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Payload Deployment and Retrieval System Nominal Operations

PDRS NOM OPS 2102

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Mission Operations Directorate
Training Division
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Preface

This handbook will serve as an aid to the instructor and student of the payload deployment and retrieval system (PDRS) during preparation for training sessions in the manipulator development facility (MDF), systems engineering simulator (SES), and the Shuttle mission simulator (SMS). It contains background information and standard rationale for some of the procedures contained in the PDRS Operations Checklist. The focus of this handbook will be on nominal operations and will not cover malfunction procedures or PDRS-related malfunctions. It is intended that this book can be used as a reference for both online and offline work.

The PDRS procedures in this workbook are provided as an example of the format and terminology that is found in the Flight Data File (FDF). Its use in this book is not intended to represent the actual procedures that were in effect at any given time. Rather, they represent a composite of procedural steps that have been considered and/or accepted for FDF use. The student should reference the latest version of those FDF products that relate to PDRS when studying this workbook. At no time should the procedures in this workbook be considered as the representatives for those found in the FDF.

Within each of the first three sections, the individual procedures listed in the checklist are discussed in detail, and subsystem diagrams are provided for further reference. There are individual sections for each of the following systems: the manipulator positioning mechanism (MPM)/manipulator retention latches (MRLs), the joint drive system, and the remote manipulator system (RMS) software. The final section contains suggested techniques for "flying" the RMS and a discussion of position and attitude display information.

When a question arises, the instructor can look up the name of the procedure for a brief explanation of the step in question. If further explanation is needed, it may be necessary to refer to the PDRS Console Handbook, vol. II, the Flight Systems Software Requirements (FSSR), procedural handbooks, or expert personnel. When the instructor and the student are satisfied with the explanation, please submit a copy of both the question and the answer, including sources and page numbers, to the author so that this information can be considered for inclusion in the next update to this book.

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Section 1: Activate Temp Monitor

This procedure is usually performed during the post insertion activities and can be found in the Post Insertion Checklist under the heading PWR-UP RMS TO TEMP MODE. The procedure outlined here was taken from the PDRS Operations (OPS) Checklist (C/L) All Vehicle. Two additional steps were included for this book; they are the steps for remote manipulator system (RMS) ac powerup and shoulder brace release.

ACTIVATE TEMP MONITOR

017 ✓MEC (two) - OFF

SM GPC MEMORY

✓LAUNCH 1, ITEM 16 assigned to SM GPC

MA73C:F ✓cb AC1 RMS PRI ϕA - cl
✓cb AC2 RMS B/U ϕA - cl

✓RMS SEL - OFF
✓PWR - OFF

✓RMS PWR - PRI (MA)

CRT SM 94 PDRS CONTROL (MA, GPC DATA lt-on, if calling SPEC 94 for first time)

I/O ON - ITEM 5 EXEC (*)

SAFING - CANCEL (tb-bp)
✓GPC DATA lt-off

PARAM sel - PORT TEMP
JOINT - CRIT TEMP

PORT RMS HTR A - AUTO
RMS SEL - PORT (MA, REACH LIM lt - on, SINGULAR lt - on)
SHLDR BRACE REL - PORT (hold for 2 sec following tb - gray)
RMS SEL - OFF

- **✓MEC (two) - OFF**

The master events controller (MEC) is a line replaceable unit (LRU) which provides for the transfer and signal conditioning of control and measurement data between the general purpose computers (GPCs) and the Orbiter external tank (ET), and solid rocket booster (SRB) pyrotechnic and control devices. There are two MECs whose function is to receive digital commands through sequential hardware during launch, SRB separation, and ET separation. Both MECs are powered on at prelaunch and powered down after postinsertion. One of the data interfaces used by the MECs is launch data bus (LDB) 1. This data bus is also used by the PDRS for GPC/manipulator controller interface unit (MCIU) communication. The MECs must be powered off to avoid possible spurious commands' being issued from the MECs during PDRS operations while on orbit.

- **SM GPC MEMORY**

  ✓LAUNCH 1, ITEM 16 assigned to SM GPC

During post insertion activities, the system management (SM) GPC software is transitioned to operational sequence (OPS) 201. This reconfiguration reassigns LDB1 to GPC 4, thus allowing use of this data bus by GPC 4 (nominally the SM GPC) and by the MCIU.

- ✓cb AC1 RMS PRI ØA - c1
  ✓cb AC2 RMS B/U ØA - c1

The PDRS uses ac current to power the dedicated display and control (D&C) panel lighting and to activate the shoulder brace release mechanism (figure 1-1). Closing the ac circuit breakers provides ac power to the RMS power switch. Primary ac power (AC1 ØA) provides the power for the D&C panel numerics, annunciator lights, edge lighting and the shoulder brace release single-phase ac motor. Backup ac power (AC2 ØA) is only used to power the edge lights.

- **RMS PWR - PRI (MA)**

Prior to selection of RMS primary power, the operator is asked to verify the position of the RMS SELECT switch and the RMS POWER switch. Both switches should be in the OFF position. Moving the RMS POWER switch to PRIMARY sends dc power to the RMS SELECT switch, the D&C panel, and the MCIU; ac power is sent to the SHOULDER BRACE RELEASE switch and the primary RMS lighting (figure 1-1). Primary dc power for the RMS POWER switch comes through a 2-amp fuse on panel A8 from dc bus main (MN) A. The MCIU draws power from a 10-amp remote power controller (RPC) off dc bus MNA at forward power controller (FPC) 1. With the RMS POWER switch in the BACKUP position, dc power is provided only to the RMS SELECT switch, and ac power is only provided for backup lighting. Backup dc power comes through a 2-amp fuse on panel A8 from dc bus MNB. The MCIU receives no power when backup RMS power is selected.

Placing the RMS POWER switch to PRIMARY generates an RMS master alarm. This alarm is generated because the D&C panel powers up faster than the MCIU, thereby causing the master alarm light and tone to annunciate before the MCIU can respond with the proper master alarm flag. This is a normal condition and will occur every time the RMS POWER switch is cycled OFF and back to PRIMARY.

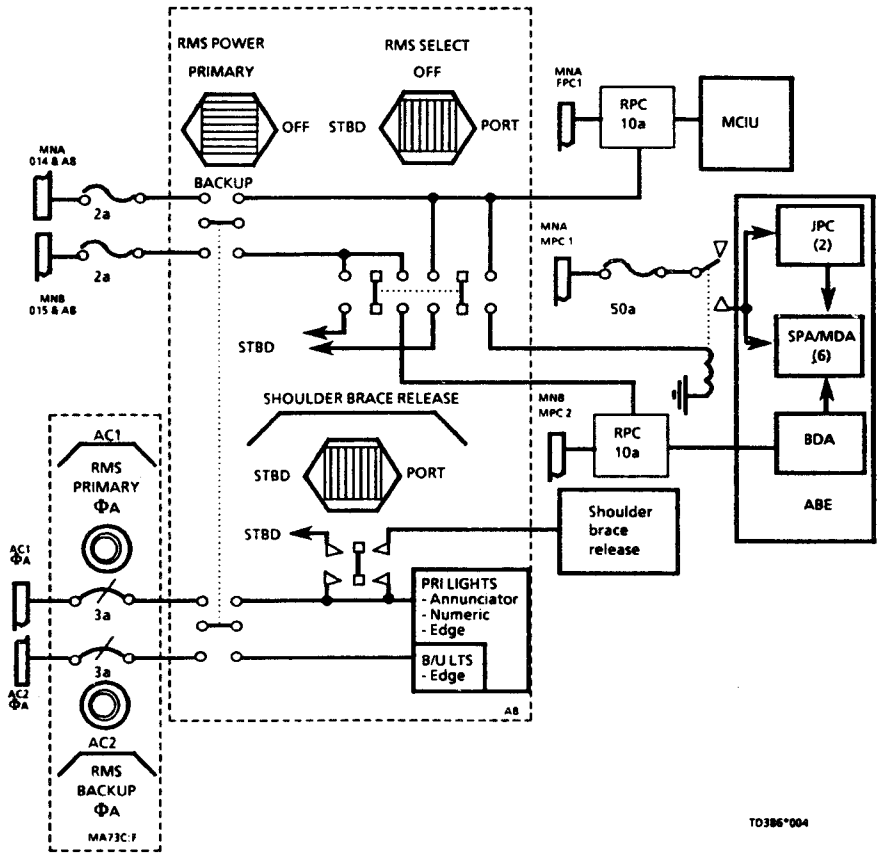


Figure 1-1.– RMS power.

- **SM 94 PDRS CONTROL** (MA, GPC DATA lt-on, if calling SPEC 94 for first time)

The first time SPEC 94 is called up, the GPC RMS software goes through an initialization process. One of the results of the software initialization is a poll of the MCIU by the GPC to initiate input and output (I/O). This poll causes the watchdog timer in the MCIU to start counting. The watchdog timer runs out in 252 msec (six MCIU cycles) if the MCIU does not communicate correctly with the GPC. Since GPC/MCIU I/O is not active at this point, the watchdog timer runs out, generating an RMS master alarm and GPC DATA light. This event will only occur in this fashion the first time SPEC 94 is called.

- **I/O ON - ITEM 5 EXEC (*)**

The RMS software interfaces with RMS hardware using a bi-directional serial data bus (LDB1) to the MCIU. The MCIU uses a standard Orbiter multiplexer interface adapter (MIA) to provide the functional interface between the MCIU and LDB1. Communication between the GPC and MCIU is accomplished via message block transfer of fixed length: one length for input (MCIU to GPC) and one length for output (GPC to MCIU). Executing an item 5 on SPEC 94 causes this communication process to begin. Every 80 msec, when the GPC is communicating with the MCIU, the GPC

- Requests and receives an input message block from MCIU
- Processes this message block using RMS software principle functions
- Transmits an output message block with the results of the processing to the MCIU

- **SAFING - CANCEL (tb-bp) (/GPC DATA lt-off)**

The safing function is an RMS safety feature designed to prevent uncommanded arm motion. Every time the RMS is powered OFF and back to PRIMARY, the arm will be placed in the "safe" condition by the MCIU. Safing commands zero joint rates at the joint servos and provides maximum current available to drive the joints to prevent arm motion. It also causes the MCIU to ignore further drive commands issued by the GPC.

Safing was included as part of the RMS to supplement crew reaction time in the event of certain RMS malfunctions. The system was designed to power up in the safe configuration to prevent possible electrical surges from moving the arm during powerup. It is necessary to cancel safing at this time in order to turn off the GPC DATA light. The safing talkback (tb) remains barberpole (bp) until an arm is selected (port or starboard)

- **PARAM sel - PORT TEMP**
  JOINT - CRIT TEMP

Placing the PARAMETER select rotary switch in the PORT TEMP position and the JOINT select rotary select switch in the CRIT TEMP position allows the RMS software to display the most out-of-range temperature on the RMS digital display light emitting diodes (LEDs). Indicator no. 1 gives the temperature of the joint position encoder LEDs, indicator no. 2 gives the temperature of the arm based electronics (ABE) at each joint, and indicator no. 3 displays the joint identification (ID). The joint IDs are defined with the temperature limits in the REF DATA section of the PDRS OPS C/L-All Vehicle.

The temperature of the joint position encoders is critical to arm operation because they must remain within operational limits to work properly. During the course of a mission, the RMS is only fully powered up when RMS checkout is being performed and when the RMS is being used to fulfill mission objectives. In between checkout and periods of use, the arm is in temp monitor mode with only one set of heaters powered on. On some previous missions, the RMS master alarm and CHECK CRT caution and warning light have come on when the RMS was reselected after long periods of RMS inactivity. The reason for the CHECK CRT light and master alarm's activation was cold position encoders' giving false joint angle readings to the RMS software. Resetting the Position Encoder Check on SPEC 94 (item 12 followed by item 11) solves the problem, and operations should proceed as normal. It is advisable to contact the ground support personnel if this occurs.

- **PORT RMS HTR A - AUTO**

Placing the port RMS HEATER A switch to AUTO provides power to the primary system RMS heaters (figure 1-2). The RMS can be effectively heated by only one heater system during periods of non-use; however, for RMS operation, both heater systems are required to be powered on at least 1 hour prior to use.

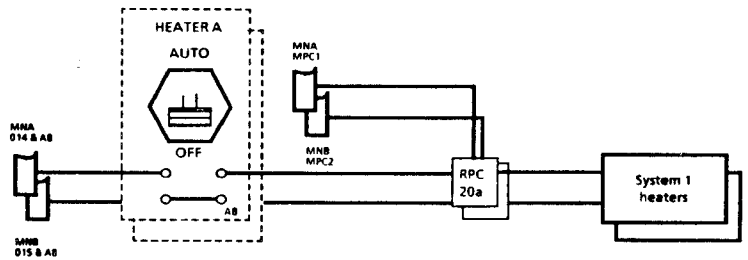


Figure 1-2.–RMS heater systems.

The actively controlled heater system is a redundant heater system that supplies 525 W of heater power at 28 V dc to 26 heaters located throughout the arm (figure 1-3). The dc power for heater systems A and B comes from dc buses MNA and MNB, respectively. With heater switch A or B in the AUTO position, the individual heater is turned on and off by quadredundant thermostats, designed to operate within the 14° to 430° F temperature range. The temperature of the RMS can be monitored by the operator and the GPC software as long as the RMS POWER switch is in the PRIMARY position and GPC/ MCIU I/O is active (temp monitor mode).

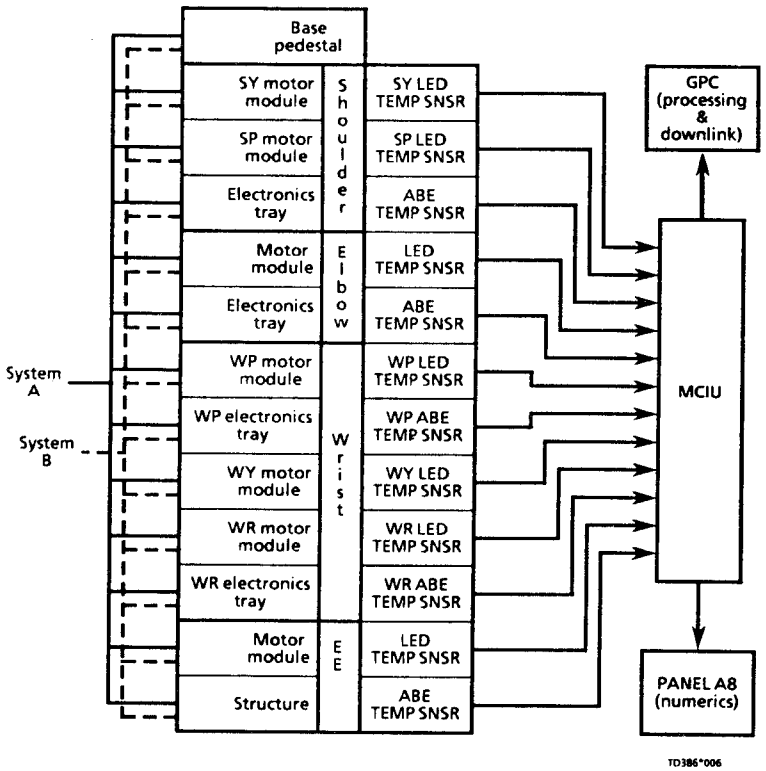


Figure 1-3.–RMS heaters.

- **SHLDR BRACE REL - PORT (hold for 2 sec : following tb - gray)**

The RMS SELECT switch is placed to the PORT position prior to activation of the SHOULDER BRACE RELEASE switch. The effects of selecting an arm will be discussed in section 2.2, but the reason for selecting an arm at this point is to provide power to the shoulder brace release microswitch. This allows the MCIU to drive the SHOULDER BRACE RELEASE tb so it can be monitored during this step. Placing the SHOULDER BRACE RELEASE switch to PORT causes actuation of the port shoulder brace motor. Nominal release time is 8 seconds. The procedure calls for the switch to be held an additional 2 seconds to assure that the release mechanism is completely released.

The reason for having a shoulder brace is to minimize possible high-pitch axis moment loading on the shoulder-pitch gear train during lift-off. The brace provides an alternative/supplementary load path from the electronics compartment to the shoulder yaw joint structure so as to maintain the shoulder pitch joint torque below the gear train endurance load limits.

The brace assembly consists of two basic parts: the brace structure, and the release mechanism (figure 1-4). The brace structure consists of a cradle doubler attachment to the electronic compartment and a twin strut arrangement, the lower end of which terminates in the release mechanism. The release mechanism is a linear type of circular collet. The actuating device is a single-phase ac motor acting through a reducing gearbox and lead screw to provide linear motion to the actuation shaft. The actuating shaft expands the collet fingers into engagement with the locking stub (figure 1-5).

The RMS SELECT switch is placed back to the OFF position after the shoulder brace is released to save power, because the arm does not need to be powered while not in use.

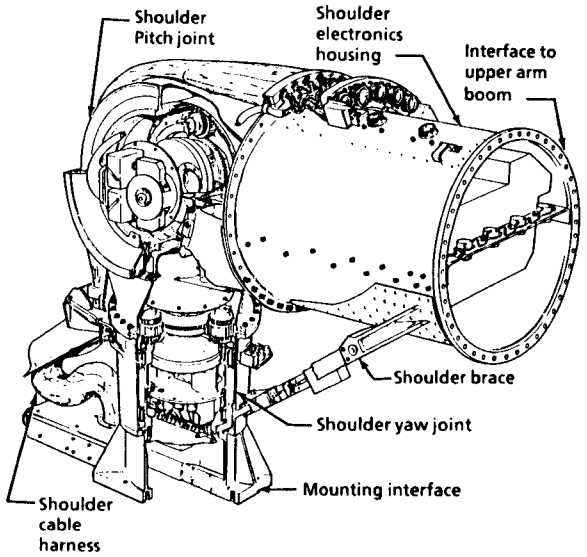


Figure 1-4.– Overall configuration of the shoulder joint.

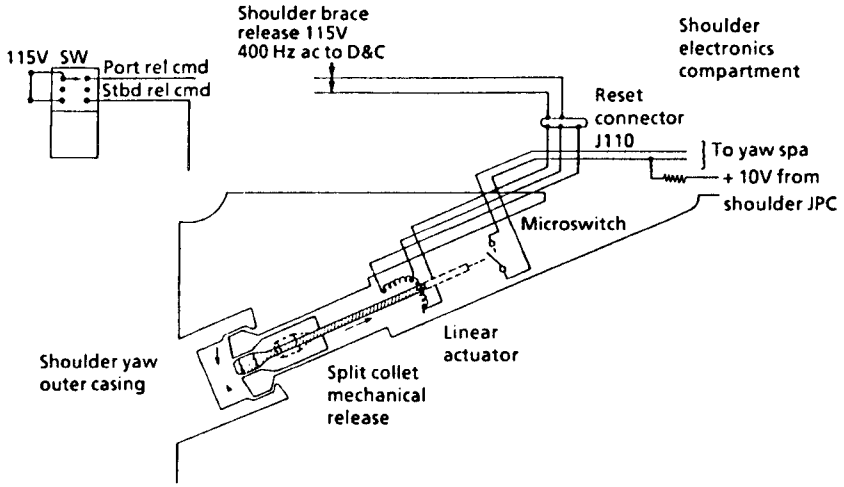


Figure 1-5.– Shoulder brace.

Section 2: RMS Powerup

This procedure is taken from the PDRS OPS C/L. The RMS operator is directed to this procedure in the detailed timeline portion of the Crew Activity Plan (CAP).

Included in this procedure are the steps to deploy the RMS. Normally, the RMS is deployed during postinsertion activities and these steps are bypassed when this checklist is executed. Also, the note under the procedure heading (Assumes RMS in TEMP MONTR MODE) refers to the fact that the RMS should be in temp monitor mode prior to executing this procedure. The normal order for RMS activities during a mission is to first deploy the arm, place the RMS into temp monitor mode, then perform RMS powerup and checkout--all prior to use of the RMS for its mission objectives.

RMS POWERUP
(Assumes RMS in TEMP MONTR MODE)

1 PLB LTS, CCTV ACT

A7 PL BAY FLOOD - as reqd

Perform TV ACT, VTR ACT, TV/VTR Cue Card
TV CAMR PWR as reqd - ON

✓Physical integrity of arm, EE, blankets

2 RMS SEL (IDLE MODE)

✓MODE - not DIRECT
✓BRAKES - ON (tb-ON)
✓RMS SEL - OFF
✓PWR - PRI

CRT [SM 94 PDRS CONTROL]

✓I/O ON, ITEM 5 - (*)
✓ENA, ITEM 9,11 - (*)

RMS SEL - PORT (if cradled, MA, C/W RCH LIM lt-on (SP,EP), SINGULAR lt-on (EP))

✓SAFING tb - gray

	X	Y	Z	PITCH	YAW	ROLL
✓	-1282	-108	-445	0	0	0
	SY	SP	EP	WP	WY	WR
✓	0	0	0	0	0	0

3 CONFIGURE POWER

R13L PL BAY MECH PWR SYS (two) - ON

4 MPM DEPLOY

If MPM stowed:

CRT [SM 94 PDRS CONTROL]

✓RMS SHLD DPLY (two) = 0

* If either MSW show "1" drive MPM *
* for single motor time (68 sec) *

PORT RMS - DPY (tb-DPY) (68 sec)
- OFF

If motor drive time > 34 sec, contact MCC

5 MRL RELEASE

CRT [SM 94 PDRS CONTROL]

✓RMS AFT, MID, FWD REL (six) = 0

* If any show "1" drive MRL *
* for single motor time (18 sec) *

DAP: VRCS or free drift • •

PORT RMS RETENTION LAT - REL (tb-REL) (18 SEC MAX)
- OFF

If motor drive time > 18 sec, contact MCC

6 RECONFIGURE POWER

R13L PL BAY MECH PWR SYS (two) - OFF

7 AUTO BRAKE CHECK

BRAKES - OFF (tb-OFF)

CRT SM 94 PDRS CONTROL

AUTO BRAKE CHECK - ITEM 27 EXEC (*)

✓BRAKES tb - ON

.....If BRAKES tb - OFF.....
. BRAKES - ON .
. Do not proceed. Do not use RMS. .
. Contact MCC .
.....

BRAKES - ON
- OFF (tb-OFF)

CRT ✓AUTO BRAKE CHECK - ITEM 27 EXEC (no *)

BRAKES - ON (tb-ON)

8 ARM UNCRADLE

WARNING
Arm temperatures must be within limits (no alarms) prior to uncradling

CAUTION
Use RMS vernier rates while within ~10 ft of structure

PARAM sel - JOINT ANGLE
BRAKES - off (tb-OFF)
MODE - SINGLE, ENTER

SINGLE DR to approx:

	SY	SP	EP	WP	WY	WR
1	0	0	0	+5	0	0
2			+1			
3		+25				
4			-25			

BRAKES - ON (tb-ON)

	X	Y	Z	PITCH	YAW	ROLL
✓	-1282	-108	-445	0	0	0

DAP: as reqd

- **PLB LTS, CCTV ACT**

1 PLB LTS, CCTV ACT

A7 PL BAY FLOOD - as reqd

Perform TV ACT, VTR ACT, TV/VTR Cue Card
TV CAMR PWR as reqd - ON

✓Physical integrity of arm, EE, blankets

If the Orbiter attitude has the payload bay shaded from direct sunlight or the Orbiter is in darkness, it will be necessary to activate some payload bay floodlights. Switches for activating the floodlights are on panel A7.

The Orbiter closed circuit television (CCTV) system is activated at this time also (provided it has not already been turned on). Use of the CCTV system is not mandatory for PDRS operation, but is highly recommended and useful. Prior to actually moving the RMS, the RMS operator is advised to check the physical integrity of the RMS. This can be done using the out-of-the-window view and the CCTV cameras as well.

After visual inspection is complete, it is recommended that camera B (aft-port camera) be positioned to view the aft-most manipulator positioning mechanism (MPM) pedestal, and camera C (aft-starboard camera) be positioned to view the mid-MPM pedestal (provided there are no payloads in the bay obstructing this view). Placing cameras B and C in these positions allows closer monitoring of the RMS deploy and uncradle procedures.

- **RMS SEL (IDLE MODE)**

2 RMS SEL (IDLE MODE)

✓MODE - not DIRECT
✓BRAKES - ON (tb-ON)
✓RMS SEL - OFF
✓PWR - PRI

CRT SM 94 PDRS CONTROL

✓I/O ON, ITEM 5 - (*)
✓ENA, ITEM 9,11 - (*)

RMS SEL - PORT (if cradled, MA, C/W RCH LIM lt-on (SP,EP), SINGULAR lt-on (EP))

✓SAFING tb - gray

Before an arm is selected, the RMS operator is asked to verify the positions of the MODE select switch, the BRAKES switch, the RMS SELECT switch and the RMS POWER switch. GPC/MCIU I/O should be verified on SPEC 94 as well. Also on SPEC 94, items 9 and 11 should have asterisks (AUTO BRAKE enable and POS ENC CK enable). The MODE select switch needs to be in a position other than DIRECT, because the arm would be in MODE when the RMS SELECT switch is placed to the PORT position if the MODE select switch is in DIRECT. The other switch positions called for and GPC/MCIU I/O active are the conditions of temp monitor mode and the nominal state of the RMS at this point. The auto brake and position encoder check functions are enabled under normal operating conditions and are initialized in that state. If during verification of items 9 and 11 the operator encounters one of the functions disabled, this could be an indication of a possible problem with the system, and the ground support personnel should be notified at this point.

- **RMS SEL - PORT**

Placing the RMS SELECT switch to the PORT position enables dc power to be sent to the port arm. When PRIMARY power is selected, the arm draws power through a 50-amp fuse off dc bus MNA at midpower controller (MPC) 1 (figure 2-1). When backup power is selected, the arm draws power through a 10-amp RPC off dc bus MNB at MPC2. With the RMS now fully powered, the GPC RMS software can begin to monitor the position and condition of the arm.

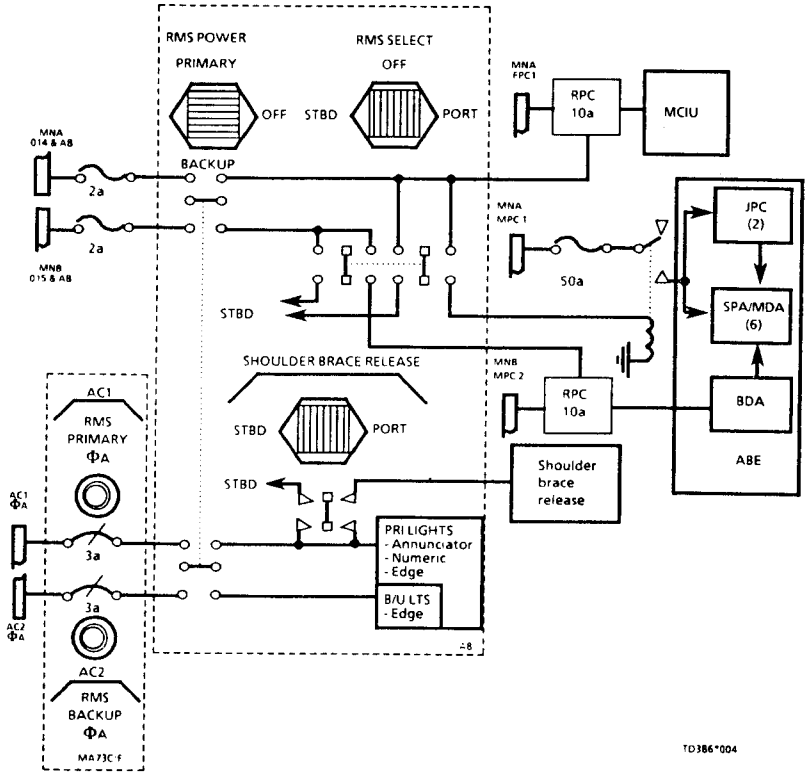


Figure 2-1.– RMS power.

When an arm is selected, the GPC RMS software reads the position encoders located at the joints to determine where the arm is. The arm is cradled at this time, and an RMS master alarm is generated by the software because the RMS is in reach limit and singularity conditions in this position. Reach limits refer to physical travel limits of the joints, and singularities refer to degree-of-freedom losses under certain operating conditions. With the arm in the cradled position, both the shoulder pitch and elbow pitch joints are at their respective reach limits and the singularity in effect is called the planar pitch singularity. Section 5 will discuss reach limits and singularities in greater detail.

●● **/SAFING tb - gray**

The last part of this procedure calls for the operator to verify that the safing tb has gone from bp to gray, thus indicating safing has been canceled. Safing is canceled during the activate temp mode procedure to turn off the GPC data light. When this is done, the MCIU issues a cancel safing command and resets the servo input latches at the joints. The servo input latches cannot be reset until an arm is selected and thus powered.

The RMS software is now in idle mode. That is, the RMS ac circuit breakers are closed, the RMS POWER switch is in the PRIMARY position, GPC/MCIU I/O is established, an arm is selected, and safing is canceled.

● **CONFIGURE POWER**

3 CONFIGURE POWER
R13L PL BAY MECH PWR SYS (two) - ON

The MPM/MRL motors use ac power which is activated by placing the payload bay mechanical power switches to the ON position (figure 2-2). Both MPM and MRL systems use dc control power and ac motor power.

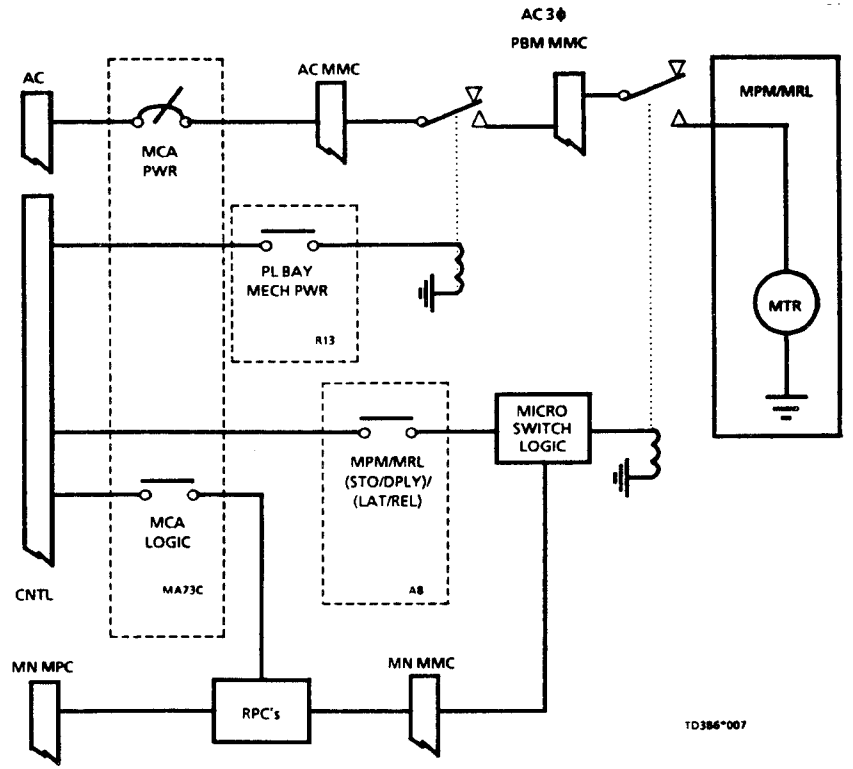


Figure 2-2.– MPM/MRL power.

- **MPM DEPLOY**

4 MPM DEPLOY

If MPM stowed:

CRT [SM 94 PDRS CONTROL]

✓RMS SHLD DPLY (two) = 0

* If either MSW show "1" drive MPM *
* for single motor time (68 sec) *

PORT RMS - DPY (tb-DPY) (68 sec)
- OFF

If motor drive time > 34 sec,
contact MCC

●● SM 94 PDRS CONTROL ✓RMS SHLD DPLY = 0

The procedure has the operator check SPEC 94 prior to MPM operation to check for any "1's" indicating deploy. The purpose for checking the microswitch states prior to performing the operation is that a deploy microswitch on either system indicates that the motor associated with that microswitch will not drive when given the deploy command.

●● PORT RMS - DPY (tb-DPY) (68 sec max)

Placing the PORT RMS DEPLOY switch to the DEPLOY position activates the MPM drive motors to deploy the arm. Normal stow/deploy time is about 30 seconds. Any time longer than 34 seconds indicates that one of the motor systems did not function properly. The operator must monitor MPM operation times to check for single motor drive times. The maximum time the DEPLOY/STOW switch should be left in either the DEPLOY or STOW positions is 68 seconds, which is maximum single motor operation time.

- **MRL RELEASE**

5 MRL RELEASE

CRT [SM 94 PDRS CONTROL]

✓RMS AFT, MID, FWD REL (six) = 0

* If any show "1" drive MRL *
* for single motor time (18 sec) *

DAP: VRCS or free drift · ·

PORT RMS RETENTION LAT - REL (tb-REL)
(18 SEC MAX)
- OFF

If motor drive time > 18 sec,
contact MCC

●● SM 94 PDRS CONTROL ✓RMS AFT, MID, FWD REL (six) = 0

The procedure has the operator check SPEC 94 prior to MRL operation to check for any "1's" indicating release. The purpose for checking the microswitch states prior to performing the operation is that a release microswitch on either system indicates that the motor associated with that microswitch will not drive when commanded to release.

●● DAP: VRCS or free drift

The reference to the digital autopilot (DAP) concerns an RMS flight rule which states that the DAP must be in free drift or have vernier reaction control system (VRCS) jets selected when the arm is in a reach limit or a singularity. The reason for this flight rule is to avoid overstressing the arm. Primary RCS jet firings with a joint in a reach limit could cause that joint to hit its hard stop. Primary RCS jet firings while in a singularity could cause a joint or arm boom to be stressed with loads greater than design limits.

●● PORT RMS RETEN LAT - REL (tb-REL)

Placing the PORT RMS RETENTION LATCH switch to the RELEASE position activates the MRL drive motors to release the arm. Normal RELEASE/LATCH time is about 7 seconds. Any time longer than 7 seconds indicates that one of the motor systems did not function properly. The operator must monitor MRL operation times to check for single motor drive times. The maximum time the RELEASE/LATCH switch should be left in either the RELEASE or LATCH positions is 18 seconds which is maximum single motor operation time.

- RECONFIGURE POWER

6 RECONFIGURE POWER

PL BAY MECH PWR SYS (two) - OFF

The payload bay mechanical power switches are turned off when MPM/MRL operations are finished because ac power for operating the motors is no longer needed.

- **AUTO BRAKE CHECK**

7 AUTO BRAKE CHECK

BRAKES - OFF (tb-OFF)

CRT SM 94 PDRS CONTROL

AUTO BRAKE CHECK - ITEM 27 EXEC (*)

✓BRAKES tb - ON

.....If BRAKES tb-OFF.....
. BRAKES - ON .
. Do not proceed. Do not use RMS. .
. Contact MCC .
.....

BRAKES - ON
- OFF (tb-OFF)

CRT ✓AUTO BRAKE CHECK - ITEM 27 EXEC (no *)

BRAKES - ON (tb-ON)

The auto brake function is verified prior to arm uncradle. Performing an item 27 on SPEC 94 causes the software to initiate auto braking on all joints. There is an RMS flight rule which requires auto brakes for all computer-supported modes. Without proper operation of the auto brake function the RMS can only be operated in direct or backup modes.

The check is performed by taking the BRAKES switch to the OFF position and executing an item 27 on SPEC 94. This action should cause the BRAKES tb to go on and an asterisk should appear next to the 27 on SPEC 94. Cycling the BRAKES switch ON and back OFF resets the auto brakes function. The brakes tb should go off when the BRAKES switch is cycled back to the OFF position, and the asterisk should be removed next to item 27 on SPEC 94.

- **ARM UNCRADLE**

8 **ARM UNCRADLE**

> WARNING
> Arm temperatures must be within limits (no alarms) prior to uncradling

> CAUTION
> Use RMS vernier rates while within ~10 ft of structure

PARAM sel - JOINT ANGLE
BRAKES - OFF (tb-OFF)
MODE - SINGLE, ENTER

SINGLE DR to approx:

	SY	SP	EP	WP	WY	WR
1	0	0	0	+5	0	0
2			+1			
3		+25				
4			-25			

BRAKES - ON (tb-ON)

	X	Y	Z	PITCH	YAW	ROLL
✓	-1261	-146	-552	4.7	1.7	0

DAP: as reqd

●● **WARNING**

The arm temperatures must be within operating limits prior to arm uncradling. Out of limits cold temperatures could cause sluggish joint motion or incorrect joint angle readings from the joint encoders. Out of limits hot temperatures could be a possible indication of an electrical short in the system or a heater element stuck on and could result in joint motor burnout.

●● **CAUTION**

The arm should be operated in vernier rates whenever close to structures. The RMS rotational hand controller (RHC) contains a slide switch located in the thumb position to provide selection between coarse and vernier operating rate limits. The required rate for uncradling the arm is vernier. This rate is required until the arm is clear of the MPM, which as a general rule is until the shoulder pitch joint is at least 7°.

●● **PARAM sel - JOINT ANGLE**

Placing the PARAMETER select rotary switch to the JOINT ANGLE position provides the operator with a joint angle readout (in degrees) on the RMS D&C panel of the joint being moved. Selection of the joint to be displayed is done using the JOINT select rotary switch on the RMS D&C panel. The joint angle is displayed on LED 3 (the right-hand LED) of the RMS D&C panel, and the other two LED displays are blank. The angle will be displayed in the range of ± 180° for all joints except wrist roll, which is ± 447°.

●● BRAKES - OFF (tb-OFF)

Each joint of the arm has a mechanical brake (figure 2-3) to prohibit joint motion. The brakes operate on a power-off, brakes-on basis. The brakes are activated by the BRAKES switch on panel A8U, which sends a hardwire signal to a brake logic function in the MCIU. The MCIU then applies 28 V dc on a hardwired brake bus to the ABE (figure 2-4), and generates an all brakes flag and transmits it to the GPC. When the GPC receives the all brakes flag, it sets the software to idle mode and commands zero rates to all joints. The hardwired command applies the brakes on all motor shafts and goes to each joint motor drive amplifier (MDA) and opens the servo command path to all motors.

When the brakes are removed (moving the BRAKES switch to OFF), the MCIU removes the all brakes flag and the GPC RMS software enters position hold submode to maintain the arm position until a mode is selected.

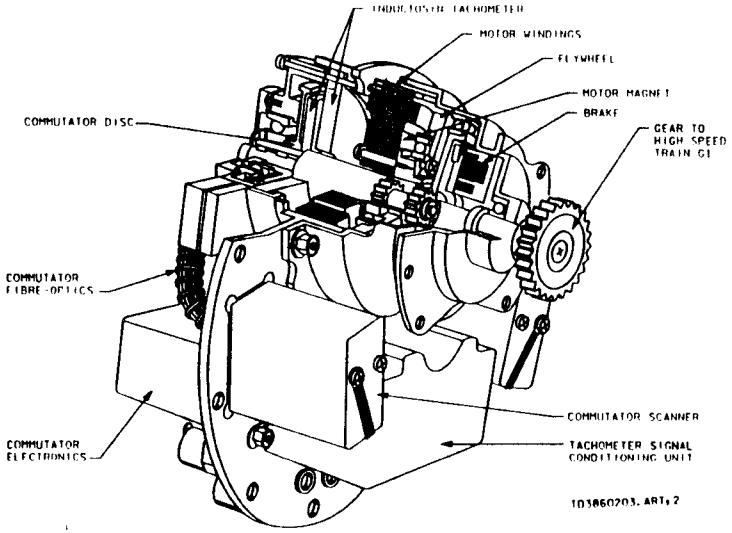


Figure 2-3.– Typical motor module configuration.

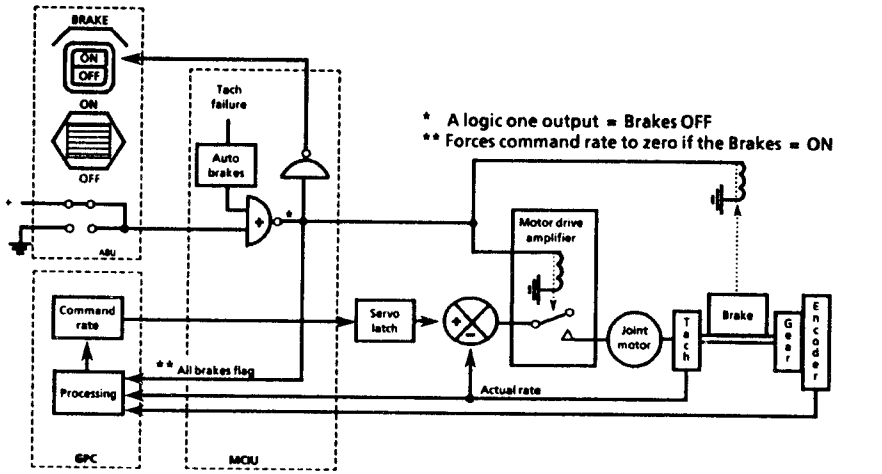


Figure 2-4.– Brakes and servo loop.

●● MODE - SINGLE, ENTER

The arm is uncradled using single mode. Single mode enables the arm to be moved by commanding one joint at a time. Arm motion is commanded by using the JOINT select rotary switch to choose which joint to drive and by moving the SINGLE/DIRECT DRIVE switch to the plus or minus position (up or down) depending on which motion is desired. The valid conditions for entry into single mode are

- Primary RMS power selected
- MCIU/GPC I/O established
- Arm selected
- Safing canceled
- Brakes off
- SINGLE/DIRECT DRIVE switch in detent
- No arm motion

●● SINGLE DR to approx:

	SY	SP	EP	WP	WY	WR
1	0	0	0	+5	0	0
2			+1			
3		+25				
4			-25			

This is the convention used to specify a single-joint task. When it is necessary to drive the joints in a particular order, the procedure will be laid out in this manner. When the joint order is not specified it is the responsibility of the operator to choose the order of joint movement achieving the final configuration without collision. The joints are listed in the order they appear on the manipulator arm starting from the shoulder going to the wrist. The sign convention for driving the arm in single mode (when viewing the cradled manipulator arm from the aft flight deck) is: up and outboard joint motions, positive; and down and inboard, negative.

●● BRAKES - ON (tb-ON)

The BRAKES switch is placed in the ON position whenever an RMS procedure is complete and the RMS is not being used.

●● DAP: as reqd

The manipulator arm is no longer in a singularity or reach limit condition at this time; therefore, the RMS DAP constraints for no primary reaction control system (RCS) jet firings are removed.

Section 3: RMS Checkout

RMS checkout is performed after the arm has been powered up and uncradled, prior to any planned use of the RMS to fulfill any mission objectives.

TV Camera Checkout

1 TV CAMERA CHECKOUT

A7 ✓TV CAMR PWR A,B,C,D,RMS - ON as reqd

Before beginning checkout of the RMS, the cameras that have not been turned on at this point must be turned on and checked for proper operation.

Single Drive Test

The first operating mode that is checked out is single mode. Single mode has been partially verified at this point because it was used to uncradle the arm. The remaining joints which have not been checked are shoulder yaw, wrist yaw, and wrist roll.

2 SINGLE DRIVE TEST

RATE - COARSE (RATE MIN tb-OFF)
RATE - VERN (RATE MIN tb-ON)
PARAM sel - JOINT ANGLE
JOINT sel - WY

BRAKES - OFF (tb-OFF)
MODE - SINGLE, ENTER
 Verify no arm motion
Drive WY, WR, and SY
 Verify correct joint responses
BRAKES - ON (tb-ON)

- **RATE - COARSE, VERN**

The RATE LIMIT slide switch on the RMS RHC is activated to verify proper operation of the rate limit select function. Pulling the slide switch towards the palm side of the hand controller should always be the vernier rate position and should be indicated by the RATE MIN tb displaying ON. With the slide switch in the forward (away from the operator) or COARSE position, the RATE MIN tb should display an OFF.

- **PARAM sel - JOINT ANGLE**

The PARAMETER select rotary switch is placed in the JOINT ANGLE position so that the angle of the joint being driven will be displayed on the RMS LED display.

- **Verify no arm motion**

Immediately after selecting the operating mode, the operator should visually monitor the arm to make sure that no motion occurs in any of the joints.

- **Drive WY, WR, and SY**

There is no specific time requirement for driving each joint during the single-mode, joint-drive checkout. Each joint must be driven in both the positive and negative directions.

- **Verify correct joint responses**

To establish a sign convention for joint motion, consider the arm in the cradled position. A positive drive command on any of the pitch joints should cause the selected joint to rotate the arm components aft of that joint up and away from the Orbiter structure. A positive drive command on either yaw joint should cause the selected joint to rotate the arm components aft of that joint outboard and away from the Orbiter structure. A positive drive command for the wrist roll joint should cause the joint to rotate clockwise as viewed from the aft flight deck. Joint motion should be monitored during this procedure to verify correct response.

B/U Drive Test

One of the RMS flight rules states that "RMS operations shall cease and the arm shall be cradled and latched if backup plus one other primary single-joint mode is not available to drive each joint." As a result of this rule, backup mode is checked out immediately following validation of single mode.

3 B/U DRIVE TEST

```
✓B/U PL REL - OFF
 RMS SEL - OFF
 B/U JOINT sel - WY
 RMS PWR - B/U
     SEL - PORT
  Verify no arm motion
 Drive each joint '+' and '-'
  Verify correct joint responses
```

- ✓B/U PL REL - OFF

The BACKUP PAYLOAD RELEASE switch should be placed in the OFF position prior to selecting backup power. This prevents inadvertent operation of the backup payload release mechanism.

- RMS SEL - OFF

The proper method of powering down the RMS is to deselect the arm prior to placing the RMS POWER switch to the OFF position. Placing the RMS SELECT switch to OFF removes primary power from the arm.

- B/U JOINT sel - WY

Each joint is driven starting with wrist yaw. The BACKUP CONTROL JOINT select switch is placed to the WRIST YAW position prior to entering backup mode.

- RMS PWR - B/U

Placing the RMS POWER switch to the BACKUP position provides dc power to the RMS SELECT switch, and ac power for backup lighting (figure 3-1). Backup dc power is drawn through a 2-amp fuse on panel A8 from dc bus MNB. The MCIU is not powered when backup power is selected; therefore, there is no RMS communication with the Orbiter SM GPC. The operational limitations which result from using backup mode include loss of joint angle readouts, loss of temperature data, loss of RMS telemetry data available to the ground, loss of all computer supported operating modes, and loss of all RMS caution and warning detection and annunciation capability.

- **RMS SEL - PORT**

Selecting an arm with backup power provides power to the arm from MNB at MPC2 (figure 3-1) and places the RMS in backup mode. Backup mode provides the capability of driving the arm on a joint-by-joint basis. Joint response to positive and negative drive commands is the same direction as single mode. A drive command issued by using the BACKUP DIRECT DRIVE switch provides 6.7 volts to the selected joint, and the joints not being driven are held in place by the brakes.

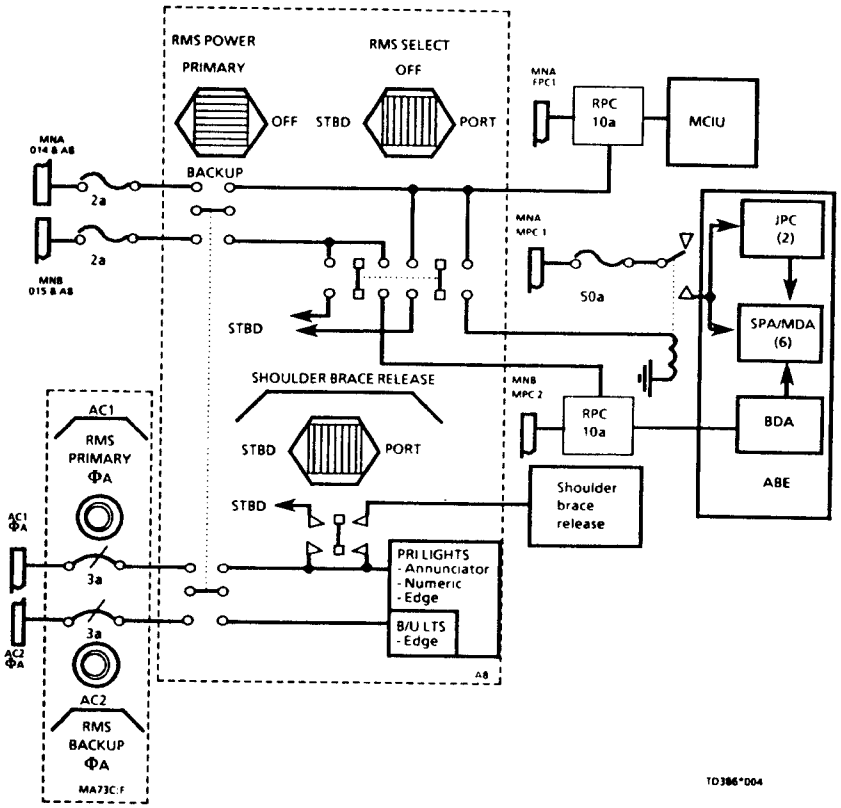


Figure 3-1.– RMS power.

- **Verify no arm motion**

The arm should be monitored for motion when the RMS SELECT switch is placed to the PORT position since once an arm is selected in backup power, it is in mode.

- **Drive each joint**

There is no time limit for driving each joint in backup mode. The only stipulation is that the operator drive each joint both in the positive and negative directions and verify proper joint response to each command.

Reconfigure To Primary Power

Following verification that backup capability exists for all joints, the RMS is reconfigured to primary power so that arm checkout can continue. The arm is deselected, the power is placed back to primary, I/O with the GPC is re-established, the arm is reselected, and safing is canceled.

4 RECONFIGURE TO PRIMARY POWER

RMS SEL - OFF
PWR - PRI (MA)

CRT SM 94 PDRS CONTROL

I/O ON - ITEM 5 EXEC (*)
RMS SEL - PORT
SAFING - CANCEL (tb gray)

DIRECT DRIVE TEST

The purpose of direct drive checkout is twofold. The primary reason is to verify the proper operation of direct drive. In addition, the ground support personnel monitor RMS telemetry data during this check to assure that each joint is functioning properly; i.e., that each joint reaches steady state in a given time frame. In order for the ground to be able to perform this check, the arm must be in a known configuration prior to starting the direct drive checkout. The configuration used is the same configuration used to perform the end effector (EE) checkout. The arm is driven to this position using single mode since single mode has been validated at this point. Camera B is usually set up to view the EE to aid in monitoring the wrist joint during the check.

5 DIRECT DRIVE TEST

PARAM sel - JOINT ANGLE
BRAKES - OFF (tb-OFF)
MODE - SINGLE, ENTER
SINGLE DR to approximately:

SY	SP	EP	WP	WY	WR
0	+25	-25	-45	-15	0

JOINT sel - WP
✓BRAKES - OFF (tb-OFF)
MODE - DIRECT (lt-OFF)
SINGLE/DIRECT DR - '+'
Verify joint does not drive

BRAKES - ON (tb-ON)
✓DIRECT lt - on
Verify no arm motion, then
For each joint:
Drive '+' for 12 sec continuously
wait 30 sec, then
Drive '-' for 12 sec continuously
Verify correct joint responses and
that only selected joint drives

MODE - not Direct (lt-OFF)
JOINT sel - WR
SINGLE/DIRECT DR - '+'
Verify joint does not drive

- ✓BRAKES - OFF (tb-OFF)

The BRAKES switch should be left in the OFF position after completion of the single-mode setup.

- JOINT sel - WP

The JOINT select switch is placed in the WRIST PITCH position prior to placing the MODE select switch to the DIRECT drive position. In the event of a malfunction in the direct drive circuitry, the wrist pitch joint will be least likely to cause damage to the Orbiter or payload and can be easily seen if it moves.

- MODE - DIRECT (lt-OFF)

The conditions for entering direct mode are primary RMS power selected, port arm selected, BRAKES switch ON, and MODE select switch to DIRECT. The BRAKES switch is OFF at this point; therefore, the DIRECT mode light should remain off when DIRECT is selected with the MODE select switch. This step is designed to catch possible electrical shorting of the BRAKES switch.

- BRAKES - ON (tb-ON)

Placing the BRAKES switch ON with the MODE select switch in the DIRECT position puts the arm in direct mode. The direct mode light annunciator should now be lit.

- **Verify no arm motion, then select each joint:**

After establishing direct mode, the operator should verify that none of the joints is moving. Next, the operator should drive each joint in turn. The SINGLE/DIRECT DRIVE switch should be held up (positive) and down (negative) continuously for at least 12 seconds for each position. This is the minimum time necessary for each joint to reach steady-state speed. As each joint is being driven, the arm should be monitored for correct motion of the commanded joint and to verify that no other joints are moving. The 30-second wait between joint drives is to allow oscillations in the arm to damp out.

- **MODE - not Direct (lt-OFF)**

To terminate activation of direct mode, the MODE select switch is repositioned to a mode other than direct. The direct mode indicator light should become extinguished when this is complete. This checks for possible electrical shorting of the contacts in the MODE select switch.

- **SINGLE/DIRECT DR - '+'**

The final part of the direct drive checkout is to activate the SINGLE/DIRECT DRIVE switch after leaving direct mode. This checks for possible electrical shorting of the contacts in the MODE select switch to the SINGLE/DIRECT DRIVE switch.

Hand Controller Check

6 HAND CONTROLLER CHECK

CRT | SM 96 PDRS STATUS |

BRAKES - OFF (tb-OFF)
MODE - SINGLE, ENTER
SINGLE DR to approximately:

SY	SP	EP	WP	WY	WR
0	+35	-25	-45	-15	0

BRAKES - ON (tb-ON)

DAP: VERNIER or free drift • •

RATE - COARSE (RATE MIN tb-OFF)
BRAKES - OFF (tb-OFF)
MODE - TEST, ENTER
Verify no arm motion
THC, RHC - Each axis in turn, deflect hand controller gradually to hardstop

Verify no arm motion
Verify actual rates are zero
Verify commanded rates are proportional to deflection

BRAKES - ON (tb-ON)
DAP: as reqd

- **DAP: VERNIER or free drift**

The DAP must be configured for free drift attitude control mode prior to entering test mode. In test mode, the arm is totally "limp" because the current attenuation word is set to maximum current attenuation (15/15), minimum current available (0/15). Primary RCS jet firings could result in uncommanded arm motion.

- **MODE TEST, ENTER**

Test mode is used to check out the RMS hand controller command path. Translational and rotational commands are processed by the GPC and sent out over the ABE data bus with maximum current attenuation. Certain malfunctions could cause loss of current attenuation and subsequently cause undesired arm motion. Therefore, the arm should be monitored closely for motion when in test mode.

- **THC, RHC - Each axis in turn, etc.**

The operator should manipulate each RMS hand controller. The purpose of this check is to verify the handcontroller command path and to monitor the hand controllers for proportionality. The proper method of performing the checkout is to deflect a single axis of one hand controller from the detent position and slowly ramp the command in until the hardstop is reached. The command should be removed in the same manner, and the procedure is then repeated for all axes on each hand controller.

- **BRAKES - ON (tb-ON)**

The BRAKES switch is placed back into the ON position following completion of the hand controller checkout.

- **DAP: as reqd**

With the arm out of test mode and in the EE checkout position, there are no longer any RMS constraints for DAP configuration.

Manual Augmented Modes Check

For new hardware, the checkout of the manual augmented modes is recorded. This is done so that in the event of a malfunction the arm response can be visually analyzed postflight.

7 MANUAL AUGMENTED MODES CHECK

```
RATE - VERN (RATE MIN tb-ON)
PARAM sel - RATE P/Y/R

BRAKES - OFF (tb-OFF)
MODE - END EFF, ENTER
RHC - Command '+' then '-' for 2-3 sec in
 pitch, yaw, then roll

Verify correct arm response
 and ✓ digital rates displayed

PARAM sel - VEL X/Y/Z
MODE - ORB UNL, ENTER
THC - Each axis in turn

Verify correct arm response
 and digital velocity displays

THC - '-X'
RATE HOLD - depress (momentary)
Release THC
 Verify rate hold function, then
RATE HOLD - depress (momentary)
 Verify arm motion stops

Verify each mode light illuminates
  MODE - ORB LD, ENTER
       - PL, ENTER
BRAKES - ON (tb-ON)
```

- **RATE - VERN (RATE MIN tb-ON)**

Vernier operating rates are selected prior to performing the manual augmented modes checkout.

- **PARAM sel - RATE P/Y/R**

The PARAMETER select switch is placed in the attitude rate monitoring position (RATE P/Y/R) prior to operating the RHC in end effector mode during the manual augmented modes checkout. When RATE P/Y/R is selected, the three indicators display the pitch, yaw, and roll components of the total rotational rate of the point of resolution (POR) resolved about the X, Y, and +Z axes of the Orbiter body coordinate system (for Orbiter operating modes), and about the EE or payload coordinate systems (for EE and payload operating modes, respectively). Placing the PARAMETER select switch in this position allows digital monitoring of arm rotational rates during the RHC portion of the RMS checkout.

- **BRAKES - OFF (tb-OFF)**

The BRAKES switch must be placed in the OFF position before mode entry can be achieved.

- **MODE - END EFF, ENTER**

Depressing the MODE ENTER pushbutton initiates mode entry. The necessary conditions for entry into the manual augmented modes are

- RMS POWER - PRI

- RMS SELECT - PORT

- RMS I/O - active (SPEC 94, item 5)

- SAFING - not in progress

- BRAKES - OFF

- RHC and THC - in detent

- No arm motion (within a certain tolerance band defined by I-loads) unless switching from another manual augmented mode

- Control mode enter received

- **RHC - Each axis in turn**

The arm should be monitored visually as this step is being performed to verify proper arm response to RHC commands. The RMS LED displays should also be monitored as an additional check of proper RMS operation. The check is performed by deflecting a single axis of the RHC and monitoring arm response. The desired result should be arm motion corresponding to both the direction and magnitude of the commanded input.

- **PARAM sel - VEL X/Y/Z**

The PARAMETER select switch is placed in the velocity monitoring position (VEL X/Y/Z) prior to operating the translation hand controller (THC) in Orbiter unloaded mode during the manual augmented modes checkout. When VEL X/Y/Z is selected, the three indicators display the X, Y, and Z components of the velocity vector of the POR expressed in the Orbiter body coordinate system (for Orbiter operating modes), and in EE or in the payload coordinate system (for EE and payload operating modes, respectively). The units are in feet per second and are displayed with a resolution of 0.01 ft/sec. Placing the PARAMETER select switch in this position allows digital monitoring of arm translational rates during the THC portion of the RMS checkout.

- **RATE HOLD - depress (momentary)**

The RATE HOLD switch is mounted on the left half of the RHC hand grip assembly and is a thumb-operated pushbutton. The rate hold function maintains the POR translational, as well as rotational, rates to their commanded values. Rate hold is activated by momentarily depressing the RATE HOLD switch while inputting a rate command using either the THC or the RHC, or both simultaneously.

For this check only a '-X' THC command is input, and then rate hold is activated. The THC is released and the arm should be monitored to verify proper operation of the rate hold function. The proper response for this check should be that the arm continues to move in the same direction and rate which were in effect when the RATE HOLD switch was depressed. Removal of the rate hold function is accomplished by again momentarily depressing the RATE HOLD switch. The arm should stop.

- **Verify each mode light lights:**

The MODE select switch should be placed in the remaining manual augmented mode positions and the MODE ENTER switch should be depressed in each position. This check verifies proper operation of the MODE select switch and the RMS software for each manual augmented mode.

OPR CMD Mode (OCAS) Check

The purpose of performing the operator command mode checkout is to verify proper operation of the AUTO SEQ PROCEED/STOP switch, the MODE select switch in the OPR CMD position, and the supporting software. The checkout is performed by first placing the arm in a known position using single mode and then proceeding with operator command mode. This checkout is recorded using the onboard video tape recorder (VTR) equipment for new RMS hardware.

8 OPR CMD MODE (OCAS) CHECK

BRAKES - OFF (tb-OFF)
MODE - SINGLE, ENTER

SINGLE DR to:

X	Y	Z	PITCH	YAW	ROLL	PL ID
-1196	-247	-649	15	344	334	0

✓	SY	SP	EP	WP	WY	WR
	+10	+45	-35	+0	-30	-25

BRAKES - ON (tb-ON)

CRT SM 94 PDRS STATUS

✓PL ID, ITEM 3 - 0
✓PL INIT ID - ITEM 24 - 0

Load OPR CMD for checkout

-1237, -117, -497, 316, 337, +355

RATE - COARSE (RATE MIN tb-OFF)

BRAKES - OFF (tb-OFF)
MODE - OPR CMD, ENTER
✓AUTO SEQ READY lt - on
AUTO SEQ - PROCEED, after ~ 3 sec
- STOP

Verify arm stops
AUTO SEQ - PROCEED
When AUTO SEQ IN PROG lt - off,
BRAKES - ON (tb-ON)

SY	SP	EP	WP	WY	WR
0	+25	-25	-48	-9	0

X	Y	Z	PITCH	YAW	ROLL	PL ID
-1237	-117	-497	316	337	355	0

- **PL INIT ID - ITEM 24 + 0 EXEC**

The RMS software uses the PL INIT ID to initialize the POR and associated joint rates for an operator commanded auto sequence (OCAS).

- **Load OPR CMD for checkout**

The nomenclature adopted to describe an OCAS maneuver has been standardized and will appear this way in all PDRS FDFs. The numbers which follow the "Load OCAS for" instruction in the FDF correspond to X, Y, Z, pitch, yaw, and roll, respectively. The numbers are loaded into items 18 through 23 on SPEC 94 in the order in which they appear. Upon completion of entering the end point numbers, an item 25 (SPEC 94) is executed. This item entry causes the software to check to see if the arm can attain some combination of joint angles that will place the POR (designated by item 24) at the coordinates input by the operator. The software check will respond with either a GOOD or FAIL indication next to item 25. The GOOD response indicates that the point is attainable by the hardware, not that the point is desirable or safe, or avoids collision.

The command check (item 25) only validates the end point. It does not check the path the arm must travel to get to the end point. Therefore, the possibility for collisions, singularities, and joint reach limits exists along the trajectory which the arm will travel. The operator must be aware of these conditions and must monitor arm motion during the OCAS maneuver.

- **BRAKES - OFF (tb-OFF)**

The brakes must be removed to allow entry into operator command mode.

- **MODE - OCAS, ENTER**

Depressing the MODE ENTER pushbutton initiates mode entry. The necessary conditions for entry into operator command mode are

- RMS POWER - PRI
- RMS SELECT - PORT
- RMS I/O - active (SPEC 94, item 5)
- SAFING - not in progress
- BRAKES - OFF
- The AUTO SEQ PROCEED/STOP switch in its center position
- No arm motion
- Control mode enter received

Operator command mode can be entered without performing any entries on SPEC 94 (items 18 through 25). The auto sequence READY light will not be activated unless an end point has been entered (items 18 through 23) and validated (item 25), and the payload ID (item 3) matches the payload initialization ID (Item 24).

After operator command mode is entered, the operator should monitor the arm to verify no arm motion.

- **AUTO SEQ - PROCEED**

The AUTO SEQ PROCEED/STOP switch is a three-position switch: momentary up and momentary down, with spring return to center. The up position (PROCEED) activates the sequence (assuming the READY light is on) and causes the auto sequence READY light to be extinguished and the IN PROG light to come on. For this checkout, the PROCEED/STOP switch should be placed to the PROCEED position and released. After about 3 seconds, the PROCEED/STOP switch should be taken to the STOP position. During both activities, the arm should be monitored for proper operation. Stopping the arm with the PROCEED/STOP switch prior to completion of the sequence should cause arm motion to stop, the IN PROG light to be extinguished, and the auto sequence READY light to come back on. The purpose of performing this step is to verify proper operation of the AUTO SEQ PROCEED/STOP switch.

The operator command mode check is completed by again placing the PROCEED/STOP switch to the PROCEED position and allowing the sequence to complete. Termination of an OCAS is indicated by the IN PROG light being turned off and the arm stopping any motion.

- **✓SY SP EP WP WY WR**

The final step in the OCAS checkout is to verify the position of the arm by checking the individual joint angles.

EE Checkout

This checkout is for the standard EE, which will be discussed here. The nonstandard EEs are special-purpose EEs which are the responsibility of the payload customer. The special-purpose EE can replace the standard EE during ground turnaround, or be grappled and released by the standard EE on orbit.

The standard EE is a hollow cylinder 13.6 in. in diameter and 21.5 in. long, constructed predominantly from light gauge aluminum. The overall configuration of the standard EE showing the internal arrangement is shown in figure 3-2.

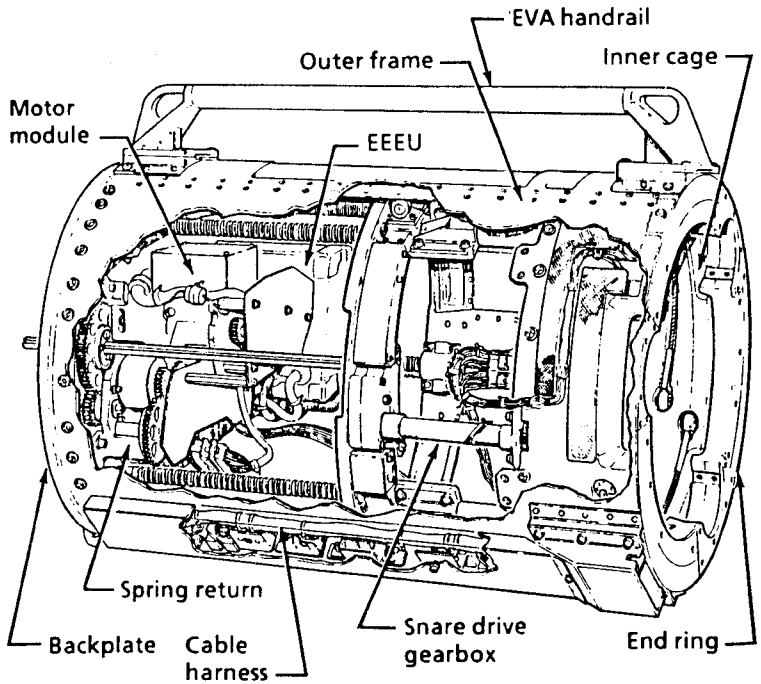


Figure 3-2.– Standard EE configuration.

A schematic of the drive train system is shown in figure 3-3. The prime channel brushless dc motor is double-ended with fail-safe (power-off, brakes-on) electro-mechanical brakes and friction clutches at each end. One end is associated with the actuation of the snare drive system, and the other end is associated with the actuation of the rigidization drive system.

The initial snaring is carried out by the prime motor's (M) driving through an engaged clutch (B), disengaged brake (A), engaged clutch (E), disengaged clutch (C), and the snare drive gear train to operate the rotating snare ring. On completion of the snaring, brake (A) is engaged; clutch (B) is released; and rigidization is carried out by the prime motor's (M) driving through an engaged clutch (C), disengaged brake (D), and the rigidization gear train to operate the rigidization carriage.

For the snare drive, the motor drives a ball spline, which transmits power to a shaft and pinion which rotates the large segmental ring gear and snare ring to close the snares. As the motor/brake/clutch assembly is stationary, and the spline and cable ring assembly moves back and forth longitudinally during rigidization, the torque is transmitted under load through the ball spline to hold the snare position.

During the rigidization/derigidization operation, the three ball screws are driven by a central gear and idler arrangement so that synchronization is maintained.

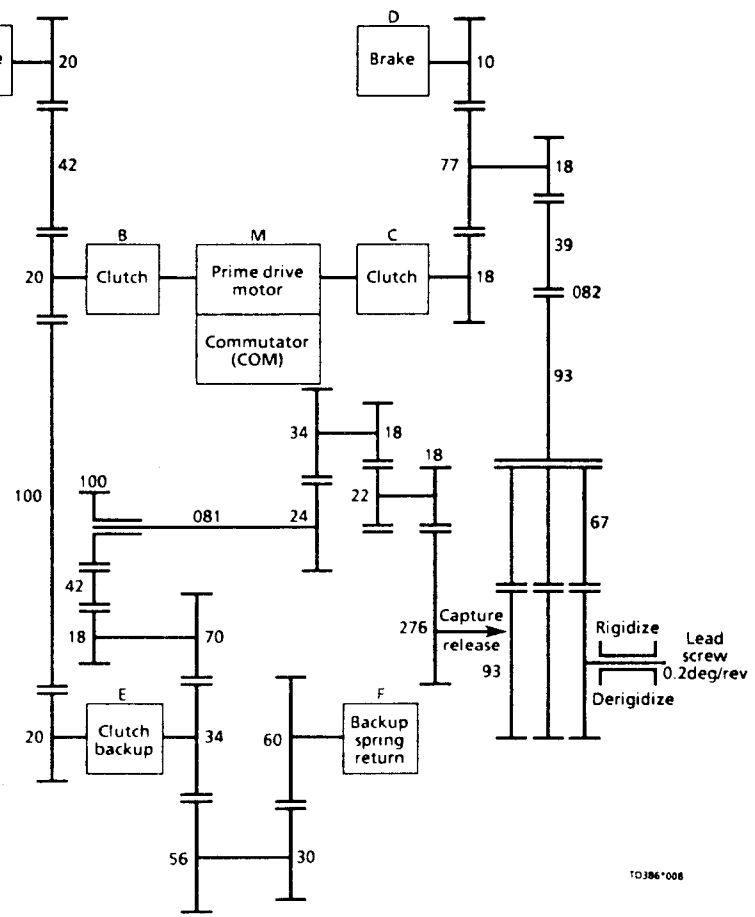
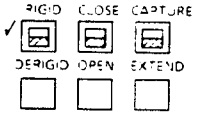


Figure 3-3.– Standard EE train schematic.

9 EE CHECKOUT

✓	SY	SP	EP	WP	WY	WR	
	0	+25	-25	-48	-9	0	
	X	Y	Z	PITCH	YAW	ROLL	PL ID
	-1237	-117	-497	316	337	355	0

A7 VID OUT pb - MON 2
IN pb - B
Adjust Camera B to view inside of EE



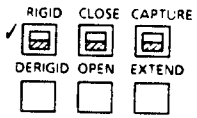
DAP: VRCS or free drift ··

✓EE MODE - OFF
EE CAPTURE - depress (2 sec)
✓OPEN tb - gray

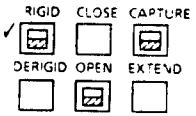
EE MAN CONTR - RIGID (2 sec)
✓EXTEND tb - gray

BRAKES - OFF (tb-OFF)
MODE - SINGLE, ENTER

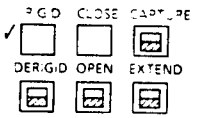
EE MODE - MAN



EE CAPTURE - depress until CLOSE tb - gray
(3 sec max)



EE MAN CONTR - RIGID until RIGID tb - gray
(20 sec max)
EE MODE - OFF ··



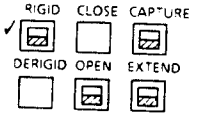
BRAKES - ON (tb-ON)

EE RELEASE - depress (2 sec)
✓CLOSE tb - gray

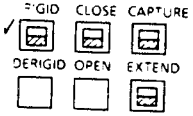
EE MAN CONTR - DERIGID (2 sec)
✓RIGID tb - gray

EE MODE - MAN

EE MAN CONTR - DERIGID until DERIGID
tb - gray (5 sec max)

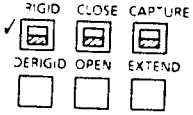


EE RELEASE sw - depress until OPEN
tb - gray (3 sec max)



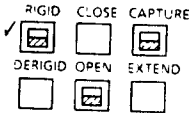
✓Snares return to grooves

EE MAN CONTR - DERIGID until EXTEND
tb - gray (20 sec max)



EE MODE - AUTO
Verify no uncommanded EE ops

EE CAPTURE sw - depress (mom)



EE MODE - OFF ··

- **DAP: VRCS or free drift**

This DAP call is necessary because the arm will be limp during part of the EE checkout. The RMS will be limp during both the capture and rigidize commands.

- **/EE MODE - OFF and EE CAPTURE - depress (2 sec)**

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

The switch is depressed with the EE MODE switch in the OFF position prior to turning the EE on. This is done to check for possible shorting of the electrical contacts in the EE MODE switch.

- **EE MAN CONTR - RIGID (2 sec)**

The EE manual control RIGID/DERIGID switch is a three-position momentary toggle switch, center OFF, which enables the operator to manually select payload to EE rigidization or derigidization. The up position of the switch is labeled RIGID, and the down position is labeled DERIGID. The switch is only enabled when the EE MODE switch is set to the MAN position. Rigidization and derigidization proceed only as long as the switch is activated.

The switch is placed in the RIGID position with the EE MODE switch in the OFF position prior to turning the EE on. This is done to check for possible shorting of the electrical contacts in the EE MODE switch.

- **MODE - SINGLE, ENTER**

Single mode is entered prior to selecting a mode for the EE. This is done so that the ground support personnel can monitor the current attenuation word to verify that the proper current attenuation limits are set. When the capture or rigidize commands are detected by the GPC, 14 bits current attenuation (equivalent to 1/15th current limit) is sent to the joint servos (except for the wrist roll joint). This puts the arm in a virtual limp condition, enabling the joints to backdrive during the capture/ rigidization process. Control over wrist roll is maintained so that the operator may remove any roll misalignment which is introduced during rigidization; however, if no roll command is present, the wrist roll current attenuation is also set to 14 bits to enable the wrist roll joint to backdrive. Recall that in test mode the arm is also limp but has the current attenuation set to 15/15 with no current available to drive the arm. The reason there is 1/15th current available during EE operations is to keep the forward/ backdrive flag set properly in the RMS software. The forward/backdrive flag is used to determine whether a joint is driving the arm or being driven by the arm.

- **EE MODE - MAN**

With the EE MODE select switch set to MAN CONTR, during capture, actuation of the CAPTURE switch causes the snares to close. Rigidization will not follow until the manual rigidize/off/derigidize switch is actuated. In the manual mode, no interlocks are provided. Hence, during operations, the CAPTURE/RELEASE switch and the manual rigidize/off/derigidize switch must be held continuously during each respective operation. This allows for complete override capability in the manual mode.

- **EE CAPTURE - depress until CLOSE tb-gray (3 sec max)**

With the EE MODE switch in the manual position, actuation of the CAPTURE/ RELEASE switch to the CAPTURE position causes the EE snare cable ring assembly to rotate, thus closing the snares. The capture operation will be maintained only as long as the switch is held. In the presence of a grapple fixture, the capture microswitches would be activated just prior to the close microswitch. There are two capture microswitches located at the base of two of the snare cables. As tension is placed on the cables, the microswitches are activated. The close microswitch is located at the end of travel limit for the rotating snare cable ring. In EE manual mode, the EE motor will operate under stall conditions if the command is not removed after the close microswitch has been activated (indicated by a gray close tb on the RMS D&C panel).

- **EE MAN CONTR - RIGID until RIGID tb-gray (20 sec max)**

Activation of the EE MAN CONTR switch to the RIGID position causes the snare assembly to draw into the EE. To achieve rigidization, the manual rigidize switch must be held until the RIGID tb indicates gray to complete the operation. As the carriage crosses the derigid position (the zero tension point), the DERIGID tb changes states from gray to bp. When the snare assembly is fully withdrawn inside the EE, the rigid microswitch is activated which causes the RIGID tb to change states from bp to gray.

- **BRAKES - ON (tb-ON)**

The brakes are turned on at this point because the RMS does not need to be in mode for the next part of the checkout. The EE can be operated without having the RMS software in an operating mode.

- **EE MODE - OFF**

The EE MODE switch is turned off, the release command is issued for 2 seconds, and then the derigid command is held for 2 seconds. This is done to check for possible shorting of the electrical contacts in the EE MODE switch and the RELEASE and DERIGID switches.

- **EE MODE - MAN**

The EE MODE switch is placed back to the manual position to complete checkout of EE manual mode. The completion of EE manual mode checkout includes driving the snare assembly to the zero tension point, opening the snares, and driving the snare assembly to the fully extended position.

- **EE MODE - AUTO (Verify no uncommanded EE ops)**

The EE MODE selection switch has the effect of coupling or decoupling the capture and rigidization sequences. During capture of a payload, with the switch set to AUTO, momentary actuation of the CAPTURE switch on the RHC causes the snares to close, followed automatically by rigidization of the payload/EE interface. Conversely, during release, momentary actuation of the RELEASE switch on the RHC causes derigidization of the interface, followed automatically by the snares opening to release the payload.

- **EE CAPTURE sw - depress (mom)**

The CAPTURE switch is momentarily activated to verify the EE auto mode logic circuitry. The snares should close; and, in the absence of a capture indication, the sequence should stop. After placing the EE MODE switch to off, the EE is now set up for the next portion of the checkout.

B/U Payload Release Test

10 B/U PAYLOAD RELEASE TEST

✓B/U PL REL - OFF
RMS SEL - OFF
PWR - B/U
SEL - PORT
Verify snares remain closed

B/U PL REL - ON (10 sec max)

B/U PL REL - OFF · ·

✓Snares return to grooves

- **✓B/U PL REL - OFF**

The BACKUP PAYLOAD RELEASE switch should be verified in the OFF position prior to placing the RMS POWER switch to the BACKUP power position. When the RMS POWER switch is placed to the BACKUP position, the EE should be checked visually to determine that the snares remain closed.

- **B/U PL REL - ON**

In the process of capturing, a spring is wound up as the snares close. In an emergency, a payload can be released using the BACKUP PAYLOAD RELEASE switch. This switch activates the backup clutch and allows the spring return device to open the snares. Opening the snares is the only EE capability that exists when backup power is selected. With a fully rigidized payload/EE situation, the operator should expect tipoff rates on the payload when releasing a free flying payload using backup payload release.

The operator should verify that the snares open and return to the proper position after activation of the BACKUP PAYLOAD RELEASE switch. The switch should be placed back in the OFF position upon completion of the checkout.

Reconfigure To Primary Power

Following verification that backup release capability exists, the RMS is reconfigured to primary power so that EE checkout can continue. The arm is deselected, the power is placed back to primary, I/O with the GPC is reestablished, the arm is reselected, and safing is canceled.

11 RECONFIGURE TO PRIMARY POWER

RMS SEL - OFF
PWR - PRI (MA)

CRT SM 94 PDRS CONTROL

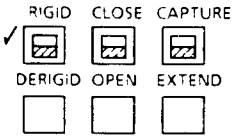
I/O ON - ITEM 5 EXEC (*)

RMS SEL - PORT
SAFING - CANCEL (tb gray)

Auto Release Check

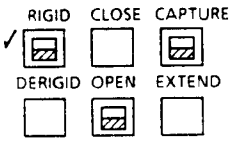
To perform the EE auto mode release checkout, the EE must first be configured to have the snares closed and the snare assembly fully rigidized. This is done using EE manual mode.

12 AUTO RELEASE CHECK

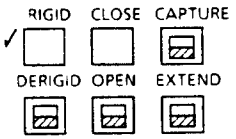


EE MODE - MAN

EE CAPTURE sw - depress until CLOSE
tb - gray (3 sec max)

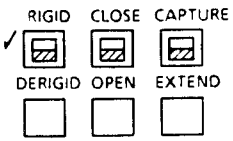


EE MAN CONTR - RIGID until RIGID
tb - gray (20 sec max)



EE MODE - AUTO

EE RELEASE sw depress (mom)
(after ~20 sec)



EE MODE - OFF ••

✓Snares return to grooves

DAP: as reqd

- **EE RELEASE sw - depress (mom)**

The release command in EE auto mode causes the snare assembly to move from the fully rigidized position to the derigid position. At the derigid position (zero tension), the snare assembly stops and the snares are opened. When the open microswitches are made on the rotating snare assembly, the snare assembly moves to the fully extended position. The operator should monitor both the EE tbs and the EE visually during this operation to verify proper operation of the EE auto mode release logic.

- **EE MODE - OFF**

The EE MODE switch is placed back to the OFF position upon completion of the EE checkout. The EE MODE switch should always be in the OFF position during times of EE inactivity. Only immediately prior to use of the EE should the EE be placed in one of the two EE operating modes. There are several failure modes which exist that could cause uncommanded EE operations with one of the EE operating modes selected.

- **DAP: as reqd**

The DAP constraints due to RMS limping have been removed.

Section 4: Manipulator Positioning Mechanism/ Manipulator Retention Latches

MPM

The MPM is the device that rotates the arm from its stowed position (11.88° inboard from longeron) to its operational position (19.48° outboard from longeron) outside the payload bay. The 31.36° total rollout moves the stowed arm out of the deployment envelope of a full-sized payload (figure 4-1). Upon completion of RMS operations, the manipulator arm must be repositioned inboard to its stowed position, or else it interferes with the closing of the payload bay doors.

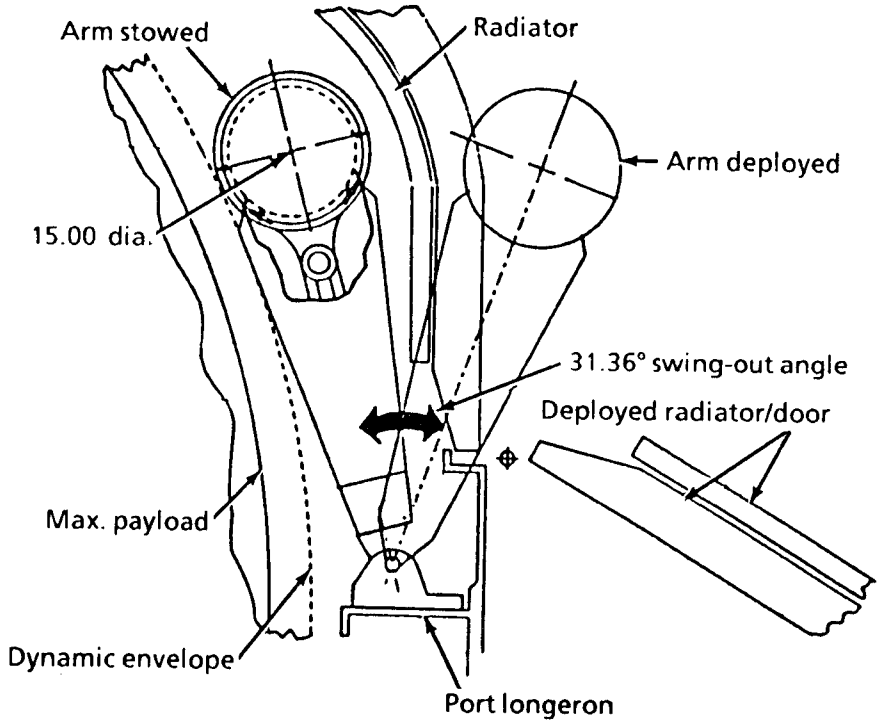


Figure 4-1.– Port RMS view looking aft.

The MPM consists of four manipulator positioning pedestals which are attached to the Orbiter sill longeron. One support is located at the shoulder joint where the arm is permanently attached, and the other three span the length of the arm and contain the MRLs. The MPM is driven by two motors connected by a mechanical differential. The power drive unit (PDU) (figure 4-2) is located near the shoulder and rotates a torque tube. The torque tube extends the length of the sill longeron and is connected to the gearbox housings of four rotary actuators located at each pedestal (figure 4-3). The pedestal drive mechanism contains overcenter locking devices that lock in both the stowed and deployed positions (figure 4-4).

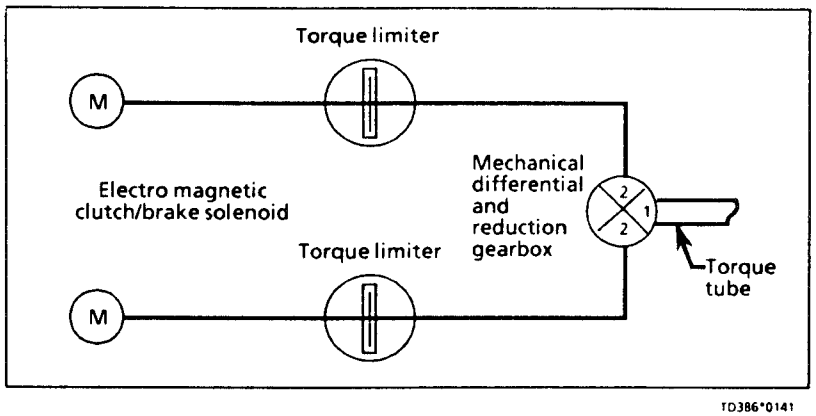


Figure 4-2.– Power drive unit.

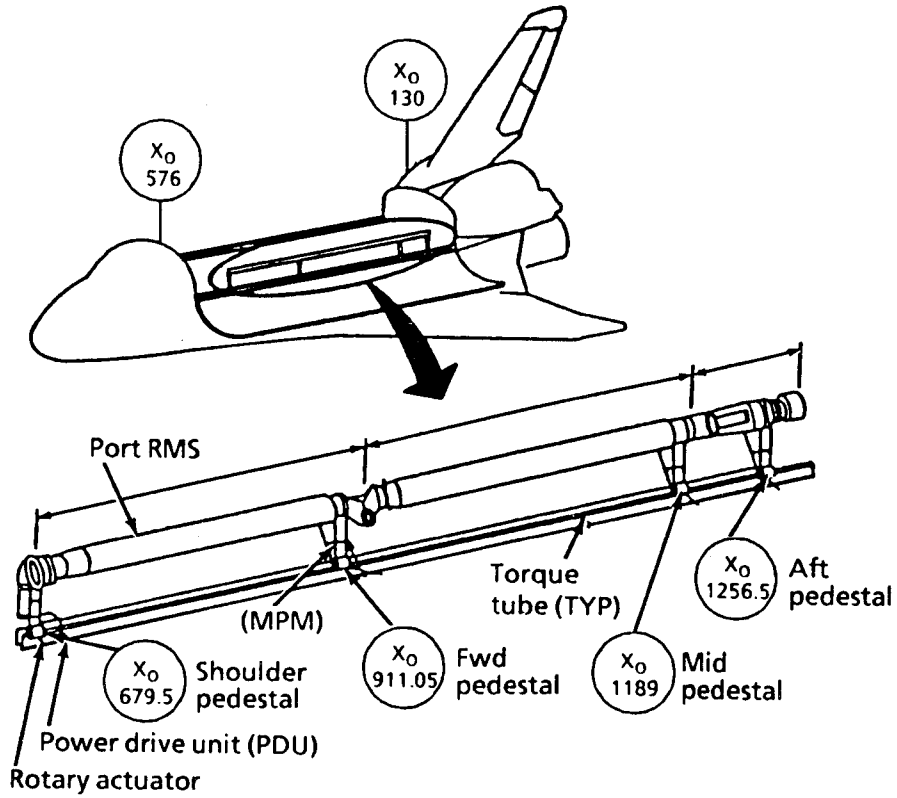


Figure 4-3.– MPM - Orbiter interface.

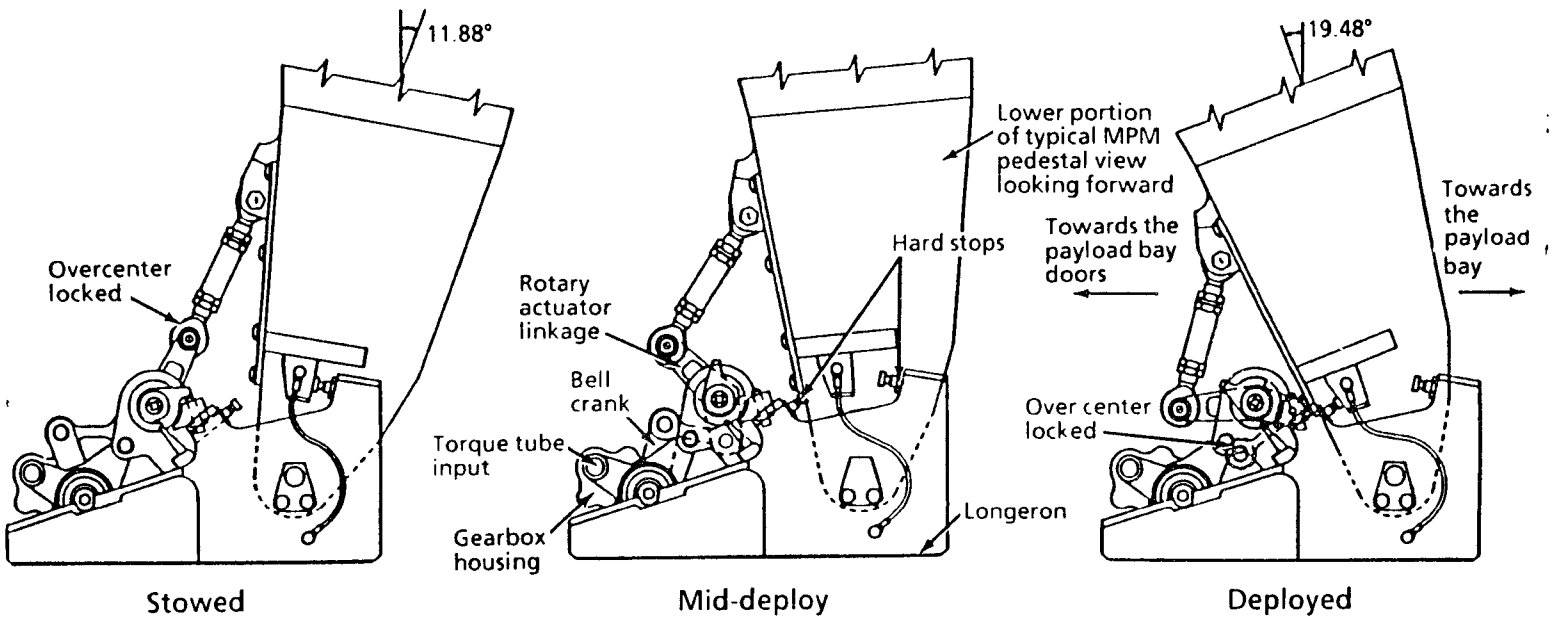


Figure 4-4.– Deployment sequence.

All MPM pedestal locations contain two sets of deploy/stow microswitches. On orbit the crew can see the conditions of the microswitches located at the shoulder only, while the ground has visibility into the condition of all deploy/stow microswitches. The microswitches located at the shoulder are part of the drive system (figure 4-5). When the arm is being deployed, the deploy microswitches shut off the drive motors. The stow microswitches act the same way for stowing. The condition of the shoulder deploy/stow microswitches for both systems can be seen on SPEC 94. The STO/DPLY tb can be driven by either system, provided all microswitches in that system get set (figure 4-6).

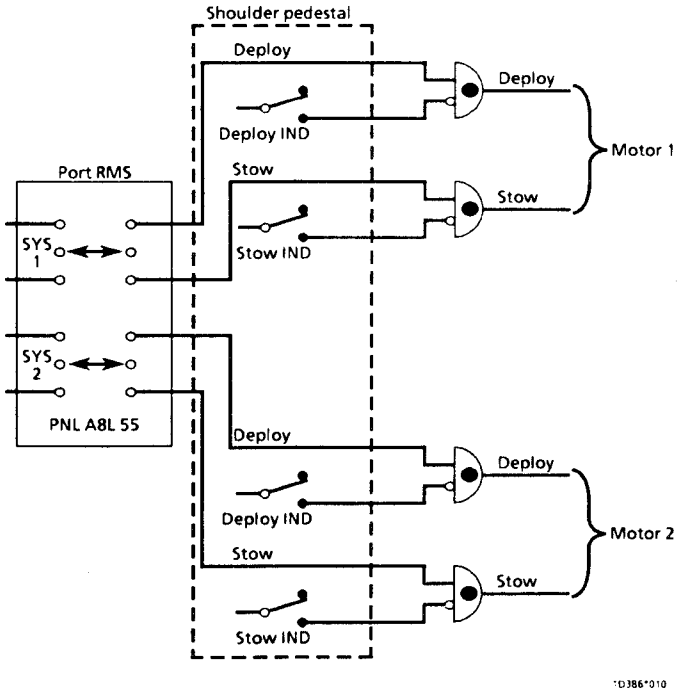


Figure 4-5.– MPM motor drive logic.

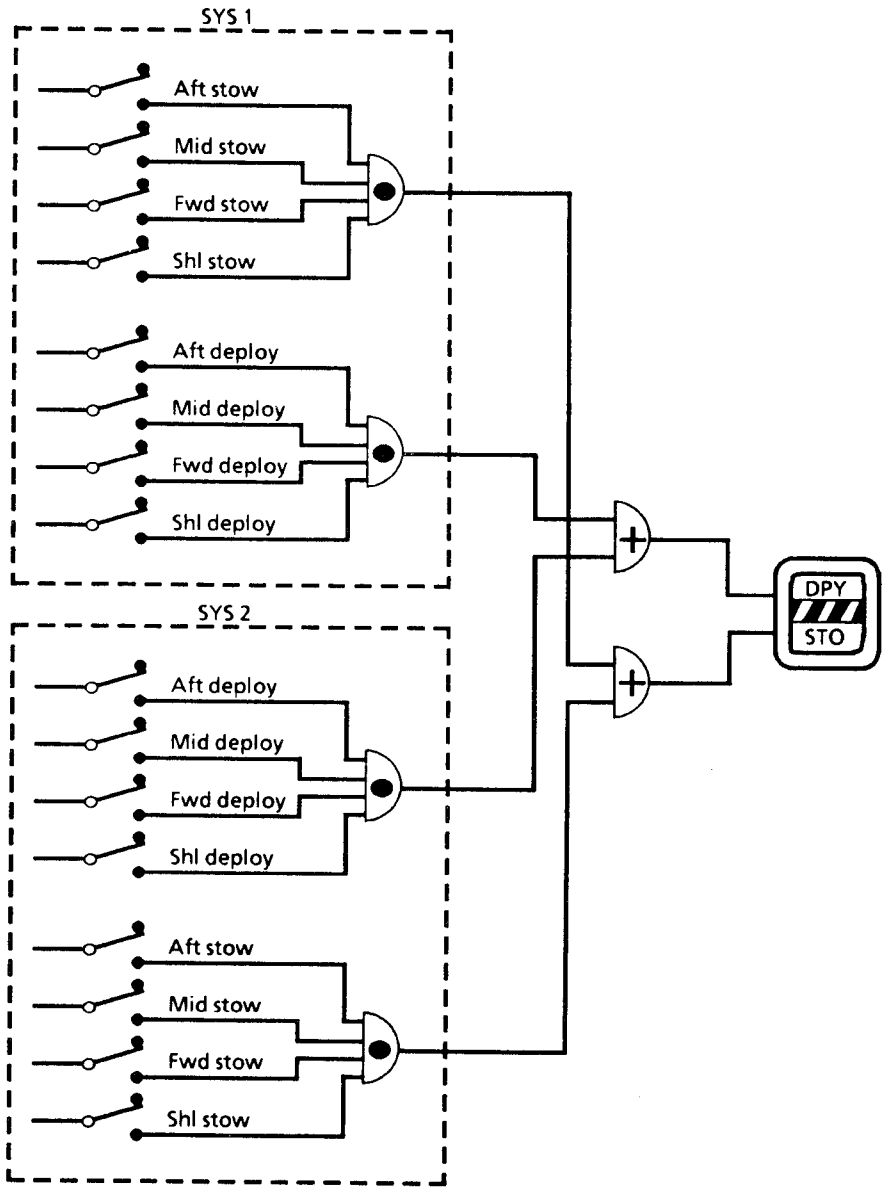


Figure 4-6.– MPM tb operation.

MRL

The arm is restrained in the cradled position by MRLs at the forward, mid, and aft MPM pedestal locations. The MRLs prevent the arm from contacting the Orbiter/ payload structures during launch and entry loads. At least two of the three MRLs must be latched to endure entry loads without arm/structure contact.

Each MRL contains two motors which drive through a differential to apply the sum of their output torques to a reduction gearbox (figure 4-7), driving the bell cranks in opposite directions with the same rotational rate. Each bell crank is physically attached to a hook actuator linkage (figure 4-8), so that rotation of the crank provides an input for hook movement. Due to linkage geometry, the hook tip travels in the Z-direction for a major portion of a latch/release sequence prior to a final Y-rotation. This insures a relatively large capture envelope in the X-Y plane and provides sufficient force for arm restraint when latched.

Gearbox actuation also rotates a slotted gear which activates the position microswitches (figure 4-7). The slot position is adjusted so that when either the fully latched or released condition is attained, a bearing on the respective microswitch will drop into the slot, pivoting the assembly so that two microswitch contacts are closed. The closing of these contacts provides logic "1" switch output, resulting in routing of this signal to the crew and ground personnel as status information, and inhibition of motor operation for that direction (figure 4- 9). The crew has visibility into system 1 latch/release microswitch operation (figure 4-10) on the REL/LAT tb and can see both systems on SPEC 94.

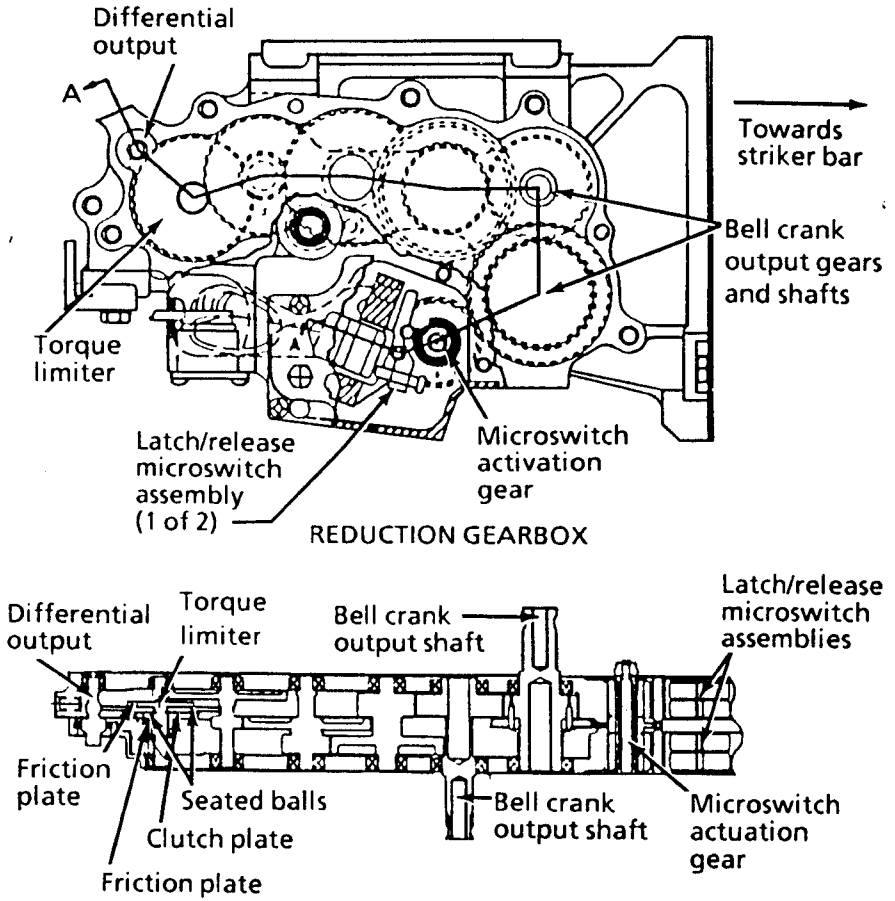


Figure 4-7.– Reduction gearbox.

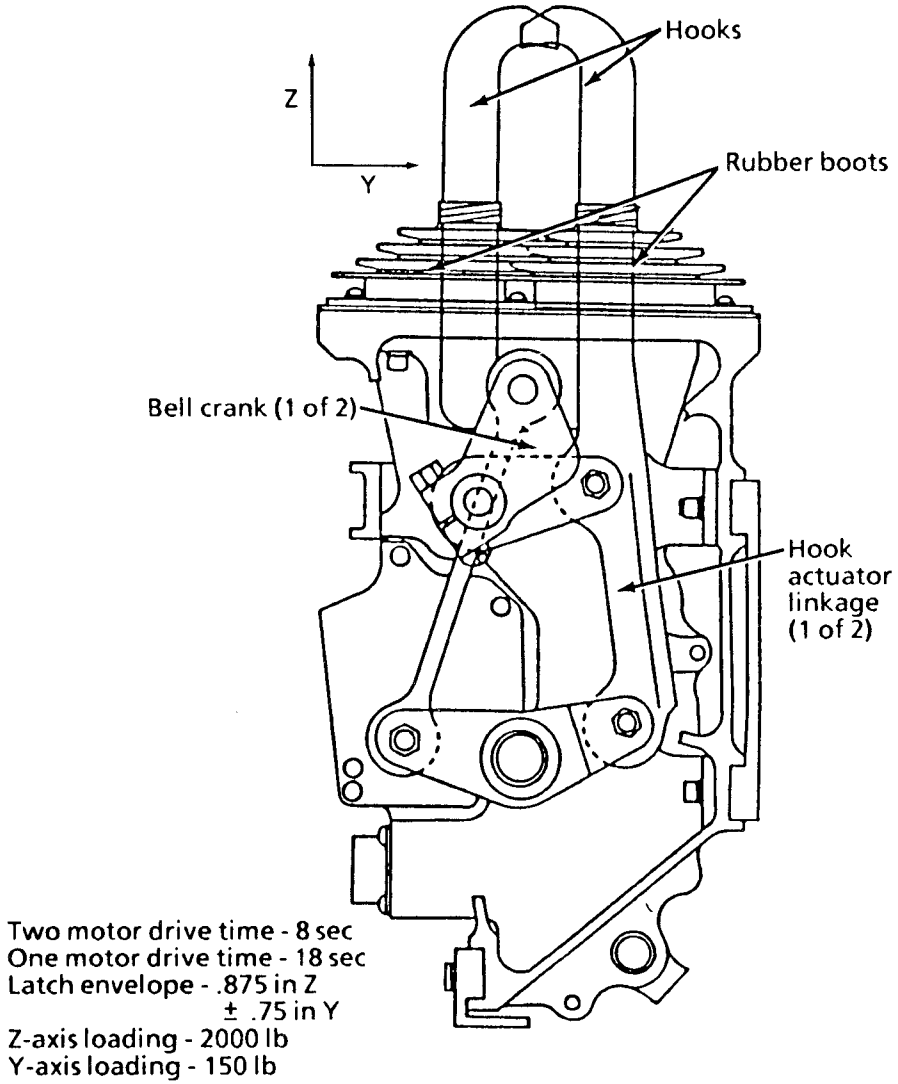


Figure 4-8.– Hook actuator.

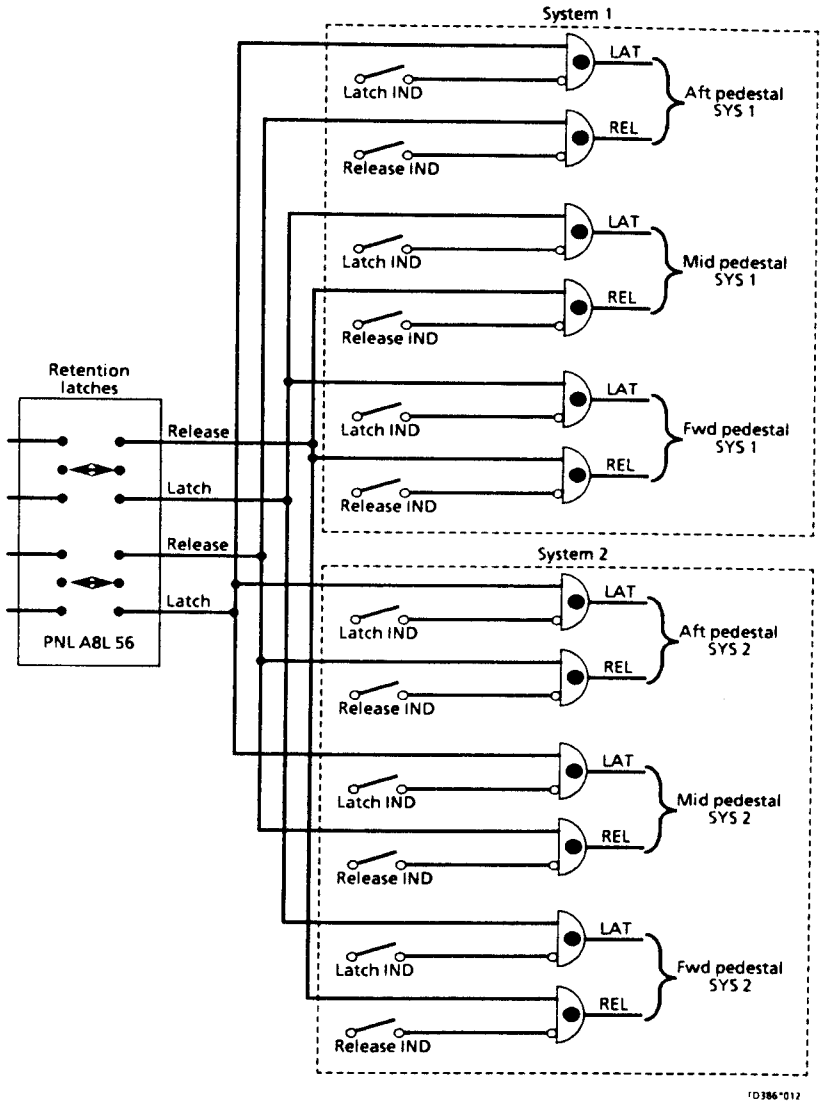


Figure 4-9.–MRL microswitch operation.

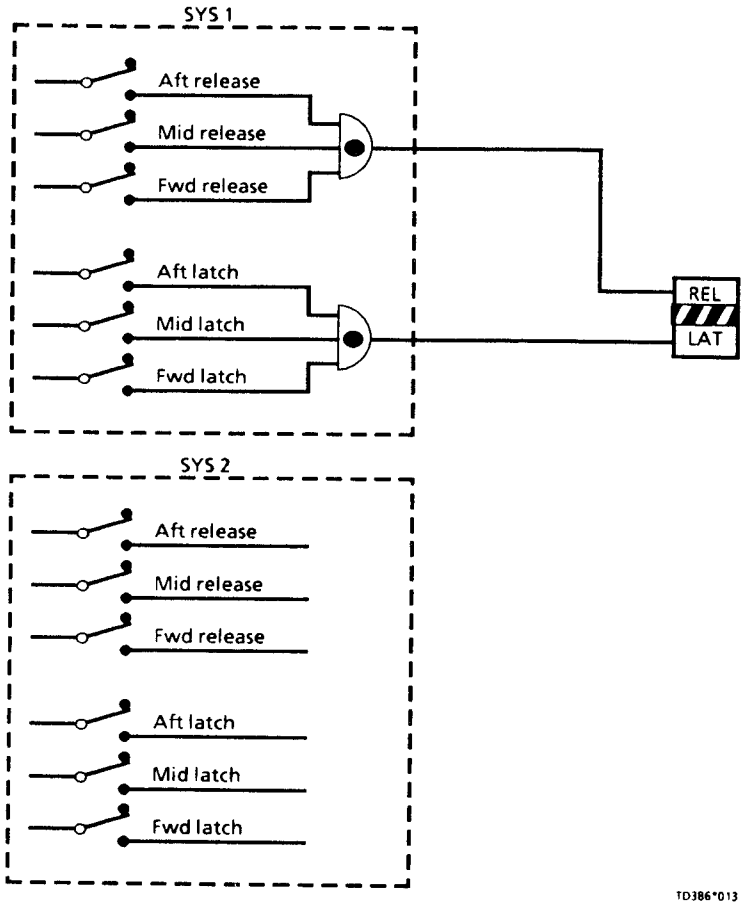


Figure 4-10.– MRL tb operation.

Section 5: Joint Drive System

Every joint of the manipulator arm is driven electro-mechanically. Configurations for the shoulder, elbow, and wrist joints are shown in figures 5-1, 5-2, and 5-3, respectively.

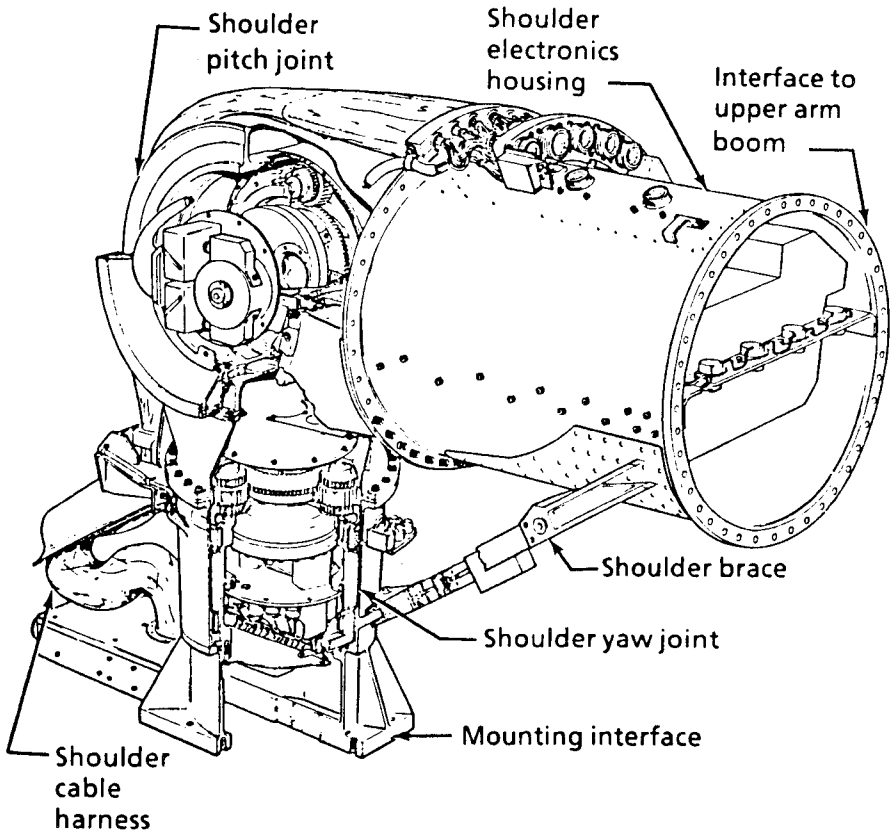


Figure 5-1.– Shoulder joint.

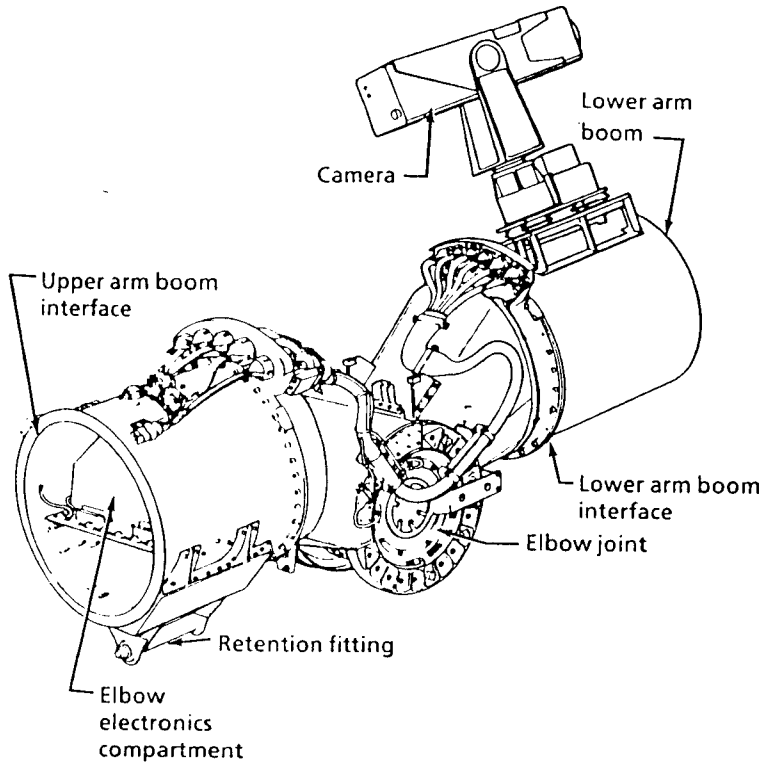


Figure 5-2.– Elbow joint.

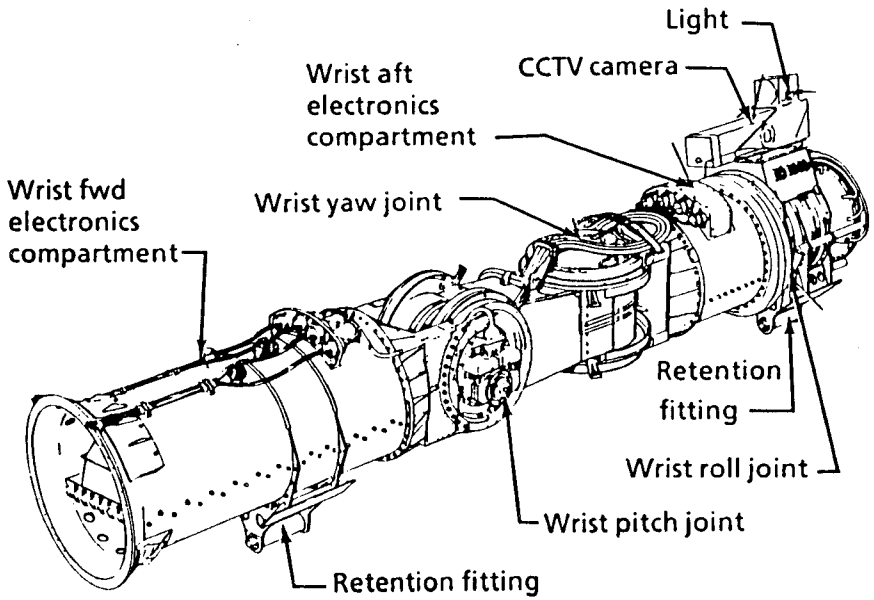


Figure 5-3.– Wrist joint.

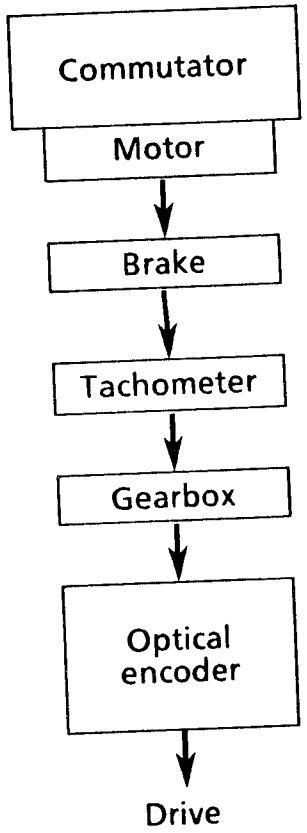


Figure 5-4.– Joint drivetrain.

Each joint drivetrain (figure 5-4) consists of the following:

- A motor module made up of a dc motor, tachometer, mechanical brake, an optical commutator, and a signal conditioning unit
- An optical encoder located on the gearbox output shaft that supplies joint position data to the control algorithms
- An epicyclic output geartrain that provides desired output speeds from the motor input

The motor module functions basically as a servomotor. The motor provides the mechanical drive for joint movement in response to commands from the MCIU during computer supported modes of operation. The overall configuration of the joint motor modules is shown in figure 5-5. Each of the six motor modules utilizes an identical, reversible, brushless dc motor which is used in both prime and backup modes. Figure 5-6 illustrates the motor and how the motor module components are configured.

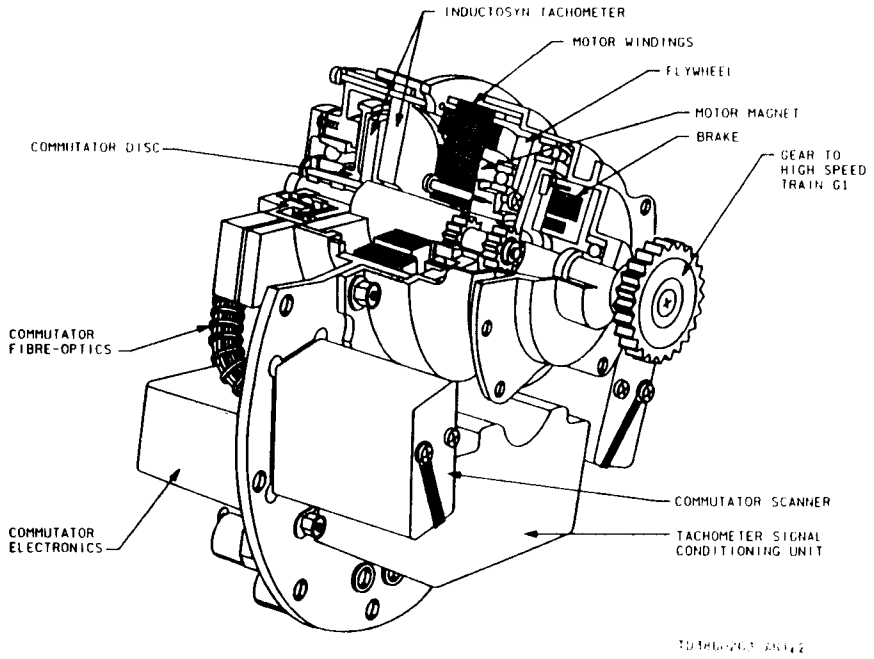


Figure 5-5.– Motor module configuration.

1 Motor housing
2 Brake unit
3 Flywheel
4 Drive shaft
5 Motor
6 Tachometer
7 Signal conditioning unit
8 Drive pinion
9 Commutation scanner assembly (CSA)
10 CSA support and protector
11 CSA electronics

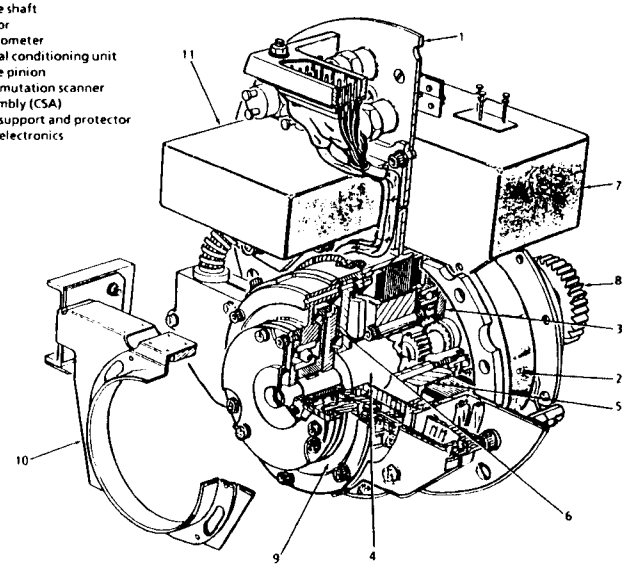


Figure 5-6.– Motor module components.

The components of the motor module work together to act as a servocontrol loop for each joint. The servo-control loop is part of the tachometer electronics (TE) within the servo power amplifier (SPA). The servo loop for one joint is illustrated in figure 5-7.

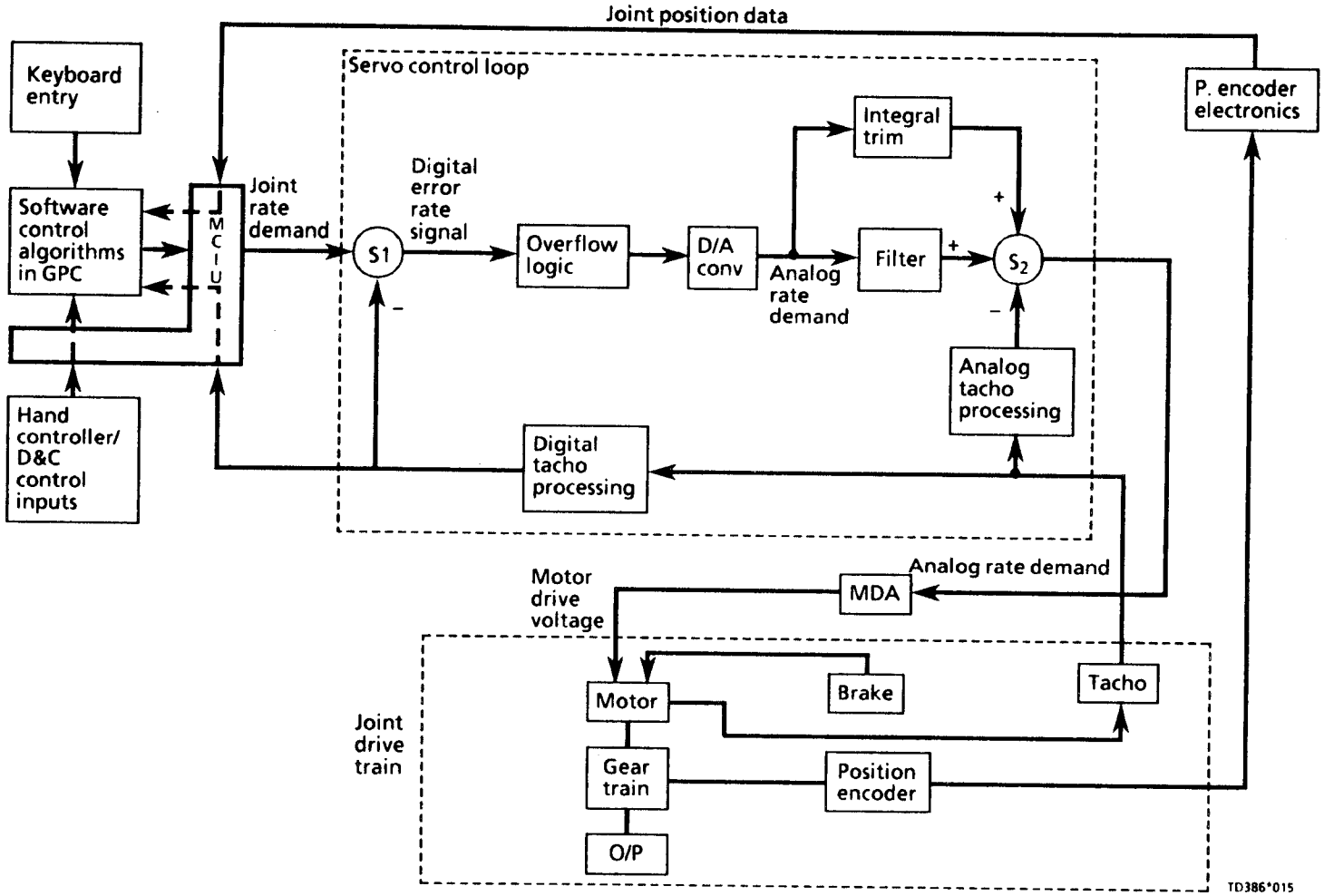


Figure 5-7.– Control system block diagram, typical joint.

In single mode, the operator supplies a fixed drive signal to the control algorithms. In response, the RMS software algorithms supply joint rate demands to drive the selected joint while maintaining joint position on the remaining, unselected joints. The MCIU formats the rate commands and ships them across the ABE data bus to the joint servos.

The rate demand supplied by the control algorithm is compared to the actual joint speed, supplied by the digital tachometer feedback at S1 (figure 5-7). The comparison results in an error signal, which is filtered and passed to the second summing junction S2. An integral trim function integrates the error signal to overcome friction effects when input commands are low. At S2 the analog (-) feedback signal is used to control high acceleration demands present in the error signal. After passing through the servocontrol, the error signal is transmitted as an analog rate demand to the MDA by varying the average power to the motor.

The motor output is then transferred to the joint gear-train. Each joint contains a low-speed gear group and a high-speed gear group. The low-speed gear ratio is the same for each joint, and the overall gear ratio differences between the six joints is achieved by changing the high speed gear ratio.

Also on the output side of the motor is the optical position encoder used to sense the angular position of the joint. It is an electro-optical device using an LED source and a single disc to provide joint angle readouts. Output from the encoder is sent to the GPC along with data from the TE. The RMS software carries out the following processing of the optical encoder and tachometer data:

- Converts the encoder signals into joint angles
- Filters the tachometer data to provide a smoothed joint rate data
- Uses the above to provide actual POR rate, position, and attitude data
- Processes commanded POR translational rates for display
- Uses computed POR position and attitude data in control algorithms to define the position of arm

Section 6: RMS Software

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

Software Mode

RMS software modes are classified as either a non-requested mode or requested mode. The nonrequested modes are suspend mode, temperature monitor mode, and idle mode. The requested modes are manual augmented modes, automatic modes, single mode, and test mode.

Suspend Mode

The software is in the suspend mode whenever the I/O with the MCIU is shut down. Entry to this mode is caused by an MCIU-to-GPC communication error, an item 6 on SPEC 94, or by placing the RMS POWER switch to OFF or BACKUP. Exit is permitted only to idle and temp modes and is accomplished by the operator's reinitiating the I/O via item 5 on SPEC 94.

Temperature Monitor Mode

Temperature monitor mode is a noncommanding mode wherein MCIU- GPC communication is established but no arm is selected for operation. Only temperature data is processed. Exit is permitted only to idle mode and is accomplished by powering an arm for operation.

Idle Mode

The software enters idle mode when MCIU-GPC I/O is established, an arm has been selected, and one of the following occurs: hardware safing, software stop, or all brakes on. In idle mode, the commanding function of the RMS software is to command all joint angle rates to zero and all current limit attenuation to zero. All monitoring functions are still performed.

Manual Modes

There are four manual modes of operation: Orbiter unloaded, EE, Orbiter loaded, and payload. The RMS software is in the manual mode whenever one of the four manual augmented control modes is selected and accepted by the RMS software. Each manual mode is a POR-rate commanding mode wherein joint motors respond in unison to inputs from the hand controllers.

Automatic Modes

The RMS software is in the automatic mode whenever operator command mode or one of the four auto modes is selected and accepted by the RMS software. Each automatic mode is a POR-rate commanding mode where individual joint commands are generated by the RMS software based on either prestored or operator-designated sets of position and attitude coordinates.

Mode Entry Requirements

The following are the requirements for entry into non-requested software modes:

- Suspend mode
  - GPC/MCIU I/O not active
- Temperature monitor mode
  - RMS POWER switch to PRIMARY
  - GPC/MCIU I/O active
  - Neither arm powered (selected)
- Idle mode
  - RMS POWER switch to PRIMARY
  - GPC/MCIU I/O active
  - Port or starboard arm powered (selected)
  - Hardware safing, brakes on, or between control modes

Transition between RMS requested software modes is carried out, provided the following prerequisite conditions are met:

- For all requested modes
  - RMS POWER switch to PRIMARY
  - GPC/MCIU I/O active
  - Port or starboard arm powered (selected)
  - Safing not in progress
  - Brakes off
  - Control mode enter received
- Manual augmented modes
  - RHC and THC in null position
  - The active arm at rest, unless the operator is switching from another manual augmented mode
- Auto modes
  - The active arm at rest
  - The auto sequence PROCEED/STOP switch in its null position
- Single mode
  - The active arm at rest
  - The SINGLE/DIRECT DRIVE switch in its null position
- Test mode
  - RHC and THC in null position
  - The active arm at rest

In addition to modes previously discussed, two submodes exist. These submodes are position-hold modes designed to maintain arm position. During position hold, the GPC commands joint rates to maintain constant joint angles.

Entry into one of the position hold submodes occurs during the following conditions:

- For both submodes
  - RMS POWER switch to PRIMARY
  - GPC/MCIU I/O active
  - Port or starboard arm powered (selected)
  - Safing not in progress
- Idle mode - position hold
  - Software in idle mode
  - Brakes off
- Manual augmented mode - position hold
  - RHC and THC in null position
  - The active arm at rest

Principal Functions

The RMS software subsystem is divided into principal functions (figure 6-1) which perform the required mathematical and logical operations to support the RMS. The description of the principal functions follows.

Specialist Function Control Segment (RMC)

Activates RMS processing and presents the PDRS CONTROL (SPEC 94) on the Orbiter cathode-ray tube (CRT). While active, the RMC monitors for valid keyboard inputs.

Item Processor (RUD)

Accomplishes initialization of the RMS software in response to item entries from the RMS SPEC display.

RMS Executive (REX)

Provides I/O management and configuration control for the RMS software system. The six basic functions of the REX are the following:

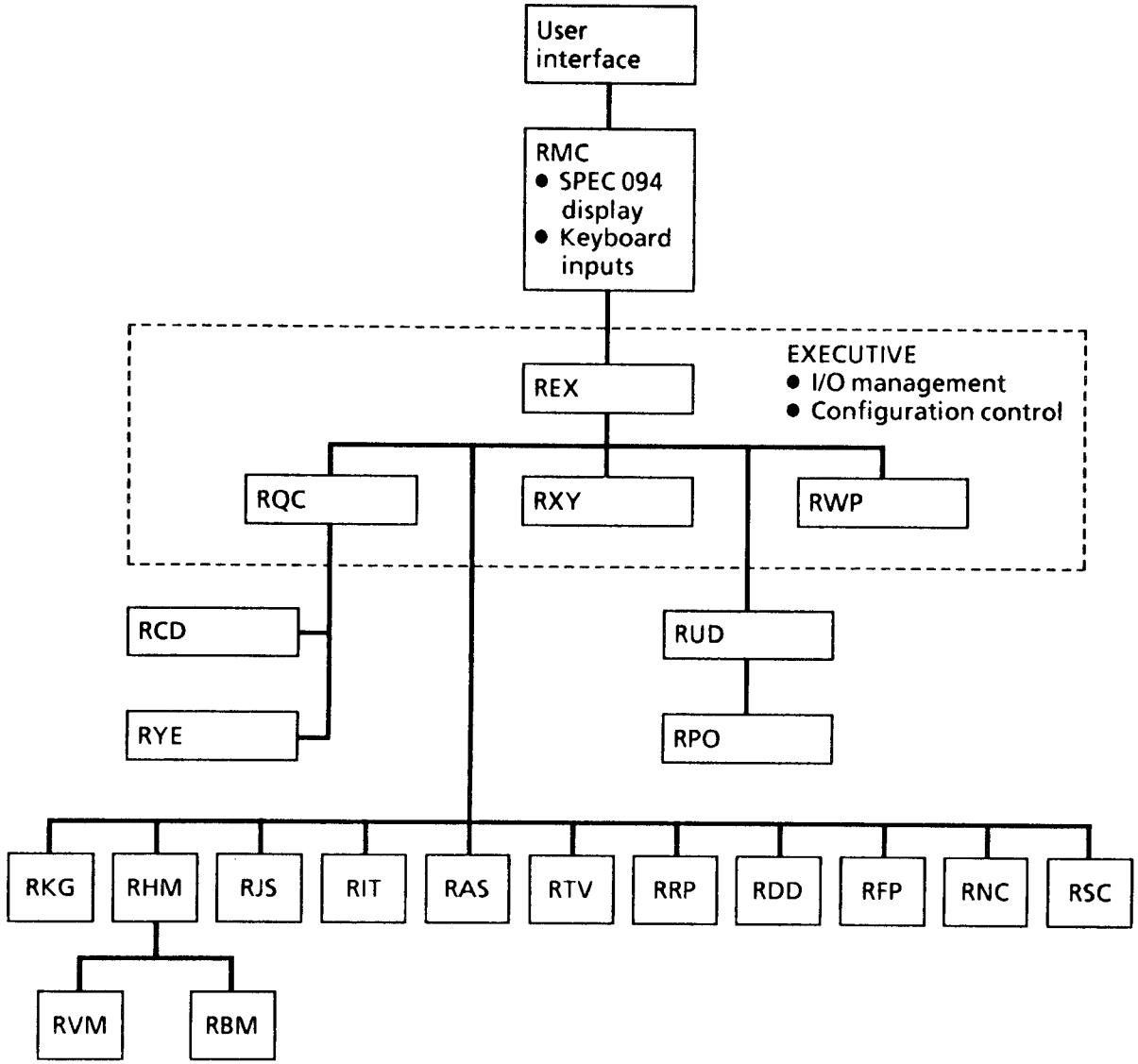
- First pass initialization
- Item input processing
- MCIU input and error control
- RMS configuration validation and control
- RMS configuration function sequencing
- MCIU output

MCIU Output Decoder (RCD)

Performs any necessary scaling, biasing, and special conditioning required to make MCIU-to-GPC software formats compatible with floating point operation.

Data Conversion Processor (RYE)

Processes hand controller signals, joint rates, and joint positions and converts thermistor unit readings to degrees Fahrenheit.



TD386*016

Figure 6-1.– Principal functions.

Kinematic Data Generator (RKG)

Performs the following functions:

- Computes sines and cosines of the arm joint angles
- Computes rotational matrices
- Derives the POR position and attitude from the joint angle data
- Performs singularity proximity processing

Single Joint Control (RSC)

Allows an operator to operate a single joint while the other joints hold their last commanded positions, via the JOINT select switch and the SINGLE/DIRECT DRIVE switch.

Resolved Position Algorithm (RPO)

Validates operator command mode sequences as a prerequisite to their execution.

Automatic Sequence Processor (RAS)

Validates and oversees the operation of RMS automatic sequences.

Resolved Rate Processor (RRP)

Resolves arm reference, system-commanded, EE translation and rotation rates into joint-angle rate commands; provides rate limiting for the latter; and manages mathematical control of singularities when they occur.

Total Velocity (RTV)

Computes the instantaneous components of the actual and commanded EE rotation and translation rates in the appropriate reference systems for display. It also computes the resultant of the actual and commanded EE translation rate components.

Position Hold (RFP)

Allows the RMS to hold joint angles at constant values. It commands the joint rates needed to maintain these constant values.

Health Monitor (RHM)

Audits the state and performance of joint angle and joint angle rate measurements, commanded joint angle rates, tachometer readings, and various software flags and hardware discretes in order to determine the inconsistencies or errors among these inputs. Should a discrepancy be found, the RHM sets the appropriate flag or discretes required for annunciation.

Temperature Processor (RIT)

Monitors temperature data derived from sensors located in the arm components to detect and annunciate out-of-limit conditions. It also determines the temperature (CRIT TEMP) which is out of limits by the largest amount.

Dedicated Display (RDD)

Converts data into the formats required to drive the two EE translation rate meters and the three digital readout monitors on panel A8U.

Hand Controller (RJS)

Converts hand controller deflections into POR commands, interprets rate hold requests and subsequent hand controller inputs, limits resultant end-effector rate commands, and transforms those commands from the coordinate system selected by the operator to the arm reference system.

Encoder Function (RNC)

Chooses the current limits that are used for the joint motors, calculates the joint motor speeds, performs test word processing, packs the fault word for downlist, and converts these and other scaled quantities to the MCIU fixed point formats.

Input Processing and Configuration Determination (RQC)

Reads and processes MCIU input data and performs configuration determination.

Configuration Initialization (RXY)

Performs initialization based on the configuration requested.

Position Hold Checks (RWP)

Determines whether position hold is requested and modifies the dispatcher-tables execution of the position hold (RFP) module.

Consistency and Encoder Checks (RVM)

Checks for a suspected joint runaway and determines if encoder position data is valid. It sets the flags for appropriate annunciation of faults via the caution and warning system.

Hardware Fault Annunciation Filtering (RBM)

Filters hardware BITE parameters for failures. When a failure is detected for at least two cycles, flags are set for fault summary page annunciation.

Section 7: Control Modes and Miscellaneous Topics

This section will focus on operating the RMS. Use of the available operating modes will be discussed as well as suggested techniques for "flying" the RMS using the manual augmented control modes. Singularities and reach limits will be covered and also some operational safety concerns.

Automatic Modes

This discussion will primarily be directed toward auto modes 1 through 4, since operator command mode was covered in section 3. Auto modes 1 through 4 are used to execute different automatic sequences. Up to 200 points divided into as many as 20 sequences may be stored in the software. This data is I-loaded premission. To access one of the sequences, the sequence must be assigned to one of the auto modes. This is done on SPEC 94 using items 13 through 16. For example, to assign automatic sequence 11 to auto mode 2, the operator would enter an item 14 plus 11 on SPEC 94.

After an automatic sequence has been assigned to one of the auto modes, the arm must be driven to the desired starting point in that sequence. The desired starting point is identified by item 17 on SPEC 94. Any point in the sequence can be used as the starting point. The arm can be driven to the starting point either manually or by using an operator commanded auto sequence (OCAS). Once the arm is at the starting point, the mode can be entered and the READY light will come on. The requirements for getting a READY light to execute an automatic sequence are

- RMS POWER - PRIMARY
- RMS I/O - ON
- RMS SELECT - PORT
- Safing - not in progress
- Auto sequence assigned to an auto mode via SPEC 94
- Starting point identified via SPEC 94
- Arm positioned at starting point
- Brakes - OFF
- The AUTO SEQ PROCEED/STOP switch in its center position
- No arm motion
- Mode enter received

If all the above conditions have been met, the automatic sequence is ready to be executed. Placing the momentary PROCEED/STOP switch to the PROCEED position begins execution of the automatic sequence, causes the READY light to extinguish, and turns the IN PROG light on. There are two types of points in an automatic sequence: pause points and fly-by points. At a pause point, the arm will stop, the IN PROG light will extinguish, and the READY light will come back on. To continue, the PROCEED/ STOP switch must again be deflected to the PROCEED position. At a fly-by point, the arm will go on to the next point in the sequence and not stop.

Methods available to stop arm motion during an automatic sequence are the same as those for stopping the

arm during an OCAS. For all automatic modes, the arm can be stopped by using the PROCEED/STOP switch, changing the position of the MODE select switch, placing the SAFING switch to the SAFE position, placing the BRAKES switch to the ON position, placing the RMS SELECT switch to the OFF position, or placing the RMS POWER switch to the OFF position. Stopping the arm during an auto mode sequence with the PROCEED/STOP switch will result in the arm motion stopping, the READY light coming back on and the IN PROG light extinguishing. Stopping the arm during an auto mode sequence using any method other than the PROCEED/STOP switch will result in exit from the auto mode and loss of the READY light when the mode is reentered. Stopping the arm during an OCAS has the same effect as during an auto sequence for all methods except that when operator command mode is reentered, the READY light will come on.

If the software drops out of mode for any reason during an auto mode sequence the arm must again be driven to a starting point corresponding with the starting point selected on SPEC 94. If the arm is positioned at one of the points in the sequence, that point can be entered as the starting point and the sequence can proceed from that point.

Listed below is an example of a flight data file (FDF) procedure for performing an automatic sequence. The example is from mission STS 51-F.

RMS 'X' AUTO TRAJECTORY

```
CRT          ¦SM 94 PDRS CONTROL¦
             PL ID - ITEM 3 +1 EXEC
             PL INIT ID - ITEM 24 +1 EXEC
             AUTO MODE - ITEM 13 +1 EXEC

             OPR CMD to pt 1
- - - - - - - - - - - - - - - - - - - - - - - - - - - -
        -800,    -60,    -800,    135,     0,    90
- - - - - - - - - - - - - - - - - - - - - - - - - - - -
        SY   ¦   SP   ¦   EP   ¦   WP   ¦   WY   ¦   WR
       -30.9 ¦ +118.8 ¦ -90.1 ¦ -63.3 ¦ -54.0 ¦ -144.2
                              or
                            +215.8

        MODE - AUTO 1, ENTER (READY lt-on)
- - - - - - - - - - - - - - - - - - - - - - - - - - - -
pt 1     -800,  -60,  -800,  135,   0,  90 (INITIAL)
- - - - - - - - - - - - - - - - - - - - - - - - - - - -
        AUTO SEQ - PRO (IN PROG lt-on)
       ✓Moves: AFT

- - - - - - - - - - - - - - - - - - - - - - - - - - - -
pt 2     -1050,  -60,  -800,  135,   0,  90   (PAUSE)
- - - - - - - - - - - - - - - - - - - - - - - - - - - -
        AUTO SEQ - PRO (IN PROG lt-on)
       ✓Rotates only

- - - - - - - - - - - - - - - - - - - - - - - - - - - -
pt 3     -1050,  -60,  -800,  45,   0,  90   (FLYBY)
- - - - - - - - - - - - - - - - - - - - - - - - - - - -
        then,
       ✓Moves: FWD

- - - - - - - - - - - - - - - - - - - - - - - - - - - -
pt 4     -800,  -60,  -800,  45,   0,  90     (PAUSE)
- - - - - - - - - - - - - - - - - - - - - - - - - - - -
        AUTO SEQ - PRO (IN PROG lt-on)
       ✓Rotates only

- - - - - - - - - - - - - - - - - - - - - - - - - - - -
pt 5     -800,  -60,  -800,  135,   0,  90    (FINAL)
- - - - - - - - - - - - - - - - - - - - - - - - - - - -
        ✓AUTO SEQ lts - off
         BRAKES - ON (tb-ON)
```

Manual Augmented Modes

Manual augmented modes of control enable the operator to direct the POR using two three-degree-of-freedom hand controllers to provide POR translation and rotation rate demands. The control algorithms process the hand-controller signals into a rate demand to each joint of the arm. The operator can carry out manual augmented control of the arm using one of the following four coordinate reference systems:

- Orbiter unloaded
- End effector
- Orbiter loaded
- Payload

For all manual augmented modes, vernier rates should be used whenever the arm/payload structure is close to the Orbiter/payload structures.

Orbiter unloaded mode is used to maneuver the unloaded arm around the payload bay. See figure 7-1. Out-of-the-window visual cues are the main source of information used to determine hand controller inputs. Maximum POR operating rate limits in Orbiter unloaded mode are 2.0 ft/sec translational and 4.76 deg/sec rotational with coarse rates selected and 0.35 ft/sec and 4.76 deg/sec rotational with vernier rates selected.

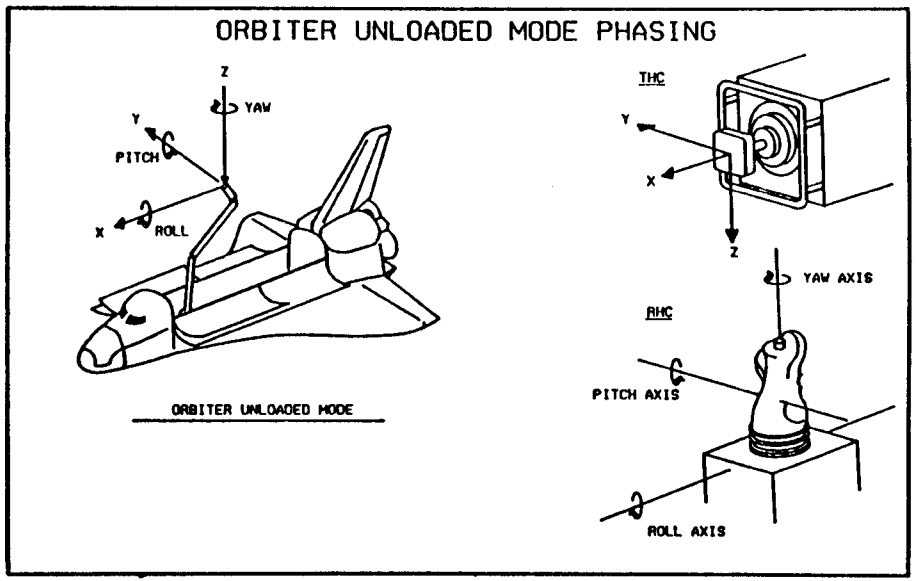


Figure 7-1.– Orbiter-unloaded mode phasing.

EE mode is used to complete the grappling of a payload. See figure 7-2. The RMS wrist CCTV camera provides the most useful information for determining hand controller inputs. Out-of-the-window and other CCTV camera views can also be useful in determining EE distance to the grapple fixture. The normal grapple is accomplished by first maneuvering the arm in Orbiter unloaded mode using out-of-the-window visual cues until the RMS wrist CCTV camera has the grapple fixture in its field of view. EE mode is then selected, and any misalignment to the grapple fixture is then corrected and the grapple is completed. The same operating rate limits exist for EE mode as those for Orbiter unloaded.

Orbiter loaded mode is used to maneuver a payload after it has been grappled by the RMS. See figure 7-3. Visual cues for determining hand controller inputs can range from only payload-bay-mounted CCTV cameras to only out-of-the-window views. The size of the payload and the configuration of the payload bay determine which visual cues provide the most information about payload position. Operating rate limits are dependent upon payload mass and are selected by item 3 on SPEC 94, payload ID.

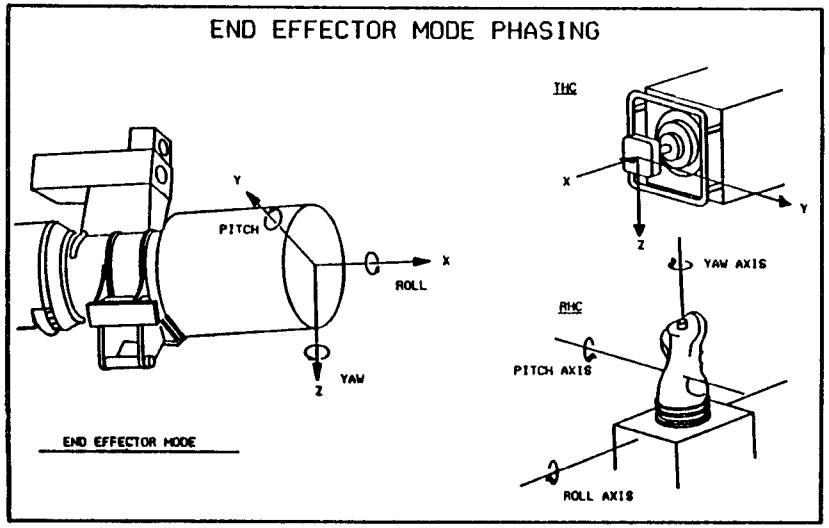


Figure 7-2.– EE mode phasing.

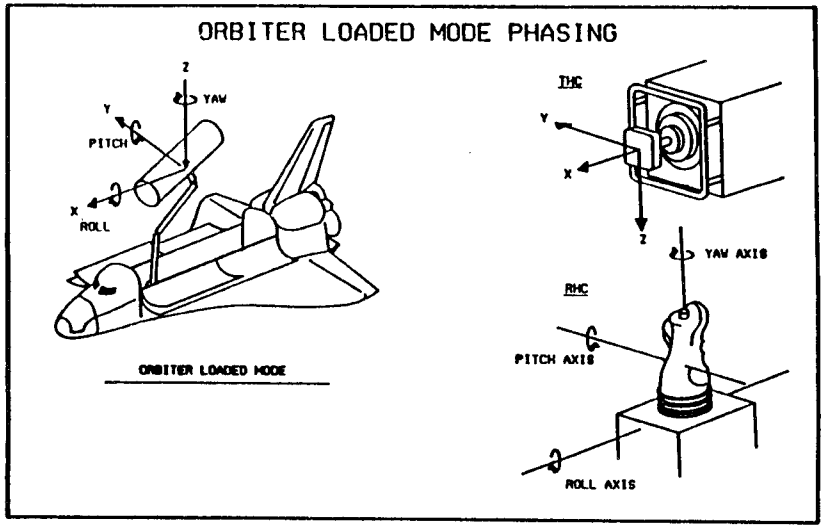


Figure 7-3.– Orbiter-loaded mode phasing.

Payload mode is used to maneuver a payload to point a particular axis of the payload at something or to move the payload along a path parallel to one of its axes. See figure 7-4. Out-of-the-window visual cues are the main source of information used to determine hand-controller inputs. Maximum rate limits are based on the same criteria and payload ID as Orbiter loaded mode.

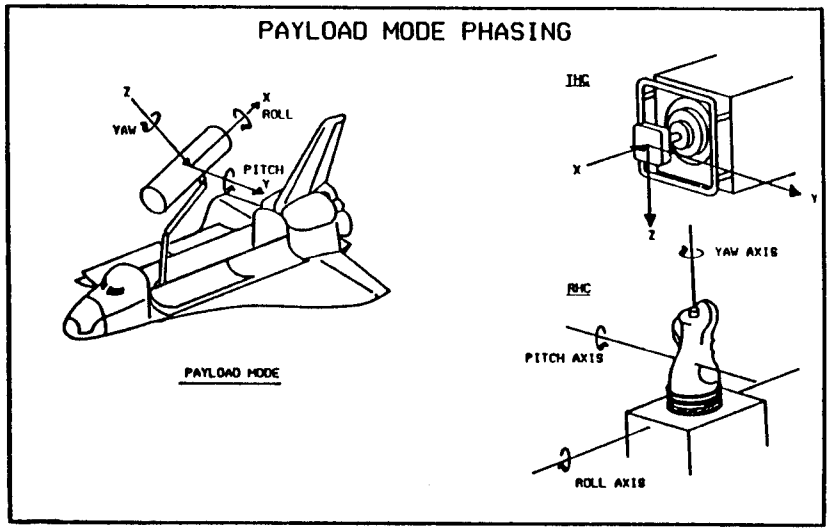


Figure 7-4.– Payload mode phasing.

Hand-Controller Use

Because of its size and shape and the nature of its control system, the remote manipulator arm becomes very dynamic when commanded to move and can generate large oscillations in response to various commands. Improper use of the RMS hand controllers can cause additional unwanted perturbations to the system. This can result in pilot-induced oscillations (PIOs) which might adversely affect what the operator is trying to accomplish with the arm.

To avoid adverse arm response, the operator must maintain proper inputs while using the RMS hand controllers during all manual augmented mode operations. The recommended method for using the RMS hand controllers is to provide rate commands using smooth gradual inputs rather than pulse inputs. All commands should be ramped in and out slowly. To cause the POR to move a small distance, the hand controllers should be deflected in the required direction a small amount and held until the desired response is achieved. Typically, untrained operators will try to use pulse inputs in a manner similar to making inputs using the SINGLE/DIRECT DRIVE switch to achieve small movements. Using pulse inputs on the hand controllers is what causes PIO and also may result in unwanted cross-coupling.

Position and Attitude Display Data

The position or the attitude of the POR can be displayed on the RMS digital display LEDs by selecting either position or attitude using the PARAMETER select rotary switch. The position of the POR is given in the Orbiter body axis reference frame. The origin for X, Y, and Z is located at the tip of the ET, and the POR position is displayed in inches measured back from that point. The

attitude is a little more complicated and is often the source of some confusion.

The attitude displayed on the RMS LEDs is always the POR attitude with respect to the Orbiter rotation axis reference frame. For an unloaded arm, the POR is the tip of the EE. The display attitude shows the degrees of pitch, yaw, and roll that the EE has been moved away from the defined zero, zero, zero attitude starting point (the cradled position). For a loaded arm, the POR is payload dependent (based on payload ID, item 3 on SPEC 94). The display attitude shows the degrees of pitch, yaw, and roll that the payload has been moved away from the defined zero, zero, zero attitude starting point. For most payload IDs, the zero, zero, zero attitude position is the berthed position for that payload. The POR attitude is always displayed in a pitch, yaw, roll Euler sequence.

The attitude display data is based on POR, not operating mode. A roll input in Orbiter unloaded or Orbiter loaded modes might not necessarily change only the roll attitude of the POR. Recall that for Orbiter unloaded and Orbiter loaded modes RHC inputs always command a rotation of the POR about X-, Y-, and Z- axes that are parallel to the Orbiter X-, Y-, and Z- axis system. Dependent upon what attitude the POR is in, RHC inputs in the Orbiter modes may or may not directly change the corresponding attitude on the attitude display. EE and payload modes are a little different. In both EE and payload modes, RHC inputs always command a rotation of the POR about its own X-, Y-, and Z- axis system. EE and payload modes can be used to more directly change the displayed attitude of the POR.

Singularities

There are three singularity conditions recognized by the RMS software. A singularity occurs when the RMS joints are configured in such a way as to cause a degree of freedom of motion to be lost. When the RMS is driven into one of the singularity regions, the operator is warned of this condition by an RMS MASTER ALARM light and tone, a singularity light on the RMS D&C panel, and an SM message on the CRT. The operator is not required to avoid these situations. The warning is given to inform the operator that unexpected motion may occur as the software issues a set of joint rates that reconfigure the arm to allow the POR to go where it is being commanded.

The operational constraints associated with singularities are that the DAP should be in VRCS or free drift, and no attempt should be made to grapple a payload while in a singularity.

Travel Limits

There are three defined limits of travel for each joint on the arm: reach limits, softstops, and hardstops. Reach limits and softstops are limits recognized by the RMS software and are defined premission. Hardstops are the physical limits of travel for each joint. Figure 7-5 shows the location of each limit for all six joints.

As the arm is moved into the region of a reach limit for one of the joints, the operator is warned of the situation by an RMS MASTER ALARM light, a Reach Limit light, and an SM message. Additionally, SPEC 96 will contain a " + " or a "-" under the appropriate joint depending on the direction the joint has been driven. These indications should be interpreted as a warning that one or more of the joints is about to reach its end of travel. The RMS software will stay in mode and accept further commands. Typically, if the same commands are input, the affected joint will drive into the softstop condition.

JOINT TRAVEL LIMIT LOCATIONS

JOINT	REACH LIMIT LOCATION	SOFT STOP LOCATION	MECHANICAL STOP LOCATION	SINGULARITY LOCATION
SHOULDER YAW	+ 175.4° - 175.4°	+ 177.4° - 177.4°	+ 180° - 180°	
SHOULDER PITCH	+ 2.6° + 140.4°	+ 0.6° + 142.4°	- 2° + 145°	
ELBOW PITCH	- 2.4° - 155.6°	- 0.4° - 157.6°	+ 2.4° - 161°	-7.6
WRIST PITCH	- 114.4° + 114.4°	- 116.4° + 116.4°	- 121.4° + 121.4°	
WRIST YAW	- 114.6° + 114.6°	- 116.6° + 116.6°	- 121.3° + 121.3°	-75/-105 +75/+105
WRIST ROLL	- 440.0° + 440.0°	- 442° + 442°	- 447° + 447°	

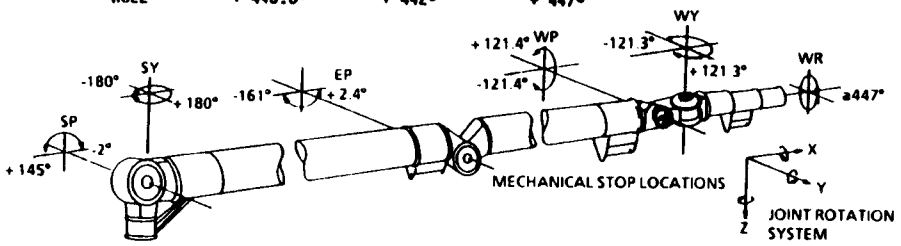


Figure 7-5.– Joint travel limit locations.

Driving one or more of the joints into the softstop region results in the RMS software's dropping out of the selected operating mode into idle mode. The only computer supported mode which can be reentered is single mode. To drive out of a softstop, single mode must be entered and the affected joint(s) driven out of the softstop region. Direct and backup modes can be used as well, but single mode is the preferred method. Once out of the softstop, all operating modes again become available for use.

If RMS operations for some reason dictate the need to drive a particular joint past the softstop region using a manual augmented control mode, the softstop function can be inhibited by executing an item 8 on SPEC 94. This must be done after the desired mode has been entered and before reaching the softstop. The softstop function works like this: while in a softstop with the brakes off, depressing the ENTER pushbutton in any mode other than single or direct causes the softstop to be enabled (item 7 with an asterisk) and does not allow the software to enter the requested mode. Depressing the ENTER pushbutton under the same circumstances with single mode selected will cause the softstop function to alternate between inhibit and enable (items 8 and 7, respectively, on SPEC 94) every time the ENTER pushbutton is pressed.

Operational Safety

The RMS was designed to be fail safe instead of fail operational. To meet this criterion, the brakes are designed to work on a power-on, brakes-off basis. Additionally, all joint rates are selected so that the arm will come to rest in under 2 feet when the brakes are placed on at full operating rates.

The primary safety concern is structural contact during RMS operations, since there is no collision avoidance logic built into the RMS software. Collision avoidance is always the responsibility of the RMS operator. This includes contact between the RMS and the Orbiter, the RMS and any payload, and the RMS/payload and the Orbiter. To help avoid collisions, vernier rates should be used whenever the RMS or RMS/payload is being maneuvered close to the Orbiter or payload structures.

The following are several operational suggestions which will enhance RMS safety:

- Always place the BRAKES switch to the ON position when the RMS is not being used
- Always keep the EE MODE switch in the OFF position except during times of use
- Watch the arm for motion during the following activities:
  - -- Placing the BRAKES switch to OFF
  - -- Entering a requested software mode
  - -- Anytime the RMS is in test mode
- Always use the BRAKES switch to stop the arm in the event of a suspected malfunction

Appendix A: Acronyms and Abbreviations

ABE	arm based electronics
bp	barberpole
C/L	checklist
CAP	Crew Activity Plan
CCTV	closed circuit television
CRT	cathode-ray tube
D&C	display and control
DAP	digital autopilot
EE	end effector
ET	external tank
FDF	flight data file
FPC	forward power controller
FSSR	Flight Systems Software Requirements
GPC	general purpose computer
I/O	input/output
ID	identification
LDB	launch data bus
LED	light emitting diode
LRU	line replaceable unit
MCA	motor control assembly
MCIU	manipulator controller interface unit
MDA	motor drive amplifier
MDF	manipulator development facility
MEC	master events controller
MIA	multiplexer interface adapter
MN	main
MPC	midpower controller
MPM	manipulator positioning mechanism
MRL	manipulator retention latch
NOM	nominal
OCAS	operator commanded auto sequence
OPS	operational sequence operations
PDRS	payload deployment and retrieval system
PDU	power drive unit
PIO	pilot-induced oscillation
POR	point of resolution
RCS	reaction control system
RHC	rotational hand controller
RMS	remote manipulator system
RPC	remote power controller
SES	systems engineering simulator
SM	system management
SMS	Shuttle mission simulator
SPA	servo power amplifier
SRB	solid rocket booster
tb	talkback
TE	tachometer electronics
THC	translation hand controller
VRCS	vernier reaction control system
VTR	video tape recorder

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LESSON CRITIQUE SHEET

LESSON CODE 2102 DATE OF MATERIAL 07/30/88

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

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

2. Comments on handout organization:

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

4. Did the lesson start from your entry level?

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

6. Additions or deletions from the lesson?

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

8. Other comments (or question):