bmatrix} 1 & & & & \\ & 1 & & & \\ & & \cdot & & \\ & & & \cdot & \\ & & & & 1 \end{bmatrix} \end{bmatrix}$$

Equation 9-F

Displacement Transformation Matrix

If it is of interest to the payload designer to know the displacements of particular points on the payload, then for each point of interest, the payload designer should supply the location, r_k or Φc(k), and the mode shape matrix, Φe(k).

The data may be supplied in tabular form as shown in Tables 9-V and 9-VI. Alternatively, the designer may supply the total displacement transformation matrix [[Φc][Φe]], which is a combination of the rigid-body and elastic displacement matrices, as depicted in Equation 9-G. The total transformation matrix will be used to compute displacements using an equation of the form of Equation 9-H.

TABLE 9-V.- PAYLOAD GRID POINT COORDINATE DEFINITIONS

Node #	PIAS Origin to Grid Point (PIAS) X	Y	Z

TABLE 9-VI.- PAYLOAD MODE SHAPE DEFINITIONS

Mode # ____ Frequency __________ Hz						
Node #	Normalized Deflection X	Y	Z	Normalized Rotation P	Y	R

$$\left[6\left[\overset{6}{\phi_c(k)}\right] \;\vdots\; 6\left[\overset{n}{\phi_e(k)}\right] \right]$$

Equation 9-G

$$\{x_k\} = [\ \phi c(k)\ \vdots\ \phi e(k)\ ]\ \begin{Bmatrix} x_I \\ q \end{Bmatrix}$$

Equation 9-H

Damping

When simulations are performed, damping will be applied to the elastic modes. One half of a percent viscous damping ($\zeta = 0.005$) will be used unless the payload designer indicates that there are compelling reasons to apply another value or another form of damping.

Level C Data Generated

10

The RMS software contains five sets of parameters for payload operations. Selection of Payload ID on Spec 94 (see Figure 2-8) determines which set of parameters is used by the RMS software to: 1) calculate joint rates; 2) display position, attitude, and rate data; and 3) determine system health. Each Payload ID (1 through 5) uses a set of the following:

POR Rate Limits:

Total Translational Coarse Rate Limit
Total Translational Vernier Rate Limit
Total Rotational Coarse Rate Limit
Total Rotational Vernier Rate Limit

X, Y, & Z Component Translational Coarse Rate Limit
X, Y, & Z Component Translational Vernier Rate Limit
X, Y, & Z Component Rotational Coarse Rate Limit
X, Y, & Z Component Rotational Vernier Rate Limit

Total Translational Vernier Rate Limit for Auto Modes
Total Rotational Vernier Rate Limit for Auto Modes

Joint Rate Limits for Each Payload:

Coarse Rate Limit for Shoulder Yaw Joint
Coarse Rate Limit for Shoulder Pitch Joint
Coarse Rate Limit for Elbow Pitch Joint
Coarse Rate Limit for Wrist Pitch Joint
Coarse Rate Limit for Wrist Yaw Joint
Coarse Rate Limit for Wrist Roll Joint

Vernier Rate Limit for Shoulder Yaw Joint
Vernier Rate Limit for Shoulder Pitch Joint
Vernier Rate Limit for Elbow Pitch Joint
Vernier Rate Limit for Wrist Pitch Joint
Vernier Rate Limit for Wrist Yaw Joint
Vernier Rate Limit for Wrist Roll Joint

Parameters that Allow Conversion from Payload to RMS Coordinate Systems:

PLOP to EE Operating System Transformation Matrix
X, Y, and Z Components of Vector from EE to POR in the POR reference frame

Gain Select Parameter:

SPA Gain Select

RMS System Health Monitoring Software Parameters:

Joint Coarse Maximum Angle Displacement Allowed for Shoulder Yaw
Joint Coarse Maximum Angle Displacement Allowed for Shoulder Pitch
Joint Coarse Maximum Angle Displacement Allowed for Elbow Pitch
Joint Coarse Maximum Angle Displacement Allowed for Wrist Pitch
Joint Coarse Maximum Angle Displacement Allowed for Wrist Yaw
Joint Coarse Maximum Angle Displacement Allowed for Wrist Roll

Joint Vernier Maximum Angle Displacement Allowed for Shoulder Yaw
Joint Vernier Maximum Angle Displacement Allowed for Shoulder Pitch
Joint Vernier Maximum Angle Displacement Allowed for Elbow Pitch
Joint Vernier Maximum Angle Displacement Allowed for Wrist Pitch
Joint Vernier Maximum Angle Displacement Allowed for Wrist Yaw
Joint Vernier Maximum Angle Displacement Allowed for Wrist Roll

Coarse Cycle Divergence Factor for Shoulder Yaw
Coarse Cycle Divergence Factor for Shoulder Pitch
Coarse Cycle Divergence Factor for Elbow Pitch
Coarse Cycle Divergence Factor for Wrist Pitch
Coarse Cycle Divergence Factor for Wrist Yaw
Coarse Cycle Divergence Factor for Wrist Roll

Vernier Cycle Divergence Factor for Shoulder Yaw
Vernier Cycle Divergence Factor for Shoulder Pitch
Vernier Cycle Divergence Factor for Elbow Pitch
Vernier Cycle Divergence Factor for Wrist Pitch
Vernier Cycle Divergence Factor for Wrist Yaw
Vernier Cycle Divergence Factor for Wrist Roll

Parameters Used to Compare Actual with Commanded Rates: (for use in the consistency check)

Actual Command Offset for Coarse Zero Rate Commands for Shoulder Yaw
Actual Command Offset for Coarse Zero Rate Commands for Shoulder Pitch
Actual Command Offset for Coarse Zero Rate Commands for Elbow Pitch
Actual Command Offset for Coarse Zero Rate Commands for Wrist Pitch
Actual Command Offset for Coarse Zero Rate Commands for Wrist Yaw
Actual Command Offset for Coarse Zero Rate Commands for Wrist Roll

Actual Command Offset for Vernier Zero Rate Commands for Shoulder Yaw
Actual Command Offset for Vernier Zero Rate Commands for Shoulder Pitch
Actual Command Offset for Vernier Zero Rate Commands for Elbow Pitch
Actual Command Offset for Vernier Zero Rate Commands for Wrist Pitch
Actual Command Offset for Vernier Zero Rate Commands for Wrist Yaw
Actual Command Offset for Vernier Zero Rate Commands for Wrist Roll

Actual Command Offset for Coarse Nonzero Rate Commands for Shoulder Yaw
Actual Command Offset for Coarse Nonzero Rate Commands for Shoulder Pitch
Actual Command Offset for Coarse Nonzero Rate Commands for Elbow Pitch
Actual Command Offset for Coarse Nonzero Rate Commands for Wrist Pitch
Actual Command Offset for Coarse Nonzero Rate Commands for Wrist Yaw
Actual Command Offset for Coarse Nonzero Rate Commands for Wrist Roll

Actual Command Offset for Vernier Nonzero Rate Commands for Shoulder Yaw
Actual Command Offset for Vernier Nonzero Rate Commands for Shoulder Pitch
Actual Command Offset for Vernier Nonzero Rate Commands for Elbow Pitch
Actual Command Offset for Vernier Nonzero Rate Commands for Wrist Pitch
Actual Command Offset for Vernier Nonzero Rate Commands for Wrist Yaw
Actual Command Offset for Vernier Nonzero Rate Commands for Wrist Roll

Offset for Decaying Actual Rates (Slope of Envelope) for Shoulder Yaw
Offset for Decaying Actual Rates (Slope of Envelope) for Shoulder Pitch
Offset for Decaying Actual Rates (Slope of Envelope) for Elbow Pitch
Offset for Decaying Actual Rates (Slope of Envelope) for Wrist Pitch
Offset for Decaying Actual Rates (Slope of Envelope) for Wrist Yaw
Offset for Decaying Actual Rates (Slope of Envelope) for Wrist Roll

Position Hold and POHS Parameters:

Position Hold Gain Factor 1 for Shoulder Yaw
Position Hold Gain Factor 1 for Shoulder Pitch
Position Hold Gain Factor 1 for Elbow Pitch
Position Hold Gain Factor 1 for Wrist Pitch
Position Hold Gain Factor 1 for Wrist Yaw
Position Hold Gain Factor 1 for Wrist Roll

Position Hold Gain Factor 2 for Shoulder Yaw
Position Hold Gain Factor 2 for Shoulder Pitch
Position Hold Gain Factor 2 for Elbow Pitch
Position Hold Gain Factor 2 for Wrist Pitch
Position Hold Gain Factor 2 for Wrist Yaw
Position Hold Gain Factor 2 for Wrist Roll

Position Hold Gain Factor 3 for Shoulder Yaw
Position Hold Gain Factor 3 for Shoulder Pitch
Position Hold Gain Factor 3 for Elbow Pitch
Position Hold Gain Factor 3 for Wrist Pitch
Position Hold Gain Factor 3 for Wrist Yaw
Position Hold Gain Factor 3 for Wrist Roll

POHS Rotational Compensator Coefficient 1
POHS Rotational Compensator Coefficient 2
POHS Rotational Compensator Coefficient 3
POHS Translational Compensator Coefficient 1
POHS Translational Compensator Coefficient 2
POHS Translational Compensator Coefficient 3

RMS Parameters Available In MCC During Flights

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The following is a list of the parameters usually available in the MCC during RMS operations. A definition of the abbreviations used follows the listing. The sample rate is given in samples/sec. When the sample rate is shown as “0”, that indicates the parameter is not available on the usual downlist format. However, it may be possible to downlist it on a temporary basis (on the variable parameters downlist) if it is required. Also note the parent words contain all of the child numbers shown.

A parent word comes down at the sample rate of the child with the highest sample rate requirement. For example, although one child may only be required at 1 sample/sec., if another child is required at 12.5 samples/sec, the parent word (and therefore all the child words) will be sampled at 12.5 samples/sec.

The bit location in the parent word is shown for each applicable child word. If no parent is shown, the child word is requested by its own parameter word. The most significant bit in the downlist format is bit 0, the least significant bit in the downlist is bit 15.

PARENT MSID	MSID	NAME OF PARAMETER	START BIT	NUMBER OF BITS	SAMPLE RATE
V54M3442P	V54X3528J	28V BRAKE COMMAND RMS	15	1	12.5
V54M3442P	V54X2021J	ABE WARNING ANNUN RMS	14	1	12.5
	V92R3323C	ACT POR P ROT RATE RMS	0	32	1
	V92R3325C	ACT POR R ROT RATE RMS	0	32	1
V54M3335P	V72L2933J	ACT POR RESULTANT VEL RMS	7	8	1
	V92R3320C	ACT POR X TRANS RATE RMS	0	32	1
	V92R3321C	ACT POR Y TRANS RATE RMS	0	32	1
	V92R3324C	ACT POR YAW ROT RATE RMS	0	32	1
	V92R3322C	ACT POR Z TRANS RATE RMS	0	32	1
V99M1863P	V92X0302X	ALL BRAKES ON FLAG DL RMS	11	1	12.5
V54M3329P	V72X2911J	ALL BRAKES ON REQUEST RMS	12	1	12.5
V99M1863P	V92X0199X	ALL BRAKES REQ DL RMS	10	1	12.5
V54M3329P	V72X2900J	AUTO 1 MODE IND RMS	7	1	12.5
V54M3329P	V72X2901J	AUTO 2 MODE IND RMS	8	1	12.5
V54M3329P	V72X2902J	AUTO 3 MODE IND RMS	9	1	12.5
V54M3329P	V72X2903J	AUTO 4 MODE IND RMS	10	1	12.5

PARENT MSID	MSID	NAME OF PARAMETER	START BIT	NUMBER OF BITS	SAMPLE RATE
V99M1864P	V93J7510C	AUTO SEQ 1 ID RMS	0	5	1
V99M1864P	V93J7511C	AUTO SEQ 2 ID RMS	5	5	1
V99M1865P	V93J7512C	AUTO SEQ 3 ID RMS	0	5	1
V99M1865P	V93J7513C	AUTO SEQ 4 ID RMS	5	5	1
V99M1866P	V92J3241C	AUTO SEQ LAST POINT RMS	8	8	1
V99M1866P	V93J7550C	AUTO SEQ START POINT RMS	0	8	1
V54M3331P	V72X2942J	AUTO SEQUENCE IN PROG IND RMS	10	1	1
V54M3434P	V72K2983J	AUTO SEQUENCE PROCEED RMS	5	1	1
V54M3331P	V72X2941J	AUTO SEQUENCE READY IND RMS	9	1	1
V54M3434P	V72K2984J	AUTO SEQUENCE STOP RMS	6	1	1
V93M0542P	V93X1727X	AUTO SW OVERRIDE ENA/DIS RMS	14	1	1
V93M0541P	V93X1731X	AXIS CHANGE ENA/DIS RMS	0	1	1
V93M0541P	V93X1733X	AXIS CHANGE-RHC RMS	2	1	1
V93M0541P	V93X1732X	AXIS CHANGE-THC RMS	1	1	1
V54M3443P	V54X3509J	BRAKE TEST FAILURE RMS	7	1	1
V54M3442P	V54X2024J	BRAKES ON IND RMS	7	1	12.5
V54M3432P	V72K2985J	BRAKES ON/OFF CMD RMS	5	1	12.5
V54M3435P	V72K3025J	CAPTURE CMD RMS	5	1	1
V54M3330P	V72X2929J	CHECK CRT CAUTION ANNUN RMS	13	1	1
V54M3334P	V72L2934J	CMD POR RESULTANT VEL RMS	7	8	1
V54M3330P	V72X2924J	CNTRL ERROR CAUTION ANNUN RMS	14	1	1
V54M3434P	V72K3027J	COARSE RATE SELECT RMS	11	1	1
V99M1867P	V92X3831X	CONSIS BRAKES ENABLE DISABLE RMS	9	1	1
V54M3433P	V72K2982J	CONTROL MODE ENTER RMS	13	1	1
	V92M0253P	CRAB REACH LIM NEG$(1:) RMS	0	16	1
	V92M0254P	CRAB REACH LIM NEG$(2:) RMS	0	16	1
	V92M0255P	CRAB REACH LIM NEG$(3:) RMS	0	16	1
	V92M0256P	CRAB REACH LIM NEG$(4:) RMS	0	16	1
	V92M0257P	CRAB REACH LIM NEG$(5:) RMS	0	16	1
	V92M0258P	CRAB REACH LIM NEG$(6:) RMS	0	16	1
	V92M0259P	CRAB REACH LIM POS$(1:) RMS	0	16	1

PARENT MSID	MSID	NAME OF PARAMETER	START BIT	NUMBER OF BITS	SAMPLE RATE
	V92M0260P	CRAB REACH LIM POS$(2:) RMS	0	16	1
	V92M0261P	CRAB REACH LIM POS$(3:) RMS	0	16	1
	V92M0262P	CRAB REACH LIM POS$(4:) RMS	0	16	1
	V92M0263P	CRAB REACH LIM POS$(5:) RMS	0	16	1
	V92M0264P	CRAB REACH LIM POS$(6:) RMS	0	16	1
	V92M0239P	CRAB SING ELP RMS	0	16	1
	V92M0238P	CRAB SING SHY RMS	0	16	1
	V92M0240P	CRAB SING WRY RMS	0	16	1
	V54M3330P	D&C C&W ANNUN DRIVE RMS	0	16	1
	V54M3329P	D&C MODE IND DRIVE RMS	0	16	12.5
	V54M3431P	D&C SWITCH INPUTS 1 RMS	0	16	1
	V54M3432P	D&C SWITCH INPUTS 2 RMS	0	16	12.5
	V54M3433P	D&C SWITCH INPUTS 3 RMS	0	16	1
	V54M3434P	D&C SWITCH INPUTS 4 RMS	0	16	1
	V54M3435P	D&C SWITCH INPUTS 5 RMS	0	16	1
	V54M3331P	D&C TALKBACK/MODE IND DRIVE RMS	0	16	1
V54M3402P	V54X2003J	D&C/MCIU COMM FAILURE BSR B2 RMS	2	1	12.5
	V92T3724C	EE ABE TEMP PORT RMS	0	16	1
V54M3443P	V54X2035J	EE CAPTURE DRIVE RMS	0	1	1
V54M3442P	V54X2034J	EE CLOSED RMS	12	1	12.5
V54M3443P	V54X3508J	EE CMDS OUT OF TOLERANCE RMS	6	1	1
V54M3443P	V54X2038J	EE DERIGIDIZE DRIVE RMS	3	1	1
V54M3330P	V72X2926J	EE DERIGIDIZE WARNING ANNUN RMS	11	1	1
V54M3442P	V54X2032J	EE DERIGIDIZED RMS	13	1	12.5
	V54M3443P	EE DRIVE WORD RMS	0	16	1
V54M3442P	V54X2030J	EE EXTENDED RMS	8	1	12.5
V54M3443P	V54X3514J	EE FLAGS STATUS FAILURE RMS	11	1	1
	V93J7507C	EE ID-PORT RMS	0	16	1
	V92T3716C	EE LED TEMP PORT RMS	0	16	1
V54M3435P	V72K2993J	EE MANUAL CONTROL DERIGIDIZE RMS	13	1	1
V54M3435P	V72K2992J	EE MANUAL CONTROL RIGIDIZE RMS	12	1	1

PARENT MSID	MSID	NAME OF PARAMETER	START BIT	NUMBER OF BITS	SAMPLE RATE
V54M3435P	V72K2990J	EE MODE AUTO RMS	10	1	1
V54M3331P	V72X2907J	EE MODE IND RMS	12	1	1
V54M3435P	V72K2991J	EE MODE MANUAL RMS	11	1	1
V54M3442P	V54X2033J	EE OPEN RMS	11	1	12.5
V54M3438P	V54U2867J	EE OUTPUT MONITOR (DERIG/RIG) RMS	4	2	1
V54M3438P	V54U2868J	EE OUTPUT MONITOR (REL/CAP) RMS	6	2	1
V54M3443P	V54X2036J	EE RELEASE DRIVE RMS	1	1	1
V54M3330P	V72X2927J	EE RELEASE WARNING ANNUN RMS	12	1	1
V54M3443P	V54X2037J	EE RIGIDIZE DRIVE RMS	2	1	1
V54M3442P	V54X2031J	EE RIGIDIZED RMS	10	1	12.5
V54M3422P	V54X2723J	EEEU BITE FLAG RMS	0	1	1
	V92T3721C	EL ABE TEMP PORT RMS	0	16	1
	V92T3712C	EL P LED TEMP PORT RMS	0	16	1
	V92H3237C	ELB P ANGLE CMD RMS	0	32	1
V92M3040P	V92X3542X	ELB P CONTROL ERROR RMS	4	1	1
V54M3312P	V54K2410J	ELB P CURRENT LIMIT DEMAND RMS	0	4	1
V54M3412P	V54X2411J	ELB P CURRENT SATURATION FLAG RMS	14	1	12.5
	V54M3412P	ELB P DATA 1 RMS	0	16	12.5
	V54M3413P	ELB P DATA 2 RMS	0	16	1
V92M3040P	V92X3532X	ELB P ENCODER CHECK FLAG RMS	10	1	1
	V54H2405J	ELB P ENCODER OUTPUT RMS	0	16	12.5
V54M3413P	V54X2423J	ELB P EXTERNAL FLAG RMS	0	1	1
V54M3412P	V54X2415J	ELB P FWD/BACK DRIVE DETECT RMS	15	1	12.5
V54M3311P	V54K2400J	ELB P RATE DEMAND FXPT RMS	0	12	12.5
V92M0255P	V92X3562X	ELB P REACH LIMIT NEG FLAG RMS	15	1	1
V92M0261P	V92X3552X	ELB P REACH LIMIT POS FLAG RMS	15	1	1
V54M3412P	V54L2401J	ELB P TACH OUTPUT RMS	0	12	12.5
V92M3472P	V92X3485X	ELP RATE ENVELOPE CHECK FAIL RMS	12	1	1
V92M3472P	V92X3479X	ELP TACH DATA CHECK FAIL RMS	6	1	1
V99M1867P	V92J3867C	ENCODER CHECK ENA/INH RMS	8	1	1
V54M3402P	V54X2009J	END EFFECTOR FAILURE BSR B8 RMS	8	1	12.5

PARENT MSID	MSID	NAME OF PARAMETER	START BIT	NUMBER OF BITS	SAMPLE RATE
V54M3413P	V54X0045X	EP BITE BIT 18 RMS	9	1	1
V54M3413P	V54X0051X	EP BITE BIT 19 RMS	10	1	1
V54M3413P	V54X0057X	EP BITE BIT 20 RMS	11	1	1
V54M3413P	V54X0063X	EP BITE BIT 22 RMS	13	1	1
V54M3413P	V54X0069X	EP BITE BIT 23 RMS	14	1	1
V54M3413P	V54X0033X	EP BITE VERIF BIT 16 RMS	7	1	1
V54M3413P	V54X0039X	EP BITE VERIF BIT 17 RMS	8	1	1
V54M3413P	V54X0075X	EP BITE VERIF BIT 24 RMS	15	1	1
V99M1863P	V92X0539X	EP FWD/BACK DRIVE FLAG DL RMS	2	1	12.5
V54M3311P	V54U0203C	EP ID RMS	13	3	12.5
V92M2846P	V92X3582X	EP JOINT SLIP ERROR DETECTED RMS	2	1	1
V54M3413P	V54C0186C	EP MOTOR CURRENT RMS	1	6	1
V54M3438P	V54U2870J	EPROM CHECK STATUS RMS	9	2	1
V92M2846P	V96X0047X	EXCEED CHECK CONTROL ERR FLAG RMS	11	1	1
V54M3443P	V54X3522J	EXTERNAL FRAME SYNC FAILURE RMS	14	1	1
V54M3312P	V54X0163X	GAIN SELECT (EP) RMS	4	1	1
V54M3314P	V54X0164X	GAIN SELECT (SP) RMS	4	1	1
V54M3316P	V54X0165X	GAIN SELECT (SY) RMS	4	1	1
V54M3310P	V54X0162X	GAIN SELECT (WP) RMS	4	1	1
V54M3306P	V54X0160X	GAIN SELECT (WR) RMS	4	1	12.5
V54M3308P	V54X0161X	GAIN SELECT (WY) RMS	4	1	1
V54M3402P	V54X2001J	GPC COMM FAILURE BSR B0 RMS	0	1	12.5
V54M3442P	V54X2022J	GPC DATA WARNING ANNUN RMS	5	1	12.5
	V54M3305P	GPC-MCIU WD05 WR R RATE DEMAND RMS	0	16	12.5
	V54M3306P	GPC-MCIU WD06 CMD DATA RMS	0	16	12.5
	V54M3307P	GPC-MCIU WD07 WR Y RATE DEMAND RMS	0	16	12.5
	V54M3308P	GPC-MCIU WD08 WR Y CURRENT LIM RMS	0	16	1
	V54M3309P	GPC-MCIU WD09 WR P RATE DEMAND RMS	0	16	12.5
	V54M3310P	GPC-MCIU WD10 WR P CURRENT LIM RMS	0	16	1
	V54M3311P	GPC-MCIU WD11 EL P RATE DEMAND RMS	0	16	12.5
	V54M3312P	GPC-MCIU WD12 EL P CURRENT LIM RMS	0	16	1

PARENT MSID	MSID	NAME OF PARAMETER	START BIT	NUMBER OF BITS	SAMPLE RATE
	V54M3313P	GPC-MCIU WD13 SH P RATE DEMAND RMS	0	16	12.5
	V54M3314P	GPC-MCIU WD14 SH P CURRENT LIM RMS	0	16	1
	V54M3315P	GPC-MCIU WD15 SH Y RATE DEMAND RMS	0	16	12.5
	V54M3316P	GPC-MCIU WD16 SH Y CURRENT LIM RMS	0	16	1
	V54M3334P	GPC-MCIU WD34 CMD EE TOT RATE RMS	0	16	1
	V54M3335P	GPC-MCIU WD35 ACT EE TOT RATE RMS	0	16	1
	V54M3442P	HARDWARE STATUS RMS	0	16	12.5
V99M1867P	V92X3121X	HC NULL FLAG RMS	7	1	1
V99M1867P	V92J3846C	INITIALIZED EE ID RMS	0	2	1
V99M1864P	V92J3845C	INITIALIZED PAYLOAD ID RMS	10	3	1
V54M3402P	V54X2008J	INTERFACE CONTROL FAIL BSR B7 RMS	7	1	12.5
V54M3443P	V54X3523J	INTERNAL FRAME SYNC FAILURE RMS	15	1	1
V54M3433P	V72K3017J	JOINT SELECT CRITICAL TEMP RMS	14	1	1
V54M3432P	V72K3016J	JOINT SELECT-EE TEMP RMS	14	1	12.5
V54M3432P	V72K3012J	JOINT SELECT-ELB P RMS	8	1	12.5
V54M3432P	V72K3011J	JOINT SELECT-SH P RMS	7	1	12.5
V54M3432P	V72K3010J	JOINT SELECT-SH YAW RMS	6	1	12.5
V54M3432P	V72K3013J	JOINT SELECT-WR P RMS	9	1	12.5
V54M3432P	V72K3015J	JOINT SELECT-WR R RMS	11	1	12.5
V54M3432P	V72K3014J	JOINT SELECT-WR YAW RMS	10	1	12.5
	V92M2846P	JOINT SLIP ERROR DETECTED RMS	0	16	1
V93M0542P	V93X1715X	JOINT SW OVERRIDE ENA/DIS RMS	2	1	1
V93M0542P	V93X1723X	JOINT SW OVERRIDE-CRIT T RMS	10	1	1
V93M0542P	V93X1722X	JOINT SW OVERRIDE-EET RMS	9	1	1
V93M0542P	V93X1718X	JOINT SW OVERRIDE-ELP RMS	5	1	1
V93M0542P	V93X1717X	JOINT SW OVERRIDE-SHP RMS	4	1	1
V93M0542P	V93X1716X	JOINT SW OVERRIDE-SHY RMS	3	1	1
V93M0542P	V93X1719X	JOINT SW OVERRIDE-WRP RMS	6	1	1
V93M0542P	V93X1721X	JOINT SW OVERRIDE-WRR RMS	8	1	1
V93M0542P	V93X1720X	JOINT SW OVERRIDE-WRY RMS	7	1	1
V54M3402P	V54X2013J	JPC FAILURE BSR B12 RMS	12	1	12.5

PARENT MSID	MSID	NAME OF PARAMETER	START BIT	NUMBER OF BITS	SAMPLE RATE
V93M0542P	V92X3589X	LOADED RATE LIMIT FLAG RMS	1	1	1
V93M0542P	V93X1730X	LOADED RATE LIMIT TOGGLE REQ RMS	0	1	1
V54M3402P	V54X2006J	MADC OUT OF TOLERANCE BSR B5 RMS	5	1	12.5
	V54M3402P	MCIU BITE STATUS REGISTER RMS	0	16	12.5
V54M3443P	V54X3510J	MCIU FAIL WARNING FAILURE RMS	8	1	1
V99M1863P	V92J3905C	MCIU FRAME IDENT CHANGE RMS	13	3	12.5
V54M3444P	V54J2040J	MCIU FRAME IDENTIFIER RMS	8	7	12.5
V99M1867P	V92X3835X	MCIU I/O ON/OFF RMS	6	1	1
	V54M3438P	MCIU MICROCOMPUTER BITE DATA RMS	0	16	1
V54M3443P	V54X3513J	MCIU NMI FAILURE RMS	12	1	1
V92M2846P	V93X1735X	MCIU OVERRIDE-ABE OVRD A RMS	7	1	1
V92M2846P	V93X1736X	MCIU OVERRIDE-ABE OVRD B RMS	8	1	1
V92M2846P	V93X1737X	MCIU OVERRIDE-ABE OVRD C RMS	9	1	1
V92M2846P	V93X1734X	MCIU OVERRIDE-SAFING CAN RMS	10	1	1
V54M3402P	V54X3524J	MCIU TEST FAILURE BSR B1 RMS	1	1	12.5
V54M3442P	V54X2020J	MCIU WARNING ANNUN RMS	0	1	12.5
V54M3443P	V54X3512J	MCIU-DETECTED HC FAILURE RMS	10	1	1
	V54M3444P	MCIU-GPC WD44 RATE DEMAND RMS	0	16	12.5
V54M3402P	V54X2011J	MCIU/ABE COMM FAILURE BSR B10 RMS	10	1	12.5
V54M3402P	V54X2007J	MCPC OUT OF TOLERANCE BSR B6 RMS	6	1	12.5
V54M3331P	V72X2938J	MINIMUM RATE IND RMS	7	1	1
V54M3433P	V72K2971J	MODE AUTO 1 RMS	8	1	1
V54M3433P	V72K2972J	MODE AUTO 2 RMS	9	1	1
V54M3433P	V72K2973J	MODE AUTO 3 RMS	10	1	1
V54M3433P	V72K2974J	MODE AUTO 4 RMS	11	1	1
V54M3433P	V72K2980J	MODE DIRECT RMS	6	1	1
V54M3431P	V72K2976J	MODE MANUAL EE RMS	12	1	1
V54M3431P	V72K2977J	MODE MANUAL ORBITER LOADED RMS	13	1	1
V54M3431P	V72K2975J	MODE MANUAL ORBITER UNLOADED RMS	11	1	1
V54M3431P	V72K2978J	MODE MANUAL PAYLOAD RMS	14	1	1
V54M3433P	V72K2970J	MODE OPR CMD RMS	7	1	1

PARENT MSID	MSID	NAME OF PARAMETER	START BIT	NUMBER OF BITS	SAMPLE RATE
V54M3433P	V72K2979J	MODE SINGLE RMS	5	1	1
V93M0541P	V93X1700X	MODE SW OVERRIDE ENA/DIS RMS	3	1	1
V93M0541P	V93X1706X	MODE SW OVERRIDE OPR CMD RMS	9	1	1
V93M0541P	V93X1707X	MODE SW OVERRIDE-AUTO 1 RMS	10	1	1
V93M0541P	V93X1708X	MODE SW OVERRIDE-AUTO 2 RMS	11	1	1
V93M0541P	V93X1709X	MODE SW OVERRIDE-AUTO 3 RMS	12	1	1
V93M0541P	V93X1710X	MODE SW OVERRIDE-AUTO 4 RMS	13	1	1
V93M0541P	V93X1703X	MODE SW OVERRIDE-END EFF RMS	6	1	1
V93M0541P	V93X1704X	MODE SW OVERRIDE-ORB LD RMS	7	1	1
V93M0541P	V93X1701X	MODE SW OVERRIDE-ORB UNL RMS	4	1	1
V93M0541P	V93X1705X	MODE SW OVERRIDE-PL RMS	8	1	1
V93M0541P	V93X1702X	MODE SW OVERRIDE-SINGLE RMS	5	1	1
V93M0541P	V93X1711X	MODE SW OVERRIDE-TEST RMS	14	1	1
V54M3433P	V72K2981J	MODE TEST RMS	12	1	1
V54M3402P	V54X3525J	NMI ANNUNCIATION BSR B4 RMS	4	1	12.5
V99M1867P	V92J3675C	OPR CMD CHECK INDEX RMS	2	2	1
V54M3329P	V72X2904J	OPR CMD MODE IND RMS	6	1	12.5
	V93H0984C	OPR DES POR P ATT RMS	0	16	1
	V93H0986C	OPR DES POR R ATT RMS	0	16	1
	V93H0981C	OPR DES POR X POS RMS	0	16	1
	V93H0982C	OPR DES POR Y POS RMS	0	16	1
	V93H0985C	OPR DES POR YAW ATT RMS	0	16	1
	V93H0983C	OPR DES POR Z POS RMS	0	16	1
V99M1867P	V93X0991X	ORB LD FLY FROM CMD REF SEL RMS	13	1	1
V99M1867P	V93X0990X	ORB LD FLY TO CMD REF SEL RMS	12	1	1
V99M1867P	V93X0989X	ORB LD NORM CMD REF SEL RMS	11	1	1
V54M3331P	V72X2908J	ORBITER LOADED MODE IND RMS	13	1	1
V54M3331P	V72X2906J	ORBITER UNLOADED MODE IND RMS	11	1	1
	V92M3472P	PACKED CONSIS FAULTS RMS	0	16	1
	V99M1863P	PACKED DL DATA 1 RMS	0	16	12.5
	V99M1864P	PACKED DL DATA 2 RMS	0	16	1

PARENT MSID	MSID	NAME OF PARAMETER	START BIT	NUMBER OF BITS	SAMPLE RATE
	V99M1865P	PACKED DL DATA 3 RMS	0	16	1
	V99M1866P	PACKED DL DATA 4 RMS	0	16	1
	V99M1867P	PACKED DL DATA 5 RMS	0	16	1
	V92M3040P	PACKED FAULTS RMS	0	16	1
	V93M0541P	PACKED OVERRIDE DATA 1 RMS	0	16	1
	V93M0542P	PACKED OVERRIDE DATA 2 RMS	0	16	1
V54M3431P	V72K3002J	PARAMETER ATTITUDE P/YAW/R RMS	8	1	1
V54M3431P	V72K3003J	PARAMETER JOINT ANGLE RMS	5	1	1
V54M3434P	V72K3006J	PARAMETER PORT TEMP LED/ABE/ID RMS	13	1	1
V54M3431P	V72K3001J	PARAMETER POSITION X/Y/Z RMS	7	1	1
V54M3431P	V72K3005J	PARAMETER RATE P/YAW/R RMS	9	1	1
V54M3434P	V72K3007J	PARAMETER STBD TEMP LED/ABE/ID RMS	14	1	1
V54M3431P	V72K3000J	PARAMETER TEST RMS	10	1	1
V54M3431P	V72K3004J	PARAMETER VELOCITY X/Y/Z RMS	6	1	1
V54M3442P	V54X2027J	PAYLOAD CAPTURED RMS	9	1	12.5
V99M1865P	V93J7505C	PAYLOAD ID-PORT RMS	13	3	1
V99M1865P	V92J3677C	PAYLOAD IDENTIFIER RMS	10	3	1
V54M3329P	V72X2909J	PAYLOAD MODE IND RMS	5	1	12.5
V92M0239P	V92X3202X	PLANAR P SINGULARITY RMS	15	1	1
V99M1863P	V92X0304X	POHS ATT HOLD RMS	7	1	12.5
V99M1863P	V92X0303X	POHS POS HOLD RMS	6	1	12.5
V99M1867P	V92X3826X	POHS_ENABLE_DISABLE_FLAG RMS	5	1	1
	V92H3333C	POR P ATT ORB STR RMS	0	32	1
	V92R3260C	POR P ROT RATE CMD RMS	0	32	1
	V92H3335C	POR R ATT ORB STR RMS	0	32	1
	V92R3262C	POR R ROT RATE CMD RMS	0	32	1
	V92R3250C	POR X TRANS RATE CMD RMS	0	32	1
	V92H3417C	POR X-POSITION DISPLAY RMS	0	32	1
	V92R3251C	POR Y TRANS RATE CMD RMS	0	32	1
	V92H3418C	POR Y-POSITION DISPLAY RMS	0	32	1
	V92H3334C	POR YAW ATT ORB STR RMS	0	32	1

PARENT MSID	MSID	NAME OF PARAMETER	START BIT	NUMBER OF BITS	SAMPLE RATE
	V92R3261C	POR YAW ROT RATE CMD RMS	0	32	1
	V92R3252C	POR Z TRANS RATE CMD RMS	0	32	1
	V92H3419C	POR Z-POSITION DISPLAY RMS	0	32	1
V54M3442P	V54X2025J	PORT ARM POWER ON/OFF RMS	3	1	12.5
V54M3442P	V54X3527J	PORT BRAKE STATUS MONITOR RMS	2	1	12.5
V54M3330P	V72X2931J	PORT TEMP CAUTION ANNUN RMS	7	1	1
V99M1863P	V92X3141X	POSITION HOLD FLAG RMS	8	1	12.5
V54M3438P	V54X2869J	PROCESSOR FAILURE FLAG RMS	8	1	1
V54M3438P	V54U2871J	RAM CHECK STATUS RMS	11	5	1
V54M3444P	V54J2810J	RATE DEMAND ID RETURN RMS	0	7	12.5
V54M3306P	V54K2800J	RATE DEMAND IDENTIFIER RMS	8	7	12.5
V54M3331P	V72X2940J	RATE HOLD IND RMS	5	1	1
V54M3434P	V72K3028J	RATE HOLD ON/OFF SELECT RMS	12	1	1
V99M1863P	V92X0198X	RATE HOLD SEL FLAG DL RMS	9	1	12.5
V93M0542P	V93X1724X	RATE SW OVERRIDE ENA/DIS RMS	11	1	1
V93M0542P	V93X1726X	RATE SW OVERRIDE-COARSE RMS	13	1	1
V93M0542P	V93X1725X	RATE SW OVERRIDE-VERNIER RMS	12	1	1
V54M3330P	V72X2930J	REACH LIMIT CAUTION ANNUN RMS	10	1	1
V99M1867P	V93X0988X	REL POR REF SEL RMS	10	1	1
V54M3435P	V72K3026J	RELEASE CMD RMS	6	1	1
V54M3425P	V72K3035J	RHC P CMD RMS	8	8	12.5
V54M3426P	V72K3037J	RHC R CMD RMS	8	8	12.5
	V54M3426P	RHC YAW AND R CMD RMS	0	16	12.5
V54M3426P	V72K3036J	RHC YAW CMD RMS	0	8	12.5
V54M3434P	V72K2916J	RMS MASTER ALARM RESET RMS	8	1	1
V54M3329P	V72X2915J	RMS MASTER ALARM SET RMS	14	1	12.5
V93M0525P	V93X3509X	RMS SINGULARITY CHECKOUT RMS	9	1	1
V93M0525P	V93X3508X	RMS SOFT STOP REACH REINSTALL RMS	8	1	1
V93M0525P	V93X3507X	RMS SOFT STOP REACH TURNAROUND RMS	7	1	1
V54M3434P	V72K2989J	SAFING CANCEL RMS	10	1	1

PARENT MSID	MSID	NAME OF PARAMETER	START BIT	NUMBER OF BITS	SAMPLE RATE
V54M3442P	V54X2023J	SAFING IN PROGRESS IND RMS	6	1	12.5
V54M3434P	V72K2988J	SAFING INITIATE RMS	9	1	1
	V92T3720C	SH ABE TEMP PORT RMS	0	16	1
V54M3407P	V54X2223J	SH BRACE RELEASED FLAG RMS	0	1	1
	V92H3236C	SH P ANGLE CMD RMS	0	32	1
V92M3040P	V92X3541X	SH P CONTROL ERROR RMS	3	1	1
V54M3314P	V54K2310J	SH P CURRENT LIMIT DEMAND RMS	0	4	1
V54M3409P	V54X2311J	SH P CURRENT SATURATION FLAG RMS	14	1	12.5
	V54M3409P	SH P DATA 1 RMS	0	16	12.5
	V54M3410P	SH P DATA 2 RMS	0	16	1
V92M3040P	V92X3531X	SH P ENCODER CHECK FLAG RMS	9	1	1
	V54H2305J	SH P ENCODER OUTPUT RMS	0	16	12.5
V54M3410P	V54X2323J	SH P EXTERNAL FLAG RMS	0	1	1
V54M3409P	V54X2315J	SH P FWD/BACK DRIVE DETECT RMS	15	1	12.5
	V92T3711C	SH P LED TEMP PORT RMS	0	16	1
V54M3313P	V54K2300J	SH P RATE DEMAND FXPT RMS	0	12	12.5
V92M0254P	V92X3561X	SH P REACH LIMIT NEG FLAG RMS	15	1	1
V92M0260P	V92X3551X	SH P REACH LIMIT POS FLAG RMS	15	1	1
V54M3409P	V54L2301J	SH P TACH OUTPUT RMS	0	12	12.5
	V92T3710C	SH Y LED TEMP PORT RMS	0	16	1
	V92H3235C	SH YAW ANGLE CMD RMS	0	32	1
V92M3040P	V92X3540X	SH YAW CONTROL ERROR RMS	2	1	1
V54M3316P	V54K2210J	SH YAW CURRENT LIMIT DEMAND RMS	0	4	1
V54M3406P	V54X2211J	SH YAW CURRENT SATURATION FLAG RMS	14	1	12.5
	V54M3406P	SH YAW DATA 1 RMS	0	16	12.5
	V54M3407P	SH YAW DATA 2 RMS	0	16	1
V92M3040P	V92X3530X	SH YAW ENCODER CHECK FLAG RMS	8	1	1
	V54H2205J	SH YAW ENCODER OUTPUT RMS	0	16	12.5
V54M3406P	V54X2215J	SH YAW FWD/BACK DRIVE DETECT RMS	15	1	12.5
V54M3315P	V54K2200J	SH YAW RATE DEMAND FXPT RMS	0	12	12.5
V92M0253P	V92X3560X	SH YAW REACH LIMIT NEG FLAG RMS	15	1	1

PARENT MSID	MSID	NAME OF PARAMETER	START BIT	NUMBER OF BITS	SAMPLE RATE
V92M0259P	V92X3550X	SH YAW REACH LIMIT POS FLAG RMS	15	1	1
V92M0238P	V92X3200X	SH YAW SINGULARITY RMS	15	1	1
V54M3406P	V54L2201J	SH YAW TACH OUTPUT RMS	0	12	12.5
V54M3410P	V54X2350J	SH/ELB JPC FAILURE RMS	12	1	1
V54M3435P	V72K3039J	SHOULDER BRACE RELEASE PORT RMS	8	1	1
V92M3472P	V92X3484X	SHP RATE ENVELOPE CHECK FAIL RMS	11	1	1
V92M3472P	V92X3478X	SHP TACH DATA CHECK FAIL RMS	5	1	1
V92M3472P	V92X3483X	SHY RATE ENVELOPE CHECK FAIL RMS	10	1	1
V92M3472P	V92X3477X	SHY TACH DATA CHECK FAIL RMS	4	1	1
V93M0541P	V93X1714X	SINGLE DRIVE SW REASSIGN RMS	15	1	1
V54M3329P	V72X2910J	SINGLE MODE IND RMS	13	1	12.5
V54M3432P	V72K3021J	SINGLE/DIRECT DRIVE MINUS RMS	13	1	12.5
V54M3432P	V72K3020J	SINGLE/DIRECT DRIVE PLUS RMS	12	1	12.5
V54M3330P	V72X2923J	SINGULARITY CAUTION ANNUN RMS	9	1	1
V99M1867P	V92X3120X	SOFT STOPS ENABLE INHIBIT RMS	4	1	1
V54M3330P	V72X2937J	SOFTWARE STOP IND RMS	8	1	1
V54M3410P	V54X0044X	SP BITE BIT 18 RMS	9	1	1
V54M3410P	V54X0050X	SP BITE BIT 19 RMS	10	1	1
V54M3410P	V54X0056X	SP BITE BIT 20 RMS	11	1	1
V54M3410P	V54X0062X	SP BITE BIT 22 RMS	13	1	1
V54M3410P	V54X0068X	SP BITE BIT 23 RMS	14	1	1
V54M3410P	V54X0032X	SP BITE VERIF BIT 16 RMS	7	1	1
V54M3410P	V54X0038X	SP BITE VERIF BIT 17 RMS	8	1	1
V54M3410P	V54X0074X	SP BITE VERIF BIT 24 RMS	15	1	1
V99M1863P	V92X0538X	SP FWD/BACK DRIVE FLAG DL RMS	1	1	12.5
V54M3313P	V54U0204C	SP ID RMS	13	3	12.5
V92M2846P	V92X3581X	SP JOINT SLIP ERROR DETECTED RMS	1	1	1
V54M3410P	V54C0185C	SP MOTOR CURRENT RMS	1	6	1
V54M3402P	V54X2010J	SPA BITE BIT A BSR B9 RMS	9	1	12.5
V54M3402P	V54X2014J	SPA BITE BIT B BSR B13 RMS	13	1	12.5
V54M3402P	V54X2015J	SPA BITE BIT C BSR B14 RMS	14	1	12.5

PARENT MSID	MSID	NAME OF PARAMETER	START BIT	NUMBER OF BITS	SAMPLE RATE
V54M3402P	V54X2012J	SPA BITE BIT D BSR B11 RMS	11	1	12.5
V54M3442P	V54X2026J	STBD ARM POWER ON/OFF RMS	4	1	12.5
V54M3442P	V54X3526J	STBD BRAKE STATUS MONITOR RMS	1	1	12.5
V54M3330P	V72X2925J	STBD TEMP CAUTION ANNUN RMS	6	1	1
V93M0542P	V93X1713X	STOWED OPS REQUEST RMS	15	1	1
V54M3407P	V54X0043X	SY BITE BIT 18 RMS	9	1	1
V54M3407P	V54X0049X	SY BITE BIT 19 RMS	10	1	1
V54M3407P	V54X0055X	SY BITE BIT 20 RMS	11	1	1
V54M3407P	V54X0061X	SY BITE BIT 22 RMS	13	1	1
V54M3407P	V54X0067X	SY BITE BIT 23 RMS	14	1	1
V54M3407P	V54X0031X	SY BITE VERIF BIT 16 RMS	7	1	1
V54M3407P	V54X0037X	SY BITE VERIF BIT 17 RMS	8	1	1
V54M3407P	V54X0073X	SY BITE VERIF BIT 24 RMS	15	1	1
V99M1863P	V92X0537X	SY FWD/BACK DRIVE FLAG DL RMS	0	1	12.5
V54M3315P	V54U0205C	SY ID RMS	13	3	12.5
V92M2846P	V92X3580X	SY JOINT SLIP ERROR DETECTED RMS	0	1	1
V54M3407P	V54C0184C	SY MOTOR CURRENT RMS	1	6	1
V54M3329P	V72X2905J	TEST MODE IND RMS	11	1	12.5
	V54M3424P	THC X AND Y CMD RMS	0	16	12.5
V54M3424P	V72K3030J	THC X CMD RMS	0	8	12.5
V54M3424P	V72K3031J	THC Y CMD RMS	8	8	12.5
	V54M3425P	THC Z AND RHC P CMD RMS	0	16	12.5
V54M3425P	V72K3032J	THC Z CMD RMS	0	8	12.5
V54M3402P	V54X2004J	THERMISTOR CKT FAILURE BSR B3 RMS	3	1	12.5
	V54M3427P	THERMISTOR DATA CURRENT FRAME RMS	0	16	1
V54M3427P	V54T2110J	THERMISTOR ID CURRENT FRAME RMS	11	5	1
V54M3427P	V54T2100J	THERMISTOR VALUE CURRENT FRAME RMS	0	8	1
V54M3443P	V54X3521J	WATCHDOG BLANKING FAILURE RMS	13	1	1
V54M3416P	V54X0046X	WP BITE BIT 18 RMS	9	1	1
V54M3416P	V54X0052X	WP BITE BIT 19 RMS	10	1	1
V54M3416P	V54X0058X	WP BITE BIT 20 RMS	11	1	1

PARENT MSID	MSID	NAME OF PARAMETER	START BIT	NUMBER OF BITS	SAMPLE RATE
V54M3416P	V54X0064X	WP BITE BIT 22 RMS	13	1	1
V54M3416P	V54X0070X	WP BITE BIT 23 RMS	14	1	1
V54M3416P	V54X0034X	WP BITE VERIF BIT 16 RMS	7	1	1
V54M3416P	V54X0040X	WP BITE VERIF BIT 17 RMS	8	1	1
V54M3416P	V54X0076X	WP BITE VERIF BIT 24 RMS	15	1	1
V99M1863P	V92X0540X	WP FWD/BACK DRIVE FLAG DL RMS	3	1	12.5
V54M3309P	V54U0202C	WP ID RMS	13	3	12.5
V92M2846P	V92X3583X	WP JOINT SLIP ERROR DETECTED RMS	3	1	1
V54M3416P	V54C0187C	WP MOTOR CURRENT RMS	1	6	1
V54M3422P	V54X0048X	WR BITE BIT 18 RMS	9	1	1
V54M3422P	V54X0054X	WR BITE BIT 19 RMS	10	1	1
V54M3422P	V54X0060X	WR BITE BIT 20 RMS	11	1	1
V54M3422P	V54X0066X	WR BITE BIT 22 RMS	13	1	1
V54M3422P	V54X0072X	WR BITE BIT 23 RMS	14	1	1
V54M3422P	V54X0036X	WR BITE VERIF BIT 16 RMS	7	1	1
V54M3422P	V54X0042X	WR BITE VERIF BIT 17 RMS	8	1	1
V54M3422P	V54X0078X	WR BITE VERIF BIT 24 RMS	15	1	1
V99M1863P	V92X0542X	WR FWD/BACK DRIVE FLAG DL RMS	5	1	12.5
V54M3305P	V54U0200C	WR ID RMS	13	3	12.5
V92M2846P	V92X3585X	WR JOINT SLIP ERROR DETECTED RMS	5	1	1
V54M3416P	V54X2750J	WR JPC FAILURE RMS	12	1	1
V54M3422P	V54C0189C	WR MOTOR CURRENT RMS	1	6	1
	V92T3722C	WR P ABE TEMP PORT RMS	0	16	1
	V92H3238C	WR P ANGLE CMD RMS	0	32	1
V92M3040P	V92X3543X	WR P CONTROL ERROR RMS	5	1	1
V54M3310P	V54K2510J	WR P CURRENT LIMIT DEMAND RMS	0	4	1
V54M3415P	V54X2511J	WR P CURRENT SATURATION FLAG RMS	14	1	12.5
	V54M3415P	WR P DATA 1 RMS	0	16	12.5
	V54M3416P	WR P DATA 2 RMS	0	16	1
V92M3040P	V92X3533X	WR P ENCODER CHECK FLAG RMS	11	1	1
	V54H2505J	WR P ENCODER OUTPUT RMS	0	16	12.5

PARENT MSID	MSID	NAME OF PARAMETER	START BIT	NUMBER OF BITS	SAMPLE RATE
V54M3416P	V54X2523J	WR P EXTERNAL FLAG RMS	0	1	1
V54M3415P	V54X2515J	WR P FWD/BACK DRIVE DETECT RMS	15	1	12.5
	V92T3713C	WR P LED TEMP PORT RMS	0	16	1
V54M3309P	V54K2500J	WR P RATE DEMAND FXPT RMS	0	12	12.5
V92M0256P	V92X3563X	WR P REACH LIMIT NEG FLAG RMS	15	1	1
V92M0262P	V92X3553X	WR P REACH LIMIT POS FLAG RMS	15	1	1
V54M3415P	V54L2501J	WR P TACH OUTPUT RMS	0	12	12.5
	V92T3723C	WR R ABE TEMP PORT RMS	0	16	1
	V92H3240C	WR R ANGLE CMD RMS	0	32	1
V92M3040P	V92X3545X	WR R CONTROL ERROR RMS	7	1	1
V54M3306P	V54K2710J	WR R CURRENT LIMIT DEMAND RMS	0	4	12.5
V54M3421P	V54X2711J	WR R CURRENT SATURATION FLAG RMS	14	1	12.5
	V54M3421P	WR R DATA 1 RMS	0	16	12.5
	V54M3422P	WR R DATA 2 RMS	0	16	1
V92M3040P	V92X3535X	WR R ENCODER CHECK FLAG RMS	13	1	1
	V54H2705J	WR R ENCODER OUTPUT RMS	0	16	12.5
V54M3421P	V54X2715J	WR R FWD/BACK DRIVE DETECT RMS	15	1	12.5
	V92T3715C	WR R LED TEMP PORT RMS	0	16	1
V54M3305P	V54K2700J	WR R RATE DEMAND FXPT RMS	0	12	12.5
V92M0258P	V92X3565X	WR R REACH LIMIT NEG FLAG RMS	15	1	1
V92M0264P	V92X3555X	WR R REACH LIMIT POS FLAG RMS	15	1	1
V54M3421P	V54L2701J	WR R TACH OUTPUT RMS	0	12	12.5
	V92T3714C	WR Y LED TEMP PORT RMS	0	16	1
	V92H3239C	WR YAW ANGLE CMD RMS	0	32	1
V92M3040P	V92X3544X	WR YAW CONTROL ERROR RMS	6	1	1
V54M3308P	V54K2610J	WR YAW CURRENT LIMIT DEMAND RMS	0	4	1
V54M3418P	V54X2611J	WR YAW CURRENT SATURATION FLAG RMS	14	1	12.5
	V54M3418P	WR YAW DATA 1 RMS	0	16	12.5
	V54M3419P	WR YAW DATA 2 RMS	0	16	1
V92M3040P	V92X3534X	WR YAW ENCODER CHECK FLAG RMS	12	1	1
	V54H2605J	WR YAW ENCODER OUTPUT RMS	0	16	12.5

PARENT MSID	MSID	NAME OF PARAMETER	START BIT	NUMBER OF BITS	SAMPLE RATE
V54M3419P	V54X2623J	WR YAW EXTERNAL FLAG RMS	0	1	1
V54M3418P	V54X2615J	WR YAW FWD/BACK DRIVE DETECT RMS	15	1	12.5
V54M3307P	V54K2600J	WR YAW RATE DEMAND FXPT RMS	0	12	12.5
V92M0257P	V92X3564X	WR YAW REACH LIMIT NEG FLAG RMS	15	1	1
V92M0263P	V92X3554X	WR YAW REACH LIMIT POS FLAG RMS	15	1	1
V92M0240P	V92X3201X	WR YAW SINGULARITY RMS	15	1	1
V54M3418P	V54L2601J	WR YAW TACH OUTPUT RMS	0	12	12.5
V92M3472P	V92X3486X	WRP RATE ENVELOPE CHECK FAIL RMS	13	1	1
V92M3472P	V92X3480X	WRP TACH DATA CHECK FAIL RMS	7	1	1
V99M1864P	V96H4997C	WRR RANGE PORT RMS	13	3	1
V92M3472P	V92X3488X	WRR RATE ENVELOPE CHECK FAIL RMS	15	1	1
V92M3472P	V92X3482X	WRR TACH DATA CHECK FAIL RMS	9	1	1
V92M3472P	V92X3487X	WRY RATE ENVELOPE CHECK FAIL RMS	14	1	1
V92M3472P	V92X3481X	WRY TACH DATA CHECK FAIL RMS	8	1	1
V54M3419P	V54X0047X	WY BITE BIT 18 RMS	9	1	1
V54M3419P	V54X0053X	WY BITE BIT 19 RMS	10	1	1
V54M3419P	V54X0059X	WY BITE BIT 20 RMS	11	1	1
V54M3419P	V54X0065X	WY BITE BIT 22 RMS	13	1	1
V54M3419P	V54X0071X	WY BITE BIT 23 RMS	14	1	1
V54M3419P	V54X0035X	WY BITE VERIF BIT 16 RMS	7	1	1
V54M3419P	V54X0041X	WY BITE VERIF BIT 17 RMS	8	1	1
V54M3419P	V54X0077X	WY BITE VERIF BIT 24 RMS	15	1	1
V99M1863P	V92X0541X	WY FWD/BACK DRIVE FLAG DL RMS	4	1	12.5
V54M3307P	V54U0201C	WY ID RMS	13	3	12.5
V92M2846P	V92X3584X	WY JOINT SLIP ERROR DETECTED RMS	4	1	1
V54M3419P	V54C0188C	WY MOTOR CURRENT RMS	1	6	1
V54M3331P	V72X2939J	X10 SCALE IND RMS	6	1	1

Abbreviations Used in Section 11 List of Parameters:

ABE - Arm Based Electronics
AMP - Amplifier

ANNUN	-	Annunciation (caution or warning to crew)
CK.	-	Check
CMD.	-	Command
COMM.	-	Commutator (used in joint motor)
CONSIST.	-	Consistency
D&C	-	Display and Control (panel)
DR	-	Drive
EE	-	End Effector
ENC.	-	Encoder
ENV.	-	Envelope
FL	-	Flag
GPC	-	General Purpose Computer
ID	-	Identification Number (used to identify which joint or thermistor, etc., being measured)
IND	-	Indicator (light telling crew mode, etc., is active)
I/O	-	Input/Output (indicates data exchange between GPC and MCIU)
JPC	-	Joint Power Conditioner
LED	-	Light Emitting Diode (used in SPA's)
MADC	-	Multiplexer Analog to Digital Converter
MCIU	-	Manipulator Controller Interface Unit
MCPC	-	Manipulator Controller Power Conditioner
MDA	-	Motor Drive Amplifier in Joint
NEG.	-	Negative
OPER.	-	Operator
PB	-	Push Button
POR	-	Point of Resolution
POS.	-	Positive
POSN.	-	Position
P/Y/R	-	POR Attitude; Pitch, Yaw and Roll
RHC	-	Rotation Hand Controller
SAT'N	-	Saturation (current saturation condition)
SEL	-	Selected (This records the crew action of selecting mode, etc.)
SH	-	Shoulder Joint
SPA	-	Servo Power Amplifier in Joint
TACH.	-	Tachometer
TEMP.	-	Temperature
THC	-	Translation Hand Controller
WR	-	Wrist Joint
X/Y/Z	-	POR Position: X, Y, and Z
+	-	Positive
-	-	Negative
x10	-	Multiplied by 10
28V	-	28 Volt Supply Line

Acronyms and Abbreviations

12

A8L	Displays and Control Panel A8 Lower
A8U	Displays and Control Panel A8 Upper
ABE	arm based electronics
ABS	Antenna Bridge Structure
ACS	attitude control system
AFD	aft flight deck
AKA	Active Keel Actuator Assembly
amp(s)	ampere(s)
ASAD	"All Singing All Dancing" (SPAR Aerospace's RMS Simulator)
ASE	Airborne Support Equipment
BITE	built-in test equipment
bp	barberpole
Btu	British Thermal Unit(s)
c.m.	center of mass
CCB	Configuration Control Board
CCTV	closed circuit television
CG	center of gravity
CL	centerline
cm	centimeter(s)
COAS	crew optical alignment sight
CPCB	Crew Procedures Control Board
CRT	cathode ray tube
D&C	Displays and Control
DAP	digital auto pilot
DB	deadband
deg	degree(s)
DIA	diameter
DIM	dimension
disp	display
DRS	Draper RMS Simulation
EE	End Effector
EEEU	End Effector Electronics Unit
EEOS	End Effector Operating System
EFGF	electrical flight grapple fixture
EMI	Electromagnetic Interference
EPS	Electrical Power System
EST.	estimate
EVA	extravehicular activity
FCR	Flight Control Room
FCS	Flight Control System
FOV	field of view
FRD	Flight Requirements Document
FRGF	flight-releasable grapple fixture
FSS	Flight Support Structure
ft	foot, feet
FWD	forward
GF	Grapple Fixture
GFAS	Grapple Fixture Axis System
GNC	guidance, navigation and control
GPC	general purpose computer
Hz	hertz
I/O	input/output
ICD	Interface Control Document
ID	identification
IFM	In-flight Maintenance
I-Load	Initial Computer Data Load
IMU	Inertial Measurement Unit
IP	Integration Plan
IUS	inertial upper stage
JSC	Lyndon B. Johnson Space Center
kg	kilogram(s)
KYBD	keyboard
LAT	latch
lbf	pounds force
LOS	line-of-sight
LVLH	Local Vertical/Local Horizontal
LWKA	Lightweight Keel Actuator
LWKL	Lightweight Keel Latch
LWLL	Lightweight Longeron Latch
m	meter(s)
MAX	maximum
MCC	Mission Control Center
MCIU	Manipulator Controller Interface Unit
MDF	Manipulator Development Facility
MFR	manipulator foot restraint
MIN	minimum

MPM	Manipulator Positioning Mechanism
MPSR	Multipurpose Support Room
MRL	Manipulator Retention Latch
MWLL	Middleweight Longeron Latch
N	Newton(s)
NBL	Neutral Buoyancy Lab
OBAS	Orbiter body axis system
OCAS	Operator Commanded Auto Sequence
OCS	Orbiter coordinate system
OMS	Orbital Maneuvering System
ORAS	Orbiter rotational axis system
ORU	orbital replacement unit
OSRS	Orbiter structural reference system
PA	Principal Axes
PAM	payload assist module
PAS	Payload Axis System
PDRS	Payload Deployment and Retrieval System
PDRSS	Payload Deployment and Retrieval System Simulator
PGHM	Payload Ground Handling Mechanism
PIAS	Payload Interface Axis System
PIM	Payload Integration Manager
PIP	Payload Integration Plan
PKM	perigee kick motor
PLOP	Payload Operating System
POR	point of resolution
POHS	Position Orientation Hold Simulator
PRCB	Program Requirements Control Board
PRCS	primary reaction control system
PRELIM	preliminary
PRLA	Payload Retention Latch Actuator
PTU	Pan-tilt unit (for camera)
RCS	Reaction Control System
REL	release
RHC	Rotational Hand Controller
RL	rate limit
RMS	Remote Manipulator System
RPS	RMS Planning System
RQMTS	requirements
RR	Rendezvous Radar
RSGF	rigidize-sensing grapple fixture
RSS	root-sum-square (The square root of the sums of the squares of associated numbers.)
SAIL	Shuttle Avionics Integration Laboratory
sec	second(s)
SES	Shuttle Engineering Simulator
SIMFAC	Simulator Facility
SM	systems management
SMS	Shuttle Mission Simulator
SODB	Shuttle Operational Data Book
Spec	specialist function
SPEE	Special Purpose End Effector
SRM	Solid Rocket Motor
SSP	Space Shuttle Program
STBD	starboard
STS	Space Transportation System
SVDS	Shuttle Vehicle Dynamics Simulator
TBD	to be determined
THC	Translational Hand Controller
TTED	Trajectory Tracking error Detection
TV	television
TVC	television camera
Vdc	volts, direct current
VL	Viewing Light
VRCS	vernier reaction control system
VTR	video tape recorder
WETF	Weightless Environment Training Facility
WLA	Wide (angle) Lens Assembly (for camera)

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