

PDRS Malfunction Workbook

PDRS MAL 2102



Melvin L. Richmond
Head, DPS/Navigation Section



Frank E. Hughes
Chief, Flight Training Branch

April 1988

Mission Operations Directorate
Training Division
Flight Training Branch

Lonnie Cundieff

Contents

Section	Page	Section	Page
1 Introduction	1-1	4.2.1 Runaway	4-3
1.1 Scope	1-1	4.2.2 Sluggish, Frozen, and Free Joints	4-3
1.2 Purpose	1-1	4.2.3 Motion Other Than Commanded	4-4
2 Display and Control	2-1	4.3 C/W Lights	4-5
2.1 Manipulator Controller Interface Unit ..	2-1	4.3.1 MCIU Light	4-6
2.2 SM GPC	2-3	4.3.2 ABE Light	4-8
2.2.1 Special Displays	2-3	4.3.3 CONT ERR Light	4-15
2.2.2 Messages	2-5	4.3.4 GPC DATA Light	4-19
2.3 Questions	2-11	4.3.5 CK CRT Light	4-24
2.4 Answers	2-12	4.3.6 RELEASE Light	4-31
3 Safety Considerations	3-1	4.3.7 PORT TEMP Light	4-32
3.1 Operator Responsibility	3-2	4.3.8 SINGULARITY Light	4-33
3.1.1 Collision Avoidance	3-2	4.3.9 REACH LIMIT Light	4-37
3.1.2 Methods of Stopping the Arm	3-2	4.3.10 DERIGIDIZE Light	4-38
3.2 System Design	3-8	4.4 Questions	4-39
3.2.1 Software Stop	3-8	4.5 Answers	4-40
3.2.2 Auto Brakes	3-8	5 Procedures	5-1
3.2.3 Auto Safing	3-9	5.1 Malfunction Procedures	5-1
3.2.4 Pause or End Point	3-10	5.2 Jettison	5-2
3.3 Questions	3-13	5.3 Back Drive	5-8
3.4 Answers	3-14	5.4 IFM	5-10
4 Failure Detection and Response	4-1	5.4.1 Display and Control Kit	5-10
4.1 Drive Times	4-1	5.4.2 Contingency Powerup	5-11
4.1.1 End Effector	4-2	5.4.3 MPM Deploy/Stow	5-11
4.1.2 Manipulator Positioning Mechanism ..	4-2	5.4.4 MRL Release/Latch	5-12
4.1.3 Manipulator Retention Latch	4-2	5.4.5 MCIU Changeout	5-12
4.1.4 Shoulder Brace Release	4-2	5.5 EVA	5-12
4.2 Arm Reaction	4-3	5.5.1 Joint Alignment	5-13
		5.5.2 MPM Deploy/Stow	5-13
		5.5.3 Tiedown	5-13

Section	Page
5.5.4 Shoulder Brace Release	5-14
5.6 Questions	5-15
5.7 Answers	5-16
6 Orbiter Failure Effects	6-1
6.1 EPS	6-2
6.2 DPS	6-19
6.3 RCS	6-22
6.4 OI	6-22
6.5 CCTV	6-25
6.6 Questions	6-26
6.7 Answers	6-27
Appendix A	A-1

Tables

Table	Page
6-1 MPM motor requirements	6-9
6-2 MPM stow and deploy microswitch status requirements	6-9
6-3 MRL motor requirements	6-15
6-4 MRL latch and release microswitch status requirements	6-15
6-5 MRL RTL microswitch status requirements	6-15
6-6 Electrical power bus loss	6-16
6-7 REF DATA memory locations	6-20
6-8 RMS, MDM and DSC list	6-23

Figures

Figure	Page	Figure	Page
2-1 C/W Lights	2-2	5-1 Arm jettison locations	5-3
2-2 SPEC 94	2-3	5-2 Wire bundle guillotine	5-4
2-3 SPEC 96	2-3	5-3 MPM separation plan	5-5
2-4 Panel A8U	2-7	5-4 Pressure-activated retractor assembly ...	5-5
2-5 Panel MA73C	2-7	5-5 Guillotine and jettison PIC	5-7
2-6 Panel A8L	2-8	5-6 Shoulder and elbow backdrive	5-8
2-7 Panel ML86B	2-9	5-7 Wrist pitch backdrive	5-9
2-8 Panel A14	2-10	5-8 Wrist yaw backdrive	5-9
		5-9 IFM breakout box	5-11
3-1 Brakes and servo loops	3-3		
3-2 Safing switch logic	3-7	6-1 RMS power	6-3
3-3 MCIU safing logic	3-11	6-2 Primary RMS power	6-4
		6-3 Backup RMS power	6-5
4-1 MCIU light logic	4-6	6-4 Backup RMS	6-6
4-2 ABE light logic	4-9	6-5 MPM system 1	6-7
4-3 RMS component data flow	4-10	6-6 MPM system 2	6-8
4-4 Control error light logic	4-15	6-7 Forward MRL	6-10
4-5 Envelope check	4-16	6-8 Mid MRL	6-11
4-6 Servo and drive system	4-17	6-9 Aft MRL	6-12
4-7 GPC data light logic	4-19	6-10 MRL microswitches and talkback	6-13
4-8 Check CRT light logic	4-25	6-11 MRL RTL microswitches and talkback	6-14
4-9 Active thermal control system	4-30		
4-10 Singularity conditions	4-33		
4-11 Shoulder yaw singularity	4-34		
4-12 Wrist yaw singularity	4-35		
4-13 Planar pitch singularity	4-36		
4-14 Reach limits, softstop, hardstop	4-37		

Section 1: Introduction

The Payload Deployment and Retrieval System (PDRS) components are designed to do a prescribed set of tasks in a harsh environment. The design criteria obviously are couched in the legacy of precision and reliability and the flight histories bear out a valid claim of success. This achievement is made notable by the fact that the PDRS design does not enjoy the comfort of extensive redundancy as found in most other space vehicle systems. Things can stop working; they can change in their operating characteristics.

Those who operate the PDRS and those who monitor and control its use must know what can go wrong, how to identify a failure, and what operational capability remains. This knowledge is gained by studying both the positive and negative aspects of PDRS operation.

The terms PDRS and Remote Manipulator System (RMS) are used interchangeably and mean essentially the same thing.

1.1 Scope

The positive aspects of RMS operation are covered in other media. Those media detail the systems and interfaces that are necessary for a correctly-working RMS. That aspect of the RMS will be referenced only briefly in this book. The PDRS Malfunction Workbook will address those topics that relate to the recognition of, identification of, and response to, RMS failures. The information contained in this book is taken, in part, from previously-

published books, drawings, briefing handouts and data prints.

This book should not be considered as a design authority and should not be considered as a complete statement on the subject of RMS malfunction cases. This book is intended to be a reference tool of functional level system descriptions for those interested in gaining an introductory level of knowledge on the subject.

1.2 Purpose

The PDRS Malfunction Workbook is presented as a training manual, providing sufficient information on the subject to assist in the preparation by its reader to participate as a student or instructor in the classroom and simulator environment. The book provides a description of failure detection and response, in the form of narrative, functional drawings, data tables and figures. The material is presented to the RMS student on a level that coincides with the book's position in the training and certification flows.

Section 2: Display and Control

The RMS displays and controls, in conjunction with an Orbiter cathode-ray tube (CRT) display and keyboard, provide the interface between the operator and the RMS subsystems. The display and control (D&C) subsystem provides the operator the capability to set up, support, checkout, operate and monitor the RMS during normal and contingency modes of operation. See figures 2-1, 2-4, 2-5, 2-6, 2-7 and 2-8 for D&C panels used during RMS operations. The panels are referred to throughout the workbook and are located at the end of this section for reference.

The supporting interface provided by the Orbiter CRT and computer keyboard provides access to the general purpose computer (GPC), which enables the operator to configure and initialize the RMS software for RMS checkout and operation, and display RMS data which cannot be displayed at the D&C.

2.1 Manipulator Controller Interface Unit

The RMS has a built in test equipment (BITE) system to detect and annunciate the occurrence of failures in the system. Not all failures are detected by the BITE. However, most critical failures are detected and undesirable arm motion is automatically stopped. All BITE functions, along with software-implemented system health checks, result in the illumination of one or more caution and warning (C/W) lights on panel A8U along with the master alarm light and tone. The system provides messages on

the fault summary page and individual failure identification on SPEC 96. (Refer to figure 2-3.)

All raw hardware BITE processing is performed by the manipulator controller interface unit (MCIU) microcomputer before being transmitted to the GPC for display and downlisting. The MCIU processes the BITE data to provide a signal to one or more of the C/W lights.

The D&C panel contains six caution and five warning annunciators to indicate the fault conditions. Additionally, a master alarm light and audio tone are provided to attract the operator's attention whenever a fault condition is detected. There are electro-mechanical flags, or talkbacks, provided to indicate safing and software stop conditions.

The master alarm activation is initiated either by the GPC (by sending a single-cycle pulse signal to the MCIU, which in turn transmits it to the D&C panel on a hardwire as a single-cycle pulse) or by the MCIU on the hardwire as a single-cycle pulse. The D&C electronics subsystem is designed to latch up to this pulse and activate the annunciator and audio simultaneously. The operator may at any time cancel both the annunciator and the audio by depressing the master alarm pushbutton. The master alarm system is designed such that if additional faults occur that result in a caution or a warning annunciator already lit, the master alarm and the audio get activated again if previously cancelled by the operator.

The following six lights of the C/W annunciator block are caution annunciators:

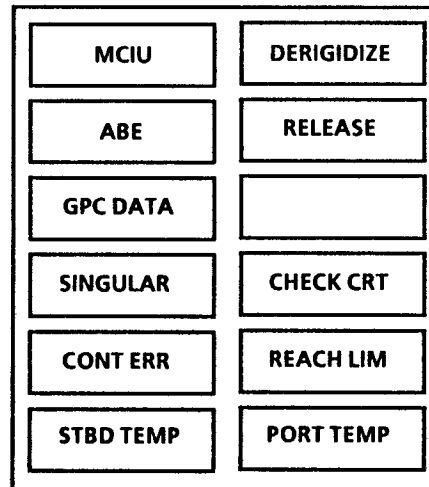
- SINGULAR
- CONT ERR
- STBD TEMP
- CHECK CRT
- REACH LIM
- PORT TEMP

The upper six lights on the annunciator block are warning indicators. Each one, when activated, indicates that the operator is required to take specific corrective action. Currently, one of the six annunciators is a spare.

- MCIU
- ABE
- GPC DATA
- DERIGIDIZE
- RELEASE

The conditions necessary to activate the C/W annunciators will be discussed in section 4.

4



TD385*204*001

Figure 2-1.- CIW lights.

2.2 SM GPC

The GPC checks cover an overall examination of each joint's behavior through the consistency check, encoder data validity and end effector behavior. It also checks the proximity of the arm to reach limits, software stops and singularities. These checks are carried out in the GPC as the System Health Monitor Function. Communication of the GPC with the MCIU is evaluated by the GPC. The temperatures of the various parts of the arm monitored by thermistors are also checked by the GPC. All the data from the MCIU is used for some special purpose. This ranges from calculating joint drive commands, verifying RMS component operation, displaying data to the arm operator and providing selected data for downlist.

2.2.1 Special displays

The GPC has two displays available for use to view data generated for a correctly-operating RMS and to see indicators of an incorrectly-operating RMS. These displays, SPEC 94 PDRS CONTROL and SPEC 96 PDRS STATUS, are shown in figures 2-2 and 2-3.

```

XXXX/094/      PDRS CONTROL  XX X DDD/HH:MM:SS
                DDD/HH:MM:SS
RMS SEL: XXXX  RMS PWR XXX  ENA INH
  PRT 1X      SOFT STOP 7X 8X
  STBD 2X     AUTO BRAKE 9X 10X
  3 PL ID XX  POS ENC CK 11X 12X
  4 END EFF X

                AUTO MODES
                1 2 3 4 17 START PT XXX
                13 XX 14 XX 15 XX 16 XX  LASTI PT XXX

                OPR CMD MODES
                END ATT 24 PL INIT ID XX
18 X ( ) XXXX 21 P ( ) XXXX
19 Y ( ) XXXX 22 Y ( ) XXXX  CMD CK 25 XXXX
20 Z ( ) XXXX 23 R ( ) XXXX

RHS SHLD STD/DPLY 26 WR RANGE X
  X X X X  AUTO BRAKE CK 27X

RHS  LAT/REL/RDY
AFT  X X X X X X
HID  X X X X X X
FWD  X X X X X X

                (XX)
  
```

TD3850027. ART, 1

Figure 2-2.- SPEC 94.

```

XXXX/XXX/096  PDRS STATUS  XX X DDD/HH:MM:SS
                DDD/HH:MM:SS
RMS SEL: XXXX
                X/P      Y/Y      Z/R
TRANS RATES ACT ±XX.XXS  ±XX.XXS  ±XX.XXS
                CMD  ±XX.XX   ±XX.XX   ±XX.XX
  ROT RATES ACT ±XX.XXS  ±XX.XXS  ±XX.XXS
                CMD  ±XX.XX   ±XX.XX   ±XX.XX
 POSITIONS ACT  ±XXXXXS  ±XXXXXS  ±XXXXXS
 ATTITUDES ACT  ±XXX.XS   ±XXX.XS  ±XXX.XS

                RMS FAULTS
                JOINTS SY SP EP WP WT WR
REACH LIMIT X X X X X X MCIU MADC X
ABE - TACH X X X X X X MCPC X
  SPA X X X X X X ICF X
  MTR DR X X X X X X ABE/MCIU
  MTR PWR X X X X X X CHECK CRT:
CONTROL ERR X X X X X X END EFF X
CK CRT- POS X X X X X X TEMP CKT X
                D&C/MCIU X

                (XX)
  
```

TD3850028. ART, 1

Figure 2-3.- SPEC 96.

The data relating to a correctly-operating RMS on these displays are discussed in other documents. The RMS FAULTS, located at the bottom of SPEC 96, are parameters that are monitored to ensure proper operation of the RMS. The status of these parameters is displayed when an anomaly has been detected for one or more of the six joints.

- REACH LIMIT is an indication that a joint has exceeded its allowable angular limit. See figure 4-14 for the reach limit values. The status text output is a +, - or is blank.
- ABE is an indication of a failure detected within one or more of the arm-base electronic (ABE) components: tachometer, servo power amplifier, motor drive amplifier, and joint power conditioner. The status text output is a down arrow or blank.
- CONT ERR indicates that the actual motion of a joint deviates from what has been commanded. The status text output is a down arrow or blank.
- CK CRT-POS indicates that one of the joint position encoders has failed. The status text output is a down arrow or blank.

The operator would view the RMS faults in the lower right corner of the display for a more specific identification of the status type of failure that has been detected in conjunction with the C/W lights on panel A8U. The status text displayed is a down arrow or blank.

- MADC indicates an inability to properly gather analog data and convert it into digital information.
- MCPC indicates an MCIU or D&C power conditioner failure.
- ICF indicates an anomaly has occurred during the verification of data handled by the intercomputer (IC).
- ABE/MCIU indicates a failure of valid data communication between the ABE and MCIU.
- CK CRT - END EFF indicates that the MCIU has detected a failure in the end effector unit (EEU) or a miscompare condition with the end effector (EE) microswitches.
- CK CRT - TEMP CKT indicates a failure or out-of-tolerance condition in the thermistor circuit.
- CK CRT - D&C/MCIU indicates a failure of valid data communication between the D&C panel and the MCIU.

2.2.2 Messages

When the MCIU detects an anomaly, it communicates this fact to the GPC; the GPC then communicates this fact and anomalies it detects to the operator. One method it uses was described in the previous subsection. Another method is to provide a message on the fault summary page and on the message line of the CRTs when the line is blank. These messages are associated with one or more of the C/W lights on panel A8U and are accompanied by an SM ALERT light and tone. The messages, and the associated C/W light are as follows:

- MCIU light

PDRS.MCIU MADC
PDRS MCIU MCPC
PDRS MCIU ICF

- ABE light

PDRS ABE SY
PDRS ABE SP
PDRS ABE EP
PDRS ABE WP
PDRS ABE WY
PDRS ABE WR
PDRS ABE JPC1
PDRS ABE JPC2
PDRS ABE COMM

- CONTR ERR light

PDRS CNTL SY
PDRS CNTL SP
PDRS CNTL EP
PDRS CNTL WP
PDRS CNTL WY
PDRS CNTL WR

- GPC DATA light

PDRS GPC

- CHECK CRT light

PDRS HC
PDRS CK CRT T CK
PDRS CK CRT D
PDRS CK CRT EE
PDRS CK CRT SY
PDRS CK CRT SP
PDRS CK CRT EP
PDRS CK CRT WP
PDRS CK CRT WY
PDRS CK CRT WR

- RELEASE light

PDRS REL

- DERIGIDIZE light

PDRS DERIG

- PORT (STBD) TEMP light

PDRS TEMP PORT (STBD)

- SINGULARITY light

PDRS SING SY
PDRS SING WY
PDRS SING EP

- REACH LIM light

PDRS RCH SY
PDRS RCH SP
PDRS RCH EP
PDRS RCH WP
PDRS RCH WY
PDRS RCH WR

Although there is no C/W light associated with wrist roll range anomalies, the GPC will display the "PDRS WR R" message if it detects a failure in the wrist roll range check.

∞

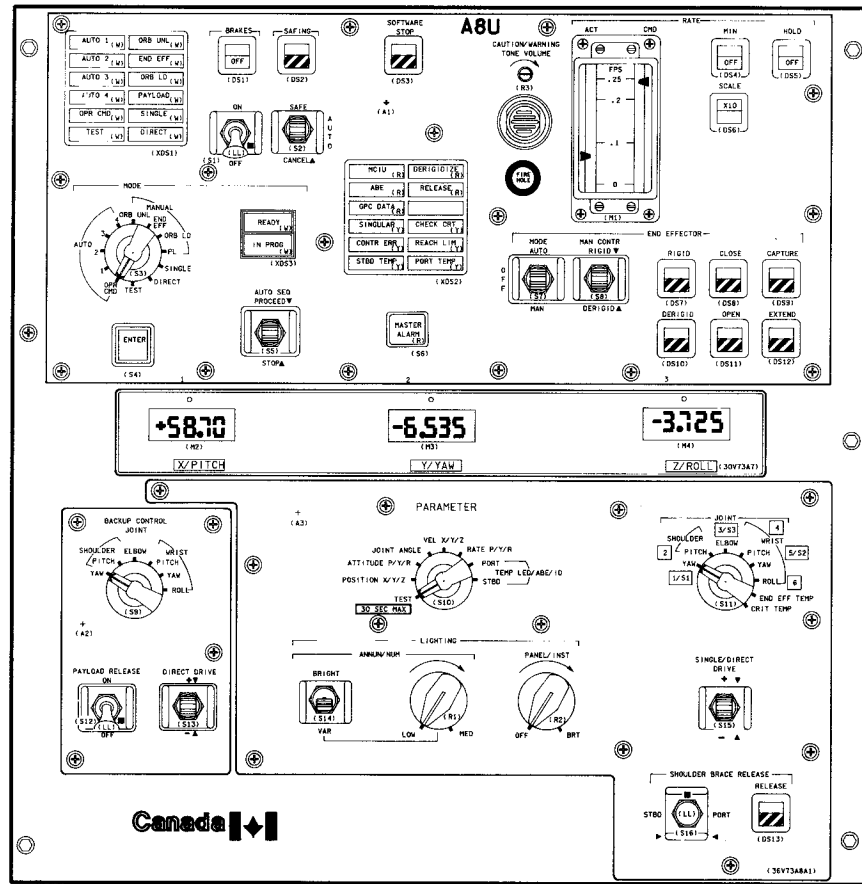


Figure 2-4.- Panel A8U.

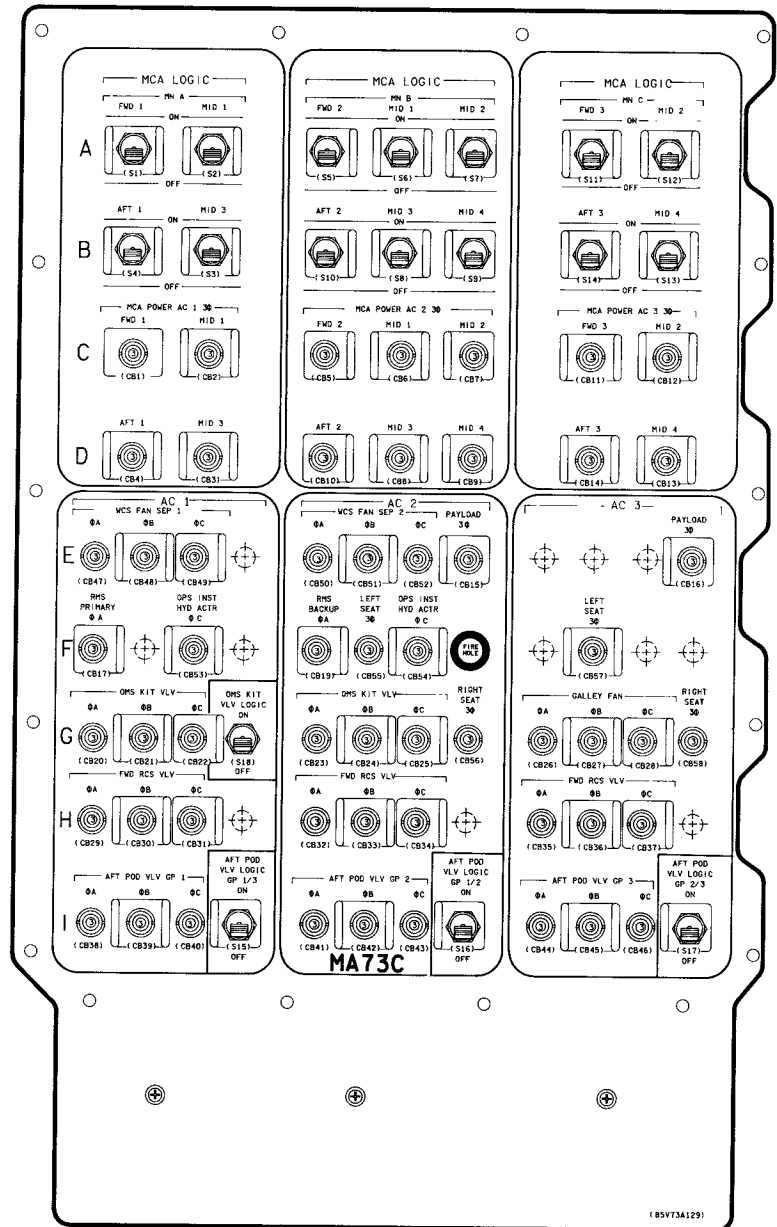
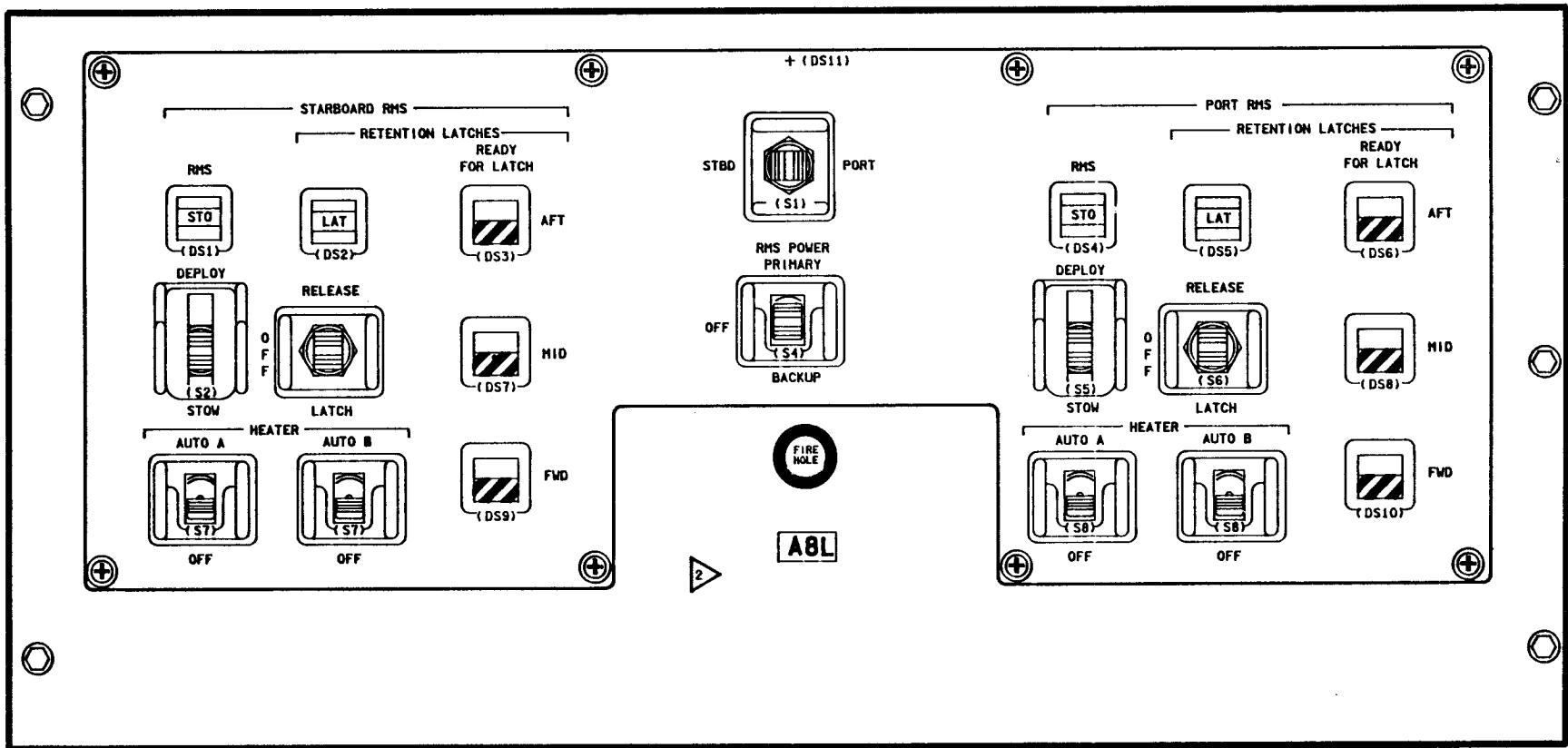


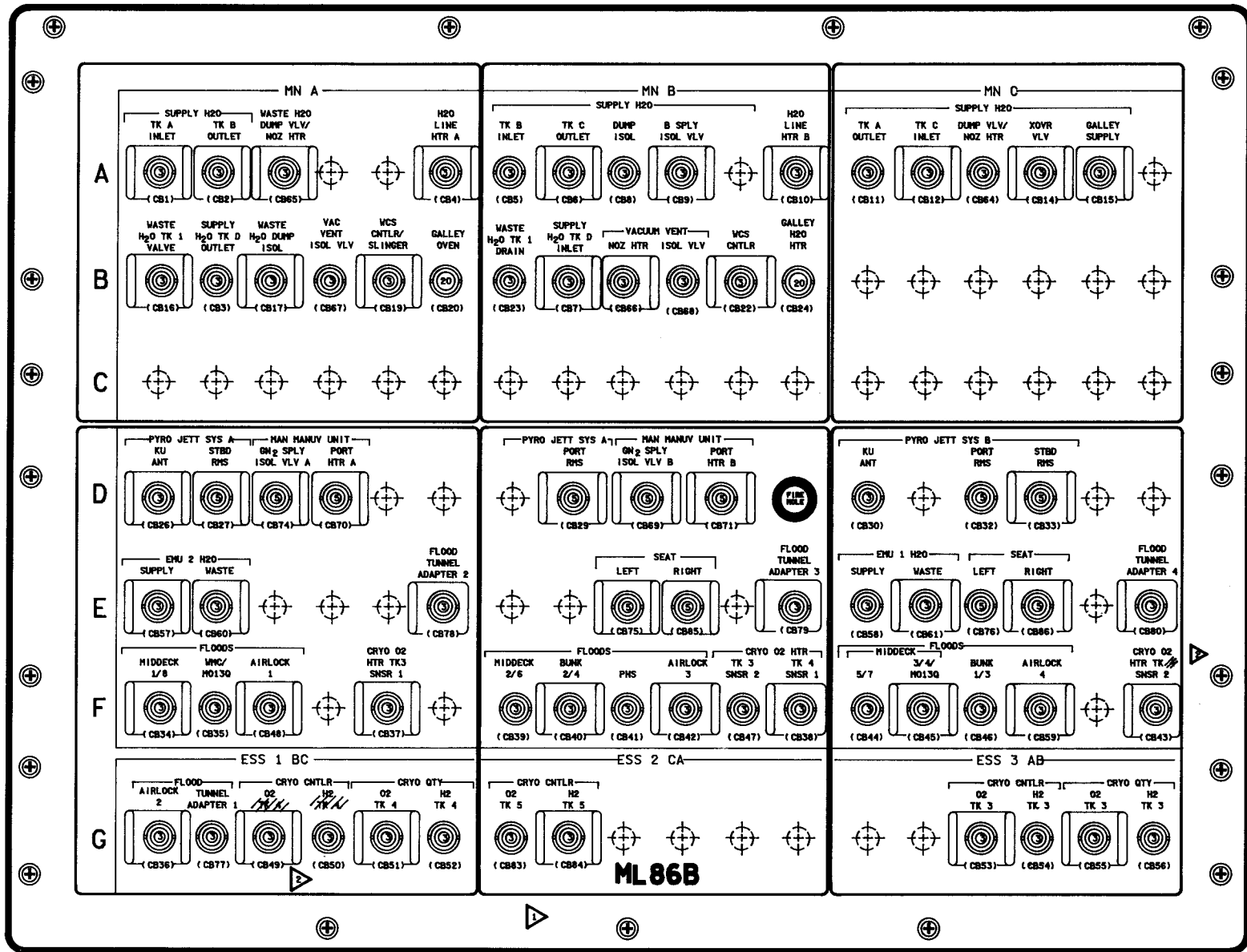
Figure 2-5.- Panel MA73C.



TD3850023, ART. 1

Figure 2-6.- Panel A8L.

11



TD3850025, ART 1

Figure 2-7.- Panel ML86B.

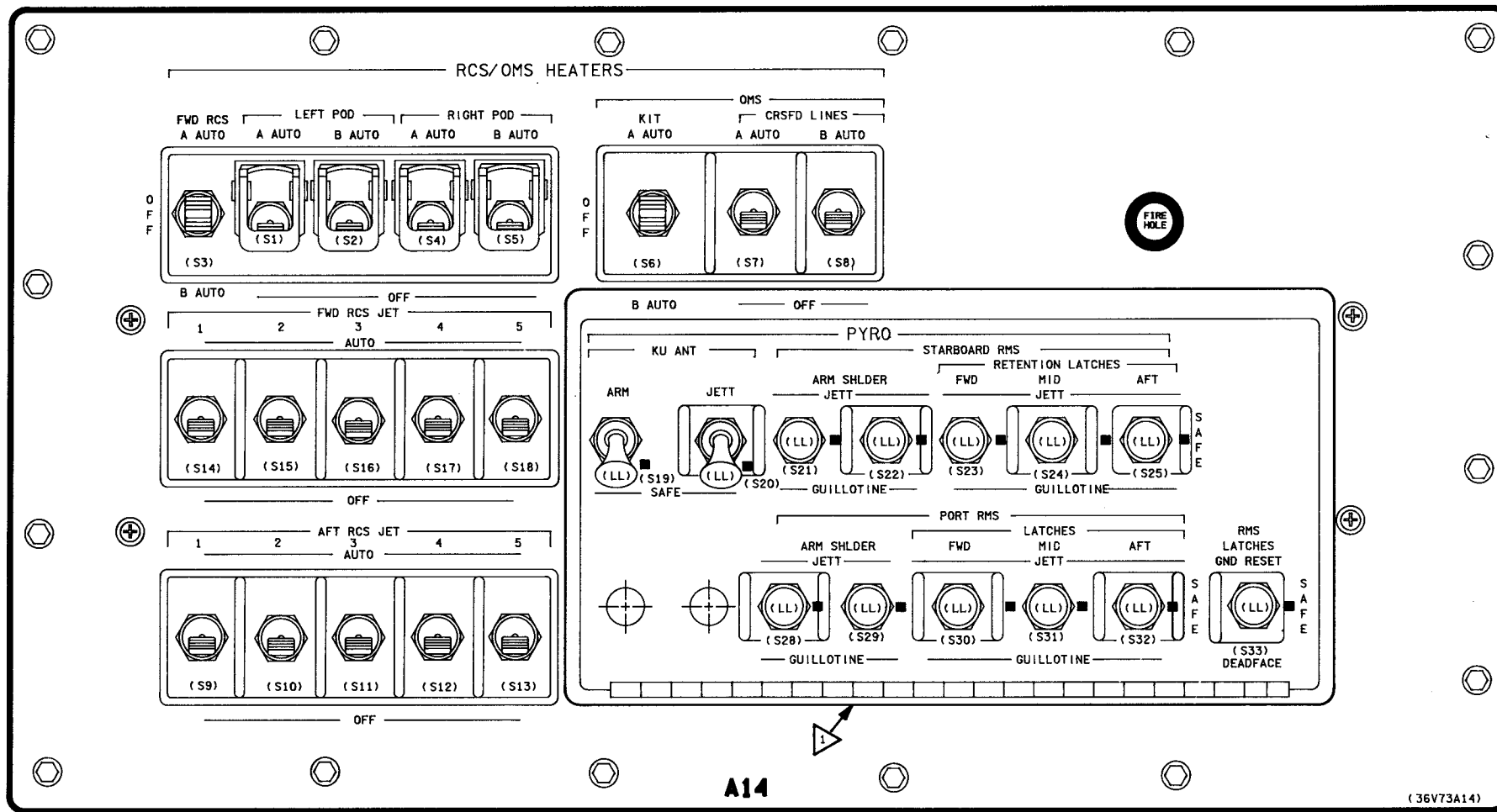


Figure 2-8.- Panel A14.

2.3 Questions

1. What D&C panels are available for use during normal and contingency modes of RMS operation?
2. What caution lights are associated with RMS operation?
3. What warning lights are associated with RMS operation?
4. What GPC displays are available for RMS operation?
5. How many different SM ALERT messages are available to accompany a CHECK CRT C/W light?

2.4 Answers

1. The D&C panels used during normal and contingency modes of RMS operation are A8U, A8L, MA73C, A14 and ML86B.
2. The caution lights associated with RMS operation are Singularity, Control Error, STBD Temp, Check CRT, Reach Limit, and Port Temp.
3. The warning lights associated with RMS operation are MCIU, ABE, GPC Data, Derigidize and Release.
4. The SM GPC displays used during RMS operation are SPEC 94 (PDRS CONTROL) and SPEC 96 (PDRS STATUS).
5. There are ten different messages that the SM GPC can provide to accompany a CHECK CRT light. They relate to the hand controllers, the temperature circuits, D&C, end effector and the position encoders for each of the six joints.

Section 3: Safety Considerations

The safety design of any system is based on two concepts. The system must be able to continue in some level of capability, albeit degraded, in spite of some amount of component failure. On the other hand, a system must be controllable to the extent that, in spite of a certain amount of component failure, the system can be governed sufficiently by itself and/or its operator such that further damage to that system, other systems, and the operator can be avoided.

The RMS is designed to be fail-safe such that, for any failure within the system, the system is capable of

- Releasing a payload, if attached, and be driven back to the retention system on the Orbiter longeron for restowing and return to earth; or
- Releasing a payload, if attached, and be driven to a configuration enabling the arm to be safely jettisoned from the Orbiter at the shoulder joint; or
- Jettisoning the payload and arm as one entity if the payload cannot be released

After certain failures, it will still be possible to continue system operation in the prime channel mode; however, a backup channel is provided for operation with reduced performance to satisfy the fail-safe criteria detailed above.

On the other side of the coin, before the bull is taken into the china shop, a certain degree of control must exist. Before one can fully realize what a mechanical system such as the RMS can do to itself, the Orbiter, payloads and the crew, he should consider some of the performance design data. It is designed to unberth, move about and deploy or reberth a 65,000-lb payload. It can exert a combined 12-lb sheer force and a 160-ft-lb bending moment at the end effector. It can produce a 230-ft-lb torque about the end effector axis.

The RMS control system comprises three major functional areas

- Human operator interfacing with the control system via D&C
- Control algorithms resident in RMS software, interfacing with the D&C and arm via the MCIU
- Joint servos and sensors, resident within the arm

Control of the RMS joint servos is affected by the operator either directly from the D&C or via the control algorithms within the RMS software.

3.1 Operator Responsibility

The RMS is a man-machine system, and, as such, man forms a direct part of the control system. The operator is provided with displays to inform him of arm status at any time during normal operation of the arm. Primary source of arm position and attitude data is provided by the operator's own direct vision through the aft and overhead windows and is augmented by closed circuit television (CCTV) views from arm-mounted and payload bay cameras.

The operator can bring the arm to rest at any time and is ultimately responsible for collision avoidance.

3.1.1 Collision Avoidance

The RMS is designed such that a combination of operational procedures, intrinsic electrical and/or mechanical features, and preprogrammed automatic trajectories will preclude collision of any portion of the arm or the grappled payload with any part of the Orbiter, attached payloads and any movable extrusions. All RMS operations are to be performed with the aid of CCTV and/or direct visual observation. The RMS should never be set in motion in any of its control modes unless the operator has sufficient visual information to monitor the operations being performed.

3.1.2 Methods for Stopping the Arm

There are several methods for stopping arm motion and/or preventing arm motion. Some are initiated by the

operator and will be discussed in this subsection. Those that are initiated by system design will be discussed in subsection 3.2.

3.1.2.1 Brakes. The brakes are the most positive and sure method of stopping the arm motion and preventing arm motion. One of the flight rules states, "The brakes instead of safing are to be used for contingency stopping of the arm." Activation of the brakes can be achieved via operator use of the BRAKES switch on panel A8U or by an AUTO BRAKES command from the GPC; the effects are identical.

When brakes are requested, via either method, the MCIU controls a 28-V dc signal on the hardwire circuits to brakes in each of the six joints. See figure 3-1. The brakes operate on a power-on, brakes-off basis. When activated, the following actions occur:

- BRAKES talkback transfers to ON.
- An ALL BRAKES flag is sent to the GPC.
- The GPC enters idle mode (as opposed to staying in the current operational mode).
- The GPC commands zero rates to all joints.
- The GPC inhibits the position hold submode.
- The brakes clamp mechanically onto each of the motor shafts.
- The servo command paths to all motors are open-circuited.

Obviously, since one of the requirements for being in direct mode is having the BRAKES switch on, stopping the arm while in direct mode must be achieved via other means. The best of these are command removal and

mode change (returning the SINGLE/DIRECT drive switch to detent and moving the mode switch out of the DIRECT position, respectively). Either of these actions leaves the arm in a condition of having all brakes on.

17

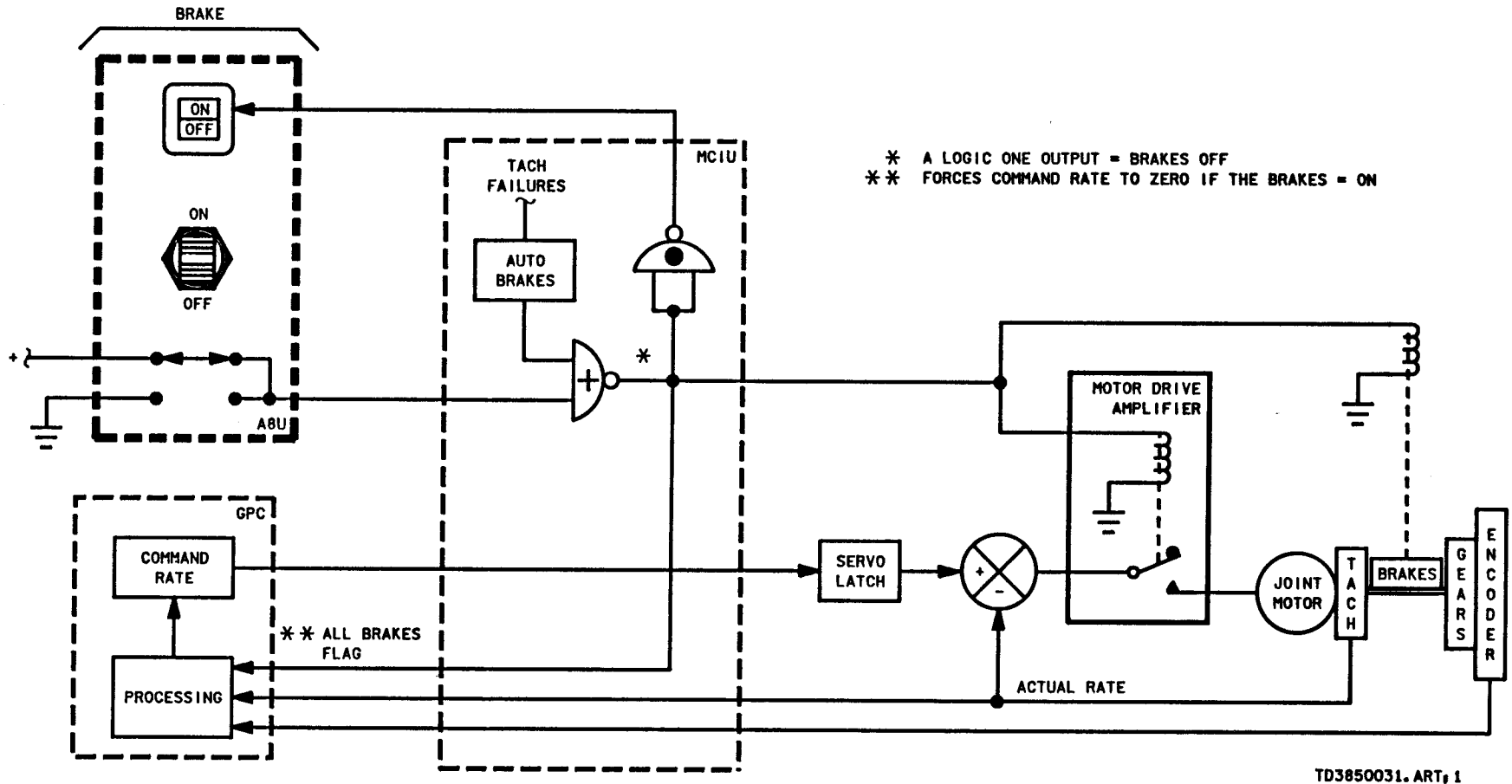


Figure 3-1.- Brakes and servo loop.

3.1.2.2 Command Removal. Stopping the movement of a normally operating arm is best done by removing the command. How the command is removed and the resulting effects obviously depends on the mode. The abruptness of putting on the brakes does not allow smooth arm operation, but is the only choice when using direct or backup. In these modes, the brake is lifted on a joint when that joint is commanded; the brake is reapplied immediately when the command to the joint is removed.

In the augmented modes, the command(s) is (are) removed by returning the hand controller(s) to detent or when in SINGLE mode, returning the SINGLE/DIRECT drive switch to detent. When this occurs, the GPC software stays in mode and commands zero rates to all joints until they are below an I-loaded threshold. At that time the GPC enters its position hold submode by snapshotting the present joint angles and commanding rates to the joints that are proportional to the detected angular errors.

In the auto modes, placing the AUTO SEQ switch to STOP will remove the command to the joints. When this is done, the actions of the previous paragraph are accompanied by the PROCEED light going off and the READY light coming on.

3.1.2.3 Mode Change. Entering one of the augmented modes is accomplished by positioning the MODE switch to the desired mode, placing the BRAKES switch off and depressing the ENTER pushbutton. The GPC makes a determination of the following additional requirements before entering mode:

- Brakes off (as indicated by switch and talkback)
- Hand controllers in detent
- SINGLE/DIRECT drive switch in detent
- AUTO SEQ switch in detent
- Safing not in progress
- No joint motion
- No joint in soft stop

Should the GPC not enter the requested mode, the operator has no malfunction procedure to rely on. He must create his own troubleshooting procedure by reviewing the status of the requirements mentioned above and/or coordinate a system check with ground support personnel.

An operator exits the augmented modes by placing the BRAKES switch on or by changing the position of the MODE switch. Following any MODE switch change, the GPC enters the idle mode and commands zero rates to all joints until they are below the threshold. It then enters position hold submode.

As noted earlier, entering DIRECT mode is accomplished by placing the BRAKES switch on and rotating the MODE switch to DIRECT. Depression of the ENTER pushbutton is not necessary. Exiting DIRECT mode is accomplished by rotating the MODE switch to a position other than DIRECT. This action should take place immediately any time the operator detects incorrect motion of the arm while in DIRECT mode.

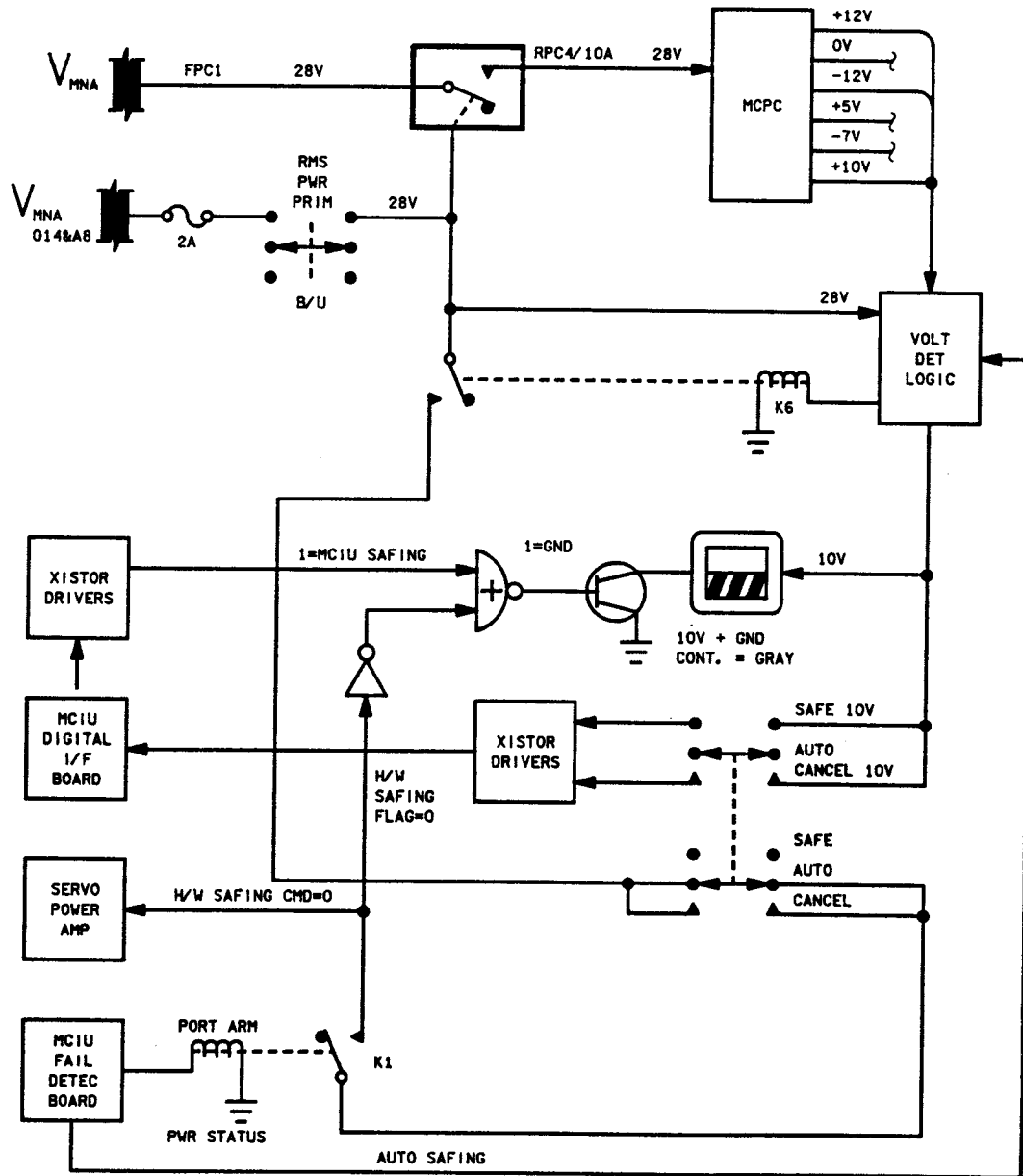
3.1.2.4 Manual Safing. There are two types of safing, MCIU and hardware. Both types can be initiated manually and both types can be initiated by various failure detection and BITE conditions. When the system itself initiates safing of either type, it is sometimes referred to as auto safing. Auto safing will be discussed further in subsection 3.2.3.

The MCIU safing action loads zero rate commands into the MCIU output registers, overriding any rate commands from the GPC. These rate commands are then transmitted to the servo input latches via the arm based electronics (ABE) data bus. The other type of safing is called hardware because it is designed to load the servo input latches with zero rate commands via hardware, bypassing the MCIU and ABE data bus route.

The operator can initiate both MCIU and hardwire safing by placing the SAFING switch to SAFE. Refer to figure 3-2. This switch has two sets of contacts, one of which uses a 10-V source to initiate MCIU safe and cancel commands; the other set of contacts uses a 28-V source which, when interrupted, initiates hardwire safing. As can be seen from the drawing, the 28-V circuit to the servo power amplifier (SPA) can be opened in several places besides the switch. The GPC has no visibility of the 28-V interruption and will remain in mode during the hardwire safing. However, since the switch activation invokes MCIU safing as well, the GPC receives a safing in progress signal from the MCIU and responds by dropping out of mode.

Both types of safing cause the SAFING talkback to go barberpole and both types bring the arm to rest. Once the safing conditions no longer exist, the operator can cancel safing by placing the SAFING switch momentarily to the CANCEL position.

3.1.2.5 Power Down. Should all of the built-in and manual means of stopping the motion of the arm fail to do so, the operator should place the RMS POWER switch to the OFF position. A joint motor with no power cannot drive regardless of the erroneous signals it is receiving. Also, interruption of power to the brakes allows them to revert to their clamped state.



TD3850032. ART, 3

Figure 3-2.- Safing switch logic.

3.2 System Design

The RMS is designed, in conjunction with GPC software, to monitor a key group of system parameters such that it can stop or prevent arm motion when one or more of these parameters indicate the existence of a failure condition. It has been shown, in simulations, that under worst case failure conditions, the POR can travel many feet after operator detection and response. In some cases, such as hitting a joint hardstop, the arm does not have to travel very far after the operator gets the reach limit caution light.

The system can stop arm motion with a variety of methods; the type and potential severity of the failure dictates the method selected. Although reaching a pause point or end point of an automatic sequence should not be construed as a failure situation, it is a way for the system to stop arm motion and will be mentioned briefly in this subsection for comparison purposes.

3.2.1 Software Stop

The GPC software monitors the encoder output from each joint and compares the resultant joint angle with a predefined limit in the program. The RMS is designed to warn the operator that he is about to reach the end of travel for any joint, and to bring the arm to rest under software control when a joint crosses the softstop limit.

Joint softstop limits are positioned just inside the reach limit thresholds at a point such that the arm can come to a stop before reaching the hardstop. If the softstop enable flag is set, the GPC will transition to idle mode upon detecting a joint at its upper or lower softstop location.

The GPC will set all joint current limits to maximum, command zero rates to all joints and inform the MCIU so that it can signal the SOFTWARE STOP talkback to go barberpole.

Single, direct and backup are the only modes available to drive a joint out of its softstop region. Upon entering single mode in this condition, the softstop enable flag is reset, as indicated by ITEM 8 on SPEC 94, and the talkback reverts to gray. After driving the joint out of the softstop region, the operator can select any of the augmented modes; this selection reenables the ITEM 7 softstop enable function.

If the softstop region is entered while driving the arm in the direct mode, the arm motion is unaffected, but the operator will have the SOFTWARE STOP talkback activity as a cue.

3.2.2 Auto Brakes

The RMS is designed to automatically apply the brakes under certain failure conditions in order to augment operator reaction time. The braking action itself is identical to that achieved by placing the BRAKES switch on, except that it occurs when the arm is in mode (BRAKES switch off). The miscompare of the BRAKES switch position and talkback status is the best indication of auto brakes.

There are two malfunction checks that can initiate auto brakes, the GPC consistency check and the ABE tachometer BITE check. Failures associated with these checks turn on the CONTR ERR and ABE lights, respectively. If the failure condition is temporary, the auto brakes function can be reset by cycling the BRAKES switch to on and then off. If the auto brakes condition was triggered by the GPC consistency check only, the auto brakes function can also be reset by one of the following actions:

- Cycle RMS SELECT switch to OFF and then PORT
- Cycle I/O (ITEM 6, ITEM 5) on SPEC 94
- Change the state of the LOADED flag (either off/on or on/off)

The CONT ERR light is lit, among other things that will be discussed in subsection 4.3.3, as a result of the GPC system health monitoring check called the consistency check. It consists of two special functions designed to catch dynamic malfunctions and bring the arm to rest via auto brakes. These two functions are the tachometer rate envelope check and the tachometer data check. The fundamental concept of the consistency check is to compare the commanded motor rate with the actual tach data in the envelope check and to compare the integral of the tach output with the encoder output in the tach data check. Also, any failures that corrupt the tach data or the encoder data on their way from the arm to the GPC are caught by the tach data check.

Many of the failures caught by the tach data check are also caught by the encoder check. Consistency check activation is accompanied by a variety of lights and messages and as long as the ABE or MCIU lights are off, all other lights and messages may be ignored for trouble-shooting purposes. The consistency check is disabled if an ABE-TACH failure exists in the system.

The ABE-TACH phase lock loop BITE determines the health of the tachometer drive and output circuits as well as that of the PLL itself. When the tachometer electronics BITE flag is set, the implication is that tachometer data, either at the GPC or in the SPA servo, is unreliable or totally wrong. No modes requiring the control loops can therefore be used. Direct drive can be used but with the caution that the display of rate information is likely to be wrong; backup drive is also available. The tach BITE flag will result in illuminating the ABE light and activating auto brakes.

3.2.3 Auto Safing

The two types of safing, MCIU and hardwire, were discussed in subsection 3.1.2.4 in terms of manual initiation. The RMS, more specifically the MCIU, can also initiate both types of safing. This auto safing capability was implemented to augment the failure detection capability and reaction time of the operator subsequent to the onset of certain malfunction conditions.

The MCIU initiates hardware safing in response to problems it detects in three categories of self-test operation. As part of its BITE, the MCIU monitors the health and operation of the multiplexing analog to digital converter (MADC), MCIU power conditioner (MCPC), interface control function (ICF) and frame sync pulse. Should it determine that a problem exists in any one of these, it will illuminate the MCIU light and signal the voltage detection logic to open relay K6, thereby initiating a hardware safing. See figure 3-2. These topics will be discussed in more detail in subsection 4.3.1.

The MCIU regulates and monitors a duplex data flow over the ABE data bus. Should it determine that the MCIU-ABE data flow is flawed, it will again signal the voltage detection logic to open relay K6 and initiate hardware safing. In this case the MCIU light is not illuminated.

The MCIU initiates MCIU safing when the watchdog timer times out and during its power on initialization period. See figure 3-3. Primarily, the watchdog timer timeout results when a multiplexer interface adapter (MIA) failure is detected or valid data is not received from the GPC for three consecutive cycles. When this occurs the GPC DATA light is illuminated. This will be discussed in more detail in subsection 4.3.4.

3.2.4 Pause or End Point

Reaching a pause or end point of an auto sequence causes the GPC to command washout rates to smoothly decrease the joint rate to a value below an I-loaded threshold, at which time it enters a position hold submode based on the pause or end point joint angles.

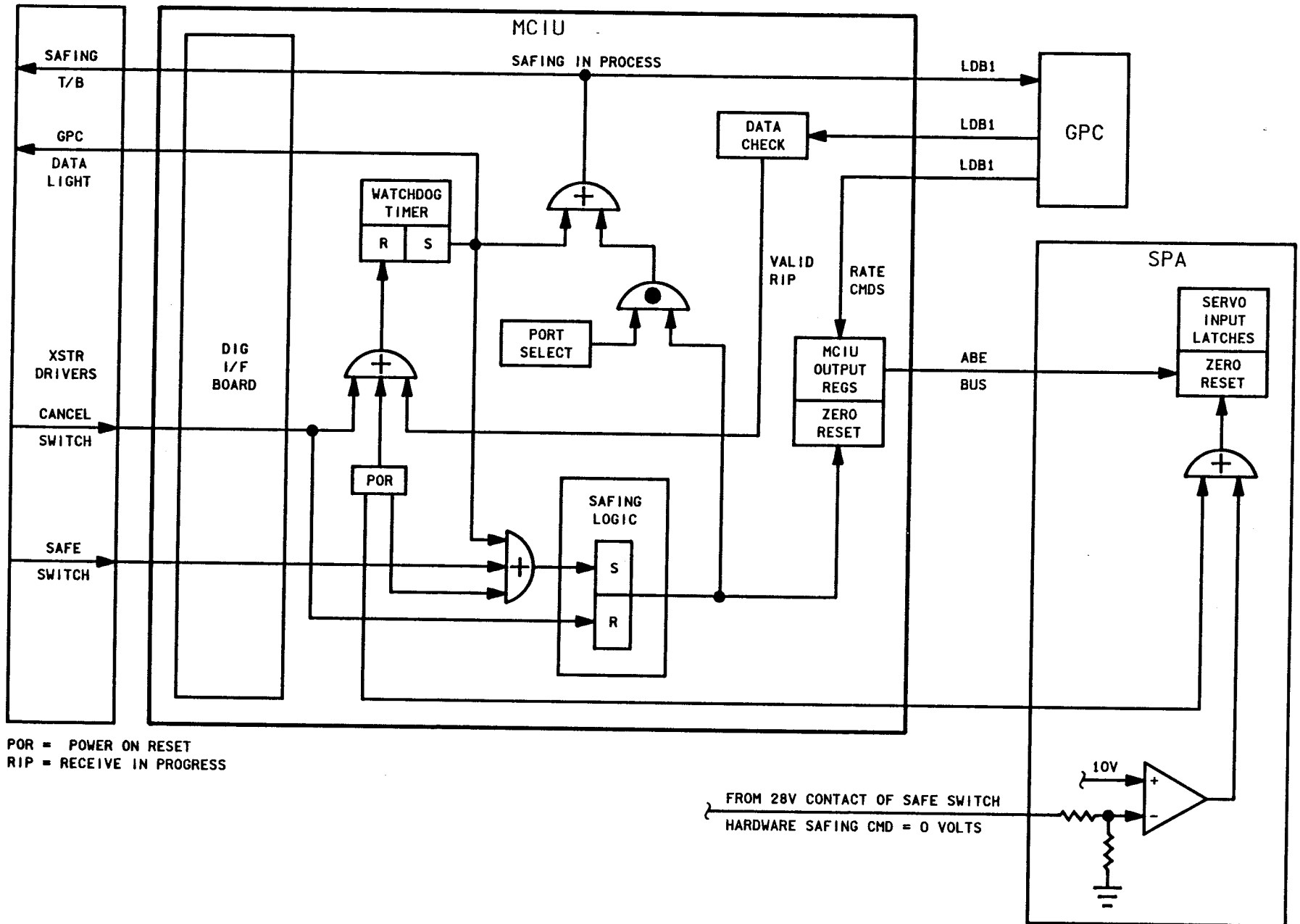


Figure 3-3.- MCIU safing logic.

TD3850033. ART, 2

3.3 Questions

1. What is the maximum payload weight that can be unberthed and deployed by the RMS?
2. Of the major components comprising the RMS control system, which one bears the greatest responsibility for stopping the arm and/or avoiding contact?
3. What is the most positive method for stopping the arm?
4. What is the best way of stopping a runaway joint while in the direct mode?
5. What conditions are examined by the GPC when entry to an augmented mode is requested?
6. What are the two types of safing and how do they differ?
7. What are the two methods of initiating the two types of safing?
8. Since the GPC drops into idle mode whenever a joint moves into the softstop region, how can the operator recover full use of the arm?
9. How can the operator confirm that arm motion has been stopped by auto brakes?
10. What are the two malfunction checks that can initiate auto brakes?

3.4 Answers

1. The RMS is designed to unberth, move about and deploy or reberth a 65,000-lb payload.
2. The operator can bring the arm to rest at any time and is ultimately responsible for collision avoidance.
3. The brakes are the most positive and sure method of stopping the arm and preventing arm motion.
4. If a joint continues to move in direct mode after returning the SINGLE/DIRECT drive switch to detent, the operator should move the MODE switch to a position other than DIRECT.
5. The GPC makes a determination of the following requirements before entering an augmented mode:
 - Brakes off
 - Hand controllers in detent
 - SINGLE/DIRECT drive switch in detent
 - AUTO SEQ switch in detent
 - Safing not in progress
 - No joint motion
 - No joint in softstop
 - Mode switch in an augmented mode position
 - ENTER pushbutton state changed from non-depressed to depressed
6. The two types of safing are MCIU, which transmits zero command rates to the servo input latches via the ABE data bus, and hardware, which loads zero command rates directly into the servo input latches via a hardware.
7. The two methods of initiating both types of safing are manual, via the SAFING switch, and auto, via the MCIU's various failure detection and BITE capabilities.
8. If any joint is in softstop, the operator must use single, direct or backup mode to move that joint out of the softstop range. The operator can then proceed with normal arm capability.
9. Auto brakes are indicated by the miscompare of the BRAKES switch position and talkback status (switch OFF, talkback ON).
10. Auto brakes can be initiated by failures detected by the GPC consistency check and the ABE tachometer BITE check.

Section 4: Failure Detection and Response

The RMS has been designed with extensive malfunction detection and response capability. The hardware BITE continuously monitors the electronics and the software functions monitor and annunciate inconsistencies in major elements of the servo loop and end effector operation. Most of these are annunciated by lights, messages or talkbacks. Malfunction procedures exist to direct investigation of these cues.

However, not all RMS failures are detected by BITE and the C/W system. Such things as switch failures, display failures, incorrect drive times, incorrect or unresponsive actions by end effector components and slow or incorrect motion of the arm are not necessarily detected by the RMS and must be observed and investigated by the arm operator.

4.1 Drive Times

Traditionally, flight crews have followed a rigorous practice of observing and recording hardware-related events such as doors opening and closing, payload activation and operation, CCTV and still camera activity, latch opening and closing and spacecraft systems tests and operation. What a crewmember sees, what he remembers and what he records during these events is invaluable in both a real-time and postmission analysis effort. It is strongly recommended that the crewmember record when an event takes place and its duration, even when perceived to be working perfectly and even when considered to be routine or repetitious.

4.1.1 End Effector

The maximum capture or release (close or open snares) time is three seconds. The maximum rigidization or derigidization time is 18.4 seconds. The capture and rigidization times may vary according to the initial misalignments of the grapple within the end effector and the motor performance due to ambient temperature changes.

4.1.2 Manipulator Positioning Mechanism

With two motors running, the manipulator positioning mechanism (MPM) will go from the 11.88° inboard (stowed) position to the 19.48° outboard (deployed) position in 34 seconds. If only one motor is operating, the task takes 68 seconds. The times are the same for moving the MPM from the deployed to stowed position. The stow and deploy times may vary slightly as motor performance reacts to ambient temperature changes.

4.1.3 Manipulator Retention Latch

Each of the three MPM's has a manipulator retention latch (MRL) assembly that can be driven by dual motors. With two motors running, the MRL's operational time is 8 seconds. If only one motor is running, the time is 18 seconds. The latch envelope for the MRL is 0.875 inch in the Z axis and ± 1.5 inches in the Y axis. However, the operational envelope is only ± 0.75 inch due to the size of the saddle opening. The position of the striker bar within this envelope could have a slight effect on the latch time, as could varying motor performance in changing ambient temperature conditions. These effects on latch operating times are probably not detectable by the arm operator, however.

4.1.4 Shoulder Brace Release

The shoulder brace is released as a result of the motion induced by a single phase ac motor. There is only one motor and it drives the brace to a fully-released configuration in 10 seconds. The talkback indicates release after 8 seconds, however, so the operator should remember the 10-second requirement.

4.2 Arm Reaction

Arm reaction, right, wrong, none at all, different from before, and so forth, is monitored and evaluated by the system and/or by the operator. Some of that evaluation is subjective, so the operator should have the arm under close observation anytime it is moving. This is important not only from the standpoint of collision avoidance, as mentioned earlier, but from the standpoint of creating a data base of arm performance. An operator should take advantage of every opportunity to evaluate arm performance, especially early in the flight, to get a feel for how the arm moves. This is important because it allows him to compare it to arm movement later in the flight and recognize any degradation or change in performance early in the failure stage of a component.

4.2.1 Runaway

What is an arm runaway? If the system or the operator thinks the arm is moving faster than commanded or is moving when no command is intended, then it is a runaway. The response by the system to a runaway might be nothing, depending on the cause, or it might be auto brakes, safing or dropping out of mode. It might or might not notify the operator of a problem with a light, tone, message or talkback. The response by the operator, as mentioned in earlier subsections, should be brakes on, or if in direct mode, moving the mode switch to some position other than DIRECT. The response to a runaway arm in the backup (B/U) mode would be to move the power switch to off.

The causes of a runaway arm can range from failures in the switches and hand controllers used by the operator to input commands, to anything in the command path up to and including the various components in the servo loop. This means that no matter where a failure occurs in the major components, D&C, MCIU, GPC and ABE, a runaway arm could result.

A runaway condition might affect a single joint or the entire arm; it might be continuous or intermittent. Most can be analyzed sufficiently to isolate the cause and to determine the remaining capabilities. Use of the malfunction procedures generally results in success in this effort. Those runaway conditions that trigger C/W annunciations, which in turn lead the operator into malfunction procedures, will be discussed in subsection 4.3.

4.2.2 Sluggish, Frozen, and Free Joints

As mentioned earlier, some problems are detected only through operator observation and visual interpretation of arm or joint response that is different from that remembered from training or earlier in the flight.

If a joint is sluggish, the operator might not notice, especially if the arm is driven mostly in the multijoint modes. Unless the operator questions joint performance, the ground support personnel might not examine the data closely enough to detect a slower-than-normal joint. The malfunction procedures direct the operator to test a suspect joint by driving in single-joint modes, but the analysis can still be subjective. Depending on the level of sluggishness, the problem could range from difficult to impossible to detect. A sluggish joint might exhibit slow acceleration but move normally once achieving joint speed. Since the envelope check only looks for actual rates different than commanded, it does not catch the sluggish joint.

According to the flight rules, and common sense, a joint that cannot be driven in any mode is considered lost. A lost joint can be either failed free or frozen and in either case, is detectable by both the operator and the system.

A free-joint situation can have brakes operational or, in the less likely case, brakes not operational. An arm that has a free shoulder pitch (SP), elbow pitch (EP), wrist pitch (WP) or wrist yaw (WY) joint with an operational brake can be cradled with the whiplash, or backdrive, procedures which will be discussed in subsection 5.3.

If a joint fails free or frozen during multijoint operations, the motion of the arm can be sufficiently different from that expected to be discernible by the operator. This, of course, assumes that the failed joint was one that was required to move a reasonable amount to contribute to the desired arm motion. With no other clues indicated, an arm operator can verify and identify a free or frozen joint using the available incorrect-arm-motion malfunction procedures.

A free or frozen joint situation can trigger CONTR ERR C/W and auto brakes indications as well. The actual rates and the commanded rates of a free or frozen joint will obviously not agree. If they do not agree for four consecutive GPC cycles, as required by the envelop check, the inconsistency will be annunciated. Again, the malfunction procedures will direct the operator through a single joint test which will verify the nature of the failure. Depending on how immovable a frozen joint is, it could require an extravehicular activity (EVA) cradling (as would a free-joint-no-brakes case) or arm jettison. Jettison and EVA procedures are discussed in subsections 5.5 and 5.2, respectively.

4.2.3 Motion Other Than Commanded

In addition to those failure types mentioned already, there are a variety of situations in which erroneous signals, data and commands can be introduced to the system to cause the arm to move in a manner different from that which is expected by the operator or GPC. Some of these are detectable and verifiable and some remain a mystery to be avoided as arm operations continue in limited modes and capabilities.

One source of erroneous operation of the system is the means available to the operator for input of commands. The hand controllers can have a bias, sluggishness or failure in one or more axes, the SINGLE/DIRECT DRIVE switch, STOP/PROCEED switch can have contact problems, and the desired position and attitude data provided to the GPC via the keyboard can be misloaded or misread internally. In these cases the GPC software has no capability of detecting the error. Generally, the malfunction procedures can lead the operator through sufficient testing to isolate a suspected cause of these problems.

Problems associated with data that is transmitted incorrectly or not at all, read incorrectly or not at all, or manipulated incorrectly are usually identified by the C/W and BITE capabilities. However this type of failure, which can occur within the major components or the data buses, can be so subtle or so intermittent that they are suspected only by the operator's judgement of arm performance. In these cases, arm operations continue but with even closer observation by both the operator and ground personnel.

Finally, most hardware failures of components in the GPC, MCIU, D&C, ABE and servo loop, while easy to detect and identify with the C/W, BITE and malfunction procedure capabilities, drive the arm in such a manner that renders its use limited or to be avoided altogether. This type of failure will be discussed more fully in subsequent sections.

4.3 C/W Lights

The eleven C/W lights, as mentioned briefly in section 2.1, are accompanied, when illuminated, by one or more of the following: master alarm (light and tone), safing and auto brakes. The reaction of the operator to a C/W annunciation should be BRAKES-ON, take a hard look at the arm and payload, observe any cues or symptoms that will help in problem analysis, and go to the malfunction procedures. These procedures, written to cover most of the clues an operator can have, are followed on an annunciation hierarchy theory. When faced with a multiple C/W light situation, the operator will troubleshoot via the following priority:

- MCIU
- ABE
- CONTR ERR
- GPC DATA
- CHECK CRT
- RELEASE
- DERIGID
- PORT TEMP

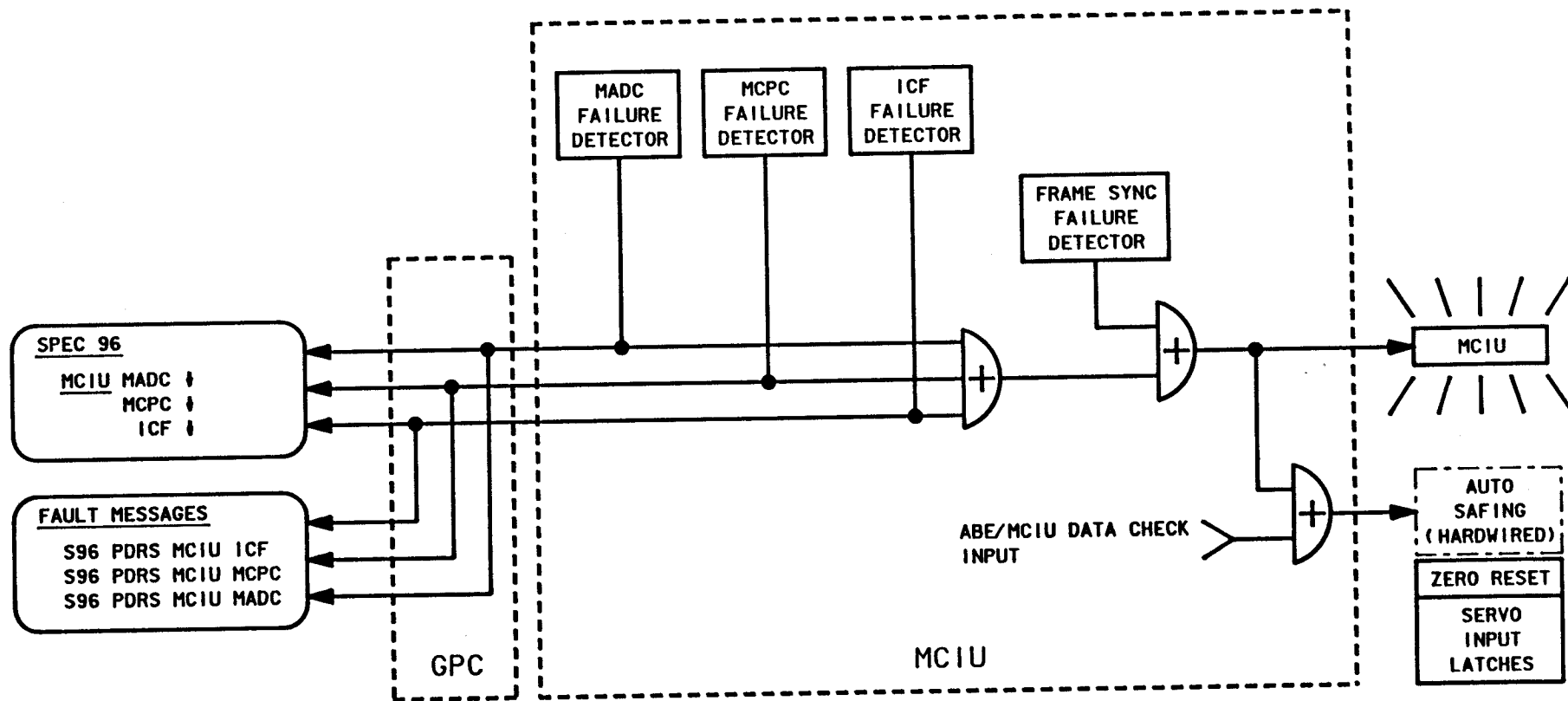
There are no procedures for REACH LIMIT or SINGULARITY lights, as these can be normal occurrences. There are failures that can result in one or both of these lights, but they will be accompanied by another C/W light.

4.3.1 MCIU Light

The MCIU investigates the integrity of the communication links between itself and the ABE, D&C and GPC. It also monitors end effector functioning, thermistor circuit operation and its own internal consistency.

There are basically four BITE functions that can result in the MCIU light being lit. Three of these functions have associated messages on S96. The fourth one is a hardwired function and provides no message on S96. See figure 4-1.

33



TD3850041. ART, 1

Figure 4-1.- MCIU light logic.

The MCIU failure warning is hardwired to the D&C panel and combined with the master alarm light and tone circuit so that in the event of a failure that results in the master alarm data path being disabled, the MCIU failure will still trigger the master alarm. The four BITE functions, upon detecting their respective failure cases, are OR'd with the ABE/MCIU communication failure flag to generate a hardwired safing signal, via the voltage detection logic, to the D&C. The GPC is not informed of this safing event.

The MADC takes the handcontroller and thermistor analog signals and converts them to a serial digital stream. This stream is routed to the microprocessor. The main multiplexer is a 16-channel device, one channel of which is subcommutated into 32 channels (16 port and 16 starboard). On these 32 channels are the thermistor signals and two calibration signals. On the other 15 main channels are the hand controller signals, three calibration voltages, and four MCPC monitor lines.

The three main calibration voltages are + 3.360 V, + 0.240 V and - 3.360 V. These are compared with digital references in the microprocessor; differences of more than two counts or ± 60 mv constitute a failure. One of the subcommutated calibrations is derived from the thermistor reference voltage; the other is the same - 3.360 V which is used on the main channel.

The only workaround to recover a failed MADC is to replace the MCIU with a spare unit. This inflight maintenance (IFM) procedure will be discussed in section 5.4.5.

The MCPC provides regulated secondary voltages for the MCIU, including the multiplexer interface adapter (MIA) and D&C panel. These voltages are monitored through the MADC. All separately derived voltages are supplied to the MADC and combined and conditioned to be within the capability of the MADC as listed below.

- + 5 V is reduced to + 3.360 V.
- + 16 V is fed to the MIA where it is regulated to + 12 V. This is then reduced to + 3.360 V.
- + 10 V and - 12 V are combined to give 0V.
- + 12 V and - 7 V are combined to give 0V.

These four voltages are compared to standards in the MCIU and, if they vary by more than 13 counts (± 390 mv), the interface control signals an error in the MCPC. The MCPC has overvoltage and overcurrent protection which causes the MCPC to shutdown. Under these circumstances, the MCIU will fail completely and no MCPC failure indication will be given directly. However, all D&C panel lamps will go off (including numeric displays) and all talkbacks will switch to their unpowered state.

The likely result of a degradation of MCPC voltages is unreliable operation of the MCIU. At best, there will be no effect and, at worst, all communication and processing will be faulty. Direct drive and B/U modes will remain operational. All other modes may be affected, as may all monitoring.

The only workaround to recover a failed MCPC is to replace the MCIU with a spare unit.

The interface control BITE performs tests in three separate categories. In the first, performed within the microcomputer, there is a test of the storage circuits, which includes checks of the read only memory (ROM), random access memory (RAM) and control processing unit (CPU). The second category is a check of the arithmetic circuits and is performed every cycle. It is specifically known as a read/write pulse count check and is performed on the failure detector board of the MCIU. Finally the third category, which provides for a check of at least 70 percent of the logic circuit every cycle, is achieved by performing an MCIU test word check on the failure detector board. Any anomaly found during these checks results in an ICF failure flag being generated.

The exchange of data between the microcomputer, and the digital and analog interfaces, and the failure detector board is controlled by the microcomputer synchronous processing program, which also includes most of the microcomputer self-testing. The frame sync pulse which initiates the synchronous processing function is generated every 42 ms by the MCIU master clock in the computer interface, and causes a microcomputer hardware interrupt to occur. The interrupt service routing begins the synchronous processing program. The primary function of the synchronous processing program is to control the interface boards which communicate with the ABE and the D&C panel.

The sync detection circuit function consists of monitoring the frame sync pulses, and provides a signal to the MCIU failure logic whenever the frame sync pulse is missing for two cycles in a row. The signal is OR'd with the MCIU warning signal to provide the MCIU failure annunciation.

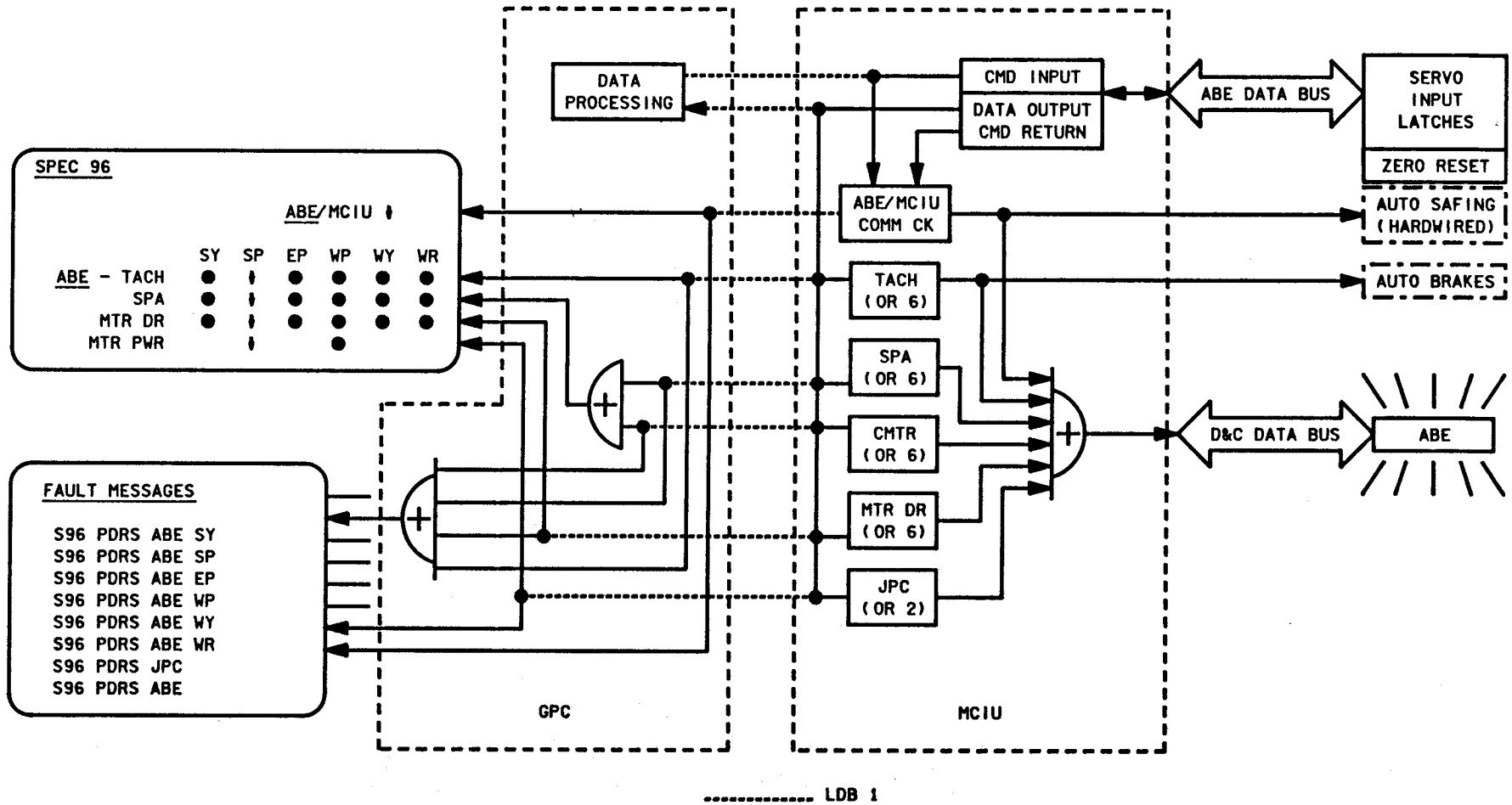
4.3.2 ABE Light

The ABE warning light is the second light in the RMS C/W hierarchy. If the ABE warning light is on as well as the MCIU light, the troubleshooting should be accomplished as per the MCIU malfunction procedures.

The ABE warning consists of 27 different BITE flags generated as a result of 6 different BITE circuits.

- ABE/MCIU communication (1)
- ABE/TACH phase lock loop (6)
- ABE/MDA current limit (6)
- ABE/SPA + 28 V (6)
- ABE/Commutator (6)
- ABE/JPC out of tolerance (2)

The 27 flags are generated in 9 different electronics units within the RMS. See figure 4-2.



TD3850042. ART, 1

Figure 4-2.- ABE light logic.

The major components of the arm are as follow:

- Six joints
- Six servo power amplifiers (SPAs) and associated motor, gearbox assembly, motor drive amplifier (MDA), tachometer electronics (TE), signal conditioning unit (SCU) and encoder
- Six brakes
- Shoulder joint power conditioner (JPC), supplying power to shoulder yaw (SY), SP and EP joints
- Wrist JPC supplying power to WR WP and WY joints
- End effector electronic unit (EEEU)
- Single backup drive amplifier (BDA) to drive 6 joints
- Six B/U commutators
- A data bus feeds commands from the MCIU to each SPA, the information passing through the nearer SPAs to the farther ones. A return data bus takes joint data back to the MCIU in a similar fashion. See figure 4-3.

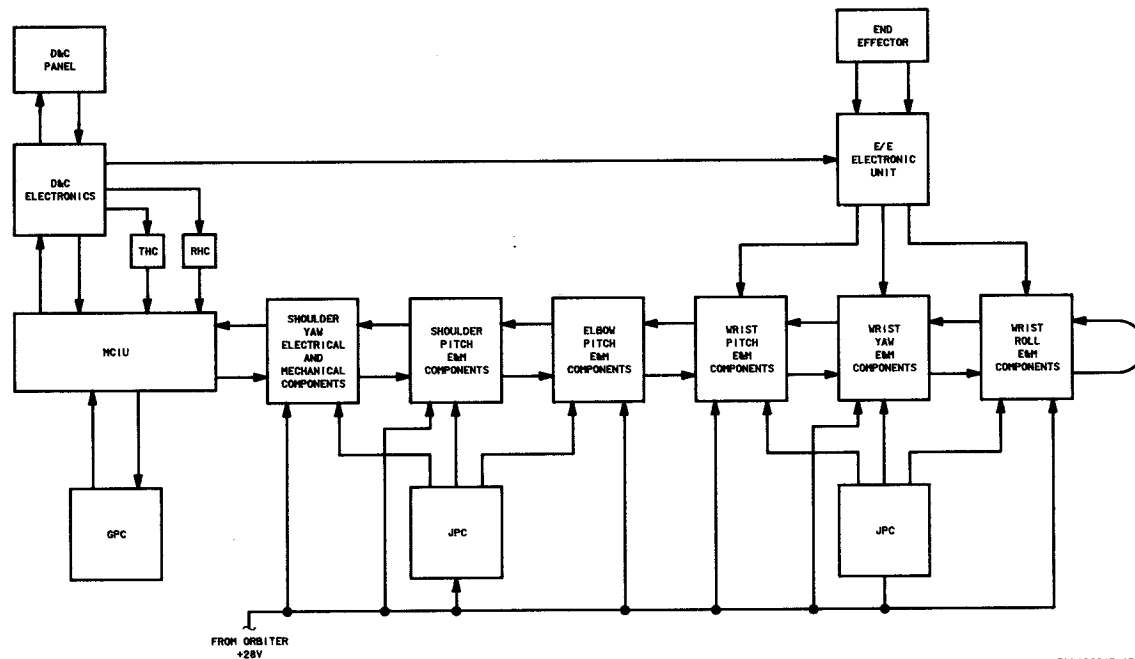


Figure 4-3.- RMS component data flow.

The commands are processed in the SPA, in particular in the MDA and TE and the resultant motor drive command is fed to the motor module. Encoder, tachometer and commutator data are fed back from the electromechanical assembly to the SPA where they are used as feedback and control signals. Tachometer and encoder data are fed back to the MCIU on the return data bus along with the flags (including the BITE flags) which indicate SPA state.

38 The 27 flags generated as a result of the ABE BITE consist of 4 BITE flags generated in each SPA, 1 BITE flag generated in each JPC and an overall communication check flag generated in the MCIU. The MCIU generates six BITE status register bits and after 3N filtering (checks for occurrence in three successive cycles) them, ORs them together to generate the ABE light and master alarm. The ABE light command is transferred to the D&C panel on the MCIU/D&C data bus, as opposed to a hardwire. The MCIU, in addition to providing the warnings, implements auto safing if the ABE/MCIU communication BITE bit is set or auto brakes if the ABE/TACH BITE bit is set.

ABE failures, in general, result in a loss of computer-supported modes as a minimum. Certain failures can result in loss of direct and backup modes. D&C displays in some cases are unreliable even though there is no direct effect on them.

ABE faults are displayed on S96 as raw BITE information rather than BITE status register (BSR) information. The fault summary messages are structured from the raw BITE information, the emphasis being on displaying the failed joint rather than the failure itself. This is done by taking the faults associated with a particular joint and OR'ing them to obtain an ABE XX message where XX is the joint designation. On S96, ABE-Commutator and ABE-SPA BITE bits are OR'd together to obtain the ABE-SPA message.

As mentioned earlier, the data transfer between MCIU and ABE is configured such that all data contained in the transmission from MCIU to ABE is returned back to the MCIU along with ABE to MCIU data. The microprocessor compares the data transmitted to the data returned. If any discrepancy exists, the ABE/MCIU communication failure flag is generated.

After the twelve command words from MCIU have passed through the last (WR) SPA, it is looped around and fed into the return data bus. Thus the command data are clocked up the shift registers, which are on the MCIU/ABE command data bus, until they reach the last SPA. The data are then transferred into the SPAs. At the same time, the return data are latched into the output shift registers. The whole data stream, data return plus command data, is then clocked back to the MCIU.

The parts of the system which are checked are the input and output circuitry of the MCIU which service the ABE and the shift registers, and the wiring of the data buses to and from SPAs. This constitutes the whole of the MCIU/ABE communication channel, except for the transfer mechanism within the SPAs. This check also catches failures of the JPC.

With a fault in the MCIU/ABE data transfer, neither the commands to the SPAs nor the data returned from them can be assumed to be accurate. Only direct drive and backup modes would then be used.

The tachometer phase lock loop (PLL) BITE was discussed briefly in subsection 3.2.2 in its application to auto brakes. In the tachometer system, an oscillator output is used to provide two inductosyn drives, in quadrature. The rotating sensor coil is inductively coupled to a pulse-shaping circuit, which is a narrow-band filter with hysteresis, and is used for noise suppression. From the pulse shaper, the tachometer signal is fed to a PLL. In the loop, the frequency modulation caused by the rotation of the motor shaft is tracked and detected. The detected (analog) output is used in a later stage of the servo loop, but the digital output of the voltage controlled oscillator (VCO) is fed through a counter and latch to act as feedback on the rate demand from the GPC.

The BITE signal is the loop lock monitor of the phase lock loop. If the signal to the loop disappears or moves out of the capture range of the loop or the loop itself fails, the loop lock detector will indicate loss of lock. Since the PLL is at the end of the tachometer chain, all tachometer processes are checked to some degree. However, the digital processing and the interaction with the rest of the servo drive functions are not checked.

When the TE BITE flag is set, the ABE C/W light, payload deployment and retrieval system (PDRS) ABE XX (where XX is the affected joint) message, master alarm and auto brakes will result.

The tachometer electronics produces at 28 V a power failure flag such that a logic 1 indicates the main bus voltage dropping below 17 ± 2 V. The 28 V to the SPA is used in the pulse width modulator and, primarily, for power to the motor. The 28 V is compared to a voltage derived from the + 10 V line from JPC. If the voltage falls below 17 V, the comparator sets the SPA + 28-V BITE flag.

The loss of 28 V to the SPA results in a loss of drive to the joint motor. Since there is no back electromagnetic force (EMF), the joint fails free. Since the brake still works and speed and joint angle data are good, a failure of this type in the SP, EP, WP, or WY joint could lead to use of the backdrive cradle procedure. Backup drive on the affected joint is available, however, as is direct drive on the other joints.

When the SPA + 28-V BITE flag is generated, the ABE C/W light, PDRS ABE XX message and master alarm result.

The commutator BITE circuit checks for all three 1's or all three 0's on the three commutator signals. If the condition is sensed for 120 microseconds, the BITE signal is latched and stays on until cleared by power-on-reset. This can be accomplished by deselecting an arm and reselecting it again. Even though the state may disappear after detection, the flag is latched on the data bus to the MCIU.

The circuitry which is checked is the optical system of the commutator and its associated buffer circuits, together with the power supply system which drives them. However, if the supplies fail at the JPC rather than at the commutator, many other functions will be affected, including the capability to transmit the BITE flag to the MCIU.

The commutation logic in the MDA is not checked by this circuit; only the three input signals are checked. It is possible that the commutator BITE can be activated as a result of a failure in the BITE circuit itself rather than a real failure. In this case full control may still be available.

If all commutator channels fail, the affected motor is unable to run or provide torque. If only one channel fails, the available torque is reduced by about 35 percent in forward or backdrive. This would be a sluggish joint case.

When the commutator BITE flag is generated, the ABE C/W light, PDRS ABE XX message and master alarm result.

An overcurrent sensor in the supply to the output power switches on current limiter board of the SPA senses currents in excess of five amps. The BITE flag does not normally result in any auto stopping of the arm. It does disable the forward/backdrive part of the consistency check which makes it highly susceptible to false alarms.

A current sensor in the motor 28-V return line determines the level of current flowing in the motor. The sensed current is detected in a phase-sensitive detector driven by an output from the commutator pulse width logic. This detection scheme creates a signal from the sensed current.

If the detected current exceeds the current-limited level, the current-limiter circuits produce an error signal which implements the GPC-commanded current limits by controlling the pulse width modulator (PWM) and hence the motor drive. The detected current from the phase detector is fed to a BITE comparator as well as to the current limit detector. Two different limits are set, depending on whether the motor is being forward driven or backdriven/stalled. The BITE limit is set to five amps.

Malfunction of the BITE circuit itself can set the flag but comparatively few components are involved. Failure of the power supplies disables BITE but affects more than the BITE circuit. When an MDA BITE flag is indicated, it is most likely that an overcurrent situation does exist. It is acceptable to continue to use normal modes of operation unless the consistency check false alarms are excessive. In that case, direct drive should be used.

When the MDA BITE flag is generated, the ABE C/W light, PDRS ABE XX message and master alarm result.

Each JPC monitors its own output voltages and whenever any one of the conditioned voltages deviate from their normal value by 11 ± 5 percent for longer than 50 msec, the JPC (1 or 2) BITE flag is generated and transmitted to the SPA.

The maximum voltage is also fed to a separate detector where it is used to switch off the JPC if an overvoltage condition exists. An overcurrent sensor performs a similar function through some of the same circuitry, cutting off the JPC if the current taken exceeds a present level. The sensing level for the BITE function is between the worst case allowed by the SPA specification for normal functioning, and the level at which the JPC is cut off by the overvoltage circuitry. The latter level is set so that the JPC is cut off before the voltages reach the SPA damage level.

Most system failures result in an overvoltage or an overcurrent condition which trips off the JPC. That prevents the flag from being transmitted to the MCIU since the BITE circuitry and the SPA data transmission system are powered entirely from the JPC. However, conditions which set the flag without being catastrophic can result in unreliable functioning of the SPAs. The flag accounts for a minority of failures of the JPC. Transients do not set the flag unless they have a duration longer than 50 msec.

The flags are hardwired to the wrist pitch SPA (from the wrist JPC) and to the shoulder pitch SPA (from the shoulder/elbow JPC). From these they are transmitted down the return ABE data bus to the MCIU and thence to the GPC.

When a JPC BITE flag has been set, the effect of the failure is usually to make the SPA operation unreliable. In particular, the data transmission becomes suspect. The failure can be investigated by observing the other communications. If data transfer or handling is affected, the MCIU/ABE communication should show signs of failure. If other failures are indicated, it is likely that only backup drive is fully effective, although direct drive may well be. If no other indications are present, the full system capability could be assumed until some other warning indicates a more severe condition. It should be recognized that the situation could become worse to the point of total JPC shutdown.

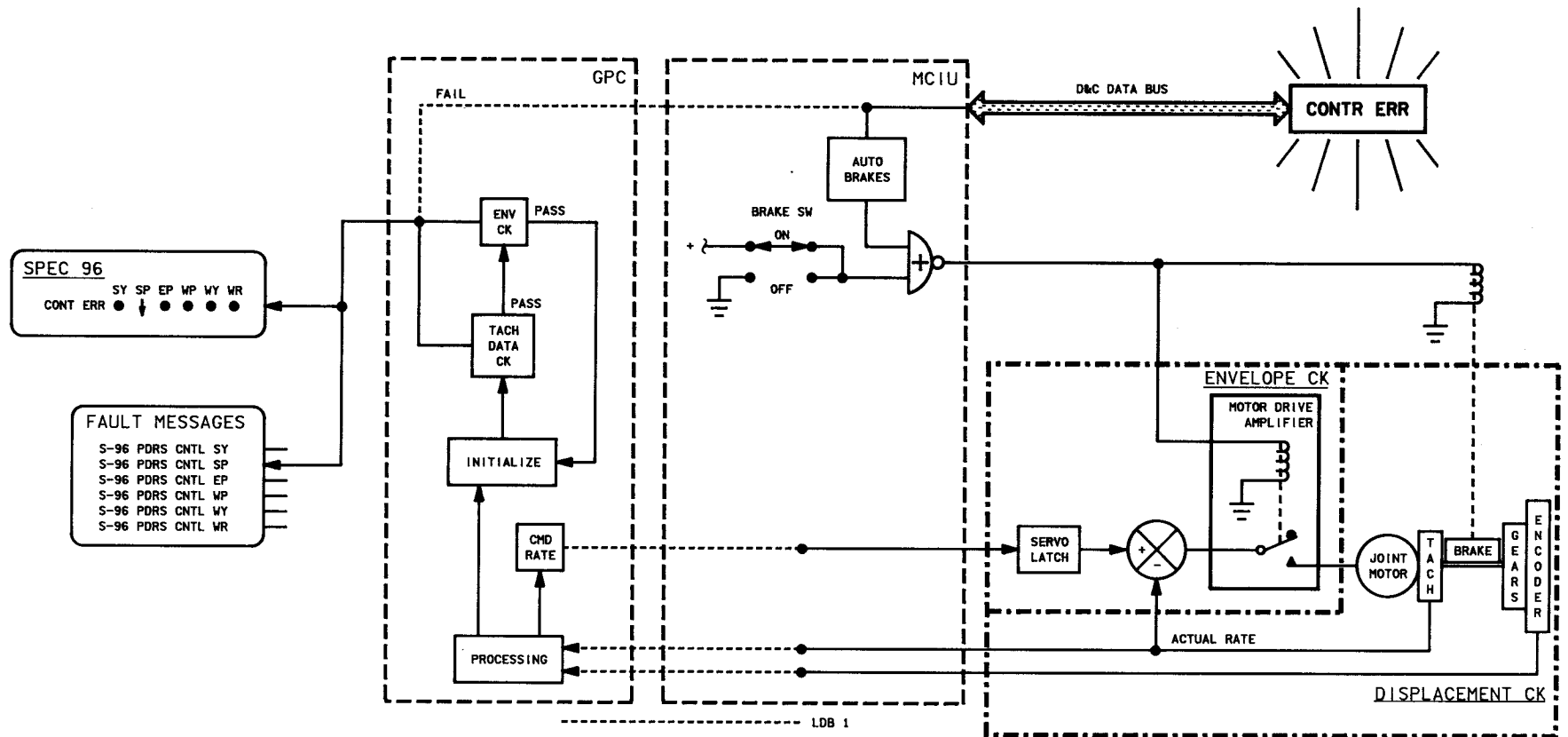
When a JPC BITE flag is generated, the ABE JPC (1 or 2) message and master alarm result.

4.3.3 CONTR ERR Light

The control error light is the third light in the RMS C/W hierarchy. It is lit as a result of a determination made by the GPC SHMF that one of the two functions of the consistency check has failed. These two functions are the

envelope check and tachometer data check. These were mentioned briefly in subsection 3.2.2 since they are involved in the activation of auto brakes. Failures affecting the consistency check also result in the CONTR ERR C/W light, down arrows, PDRS CNTL XX messages and master alarm. See figure 4-4.

42



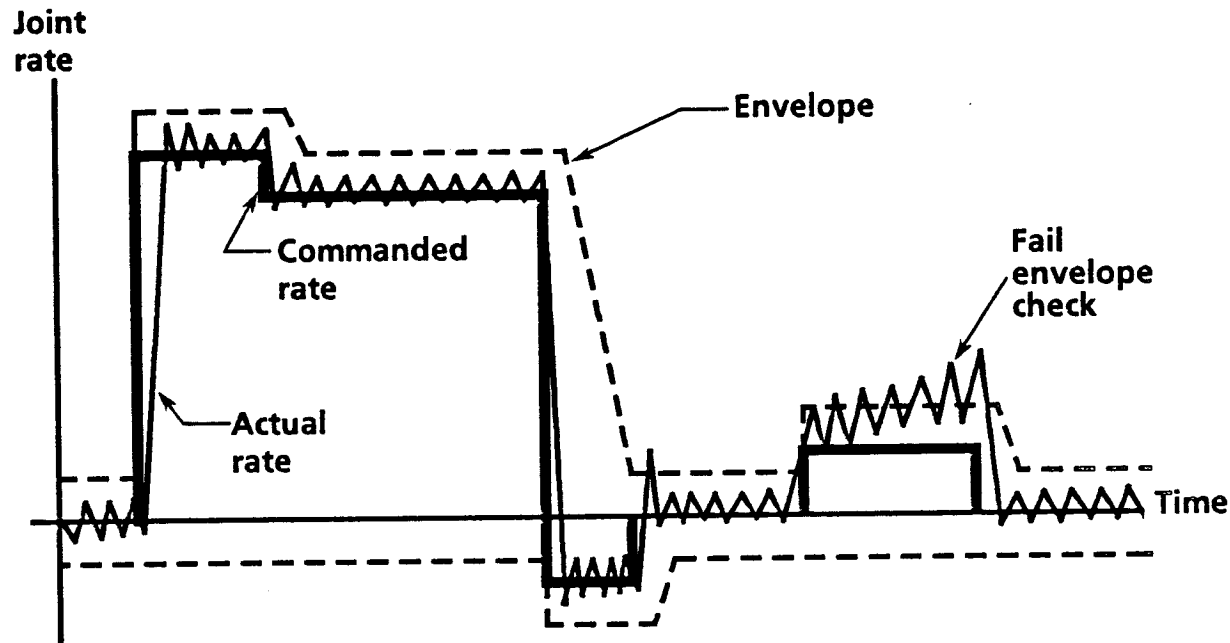
TD3850044. ART. 1

Figure 4-4.- Control error light logic.

Figure 4-5 shows a functional diagram of the envelope check. The basic concept consists of drawing an envelope around the commanded motor rate in both positive and negative direction, and comparing the actual motor speed from the tachometer with the envelope. If the actual rate is outside the envelope for four GPC cycles in a row, an error is generated. The check is only performed when the motor is in the forward drive direction. It is not performed when the backdrive flag is set. In fact, the

complete consistency check may be inhibited by the operation via keyboard entry (ITEM 10 EXEC) and is automatically inhibited when in direct drive mode, when brakes are applied, during capture/rigidization process and after detection of a tachometer or an encoder failure. However, if the MDA current limiter fails, one could get a runaway with the system always in backdrive. For this reason, if an ABE-MDA BITE bit is set, the check is done irrespective of the forward/backdrive flag status.

43



TD385*405*002

Figure 4-5.- Envelope check.

The concept of the tach data check is to integrate the tach data over successive cycles and compare it to the encoder change over the same successive cycles. If the two drift apart by more than a specific tolerance, displacement is accumulated as net joint movement. When the joint displacement exceeds a certain amount, an error is generated. If, before reaching the error limit, the encoder and tach start tracking each other, the displacement is reset to zero.

Figure 4-6 shows a simplified arrangement of a joint drive system. The figure has been divided into five parts. In general, the consistency check is designed to catch failures of these five subfunctions of the drive system. The five parts are discussed in the following paragraphs.

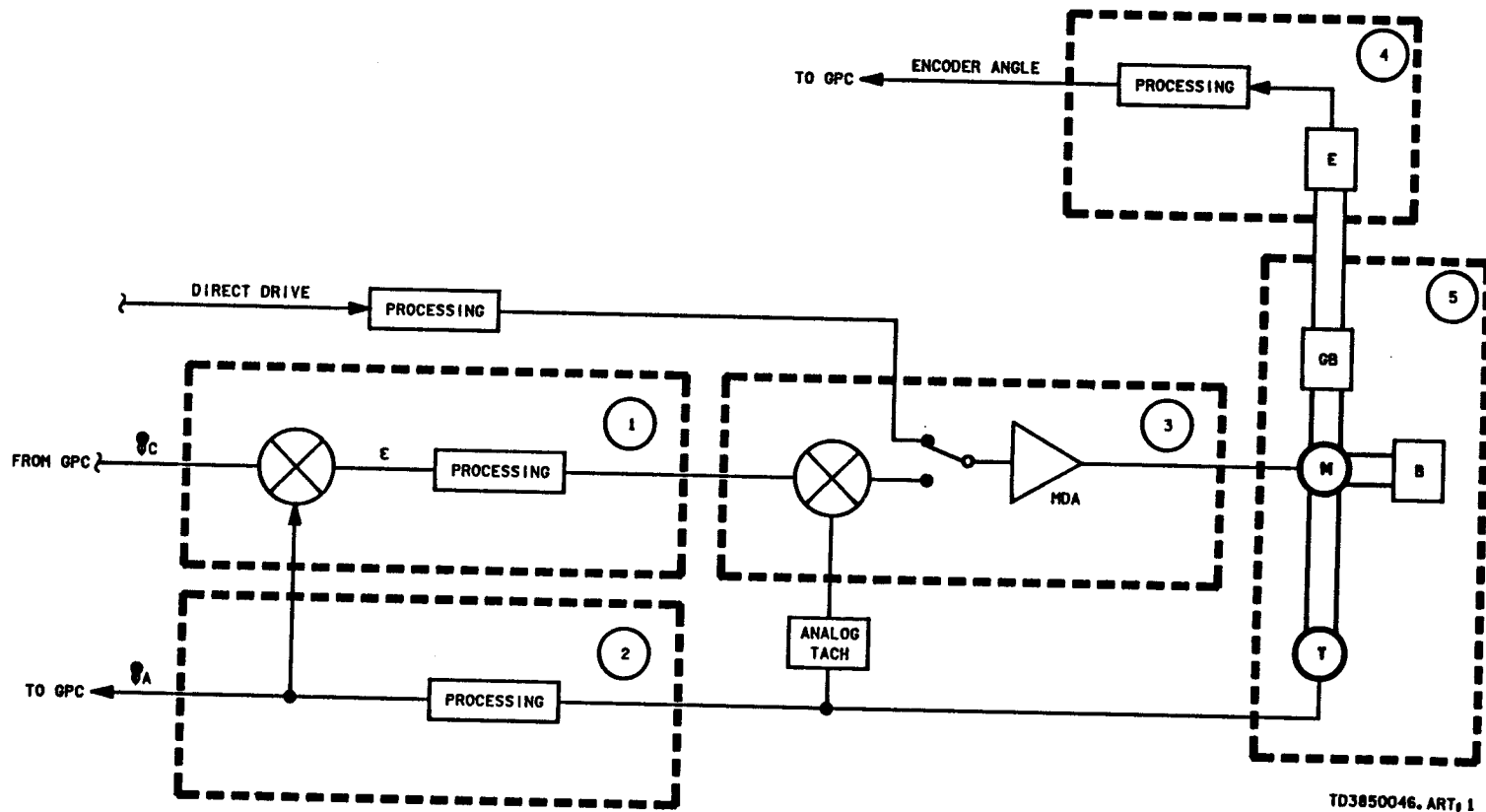


Figure 4-6.- Servo and drive system.

Area 1 is the digital section of the forward feed loop of the servo. A failure in this part could result in the wrong summing amplifier output, or processing of it, and can cause a dynamic runaway of the joint. Since the failure of this section does not corrupt the actual data (commanded rate, actual rate and encoder angle), the envelope check must be relied on to catch these failures.

Area 2 is the digital section of the feedback loop of the servo. A failure in this part could result in actual rate data being wrong and affecting the forward feed loop through corruption of the summing amplifier output data. This condition invariably results in joint runaway. In this case, the actual rate data is corrupted and hence the envelope part of the consistency check is unreliable. These failures are caught by the tach data check.

Area 3 is the analog section of the forward feed loop of the servo. In this section, the digital summation of commanded versus actual rates is converted into an analog command to the motor. A failure in this section would result in an arm runaway. The actual data from the joint are not corrupted and hence a runaway condition is caught by the envelope part of the check.

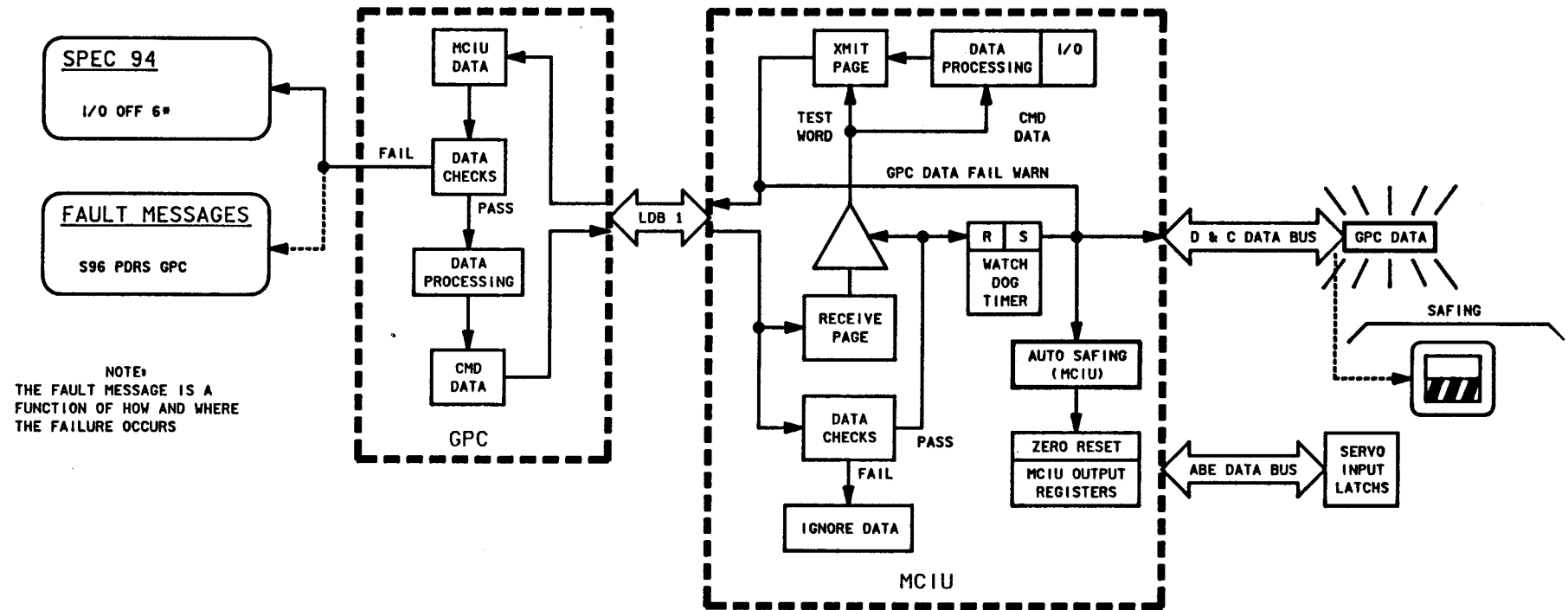
Area 4 is the encoder and its processing electronics. Joint angle data are used by the GPC control algorithms to compute the actual position of the arm and hence the rate commands for each joint. A failure in this section will result in the GPCs issuing incorrect joint rate commands for effective end point control. Even though, generally, the failures are not highly dynamic, they can result in a significant amount of uncommanded motion. These failures result in the corruption of encoder data and since encoder data are an integral part of the tach data check, they are caught.

Area 5 contains the mechanical drives, shafts and linkages of the drive train. A failure in these parts of the system could result in a free-wheeling joint. Depending upon the command, the tach integral does not track encoder movements; this would be caught by the tach data check.

4.3.4 GPC DATA light

There are various BITE checks that can result in the GPC DATA light being activated. However, none of the BITE functions have an associated S96 down arrow. The MCIU

does generate a GPC data fail flag in its BSR, which is used to drive the fault summary message "S96 PDRS GPC". This message, of course, can appear only if there is MCIU GPC communication available. See figure 4-7.



TD3850047. ART1

Figure 4.7.- GPC data light logic.

Communication is initiated by the GPC by sending a command word to the MCIU. The command word is coded as either a data transmit command or data receive command with the number of words to follow. In the case of a receive command word, the MCIU is supposed to receive a block of 45 words, the last one being a GPC test word. In the case of a transmit command word, the MCIU is supposed to transmit a block of 45 data words to the GPC, the last one being a copy of the test word from the last good transmission by the GPC.

If the MCIU does not respond to command data words, the GPC goes into bypass mode. If the MCIU does respond, but TW45 is incorrect, the GPC goes into polling mode.

47 The MIA provides the communication link between the GPC and the MCIU in both directions. The MIA recognizes the transmission by the sync bits at the start of the command words or the command data words. When a GPC to MCIU word is recognized, the following checks are performed on it:

- Code is true Manchester II except for the sync field.
- Word has 25 bits including parity.
- Parity is correct.

Failure of any of the above checks results in a MIA fail flag to the computer interface board of the MCIU and the following things happen:

- GPC data fail flag is sent to the microcomputer.
- In the case of command data words, the entire block of data is read into the RAM page assigned to the GPC receive data, but the software does not allow the RAM pages to be switched and test word to be copied.
- In the case of command words, the RIP flag is not set on the computer interface and none of the command data words get transferred to the microcomputer.
- In both cases, the entire block of data is ignored and the MCIU continues to use data from a previous valid message.

From the MIA, the data are passed on to the computer interface where they are converted from serial to parallel. If the received word is a command word as detected by the MIA, the computer interface performs the following checks:

- Address incompatibility
- Command mode bit validity
- Coded word count

Failure of any of these checks results in the receive in progress (RIP) flag being disabled and hence the entire message of 45 words does not get transferred to the RAM page. The end of block (EOB) pulse is generated but the GPC data fail flag is set and the MCIU continues to use data from the previous valid message.

If the word from the MIA is a command data word, the computer interface performs the following checks:

- Address incompatibility
- Bit validity
- Word count
- Time lapse between the command word and the first command data word

If any of these checks fail, the GPC data fail flag is sent to the microcomputer even though the entire block is read into the assigned RAM page. The software does not allow the RAM pages to be switched and test word to be copied. Therefore the entire block of data is ignored and the MCIU continues to use data from a previous valid message.

The GPC data warning light flag is implemented within the microcomputer firmware by a watchdog timer. Every time a block of data is received, a routine is executed that performs the following:

- If neither RIP nor transmit in progress (TIP) is set or if both RIP and TIP are set, the GPC communication fail flag is set within the firmware.

- If RIP is set, and a GPC communication fail flag is set, the entire block of data is ignored. Test word 45 is not copied to the transmit pages. Receive RAM pages are not swapped, and the watchdog timer is not reset to - 6.
- If RIP is set without a GPC communication fail flag, the test word is copied, the RAM pages are swapped and the watchdog timer is reset to - 6.

During the execution of the synchronous program, the GPC BITE program in the MCIU is executed whereby the watchdog timer, which is really just a counter, is incremented by 1. If the timer reads zero, the GPC data light is activated on the C/W panel and the internal safing flag is set. The SAFING talkback goes barberpole, the GPC is notified of safing in progress, and the MCIU sends zero rates and minimum current attenuation of the arm via the ABE data bus. This is MCIU safing as discussed in subsection 3.2.3.

If the GPC stops communicating with the MCIU (no command words or command data words) for six MCIU cycles, the watchdog timer times out and the GPC DATA light illumination and safing occur. If the GPC sends only transmit command words and no receive command words (one-way communication), only part of the routines are executed and again the watchdog timer times out. On the other hand, if the GPC sends only receive command words followed by a valid block of 45 command data words (one-way communication GPC to MCIU), the GPC DATA light cannot come on and the MCIU continues to update data.

When the MCIU issues safing in progress, no data can be implemented as requested by the GPC. The only available modes of operation are direct and backup. Since the checks are made on the MCIU receive data, D&C displays are frozen most of the time, especially the ones that come from the GPC. However, the end effector flags are good and both end effector (EE) auto and manual modes can be used for capture and release operations.

The GPC RMS software performs a compare operation on the TW45 that it sent to and received from the MCIU. If there is a miscompare, it ignores the entire block of data transmitted by the MCIU and continues to use the old valid block of data for its computation for one cycle. The GPC forgives but does not forget; it sends the same test word once again to the MCIU in the next block of data. If the test word miscompares once again, it quits sending data to the MCIU. However, it continues to request data from the MCIU every 80 msec (MCIU transmit mode one-way communication). The GPC then does the following:

- It goes into the suspend mode, executing only the most rudimentary RMS software.
- It turns I/O off on S94.
- It stays in the polling mode.
- It downlists only that data that does not require RMS software processing.
- It does not support data on S96.

If TW 45 does not compare because of a GPC fault of some kind, the GPC stops sending any data to the MCIU after two cycles. The watchdog timer will time out and safing will occur. The same thing holds true for failures on the transmit side of the computer interface board if these failures are not caught by other communication checks within the GPC. In these cases, the I/O must go off before the watchdog timer stops getting reset and the total time to safing might be two GPC cycles plus six MCIU cycles.

In addition to the GPC TW 45 compare performed in the RMS software, the system part of the GPC software monitors the health of all communication into or out of the GPC. The GPC has MIA's that interface with data buses and the standard code and parity checks are performed on them. Additionally, the GPC performs bit checks and address checks on the data received from the MCIU. If any failures are detected, the GPC, after two cycles, terminates total communication with the MCIU. It sets the bypass flag and turns I/O off on S94. Even though the MCIU might be healthy, the watchdog timer times out, the GPC DATA light is illuminated and safing occurs.

4.3.5 CK CRT Light

There are five BITE functions or system health checks that can result in the CHECK CRT C/W light being annunciated. The operator response is BRAKES-ON and, as the light suggests, check the CRT for further clues. Those clues are in the form of nine different down arrows on S96 and ten different SM alert messages, which are listed in subsection 2.2.2. The BITE functions are

- Position encoder check
- D&C/MCIU communication BITE
- End effector failure BITE
- Thermistor circuit check
- Hand controller hardover check

The CHECK CRT C/W light is illuminated by a signal from the MCIU failure detection board via a hardwire, rather than via the D&C data bus. As mentioned earlier, the MCIU C/W light and master alarm light are also illuminated in this fashion (all other C/W lights are illuminated by a signal on the D&C data bus). The MCIU microcomputer generates the signal to light CHECK CRT for hardware detected failures, and the GPC generates the signal and sends it to the MCIU for software detected failures. Refer to figure 4-8 for a functional representation of the CHECK CRT C/W light.

The position encoder check is implemented as a part of the GPC software and consists of two parts. Part 1 is very similar to the tach data check portion of the consistency check, where the integral of the tach is compared with the encoder change. The difference is that the integral of the tach is accumulated over a period of five seconds and compared with the encoder every cycle. The integral is reset every five seconds.

The tach integral is initialized equal to the encoder angle at the beginning of the five-second period. From then on, each and every cycle, the tach data is integrated to obtain a delta joint angle and compared with the actual encoder angle. If, during the five-second period, the two drift apart by more than one degree for two consecutive cycles, encoder error part 1 is triggered. The check is based on the assumption that tach data is reliable and the encoder is failed.

The fundamental parameters used in the check are the same as for the tach data check portion of the consistency check. Hence, under normal conditions, there is a race between the two. Encoder check part 1 is likely to be triggered for all cases normally caught by the tach data check if the consistency check loses the race for the particular failure in question. For this reason, one must not rule out a runaway condition if the encoder check is triggered without a consistency check failure indication.

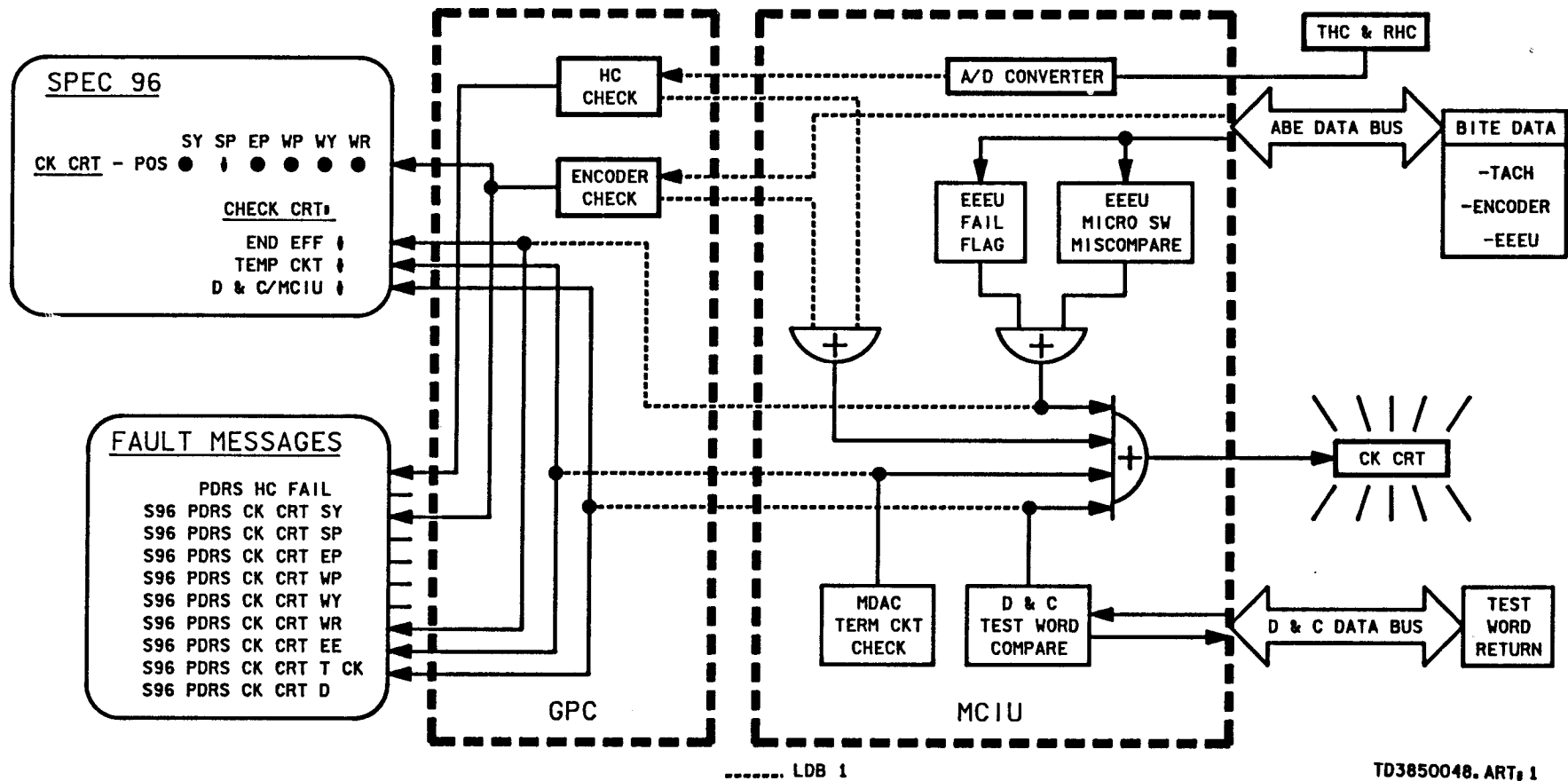


Figure 4-8.- Check CRT light logic.

Part 2 of the encoder check is simpler and is designed to catch frozen encoder data. If the tach is producing a rate signal but the encoder does not move over a period of ten seconds, an encoder error condition is assumed. In this check, the encoder data and tach data are monitored every cycle. Whenever tach data is greater than 0.7 rad/sec and the encoder does not change, the counter is incremented to accumulate the time the condition is in existence. If the accumulator shows a time of ten seconds or more, the encoder check part 2 is triggered.

It is interesting to note that if the encoder angle shifts suddenly and then becomes frozen, the consistency check does not function any more. However, both parts of the encoder check are in operation for any further movements of the joint.

Encoder check part 1 works well for high speeds and encoder check part 2 works well for very low speeds. Both parts are disabled when the tach BITE flag is set.

Since usually there is a race condition between encoder check and consistency check, both lights may be on as well as auto brakes. Under such conditions the operator should proceed with troubleshooting using the malfunction procedures for CONTR ERR light.

The various types of encoder failures generally lead to the same conclusion in the malfunction procedures, but can produce a range of effects that render the following functions unreliable, degraded or inoperable:

- Auto control mode (position mode)
- Manual augmented mode (resolved rate distribution)
- Position hold submode
- Single mode
- Joint angle, POR position data and POR attitude data
- Reach limit and software stop monitoring for the affected joint

Direct and backup modes are normally operational. In some cases a mode, such as manual augmented, may be entered but would not be necessarily prudent. The malfunction procedures direct the operator to use single joint modes in these instances. If an encoder failure is transient, the CHECK CRT light can be extinguished by operator action on S94 (ITEM 12 EXEC). The encoder check routine can be reinstated with ITEM 11 EXEC.

The D&C/MCIU communication BITE consists of two separate BITE checks performed within the MCIU. During every MCIU frame, the sixth word sent from the MCIU to the D&C is returned by the D&C in the word six slot. The microcomputer firmware compares the received test word with the transmitted test word and a miscompare results in the D&C/MCIU communication BITE bit being set in the BSR.

On the digital interface board, the parity of each incoming word from the D&C panel is checked and if the parity is not odd, a D&C parity failure bit is transferred to the microcomputer, resulting in the D&C/MCIU communication BITE bit being set in the BSR. With either test, the BSR BITE bit is 3N filtered before activating the CHECK CRT light and master alarm. Failures associated with the D&C communication make it necessary to trigger the CHECK CRT light and master alarm via hardwire.

With the failure of the data bus, all functions relying on that channel are suspect, although not necessarily wrong. The extent of the failure determines the effects. As already mentioned, some indications are hardwired and are considered valid. The controls which are not affected by the failure are those associated with the hand controllers, brake switch, end effector switches, direct drive switch and backup control switches.

The failures can range from total failure of the data bus to just a single bit fault. Even in the total failure case, substantial performance is available. If the failure is in the MCIU to D&C panel direction, the operator must rely on window, CCTV monitor and CRT observation; in many RMS operations, these are the prime sources of information anyway. If the bus failure is in the other direction, it is not possible to select computer modes after the failure has occurred. In this case, data on the D&C may be good. In either case, direct and backup modes are available, as is full capability with manual end effector operations.

The EE failure BITE consists of two separate BITE functions implemented in the EEEU and the MCIU. They are the EEEU BITE and the EE microswitch miscompare BITE. The former is implemented in the EEEU and sent to the MCIU on the ABE data bus; the latter is performed in the microcomputer by monitoring the status of six EE microswitches and determining if any of the four impossible combinations exist.

The two BITE flags are OR'd in the microprocessor to generate the EE fail flag in the BSR. If the EE fail flag is set for three MCIU frames, the CHECK CRT C/W light, master alarm, down arrow and message result. Both BITE flags are available in the downlist; an EE fail flag alone indicates microswitch miscompare and the presence of both would indicate an EEEU failure.

When not in use, the EEEU is in a standby mode. The EEEU provides a BITE flag which indicates certain failures that occur during standby in order to warn the operator prior to intended use of the EE. The circuits covered in this are the command logic, the commutator output, the motor drive and the failsafe circuit. The BITE flag is transmitted by way of the WR SPA to the MCIU, where it is OR'd with the microcomputer flag status test to generate the EE fail BSR bit.

The decoding circuit determines that a command is present and provides outputs to the drive circuitry to enable movement and to activate the particular set of brakes and clutches required for operation. The logic also determines the direction of motor rotation and this controls the commutation logic.

The decoding circuit determines that a command is present and provides outputs to the drive circuitry to enable movement and to activate the particular set of brakes and clutches required for operation. The logic also determines the direction of motor rotation and this controls the commutation logic.

A failsafe circuit operates in parallel with the decoding circuits. This detects the presence of any command. The absence of a command disables all enable circuits. Thus a failure of the main logic path cannot cause operation of the EEEU. Presence of a command disables the BITE circuit.

The BITE circuitry monitors the commutation drive signals looking for the condition where all three signals are in the same state. If such a state is detected the BITE flag is set.

If a commutator failure is detected, the signal is OR'd with a monitor of the motor drive. If any drive signal to the motor exists without a command being present, the BITE flag is set. Because of the failsafe circuit, no single failure can result with sufficient drive to result in the motor enable signal. Any potential single fault disables the drive either through the normal or the failsafe channels. The only failure which can set the bite flag is one of the motor drive switch channels. However, the BITE flag can indicate the loss of supply from the power conditioner to the BITE circuit.

The EE status is determined from six EE flags, all of which are transmitted to the MCIU from the three wrist SPAs via the ABE data bus. Capture, open and close describe the state of the snares in the capture release process. The two impossible combinations are open/close and open/capture.

The position of the snare carriage is determined from the other three flags, extend, derigid and rigid. The two impossible combinations are rigid/derigid and extend/not derigid.

These flags are used by the MCIU to control the EE commands in auto mode. If the MCIU detects an impossible combination of microswitches or the EEEU BITE bit, the EE auto mode commands are disabled. The operation can be carried out in manual mode but one or more indications will be unreliable. The failures could trigger the uncommanded release and derigidize indications also. Backup release is not affected.

The hand controller hardover check is a system level check implemented as a part of the GPC software. It compares the value of the hand controller X, Y, Z, pitch, yaw and roll axes every GPC cycle to a fixed number. The hand controllers are designed so that at no point in time the maximum deflection of the hand controller would produce greater than 123 counts (per axis) output. If any axis at any time is greater than this value, the GPC proceeds to zero this axis, display a fault summary message and notify the MCIU. The MCIU would trigger the master alarm and illuminate the CHECK CRT light. If this occurs when in the manual augmented mode, the GPC will transition to idle mode. The operator can reselect manual augmented mode and resume normal operation with all capability except the affected axis.

There are other anomalous hand controller conditions that can be present that might or might not be obvious to the GPC or the operator. One of these is zero output from one or more axes; this will be detected by using the test mode and the S96 display of commands generated from hand controller inputs. It should be remembered, however, that the commands displayed on S96 are those that the GPC has calculated from information received from the hand controllers. S96 does not display raw output from the hand controllers.

Another condition, and one that can occur temporarily (and often), is the presence of a small amount of output when the hand controller is supposedly in detent. As mentioned in subsection 3.1.2.3, the GPC requires zero output from the hand controllers before it will enter an augmented mode. In this situation, the operator sees only one symptom: the system will not enter manual augmented mode. Since the GPC will not enter test mode either, the operator is limited in his ability to troubleshoot. The usual response in this case is to tap the hand controller or manipulate the hand grip assemblies. This is effective when a spring has not fully returned the mechanism to detent. If the hand controller continues to output a signal, the operator can possibly neutralize it by displacing the hand controller in the opposite direction long enough to allow mode entry. He must contend with the undesired command, however, and more than likely would be faced with the loss of all RMS activity that relies on hand controllers in this situation.

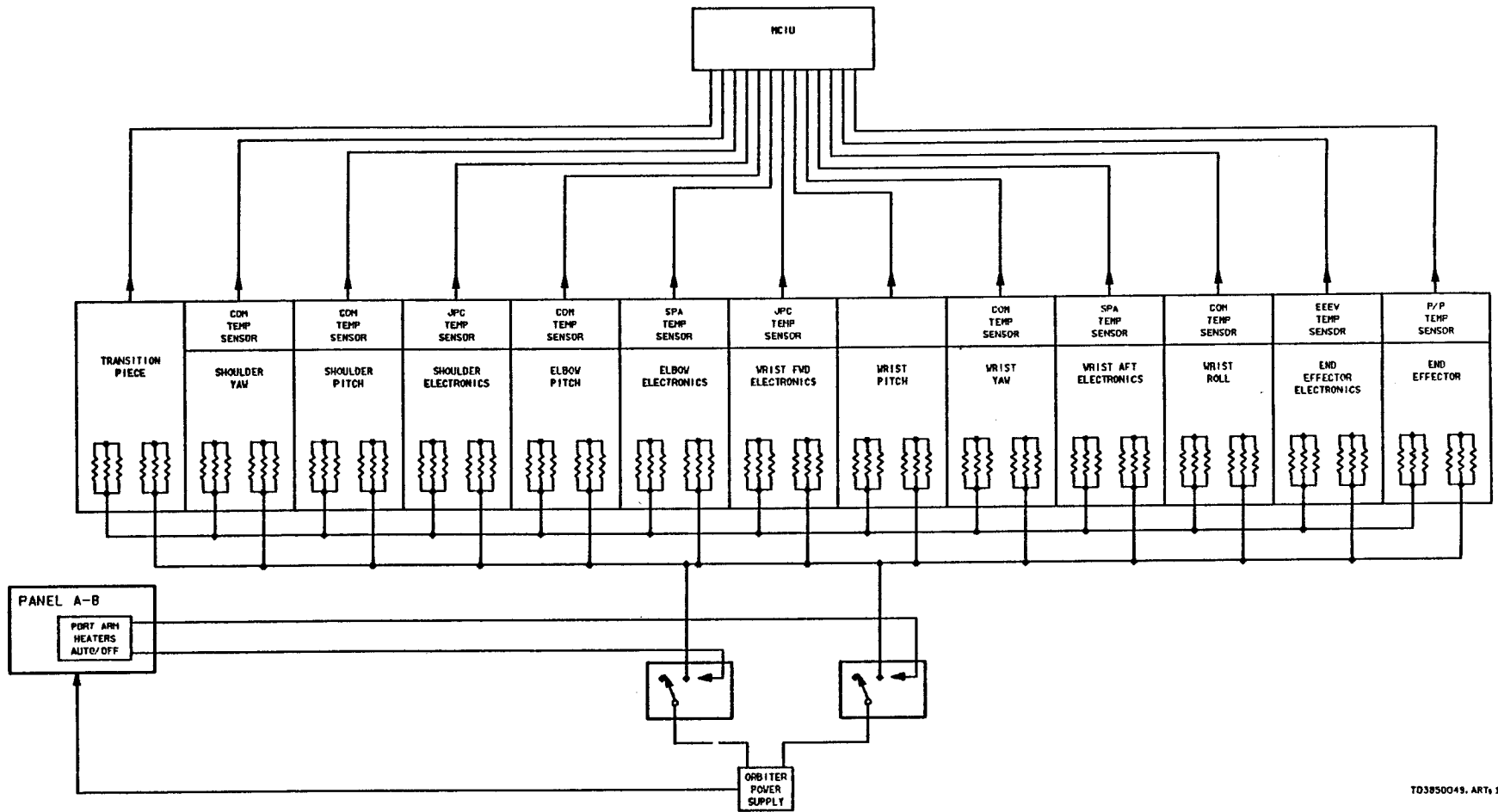
Finally, a hand controller axis can be afflicted with a biased scale factor output. In this case, there is zero output in detent, allowing manual augmented and test mode entry, but the resulting command for that axis does not correspond to the hand controller deflection. The result of this is arm motion that is different from that intended. Depending on the amount of scale factor bias, a less than full deflection in the affected axis will produce an output greater than 123 counts. This will provide an alarm and message, but releasing the hand controller satisfies the conditions for reentering mode and implies that no problem exists. This initial confusion is dispelled by following the associated malfunction procedures, which accommodate this particular failure. The operator retains full RMS capability in this situation, but must remember that the commands are biased and that the system can drop out of mode.

Thermal control is composed of passive and active thermal control systems. The passive control system consists of multilayer insulation blankets and a combination of thermal control coatings. The thermal blankets serve to protect the arm from the temperature extremes of space environment and to minimize the magnitude and specular content of reflected solar energy from the arm's surface. The five-layer material is a lightweight version of that used to line the payload bay. It can come loose, especially during the ascent phase, and the arm operator should determine its condition as soon as possible upon entering the post insertion activities. Some areas of the electronics compartments and end effector are kept free of thermal blankets and are used as heat radiators. They are covered with a special white paint that has the desired emittance values.

The active thermal control system consists of heaters, thermostats and thermistors (figure 4-9). The redundant heater system supplies 525 W of heater power to 26 heaters in each arm. The 525 W is supplied to two circuits (1050 W total for each arm), either one of which can maintain sufficient temperature for full arm operation. Two-position switches (OFF or AUTO) located on panel A8L control the heater systems. When in AUTO, the

individual heaters are turned on and off by quad-redundant thermostats, designed to operate within the 6° to -10° C (43° to 14° F) temperature range. The temperature of the arm can be monitored by the operator and the software as soon as primary power is selected and I/O is established; the arm does not have to be selected for this.

56



T03050049, ART. 1

Figure 4-9.- Active thermal control system.

The seven commutators, at the end effector and the six joints, are read by a light emitting diode/optical scanner device, sometimes referred to as LED. There is a thermistor located at each of these LEDs for temperature monitoring. There are five thermistors available for monitoring the ABE temperatures at the end effector and joints. The SP and SY ABEs share a thermistor and the WP and WY ABEs share a thermistor.

Twelve temperature thermistors per arm with a data range of -40° to 100° C (-40° to 212° F) are used to sense the temperatures. They can be displayed on the D&C panel A8U numerical indicators via the PARAMETER and JOINT select rotary switches. A table of temperature data, limits and joint IDs is provided in the reference data section of the PDRS OPS checklist.

The thermistors which monitor the temperature of the joint components are powered from a -3.8 -V supply through fixed resistors. The voltages across the thermistors are fed individually to a 32-channel submultiplexer which forms part of the MADC. The first two channels of the multiplexer are the -3.36 V which is used to check the MADC operation and the -3.36 -V derived from the -3.8 V which powers the thermistors. It is these two voltages which, after digitizing, are checked by the microprocessor.

The interface control compares the two output values corresponding to the two calibration inputs to a reference value. There is an error if more than two bits causes the interface control to signal a fault. The fault results in a bit being set into the BSR. The bit is filtered over three submultiplexer cycles (3×32 MCIU cycles) and, if present, results in the CHECK CRT light and master alarm. The GPC processes the BITE flag and provides a down arrow and message.

When a failure has occurred, the temperature data are unreliable and so are the temperature cautions on the D&C panel since these are derived from the multiplexed data. The thermostats controlling the joint heaters are not affected so that temperature control is still available.

4.3.6 RELEASE Light

The EE auto logic in the MCIU provides the following signals to the AUTO set of contacts of the EE MODE switch.

- Capture = 12 V
- Release = 6 V
- Rigidize = 12 V
- Derigidize = 6 V

The operator (via a switch on the RHC and a switch on panel A8U) provides the same signals to the MAN set of contacts of the EE MODE switch. If the port arm power status relays K1 and K2 are closed, these four voltage levels travel via hardwire to the tristate level detector circuitry in the EEEU where they are compared with $+10$ V to determine that a capture, release, rigidize or derigidize request has been made. This determination is sent to a capture/release command decode logic and a rigidize/derigidize command decode logic, which send the requested command to the appropriate circuitry within the EEEU.

After capture and rigidization, whether done in auto or manual mode, the prudent operator places the EE MODE switch to the off position to preclude the inadvertent release of a captured and rigidized payload while manipulating the rotation hand controller (RHC). Two precautionary measures are provided to back this up. One is a guard over the release switch on the RHC. The other is an inhibit signal to the capture/release command decode logic. This inhibit is called capture command enable logic, and is generated by feeding the derigid microswitch signal and the close microswitch signal through a NOT AND (NAND) gate.

Even though manual end effector operation does not require assistance from the MCIU, 10-V contacts in the capture/release and rigidize/derigidize switches inform the MCIU of the commands generated by the operator. The MCIU provides this information, as well as end effector microswitch status to the GPC.

The GPC is informed, and maintains an awareness, of the capture/release/rigidize/derigidize commands and status. If the GPC is informed of payload release without being informed of a release command, it displays a fault message and notifies the MCIU. The MCIU triggers the master alarm and illuminates the RELEASE C/W light. At this point, the arm operator should make a rigorous attempt at informing the other crewmembers of the situation and recapturing the payload. The RELEASE light illumination is not a fact that the arm operator keeps to himself because it implies that the payload is a free flyer. If it is there is potential danger of damage to the payload and Orbiter. The crew can lessen the potential with timely application of RMS/proximity operations procedures.

The light will remain on until a rigidize command is generated by the operator. The EE MODE switch can be kept in the off position while commanding rigidize for this purpose if actual EE motion is not desired.

4.3.7 PORT TEMP Light

RMS temperature control and monitoring was discussed briefly at the end of subsection 4.3.5. When thermistor data comes from the ABEs via the MCIU, the RMS software converts the values to degrees F via a look-up table. It then compares temperatures to predefined limits and if the high or low limit is exceeded for two consecutive cycles, the software generates the fault message "PDRS TEMP" and notifies the MCIU. The MCIU triggers the PORT TEMP C/W light and the master alarm.

The MCIU also selects the out-of-limit indication (or if more than one, the worst out of limit) for display on the digitals. By selecting the CRIT TEMP position on the JOINT select switch, the operator can read the ID and temperature value. If no temperatures are out of limit, this display is blank. The software will not indicate if more than one joint temperature is out of limits, but the temperatures for all the joints can be read on the digitals by selecting the appropriate position on the JOINT select switch and PORT TEMP LED/ABE/ID on the PARAMETER select switch.

4.3.8 SINGULARITY Light

Certain arm configurations result in the loss of one or more degrees of freedom. When in these configurations, the arm must be reoriented before it can accommodate additional movement in the affected degree of freedom. There are three such arm configurations, and when in one, the SINGULARITY light is illuminated to alert the operator of the condition.

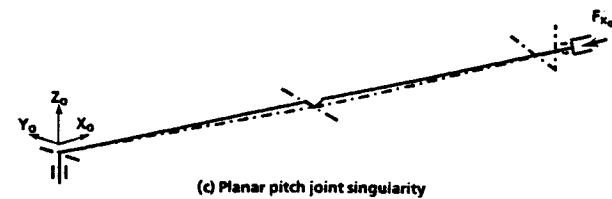
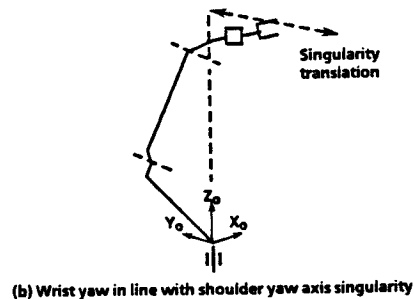
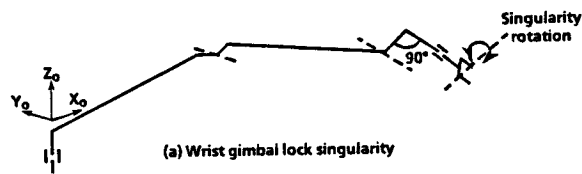
This is necessary for two reasons. First, the arm reconfiguration has the appearance of motion different from that commanded, since motion in the degree of freedom requested must be delayed. A misinterpretation of this would lead to unnecessary troubleshooting.

Second, the crew must take steps to inhibit any firing of primary RCS jets when the arm is in a singularity configuration. An arm that is mechanically not free to move in one or more degrees of freedom faces potential damage to a joint as a result of the dynamic loads produced by firing jets that have 870 lb of thrust. When the arm is in a singularity configuration, the crew goes to free drift or secondary RCS jets, which have 24 lb of thrust.

In addition to the mechanical inhibition of arm movement, singularity can be defined mathematically when normal conversion among the coordinate systems is not possible. This occurs when one row or column of the transformation matrix goes to zero.

Figure 4-10 shows the graphic representation of wrist yaw, planar pitch and shoulder yaw singularity conditions. When the arm is about to enter into one of these regions, the RMS software enters singularity management, determines what arm reconfiguration must be done, provides a fault message and notifies the MCIU. The MCIU triggers the master alarm and SINGULARITY CW light.

59



TD385*003

Figure 4-10.—Singularity conditions.

Figure 4-11 shows two views of the arm when in shoulder yaw singularity. This occurs when the WY joint axis is within three feet of the SY joint axis. The arm in this configuration experiences restricted motion that is normal to the pitch plane. Translation commands parallel to the Orbiter Y axis could be delayed as the SY and WY joints are reconfigured. The arm swings about a considerable amount to achieve this and requires even keener vigilance by the operator to preclude contact.

69

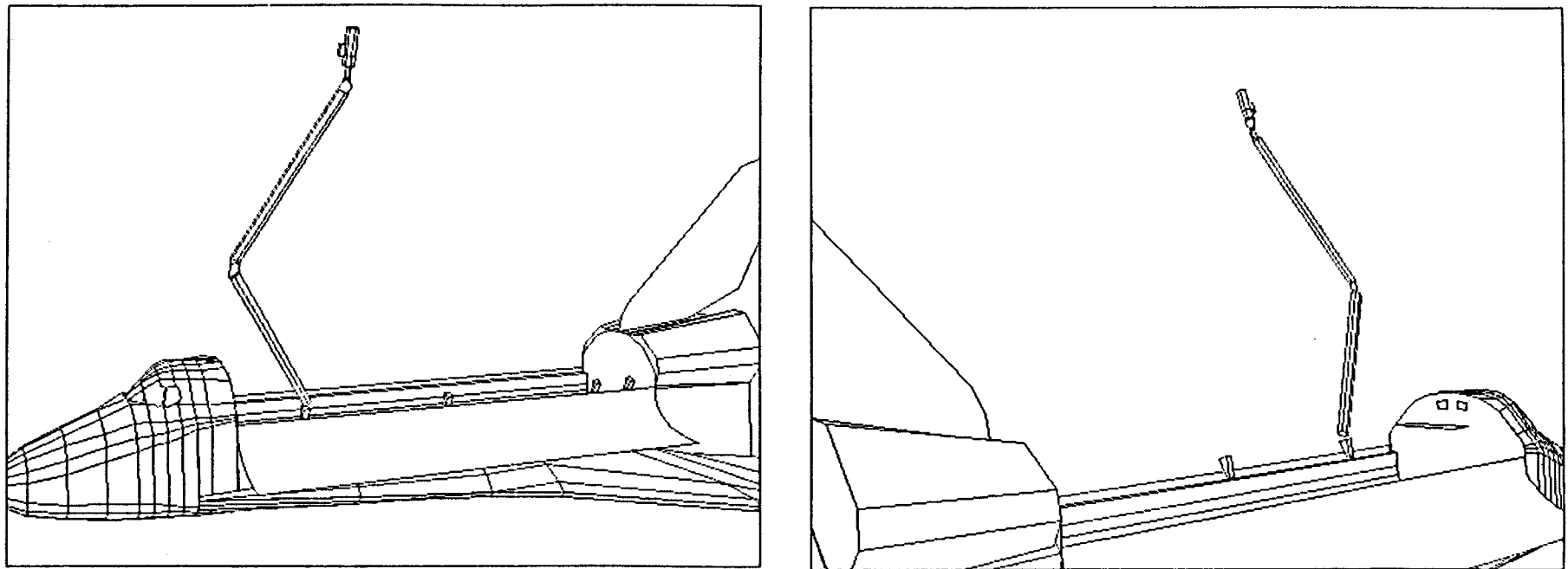


Figure 4-11.— Shoulder yaw singularity.

Figure 4-12 shows two views of the arm when in the wrist yaw singularity condition. This is sometimes called gimbal lock and occurs when the WY joint is within $\pm 15^\circ$ of $+90^\circ$ or -90° . This creates a configuration where WP and WR are parallel and requires arm reconfiguration when roll about the pitch plane is commanded.

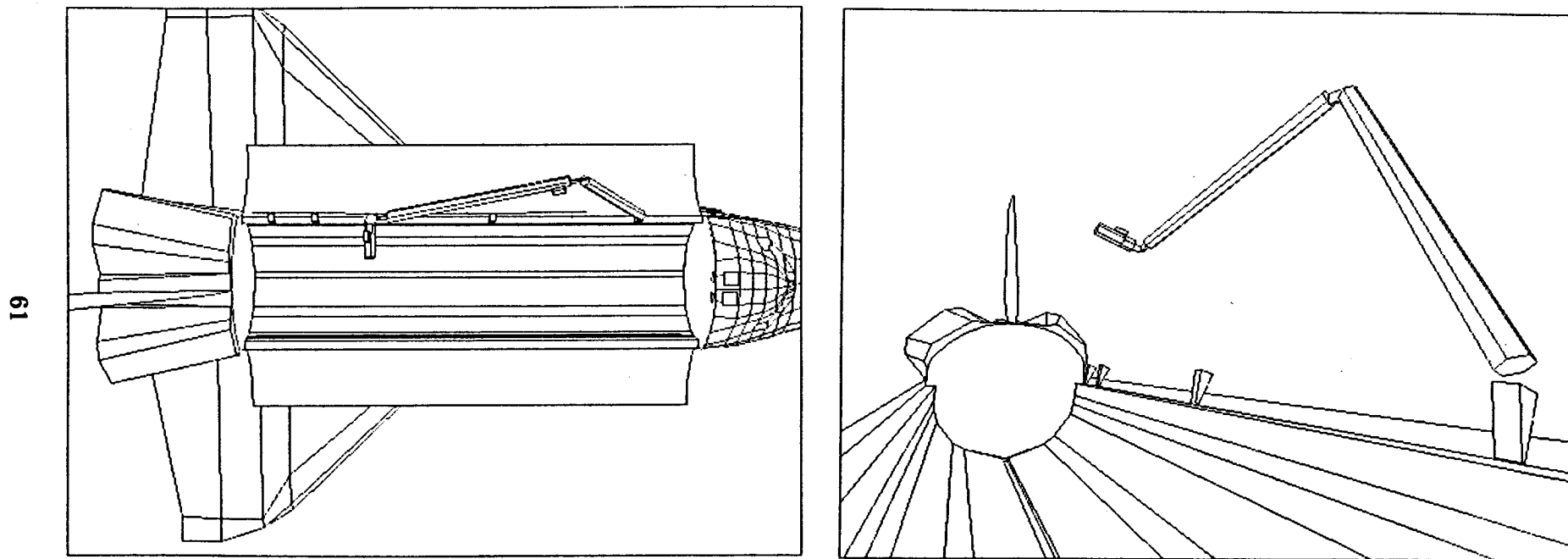


Figure 4-12.- Wrist yaw singularity.

Figure 4-13 shows two views of the arm when in the planar pitch joint singularity condition. This occurs when three pitch joints are in a line or, more specifically, when the EP joint angle is at or above -7.6° . Any degree of freedom that requires the arm to get longer is not available since the arm is essentially at its maximum length. This situation is seen anytime the arm is at or near its cradled position.

62

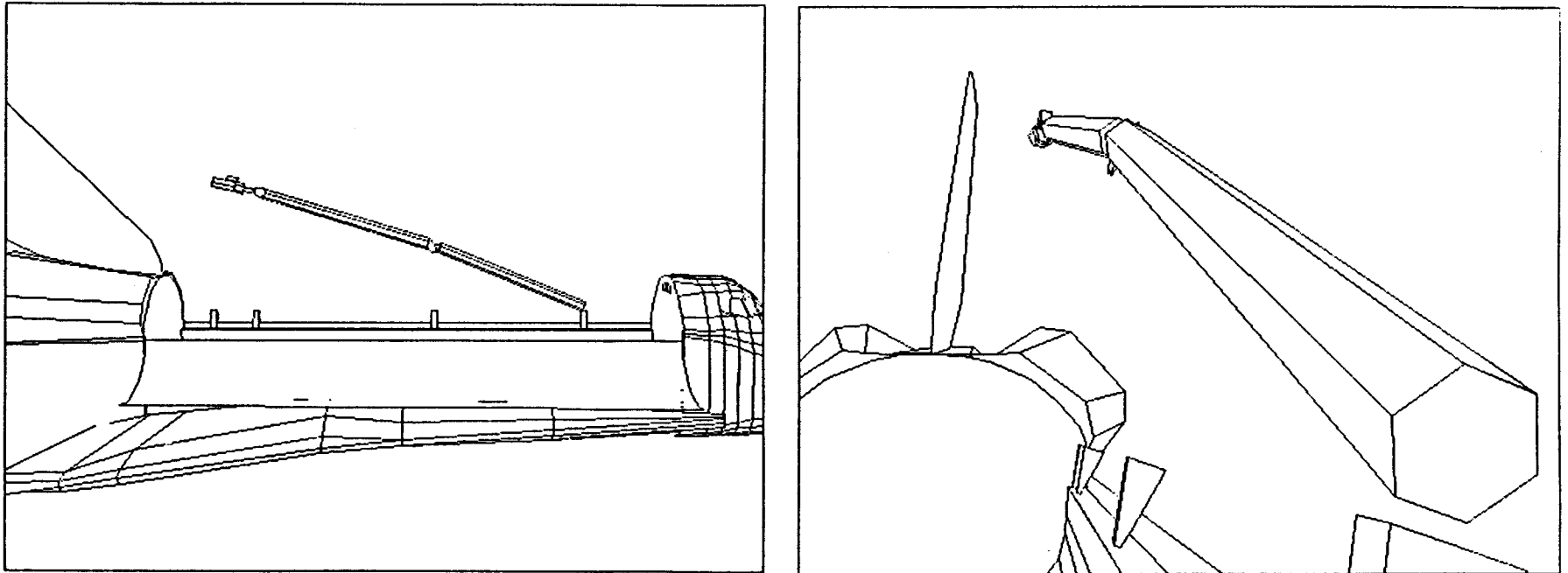


Figure 4-13.– Planar pitch singularity.

4.3.9 REACH LIMIT Light

The GPC monitors the encoder output from each joint, even when the arm is being driven in the direct drive mode, and compares the values to predefined reach

limits. These angles, in both the plus and minus directions, are generally about two degrees short of the softstop angle limits. Refer to subsection 3.2.1 for a review of softstop and refer to figure 4-14 for the values of reach limits and softstops.

Joint Travel Limit Locations

Joint	Reach Limit	Softstop	Hardstop	
Shoulder	Yaw	$\pm 175.4^\circ$	$\pm 177.4^\circ$	$\pm 180.0^\circ$
	Pitch	$+140.4^\circ$	$+142.4^\circ$	$+145.0^\circ$
		$+2.6^\circ$	$+0.6^\circ$	-2.0°
Elbow	Pitch	-2.4°	-0.4°	$+2.4^\circ$
		-155.6°	-157.6°	-161.0°
Wrist	Pitch	$\pm 114.4^\circ$	$\pm 116.4^\circ$	$\pm 121.4^\circ$
	Yaw	$\pm 114.6^\circ$	$\pm 116.6^\circ$	$\pm 121.3^\circ$
	Roll	$\pm 440.0^\circ$	$\pm 442.0^\circ$	$\pm 447.0^\circ$

63

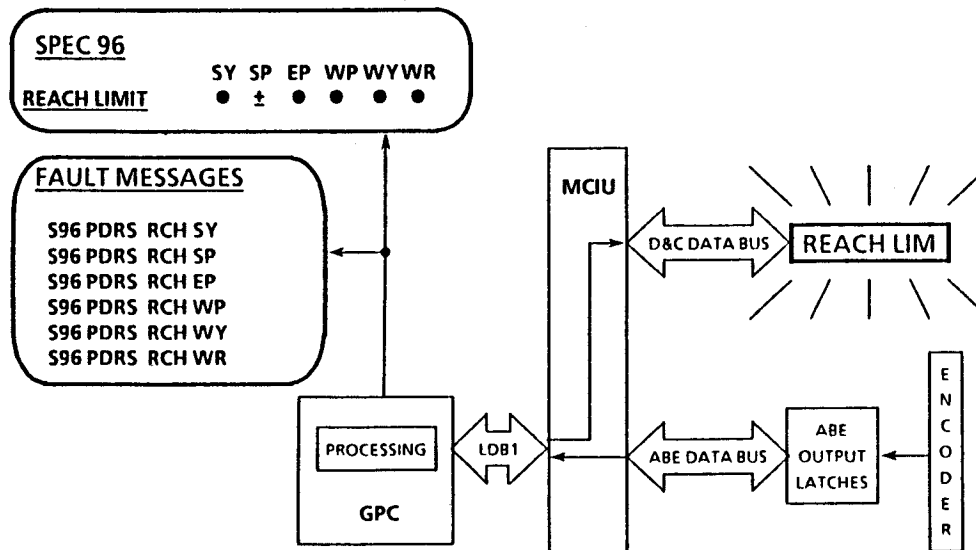


Figure 4-14.- Reach limits, softstop, hardstop.

If the GPC sees a joint angle in the reach limit region for two cycles, it alerts the operator to the condition by displaying a + or – on S96 and by providing a fault message. It also notifies the MCIU of the condition and it, in turn, triggers the master alarm and REACH LIMIT C/W light. The purpose of the reach limit caution is to inform the operator that a joint angle is very close to its softstop, which will cause the software to drop out of mode, and that the joint is very close to its travel limit. The reach limit condition does not cause the software to drop out of mode, but the operator generally switches to a single joint mode to drive the affected joint away from the reach limit. This could be done in a multijoint mode but would be more difficult.

As soon as the joint is driven out of reach limit region, the + or – sign is removed from S96 and the REACH LIMIT light is extinguished.

Reach limit and, as mentioned earlier, softstop regions of joint travel will always be encountered when the arm is cradled. Shoulder pitch will indicate a – and elbow pitch will indicate + on S96.

4.3.10 DERIGIDIZE Light

Some of the discussion on end effector operation in subsection 4.3.6 is applicable here and should be read if a review is required.

If a payload is rigidized and the GPC is informed of derigidization without seeing a derigid command, it displays a fault message and notifies the MCIU. The MCIU triggers the master alarm and the DERIGID C/W light. At this point the operator should stop all arm motion in a timely but smooth manner.

The light will remain on until a rigid command is generated by the operator. The EE MODE switch can be kept in off while commanding rigid for this purpose if actual EE motion is not desired.

4.4 Questions

1. What are the drive times for dual motor operation of the following?
 - a. EE rigidize or derigidize
 - b. MPM deploy or stow
 - c. MLR latch or unlatch
2. What is the proper response to uncommanded or runaway arm motion by the operator when in the following modes?
 - a. Computer supported
 - b. Direct drive
 - c. Backup drive
3. Under what conditions would the operator use the backdrive, or whiplash procedures?
4. When faced with a multiple C/W light situation, what light priority will the operator follow?
5. What are the four MCIU BITE functions that can illuminate the MCIU C/W light?
6. What are the six BITE circuits that can illuminate the ABE C/W light?
7. What are the two consistency checks that can illuminate the CONTR ERR C/W light?
8. What action will extinguish the GPC DATA light?
9. There are five main BITE functions that can illuminate the CHECK CRT light. What are they and where are they done?
10. Most indicators (lights, talkbacks, etc.) on panel A8U are controlled via signals sent from the MCIU on the D&C data bus. What three lights on the panel that are illuminated to alert the operator get their activation via a hardwire?
11. Upon learning of the illumination of the RELEASE light, what should the operator do?
12. If all arm temperatures are within their predefined limits, what values will be displayed upon selection of CRIT TEMP by the JOINT switch?
13. What are the three types of arm singularities?
14. What does the REACH LIMIT light signify and what effects does its illumination have on arm motions?
15. If the conditions that caused a RELEASE or DERIGID light are no longer present, how can they be extinguished?

4.5 Answers

1. The drive times for the following activities under normal (dual motor) conditions are
 - a. EE rigidize or derigidize - 18.4 seconds
 - b. MPM deploy or stow - 34 seconds
 - c. MRL unlatch or latch - 8 seconds
2. The proper response to uncommanded or runaway arm motion by the operator when in a computer supported mode is brakes-on. When in direct drive the operator should change the position of the MODE switch to something other than DIRECT. When in B/U the operator should place the power switch to the off position.
3. An arm that has a free SP, EP, WP or WY joint with an operational brake can be cradled with the backdrive, or whiplash procedure.
4. When faced with a multiple C/W light situation, the operator will troubleshoot via the following priority:

MCIU

ABE

CONTR ERR

GPC DATA

CHECK CRT

RELEASE

DERIGID

PORT TEMP

5. The four BITE functions that illuminate the MCIU C/W light are MADC failure detection, MCPC failure detection, ICF failure detection and frame sync failure detection.
6. The ABE warning consists of 27 different BITE flags generated as a result of six different BITE circuits.
 - ABE/MCIU communication (1)
 - ABE/TACH phase lock loop (6)
 - ABE/MDA current limit (6)
 - ABE/SPA + 28 V (6)
 - ABE/Commutator (6)
 - ABE/JPC out of tolerance (2)
7. The two consistency checks that can illuminate the CONTR ERR C/W light are the envelope check, which compares the actual joint rate against the commanded joint rate, and the tachometer data check, which compares the integral of the tachometer output with encoder output changes.
8. The GPC DATA light can be extinguished by canceling safing. This can be done whether an arm is selected or not; the safing itself can be initiated or canceled only if an arm is selected.

9. Two BITE functions, performed by the GPC, that result in the illumination of the CHECK CRT light, are the position encoder check and the hand controller hard-over check. Three MCIU BITE functions that can illuminate this light are the D&C/MCIU communication check, the end effector check, and the thermistor circuit check.
10. Three alert lights on panel A8U that are activated via a hardwired signal (rather than data bus) are the master alarm light, MCIU C/W light and CHECK CRT C/W light.
11. Assuming that a payload had been captured at the time of the illumination of the RELEASE light, the operator should immediately, and simultaneously, notify the other crewmembers and attempt to recapture the payload.
12. If all arm temperatures are within limits, selection of CRIT TEMP will result in a blank display.
13. The three arm singularities are shoulder yaw, planar pitch (elbow) and wrist yaw (gimbal lock).
14. The purpose of the REACH LIMIT light is to inform the operator that a joint angle is very close (a couple of degrees) to its softstop position. The reach limit condition does not affect arm motion.
15. Either the RELEASE or DERIGID light is extinguished by placing the EE MAN CONTR switch momentarily to the RIGID position.

Section 5: Procedures

So far, this workbook has concentrated on the immediate or timely responses that the operator should make to indications of off-nominal arm operation. These include the application of brakes, changing mode, removing power, notifying others and so forth. These procedures are performed as the result of an instinct that is developed by many hours of training and practice and do not allow the operator time to reference his documentation.

88

Other documents describe the procedures that the operator should follow to accomplish the less time-sensitive activities. Most of these are what are normally referred to as nominal operations. The rest are procedures that the operator relies on to troubleshoot and work around the loss or degradation of some portion of the system capability. It is these procedures that will be addressed at this point in the workbook; they are discussed only to the extent that the student will be made aware of their existence and purpose. It is strongly recommended that the use of these procedures rely on constant reference rather than memory, and that they be performed to the maximum extent possible during periods of data and voice flow between the Orbiter and ground.

5.1 Malfunction Procedures

The FDF includes a document that is formally titled Malfunction Procedures, All Vehicle. This book is informally referred to as the long form malfunction procedures. One reason for this is that the checklists outlining normal operations will include short form malfunction procedures that are provided when the troubleshooting and work around steps are short, simple or time-sensitive. These procedures are identified by encircling asterisks. Another type of short form malfunction procedure is that found in the pocket checklists. The purpose of pocket checklists is to provide the crewmember with a shortened version of those malfunction procedures that he must follow when he is strapped into a seat or for some other reason cannot accommodate the bulkiness or time requirement of the long form malfunction procedures book.

The arm operator will rely on the long form malfunction procedures most of the time to troubleshoot and work around a system loss or degradation. Currently, that is section 13 and is labeled PDRS. The operator is directed to the proper procedure, in most instances, by annunciators such as lights, messages and talkback statuses that indicate an anomalous condition. Other procedures are entered upon a more subjective evaluation of the system condition. An example of this is when arm motion is perceived to be something different from that which was commanded.

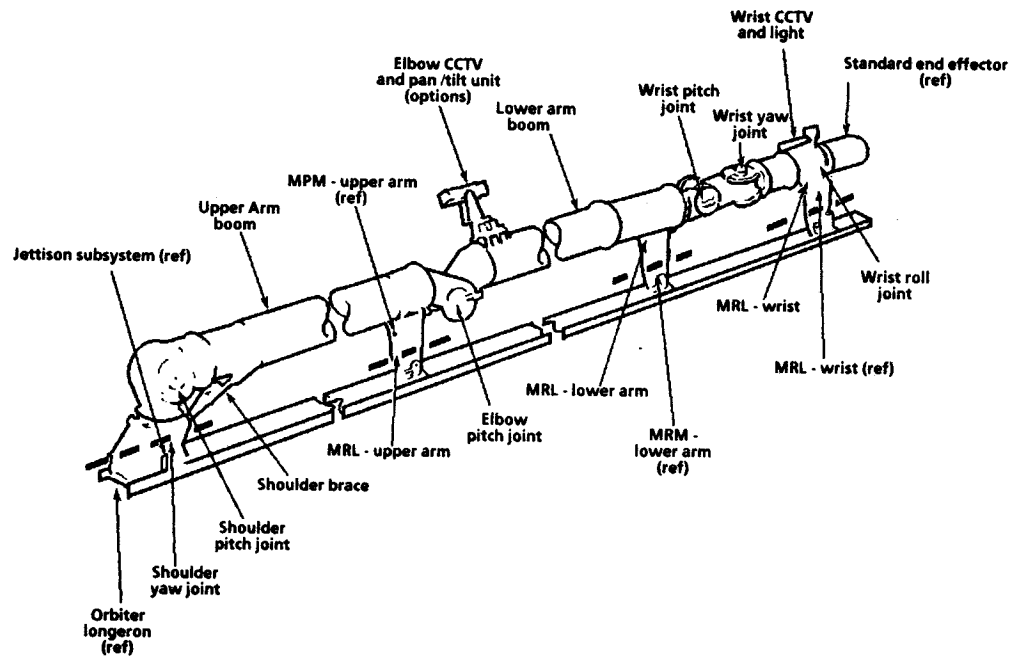
When faced with multiple annunciators, the operator follows the directions in the procedures as prescribed by a hierarchy of cues. This hierarchy is noted in the procedures and has been outlined in prior subsections of the workbook. Generally, the malfunction procedures are sufficient to guide the investigators to a fairly specific cause of the anomaly. On many occasions, the procedures give the minimum recommended capability remaining in the system even though actual capability may be more.

69

5.2 Jettison

For a large portion of the known RMS failures, an alternate method of operation or a contingency procedure will provide a means of cradling and stowing the arm to ensure a safe Orbiter entry. However, there are failure modes (frozen joint, jammed EE, jammed MPM) which can result in the inability to secure the RMS. In the event of any of these failures, the RMS could be jettisoned, with or without a payload, through utilization of a redundant jettison system.

There are two general classes of failures which can result in a jettison. The first type is an arm failure prohibiting cradling, which would require jettisoning the arm by severing the shoulder MPM pedestal. The other type of failure is within the MPM system, resulting in all four pedestals locked permanently in the deployed configuration. The specific procedure followed for this case is to cradle and latch the RMS in the MPM, deadface the latch circuitry, jettison the AFT MID and FWD pedestals, maneuver the arm (with portions of the three pedestals attached to it) to a safe position, deadface the shoulder circuitry, and jettison the shoulder pedestal. Figure 5-1 shows the areas of separation for jettisoning. The procedures for both types of jettison cases are found in the contingency operation section of the PDRS Operations Checklist, All Vehicle.



TD385*004

Figure 5-1.- Arm jettison locations.

Figure 5-2 shows an example of the location of a wire bundle and its guillotine. A wire bundle passes through the separation plane for each of the AFT, MID, and FWD pedestals to provide power for the MRL, and at the shoulder to provide power and data cabling to the ABE. Prior to mechanically separating any of the pedestals, the wire bundles must be guillotined. The guillotine blade attains the energy necessary to cut the bundle from pyrotechnically-operated pressure cartridges. To prevent potentially hazardous shorts, a deadface switch on panel A14 removes all power from the MRL wire bundles in the pedestals. After deadfacing, power cannot be resupplied to the MRLs. The wire bundle passing through the shoulder is deadfaced by positioning the RMS power and heater switches on panel A8L to off.

The jettison mechanisms are identical in design and function, and provide separation of each pedestal at the plane in close proximity to the upper attach point of the MPM actuator, as indicated in figure 5-3. This location was chosen so that the PLB door would not impact an unstowed MPM stub. The upper MPM pedestal is affixed to the lower MPM pedestal via two preloaded C-clamps. These clamps are linked to a centrally-located hook dump rod, which in turn is attached to a pressure-activated retractor assembly. The location of this can be seen in figure 5-4.

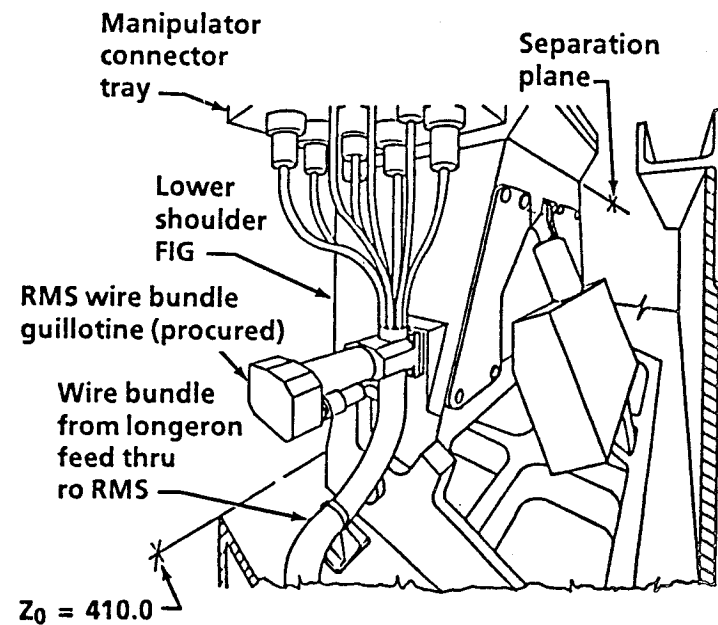


Figure 5-2.- Wire bundle guillotine.

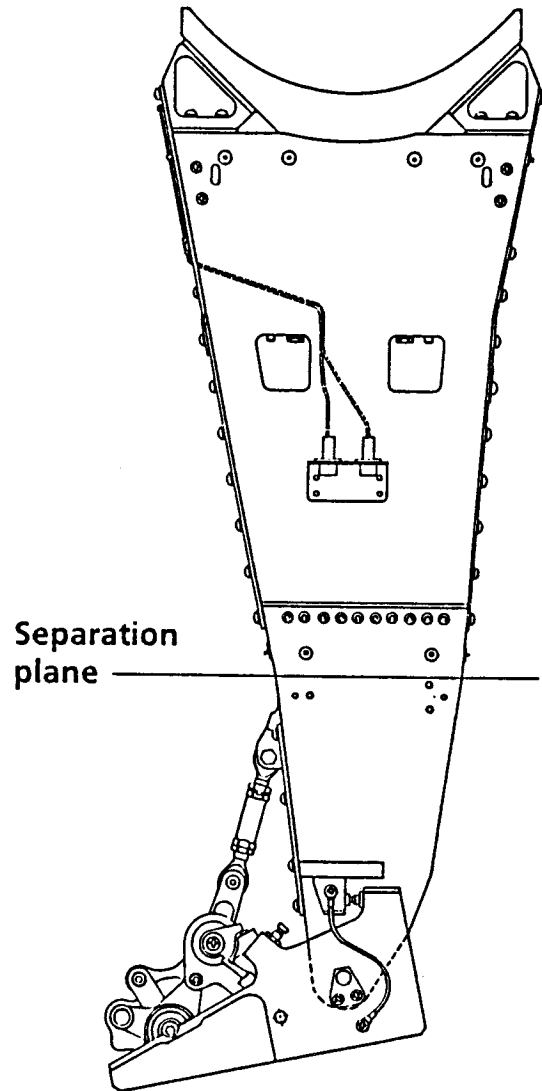


Figure 5-3.—MPM separation plane.

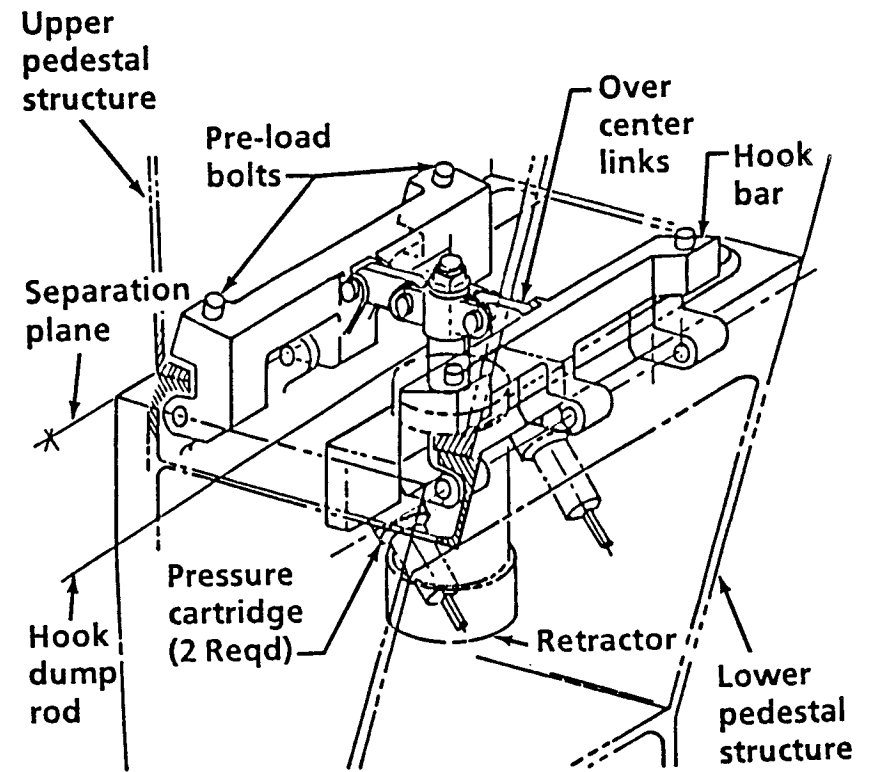
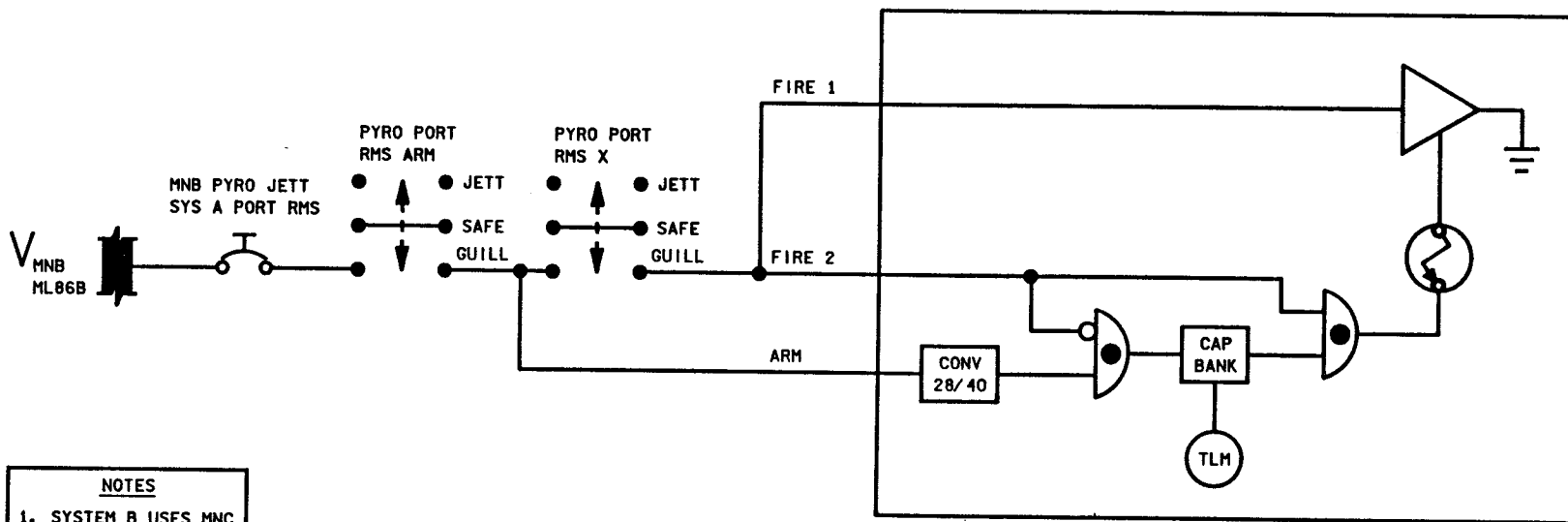


Figure 5-4.—Pressure-activated retractor assembly.

In response to a panel command, the pyrotechnic devices in an NASA standard initiator (NSI) fire two pressure cartridges into the cylinder of the retractor assembly. This increase in pressure provides enough force against the retractor piston to withdraw the hook dump rod into the retractor cavity, which rotates both C-clamps inward and releases the upper MPM. The mechanism was designed so that a minimum impulse would be introduced to the free portion of the pedestal. This ensures no unexpected or potentially hazardous movement of the arm during and after jettison.

Figure 5-5 shows a functional representation of the guillotine and jettison circuitry. The "ARM" on the PYRO switch relates to the arm and fire connotation rather than the mechanical arm connotation. A 28-V power source is provided to a converter which charges up the capacitor bank to 40.75 V in one second. If power is removed from the capacitor bank by any means (bus, circuit breaker, switch or converter) the capacitor will discharge, in fifteen seconds, to 1.5 V. The operator has no visibility in this area but ground personnel can tell if the capacitor is or has been charged up. If the NSI is fired, by signals on the FIRE 1 and FIRE 2 lines, the capacitor discharges to OV in microseconds.

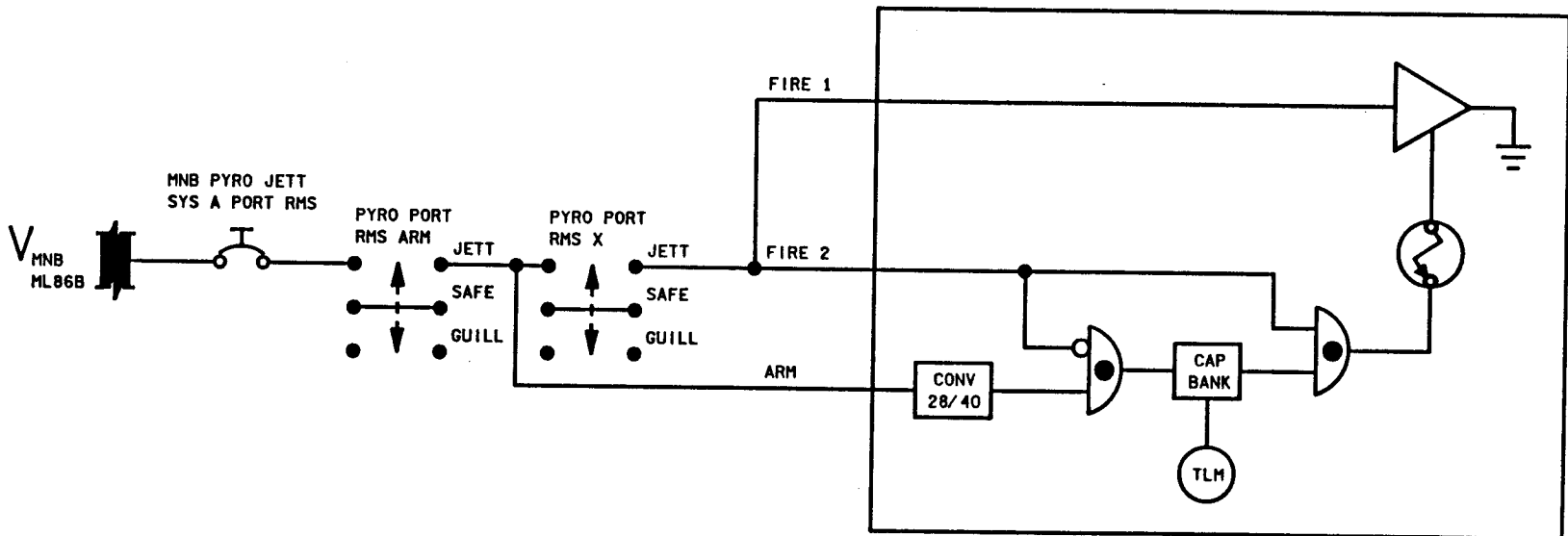
GUILLOTINE SYSTEM A



NOTES

1. SYSTEM B USES MNC
2. X = SHOULDER
 - LATCHES FWD
 - LATCHES MID
 - LATCHES AFT

JETTISON SYSTEM A



TD385055. ART. 2

Figure 5-5.- Guillotine and jettison PIC.

74

5.3 Back Drive

The PDRS OPS Checklist currently includes four procedures, which are sometimes referred to as the whiplash technique, to cradle the arm when a joint is considered to be failed free. This means the joint will not drive in any mode but must have operational brakes. The procedures apply only to SP, EP, WP and WY and make use of Newton's laws of motion and induced dynamics. The techniques for each joint are different, but are similar in that they rely on action/reaction and the timely application or release of brakes. Figures 5-6, 5-7 and 5-8 show an example of the motions involved with the four procedures.

Depending on the starting angle of the failed joint, the procedure can require many repetitions of the technique, with each one moving the joint a slight amount toward its desired zero angle. Even in worst case, however, the total time for cradling with these procedures is not considered to be excessive.

75

WHIPLASH TECHNIQUE SHOULDER/ELBOW - SINGLE MODE COMMANDING

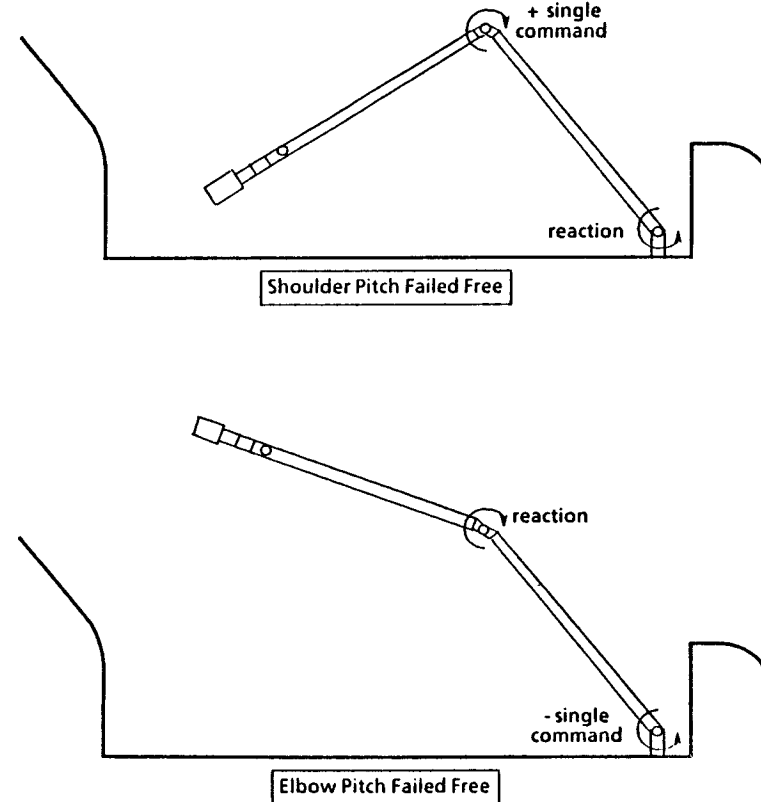


Figure 5-6.- Shoulder and elbow backdrive.

WHIPLASH TECHNIQUE
WRIST PITCH - EE MODE COMMANDING

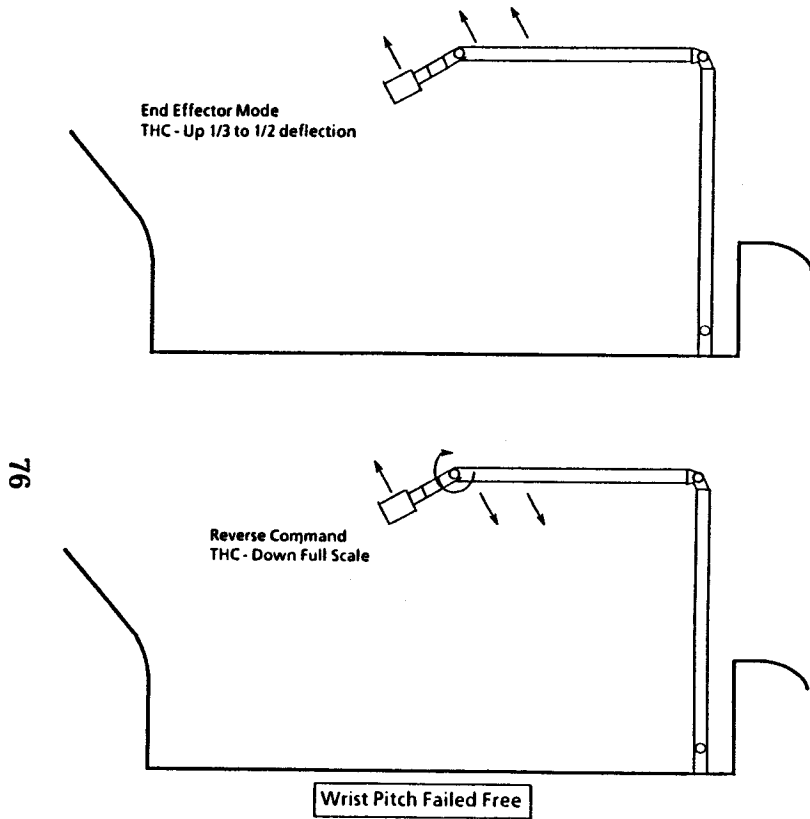


Figure 5-7.- Wrist pitch backdrive.

WHIPLASH TECHNIQUE
WRIST YAW - EE MODE COMMANDING

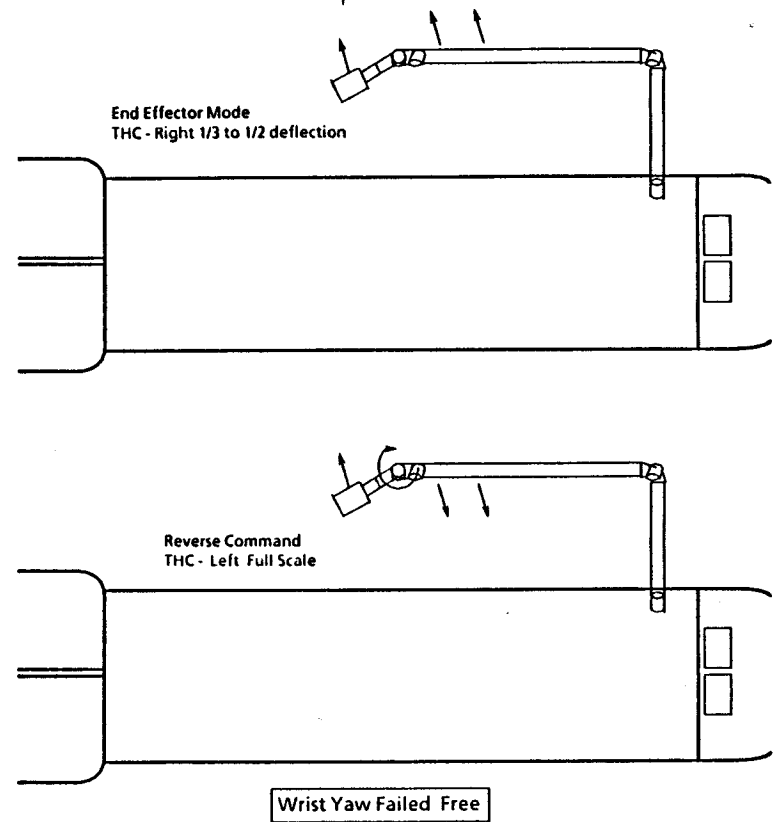


Figure 5-8.- Wrist yaw backdrive.

5.4 IFM

The value of having a human being on board a spacecraft has been debated for years. How much mechanical repair that person should attempt to do has also been debated for years. These debates will not be entertained in this book. However, if the decision has been made to send a person on a space voyage, the ability of that person to troubleshoot, repair or replace an incorrectly-working piece of equipment can quite literally save the mission. These repair and workaround procedures are grouped under the broad classification of inflight maintenance.

Those RMS-related IFM procedures that can be accomplished inside the Orbiter will be discussed in this subsection. IFM procedures requiring one or more EVA crewmembers will be discussed in subsection 5.5. In either case, only those procedures that are currently included in the FDF will be mentioned. The multitude of possible workaround and repair procedures that could be created during a mission, and those currently under consideration for FDF inclusion, will not be addressed.

5.4.1 Display and Control Kit

The RMS IFM D&C kit can be installed in about one hour and removed in less than one hour. Its purpose is to bypass certain failed switches on A8U and A8L or to recover from the loss of power to those switches. It is ready for use after the connections are made to the rear of panel A8L and a dc or ac utility outlet. The D&C kit is a specialized (RMS only) version of a breakout box and is sometimes referred to as the breakout box. It should be called D&C kit only to avoid confusion.

The D&C kit contains the following controls:

- A knob which holds, and allows replacement of, a 1/4-amp fuse. All dc voltage associated with the kit is protected by this fuse.
- SAFING INHIBIT switch. The inhibit position of this switch puts 28-V dc on the safing line so that the hardwire safing circuit is bypassed. The center and down (OFF) positions put no voltage on the line.
- SHOULDER BRACE RELEASE switch applies 115-V ac (single phase) directly to the drive motor. the center and down (OFF) positions apply no voltage.
- CAPTURE/RELEASE switch controls these EE actions. All EE switches on A8U and RHC are disabled when the kit is installed.
- RIGIDIZE/DERIGIDIZE switch controls these EE actions.
- Joint select rotary switch selects which joint will be driven by the associated DIRECT DRIVE switch. The JOINT select rotary switch on A8U will still work for single mode and joint angle readout.
- DIRECT DRIVE switch drives the selected joint in + or - direction. It does this regardless of the brake switch position on A8U so the operator must make sure that the brake switch is on.

5.4.2 Contingency Powerup

If the RMS power switch has failed, or if the 28-V power from the MNA 014 & A8 bus is lost, the IFM breakout box can be used to supply 28-V dc power to the down-stream side of the power switch. This procedure takes about three hours and can be used to resupply dc power to any switch or LRU that is accessible to the crew.

Figure 5-9 shows a sketch of the face of the IFM breakout box. Power (28-V dc) from a dc utility outlet is supplied to the box and is routed through fuses to circuits A and B. If the AUX switch is on, 28-V dc is also supplied to an outlet which can be used to hook up another breakout box (two are flown) for additional capability and flexibility. A small light on the box indicates to the user that the outlet is hot.

78 Circuits A and B can be used simultaneously, providing power to plugs that can accommodate pins for wire sizes of 22, 20, 16 and 12 gauge. Circuit B is always 28-V dc but circuit A can provide power that is variable from 1-28-V dc. A small light above the VAR knob indicates to the user that circuit A is in the variable mode. Additional lights are provided with each pin plug indicating selection and power availability.

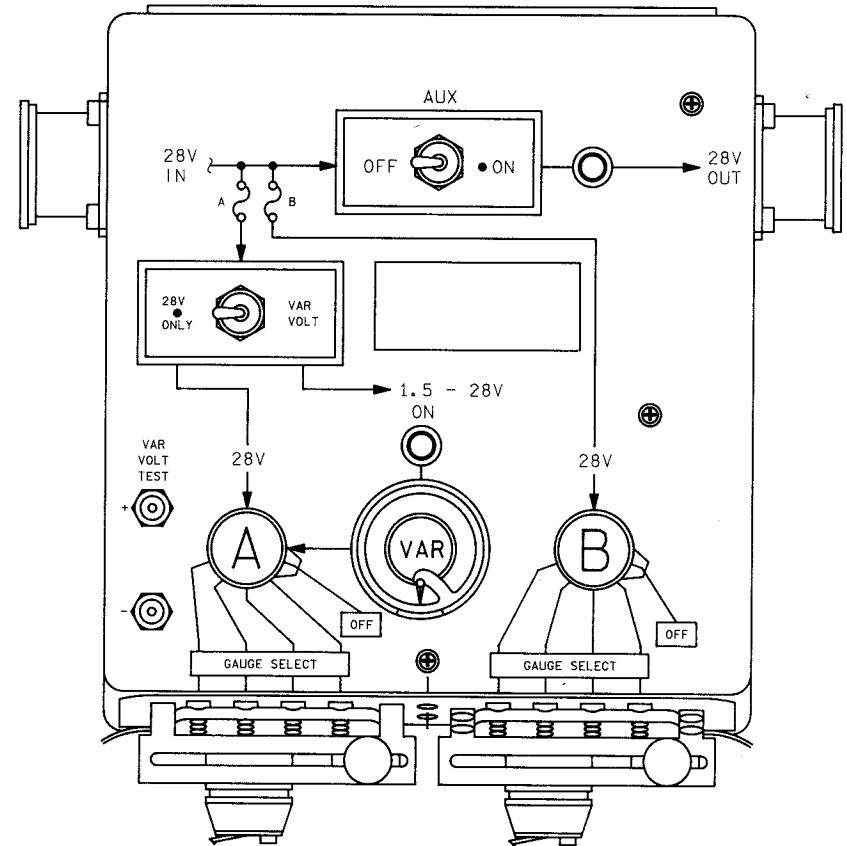


Figure 5-9.- IFM breakout box.

5.4.3 MPM Deploy/Stow

If the RMS DEPLOY/STOW switch fails, or if the 28-V power from control bus CA2 (BC1 for MPM system 2 motor) is lost, the IFM breakout box can be used to supply 28-V dc to the downstream side of the switch. The procedure requires access behind panel A8L and takes about 2 1/2 hours.

5.4.4 MRL Release/Latch

If the MRL RELEASE/LATCH switch fails, or if the 28-V power from control buses AB1 and CA1 is lost, the IFM breakout box can be used to supply 28-V dc to the downstream side of the switch. The procedure requires access behind panel A8L and takes about 2-1/2 hours.

5.4.5 MCIU Changeout

On flights that have an RMS, a spare MCIU is stowed in a middeck locker. If the MCIU fails, the crew can exchange it with the spare unit by following a procedure in the IFM checklist. This procedure requires access to panel L17 and takes about 1-1/2 hour.

5.5 EVA

The RMS is used to support a variety of planned and unplanned extravehicular activities. These are considered to be nominal operations as far as the RMS is concerned and are discussed adequately in other documentation.

When something associated with the PDRS does not work at all or functions incorrectly, an assessment is made to determine the remaining capabilities, workaround procedures and the possibilities to repair or replace the malfunctioning component. Most of this has been addressed previously in this book. In certain PDRS failure cases, one or more crewmembers can go EVA and accomplish tasks that will either allow use of the RMS, or return it to a configuration that is safe for other onorbit or reentry activities. Several EVA tasks have been developed to compensate for failures which prevent the RMS from being stowed and/or latched safely for reentry. It should be noted that almost any RMS failure can be corrected without an EVA by simply jettisoning the arm. This, of course, is generally a last resort procedure.

5.5.1 Joint Alignment

If a multiple failure case arose such that one or more joints could not be driven, or moved via the backdrive procedure, the ability to get the arm into a cradled position for latching is provided by employing the EVA RMS Joint Alignment procedure. This procedure requires an EVA crewmember to loop an RMS rope around the EE, route it through a snatch block and roller and attach it to a winch. In a worst case situation, the rope handler could have an interesting climb to get to the EE, but would have a fantastic view. Once the equipment is configured, it provides sufficient mechanical advantage to enable the crewmember to overcome the resistance of the brake, should it not be operable. On the other side of the coin, an EVA will not be performed to place a cradled RMS into an operational state unless the flight rule is waived or changed.

5.5.2 MPM Deploy/Stow

The RMS can be operated from the rolled-in or stowed position. This requires an uplink of different data to the GPC, so that it can exercise the algorithms on the basis of an arm that joins the Orbiter at an angle that is 31.36° different than that for a rolled-out or deployed position. This generally is considered to be no problem. However, in some circumstances the arm experiences problems with manipulating a payload in the rolled-in position. These problems range from a lack of clearance (very wide payloads), to undesirable load dynamics at certain positions and attitudes, to increased encounters with singularities and reach limits. These types of problems make it desirable to deploy the arm for payload operations. It is also more desirable to stow an arm rather than to jettison it.

The FDF includes a procedure that directs an EVA crewmember through the activities that will accomplish manual MPM deploy or stow configurations. The procedure makes use of a special MPM wrench that interfaces with splines on the torque shaft. The wrench design is based on the ratchet principle, slipping in one direction and engaging in the other. Rotation of the torque shaft for eight revolutions moves the MPM through the required 31.36° . Arm operation is inhibited unless the MPM is rolled all the way out or all the way in.

5.5.3 Tiedown

The MRLs at the forward, mid and aft MPMs are each driven by dual motors. This redundancy is generally sufficient to ensure a securely-latched arm. However, there are failure cases in which one or more MRLs do not latch properly. A current flight rule states that two out of three must be latched or secured prior to reentry.

An EVA crewmember, armed with the FDF procedure and a payload retention device (PRD), can strap the arm down. Two PRDs are on board to satisfy the flight rule. The arm must be close to its cradle position and the MPMs must be rolled in prior to employing this procedure. A rolled-in MPM allows exposure of, and access to, the positioning linkage. The procedure directs the crewmember to attach the fixed-end hook of the PRD to the linkage on the inboard side, route the strap over the arm and secure it to the linkage with another hook. The procedure points out the correct positioning of the PRD to avoid contact with the radiator when the port PLBD is closed. A ratchet device on the PRD then provides the capability for achieving the desired tension on the strap.

5.5.4 Shoulder Brace Release

If the RMS D&C kit does not provide the necessary workaround capability for shoulder brace release, an EVA crewmember must release the brace manually prior to any arm activity.

The brace itself is held in position by the gripping action of a circular split collet. The mechanical advantage required to linearly force the plunger of the brace out of the split collet is provided by a tool that can best be described as a metal pry bar with a foot on it. The foot is inserted into a hole beneath the lower end of the brace such that its "does" are resting against the end of the brace. One 45° downward motion of the pry bar pushes the plunger out of the split collet, freeing the brace and allowing arm activity to proceed. The brace, of course, is never reattached during flight.

5.6 Questions

1. What FDF documents are available to direct the arm operator through troubleshooting and workaround procedures following a failure indication?
2. What are the two types of arm jettison?
3. Under what failure case conditions would the arm operator employ the backdrive procedures?
4. What capabilities are recovered by the use of the RMS IFM D&C kit?
5. What arm-related capabilities are recovered by the use of the generic IFM breakout box?
6. What capabilities and options are available to the arm operator following an MCIU failure?
7. Describe the EVA technique used to align a failed joint such that the arm can be cradled.
8. Describe the function of the tool an EVA crewmember uses to deploy or stow the MPM.
9. After cradling the arm, only the AFT MRL closes. Is an EVA procedure necessary, or available, to secure the arm to the FWD and MID MPMs and, if so, what technique is used?
10. If the shoulder brace is not released by action of the switch on panel A8U or by use of the RMS IFM D&C kit, what additional action can the crew take to release it? Is release necessary and is reattaching the brace to the shoulder necessary prior to deorbit?

5.7 Answers

1. The arm operator should follow the direction given in the Malfunction Procedures, PDRS OPS Checklist, IFM checklist or EVA Checklist to troubleshoot and work around an arm-related failure indication.
2. In one type of arm jettison, the arm is latched to the MPMs, which are severed prior to separation of the arm from the Orbiter at the shoulder. In the other type, the MPMs are unaffected as the arm alone is separated from the Orbiter at the shoulder.
3. The arm operator would use the backdrive procedures to move a free but nondrivable SP, EP, WP or WY Joint to a 0° joint angle configuration in order to cradle the arm. The affected joint must have operational brakes to employ these procedures.
4. The RMS IFM D&C kit provides the arm operator with the switching capability required for releasing the shoulder brace, opening and closing the EE snares, rigidizing and derigidizing the EE snare assembly and driving each joint in a direct drive mode of operation.
5. The arm operator can use the IFM breakout box to recover the switching capability lost when the RMS POWER, MPM DEPLOY/STOW, or MRL RELEASE/LATCH switch has failed or when power to those switches is lost.
6. If the MCIU fails, the operator can still drive the arm in the direct drive and backup drive modes. He can perform the MCIU changeout IFM procedure and recover full RMS capability.

7. A failed joint can be straightened enough for arm cradling by looping a rope around the EE, routing it through a snatch block and roller and attaching it to a winch, which is then turned by an EVA crewmember.
8. An EVA crewmember can deploy or stow the MPM by manipulating a ratchet-action wrench that interfaces with the splines on the torque shaft.
9. A current flight rule requires that at least two of the three MRLs be latched or secured prior to deorbit. If this cannot be accomplished via normal latching procedures or by use of the RMS IFM D&C kit, the crewmember must rely on the EVA tiedown procedure.

After the MPMs are stowed, an EVA crewmember will secure the hooks on each end of a PRD to the MPM positioning linkage and operate the ratchet on the PRD until the tension on the strap is sufficient to hold the arm securely.

10. The arm cannot be used until the shoulder brace is released; the brace is never reattached during flight. An EVA crewmember can release the brace by forcing its plunger out of the grip of a circular split collet with a special pry bar.

Section 6: Orbiter Failure Effects

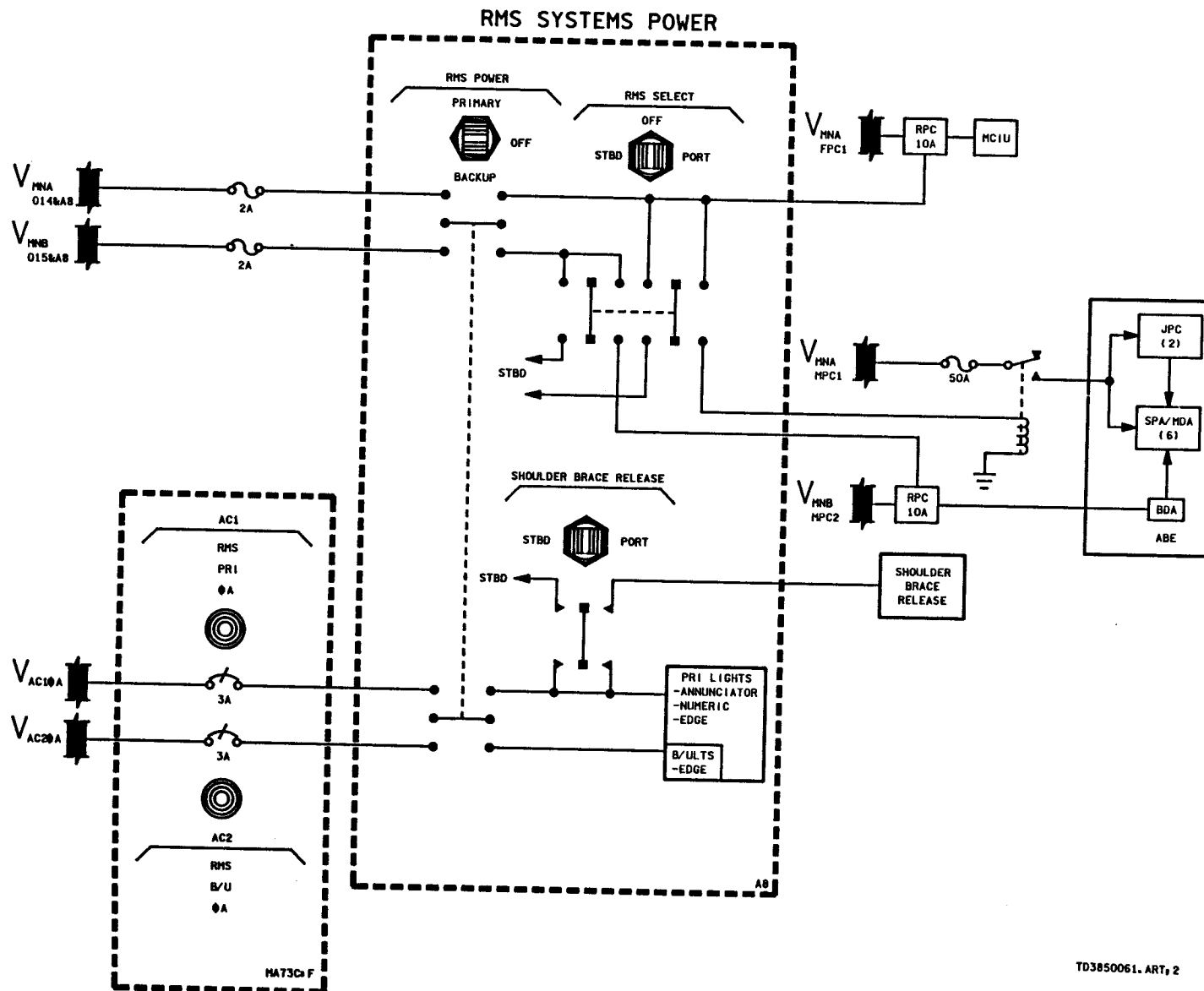
The PDRS is considered to be part of the Orbiter. It is one of a collection of components, a group that includes such things as fuel cells, computers, cabin fans and so forth. In many respects, these parts of the whole are interreliant, and are able to support, complement, hinder or disable one another. To fully understand the failure effects of PDRS, one must examine its interface with the other Orbiter subsystems. With some, such as EPS and DPS, the relationship is direct and obvious. In other cases, such as RCS, the relationship is not as obvious and is tethered by the tenuous bonds of flight rules, which change and bend with the sometimes warring philosophies of safety and necessity.

Failures in some Orbiter systems do not alter arm operation, although they might cause an end to arm operation. These situations do not require analysis or work-around by the arm operator and will not be addressed here. The following subsections contain discussions, tables and figures that attempt to define the interrelationship of the PDRS and other Orbiter subsystems. These need not be studied in great detail by the student; they should be used as reference material when review of the Orbiter/PDRS relationship is required.

6.1 EPS

The EPS generates, regulates, distributes and, to some extent, monitors the electrical power needed by the PDRS and the other Orbiter subsystems. This ac and dc power is routed and controlled by switches, circuit breakers, fuses, power controllers and diodes and is made available on a variety of buses and subbuses. The system is designed to isolate those users and segments of the circuit that are flawed, so that the remaining components can continue operation. This is accomplished by circuit protection and redundancy. This cannot be accomplished in all cases, however, and the arm operator must be prepared to determine the effect that an electrical problem elsewhere in the Orbiter has on arm operation.

Figure 6-1 shows the routing of the primary and backup power to the RMS components. Figure 6-2 shows, in a little more detail, the primary dc power routing for the RMS. Figures 6-3 and 6-4 show the backup power routing for the RMS.



TD3850061, ART, 2

Figure 6-1.- RMS power.

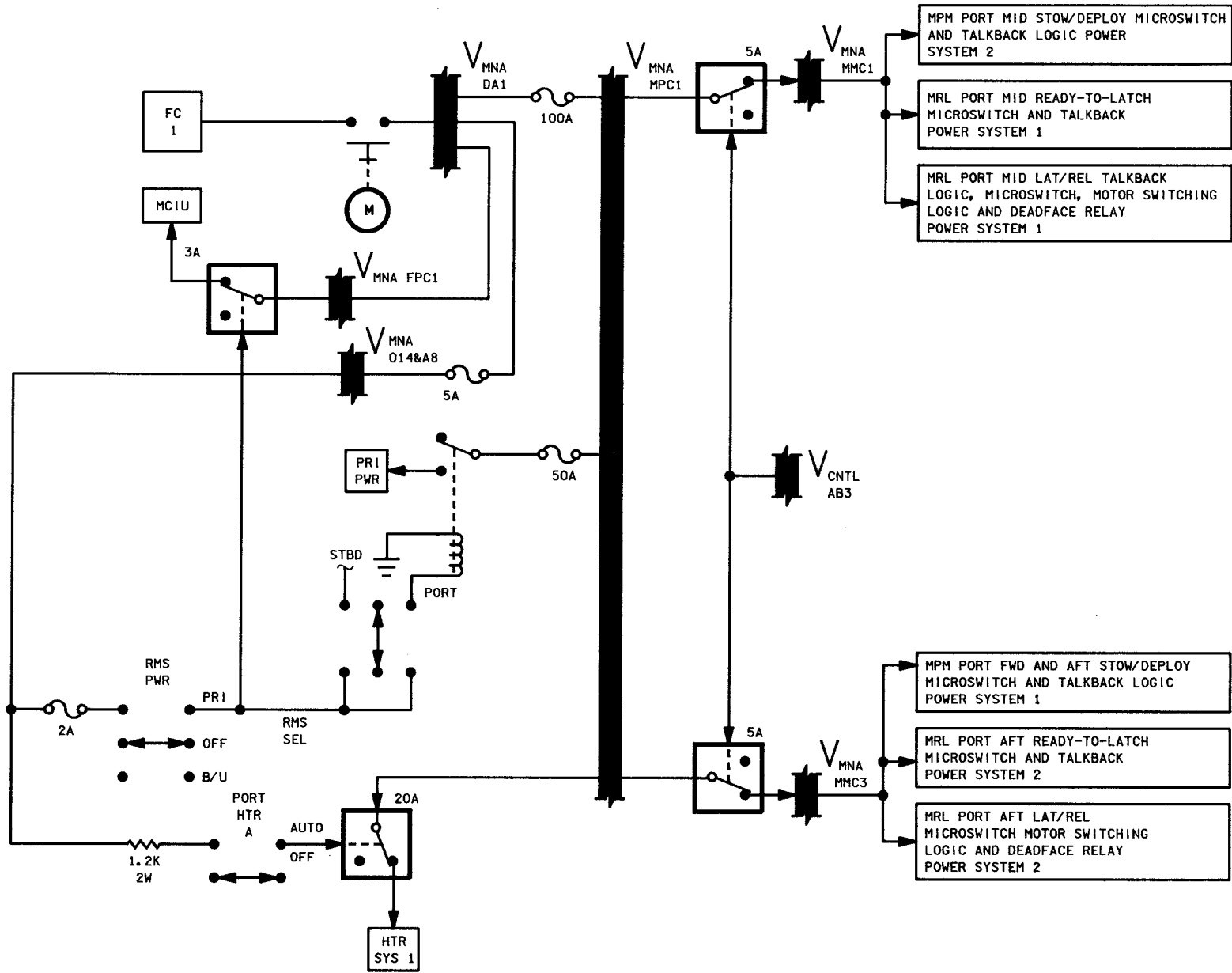
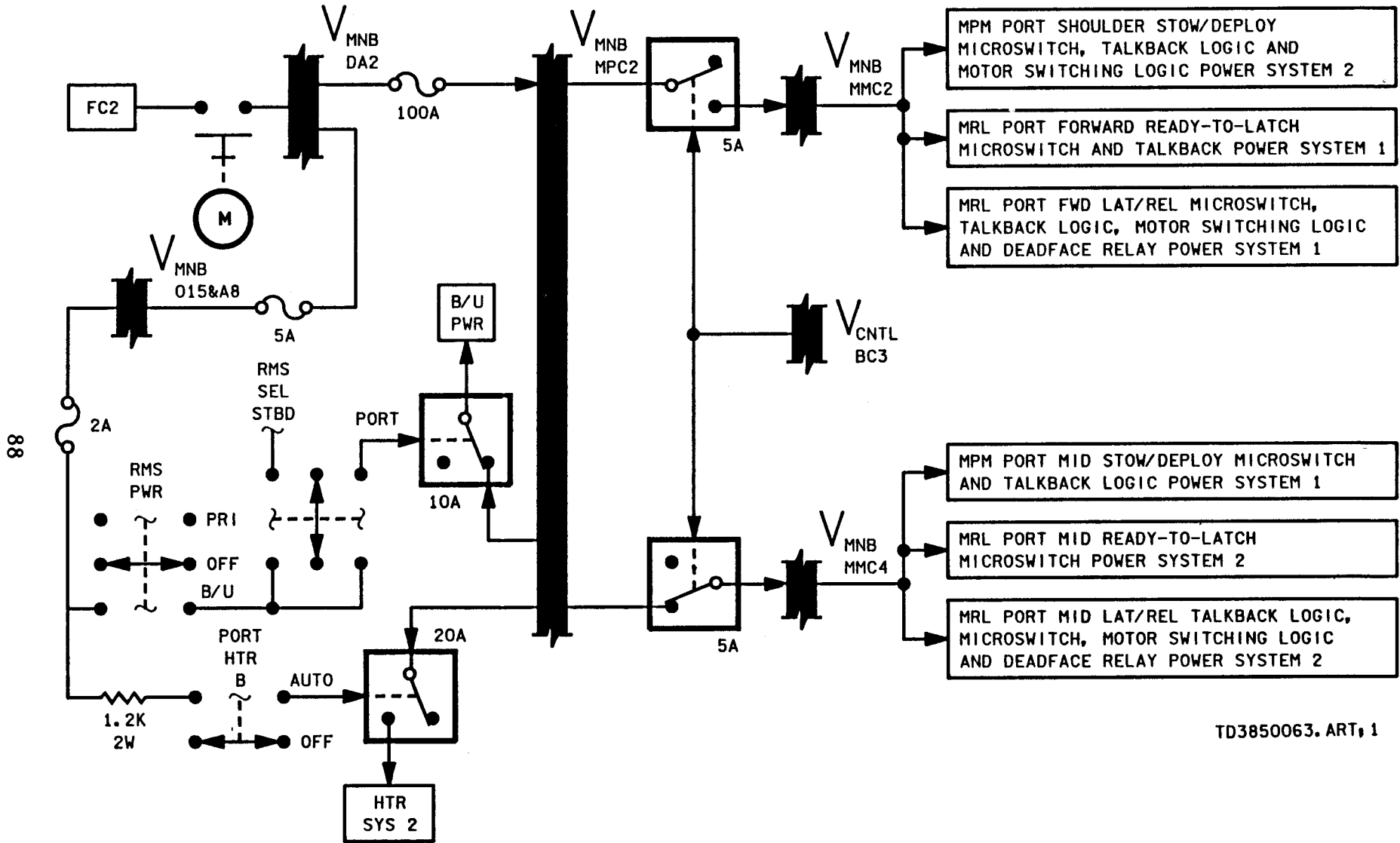


Figure 6-2.- Primary RMS power.

TD3850062. ART. 1



MPM PORT SHOULDER STOW/DEPLOY MICROSWITCH, TALKBACK LOGIC AND MOTOR SWITCHING LOGIC POWER SYSTEM 2

MRL PORT FORWARD READY-TO-LATCH MICROSWITCH AND TALKBACK POWER SYSTEM 1

MRL PORT FWD LAT/REL MICROSWITCH, TALKBACK LOGIC, MOTOR SWITCHING LOGIC AND DEADFACE RELAY POWER SYSTEM 1

MPM PORT MID STOW/DEPLOY MICROSWITCH AND TALKBACK LOGIC POWER SYSTEM 1

MRL PORT MID READY-TO-LATCH MICROSWITCH POWER SYSTEM 2

MRL PORT MID LAT/REL TALKBACK LOGIC, MICROSWITCH, MOTOR SWITCHING LOGIC AND DEADFACE RELAY POWER SYSTEM 2

TD3850063. ART, 1

Figure 6-3.- Backup RMS power.

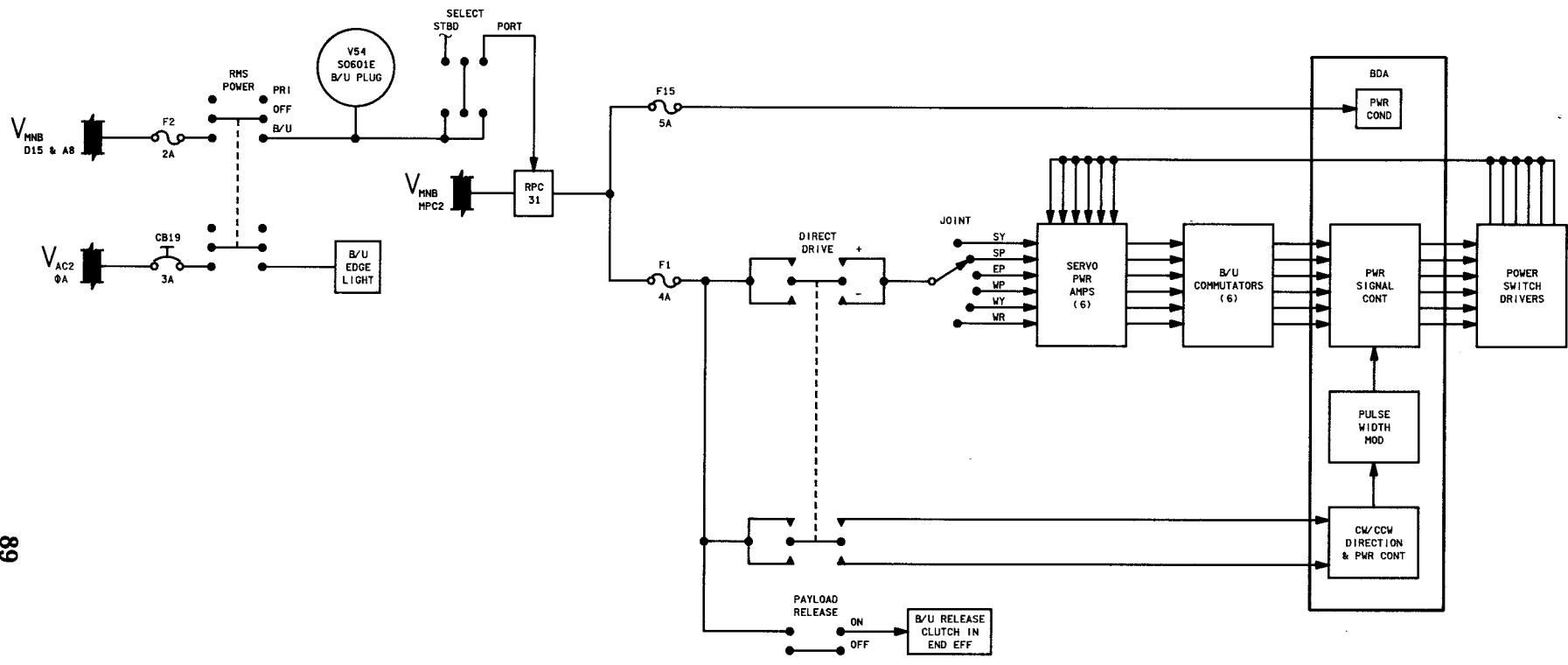


Figure 6-4.- Backup RMS.

TD3850064. ART. 1

Figures 6-5 and 6-6 show the power routing for the MPM systems 1 and 2, respectively. Tables 6-1 and 6-2 list the requirements to drive the MPM motors and to see the status of the microswitches.

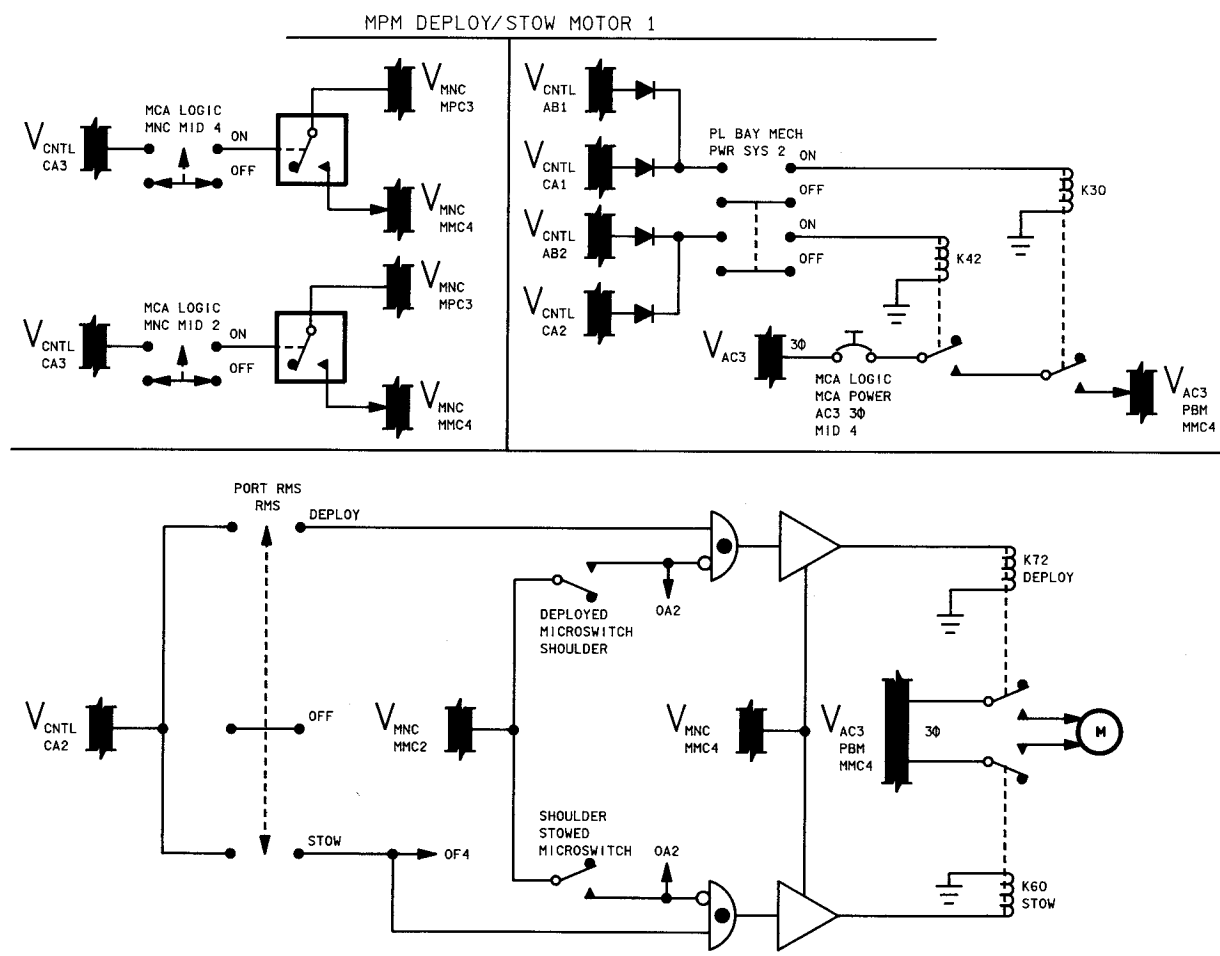
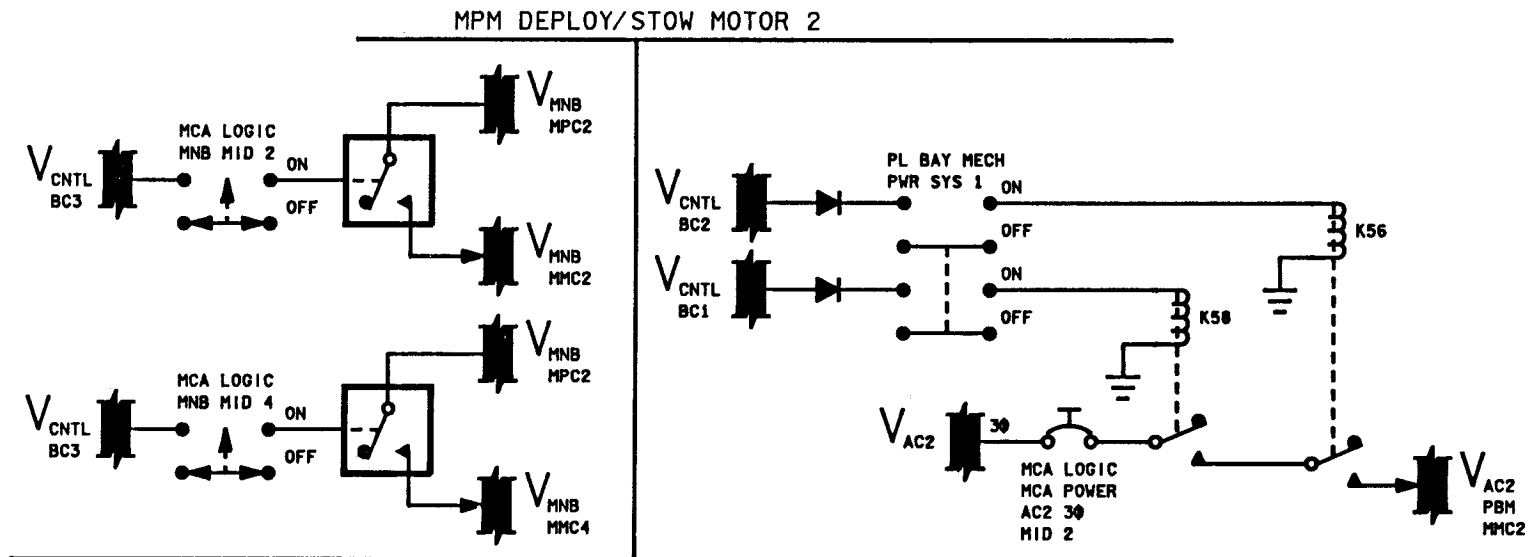


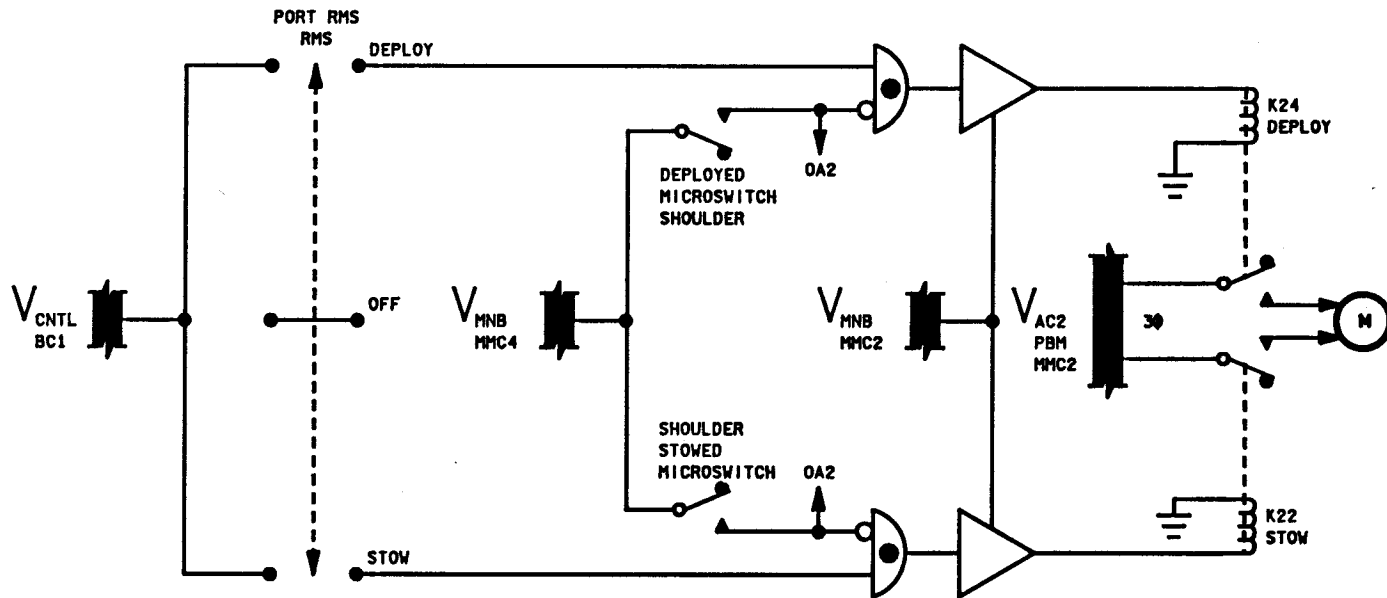
Figure 6-5.- MPM system 1.

TD3850065. ART. 2

06



16



TD3850066. ART, 2

Figure 6-6.- MPM system 2.

Table 6-1.– MPM motor requirements. ^a

System 1	CA3	CA2	MNC MPC3	MNC MMC4	AC3	AC3 PBM MMC4	AB1 + CA1	AB2 + CA2
System 2	BC3	BC1	MNB MPC2	MNB MMC2	AC2	AC2 PBM MMC2	BC2	

^a Loss of any one of the power sources (some dual) will cause loss of motor drive capability.

Table 6-2.– MPM stow and deploy microswitch status requirements. ^a

System 1	Shoulder	CA3	MNC MPC3	MNC MMC2	OA2
	Forward	AB3	MNA MPC1	MNA MMC3	OF1
	Mid	BC3	MNB MPC2	MNB MMC2	OA1
	Aft	AB3	MNA MPC1	MNA MMC3	OF1
System 2	Shoulder	BC3	MNB MPC2	MNB MMC4	OA2
	Forward	CA3	MNC MPC3	MNC MMC2	OA3
	Mid	AB3	MNA MPC1	MNA MMC1	OF4
	Aft	CA3	MNC MPC3	MNC MMC4	OA3

^a Loss of any one will cause a loss of status determination.

Figures 6-7 through 6-9 show the power routing for the forward, mid and aft MRL motors (systems 1 and 2), respectively. Tables 6-3 and 6-4 list the requirements for the MRL motors and microswitches, respectively. Figure 6-10 shows the circuitry associated with the MRL

microswitches and talkback and figure 6-11 shows the circuitry for the MRL ready-to-latch microswitches and talkbacks. Table 6-5 lists the requirements for determining the status of the MRL ready-to-latch microswitches.

93

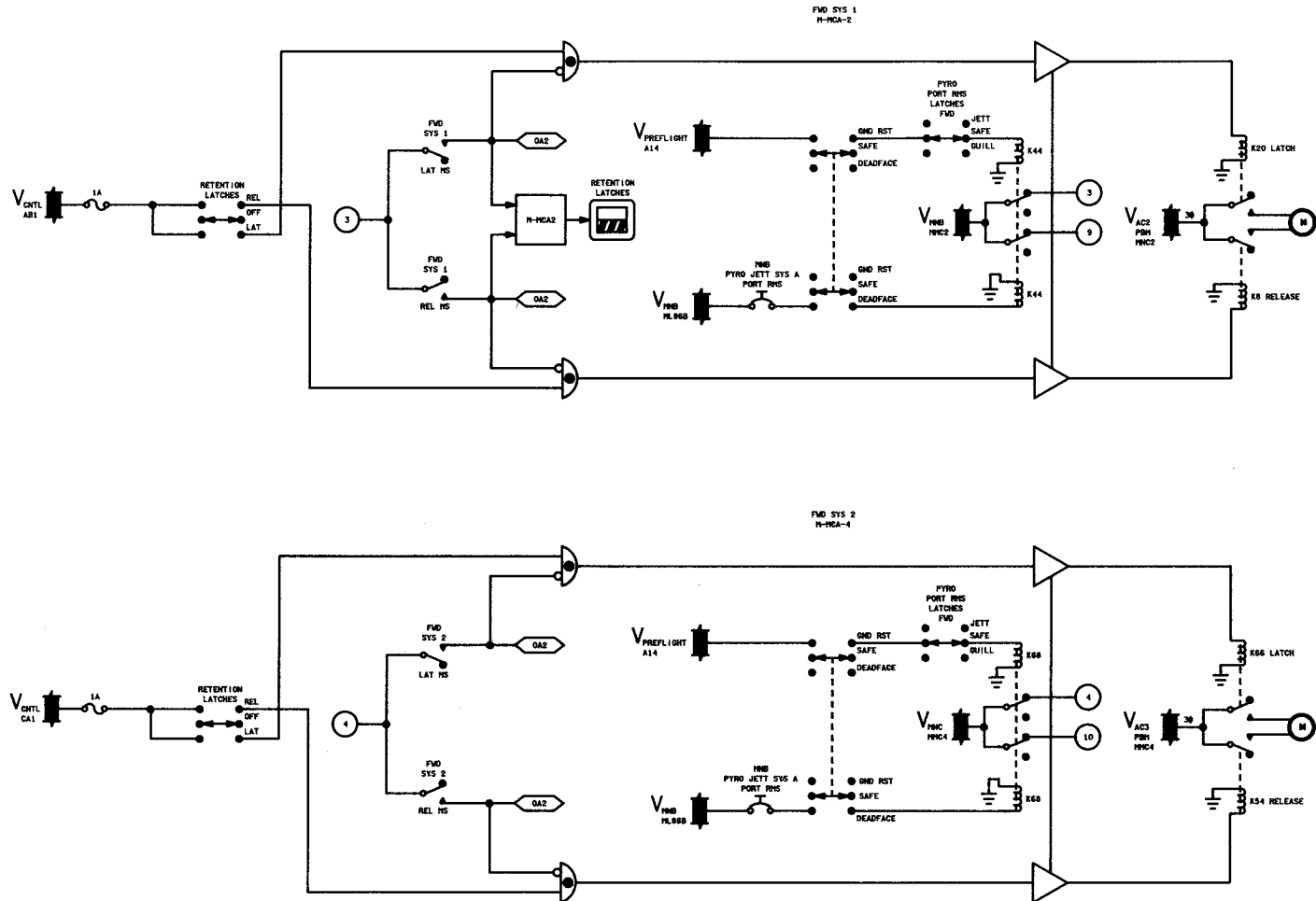
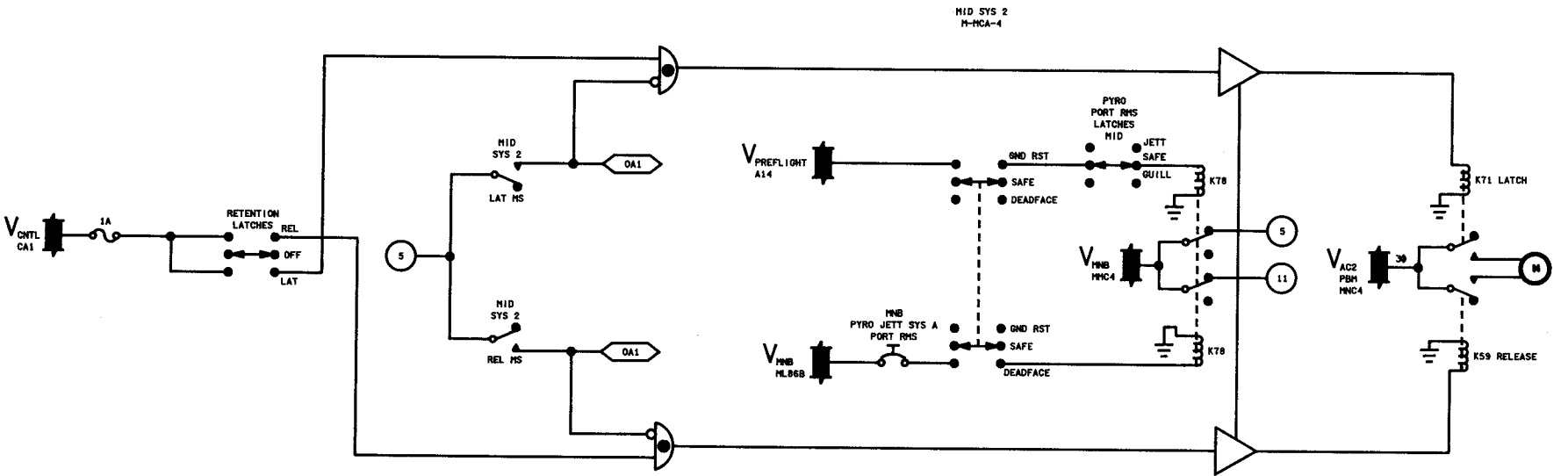
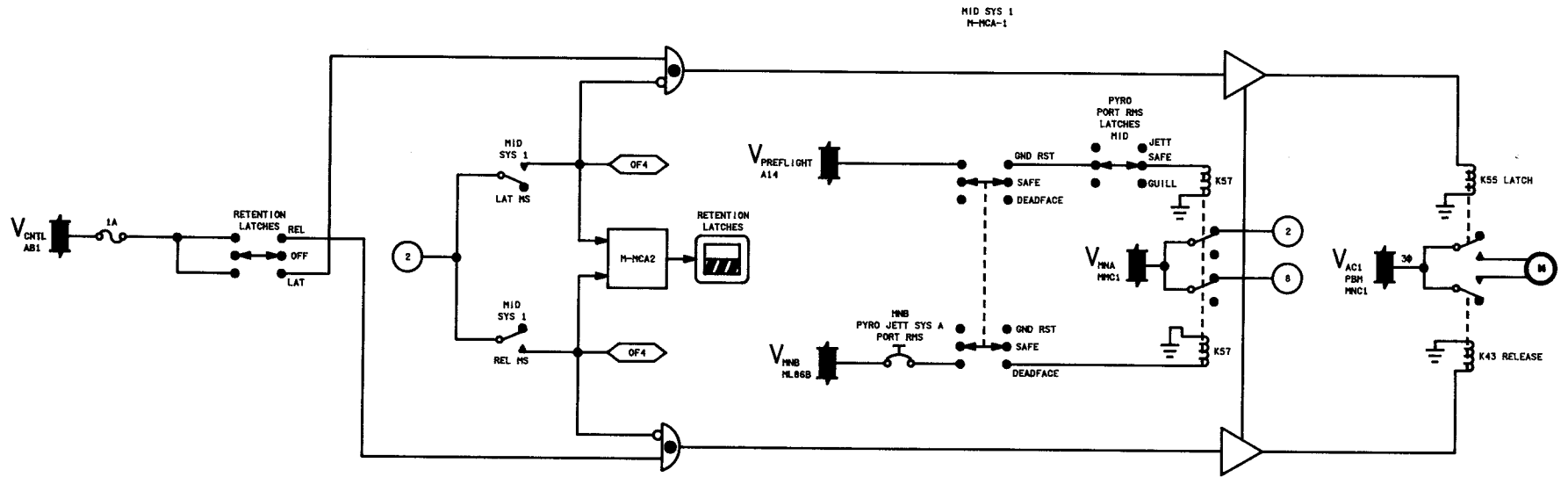


Figure 6-7.- Forward MRL.

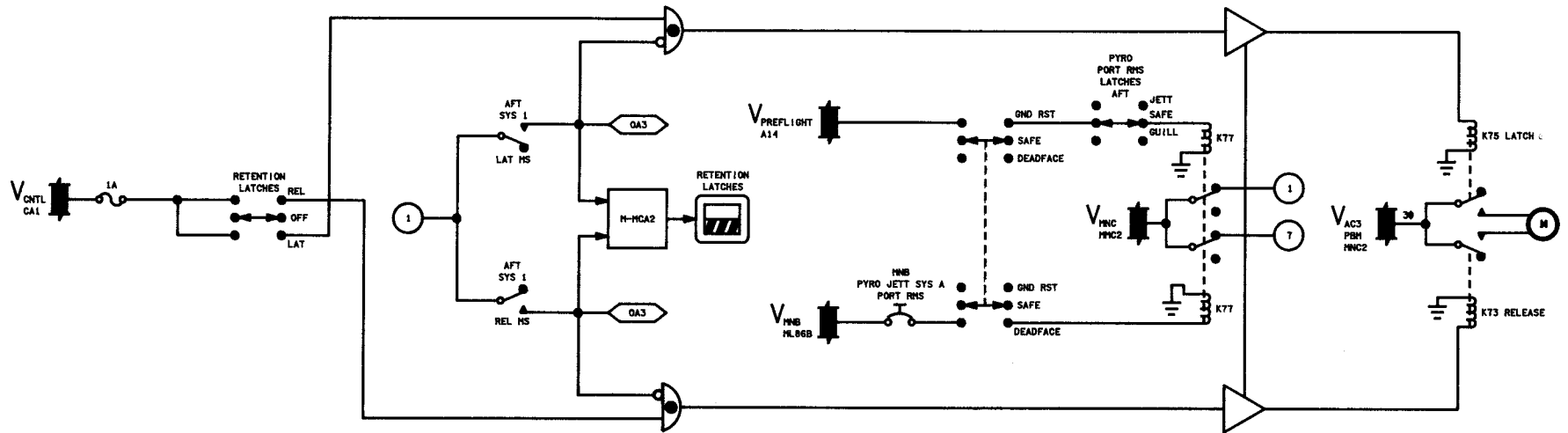
TD3850067, ART 2



TD3850068, ART. 2

Figure 6-8.- Mid MRL.

AFT SYS 1
M-NCA-2



AFT SYS 2
M-NCA-4

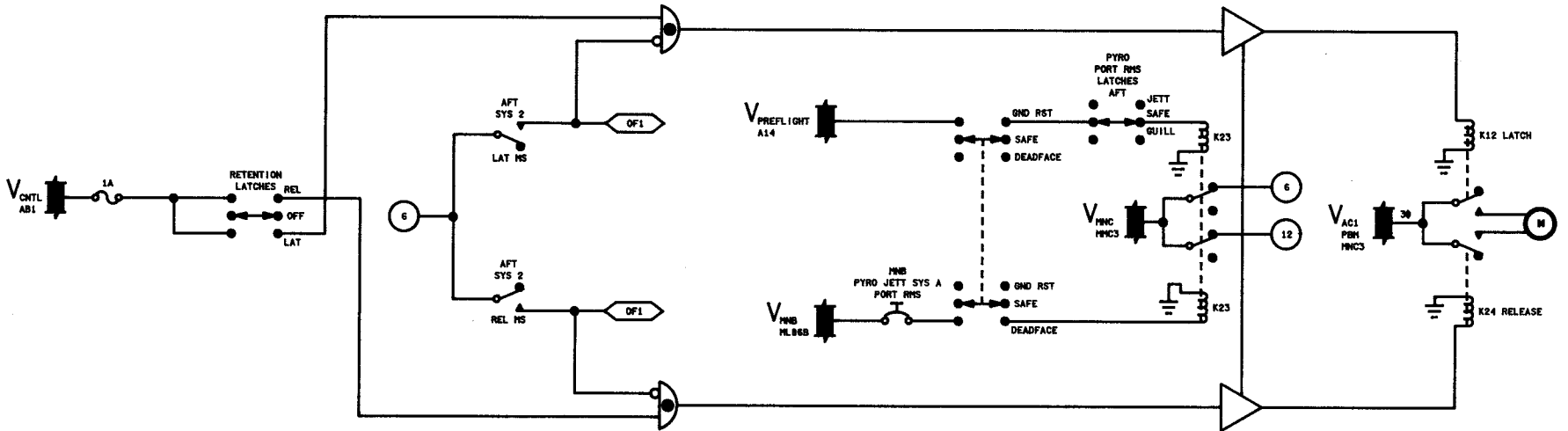
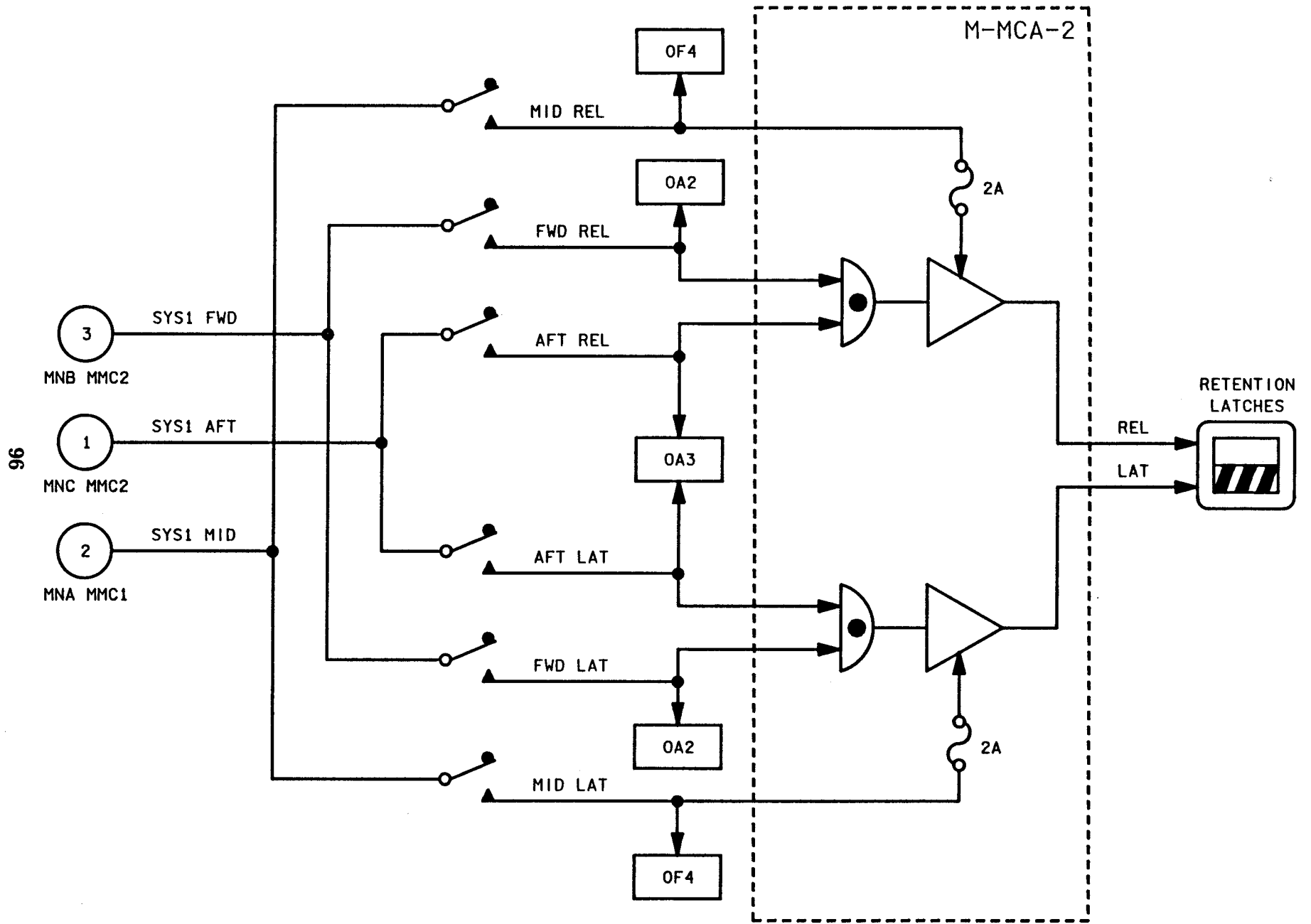


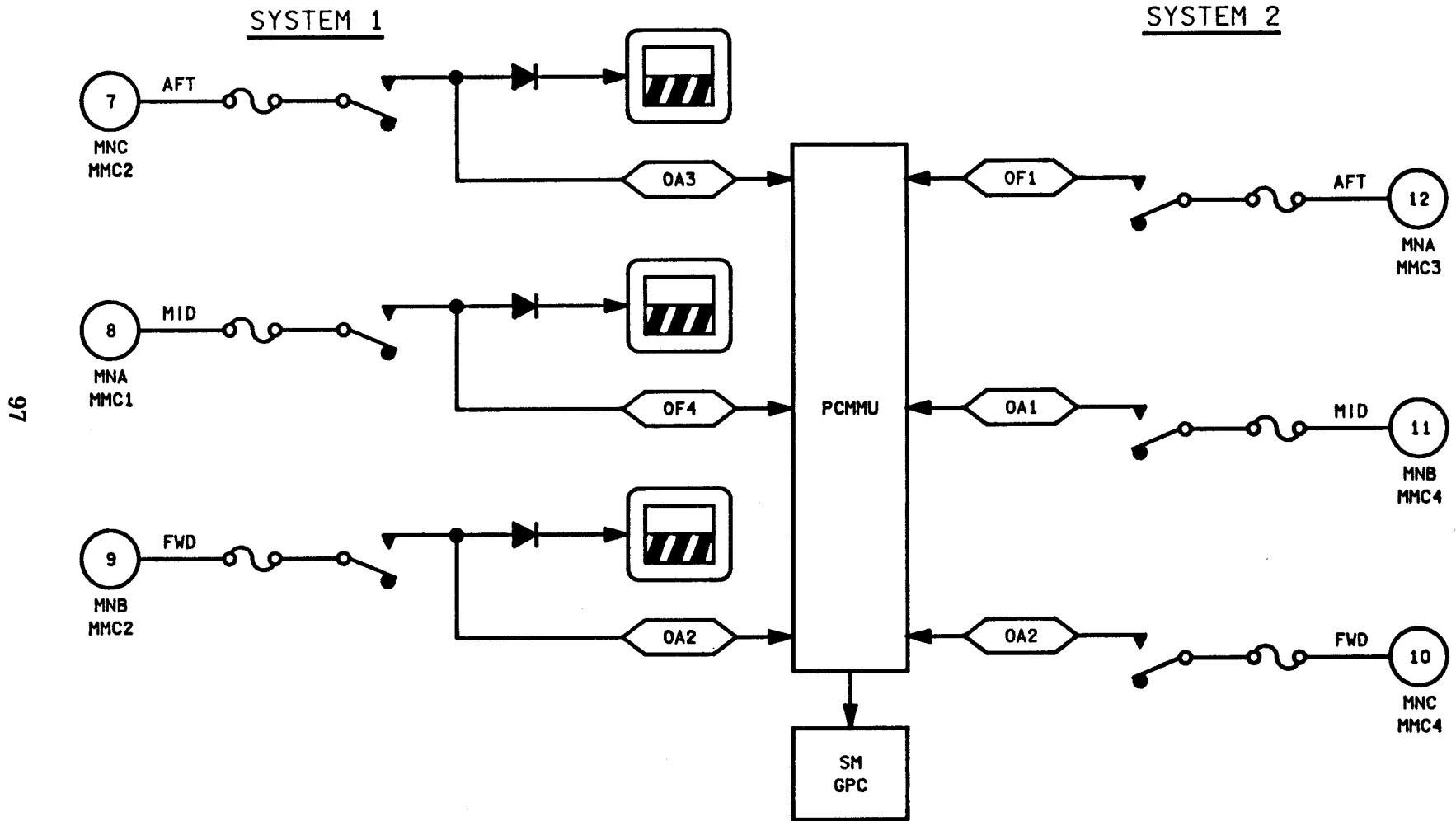
Figure 6-9.- Aft MRL.



TD3850610. ART, 1

Figure 6-10.- MRL microswitches and talkback.

MRL READY-TO-LATCH MICROSWITCHES



97

TD3850611. ART, 1

Figure 6-11.- MRL RTL microswitches and talkback.

Table 6-3.– MRL motor requirements. ^a

Forward	System 1	BC3	MNB MPC2	MNB MMC2	BC2	BC1	AC2	AC2 PBM MMC2	AB1
	System 2	CA3	MNC MPC3	MNC MMC4	CA1 + AB1	AB2 + CA2	AC3	AC3 PBM MMC4	CA1
Mid	System 1	AB3	MNA MPC1	MNA MMC1	CA2 + AB2	AB1 + CA1	AC1	AC1 PBM MMC1	AB1
	System 2	BC3	MNB MPC2	MNB MMC4	BC2	BC1	AC2	AC2 PBM MMC4	CA1
Aft	System 1	CA3	MNC MPC3	MNC MMC2	CA1 + AB1	AB2 + CA2	AC3	AC3 PBM MMC2	CA1
	System 2	AB3	MNA MPC1	MNA MMC3	CA1 + AB1	AB2 + CA2	AC1	AC1 PBM MMC3	AB1

^a Loss of any one power source (some dual) will cause loss of motor drive capability.

86

Table 6-4.– MRL latch and release microswitch status requirements. ^a

Forward	System 1	BC3	MNB MPC2	MNB MPC2	OA2
	System 2	CA3	MNC MPC3	MNC MPC4	OA2
Mid	System 1	AB3	MNA MPC1	MNA MMC1	OF4
	System 2	BC3	MNB MPC2	MNB MMC4	OA1
Aft	System 1	CA3	MNC MPC3	MNC MMC2	OA3
	System 2	AB3	MNA MPC1	MNA MMC3	OF1

^a Loss of any one will cause a loss of status determination.

Table 6-5.– MRL RTL microswitch status requirements. ^a

Forward	System 1	BC3	MNB MPC2	MNB MMC2	OA2
	System 2	CA3	MNC MPC3	MNC MMC4	OA2
Mid	System 1	AB3	MNA MPC1	MNB MMC1	OF4
	System 2	BC3	MNB MPC2	MNC MMC4	OA1
Aft	System 1	CA3	MNC MPC3	MNB MMC2	OA3
	System 2	AB3	MNA MPC1	MNC MMC3	OF1

^a Loss of any one will cause a loss of status determination.

Table 6-6 is a composite presentation of the major buses and subbuses, dc and ac, that the PDRS requires. The table lists the effects when one of the buses is lost; the effects are listed in terms of which subbus or PDRS

component is no longer available for use. This chart should be referred to anytime an Orbiter electrical problem is evident in order to quickly determine the effect on PDRS operation.

Table 6-6.- Electrical power bus loss.

<u>MNA</u>	<u>MNB</u>	<u>MNC</u>
MNA FAPC1 MNA MPC1 MNA MMC1 MNA MMC3 MNA 014&A8 MNA ML86B	MNB MPC2 MNB MMC3 MNB MMC4 MNB 015&A8 MNB ML86B	MNC MPC3 MNC MMC2 MNC MMC4
<u>AC1</u>	<u>AC2</u>	<u>AC3</u>
AC1 PBM MMC1 AC1 PBM MMC3 Shoulder Brace Release Motor (0A) PRI Panel Lighting (0A)	AC2 PBM MMC2 AC2 PBM MMC4 B/U Panel Lighting (0A)	AC3 PBM MMC2 AC3 PBM MMC4
<u>AC1 PBM MMC1</u>	<u>AC2 PBM MMC2</u>	<u>AC3 PBM MMC2</u>
MID MRL Motor System 1	MPM Motor System 2 FWD MRL Motor System 1	AFT MRL Motor System 1
<u>AC1 PBM MMC3</u>	<u>AC2 PBM MMC4</u>	<u>AC3 PBM MMC4</u>
AFT MRL Motor System 2	MID MRL Motor System 2	MPM Motor System 1 FWD MRL Motor System 2
<u>AB1</u>	<u>BC1</u>	<u>CA1</u>
FWD MRL Motor System 1 MID MRL Motor System 1 AFT MRL Motor System 2	AC2 PBM MMC2 AC2 PBM MMC4 MPM Motor System 2 FWD MRL Motor System 1 MID MRL Motor System 2	FWD MRL Motor System 2 MID MRL Motor System 2 AFT MRL Motor System 1
<u>AB2</u>	<u>BC2</u>	<u>CA2</u>
Nothing	AC2 PBM MMC2 AC2 PBM MMC4 MPM Motor System 2 FWD MRL Motor System 1 MID MRL Motor System 2	MPM Motor System 1

66

Table 6-6.- Continued.

<u>AB3</u>	<u>BC3</u>	<u>CA3</u>
MNA MMC1 MNA MMC3 MID MRL Motor System 1 AFT MRL Motor System 2 FWD MPM STO/DEP M/S System 1 AFT MPM STO/DEP M/S System 1 MID MPM STO/DEP M/S System 2 MID MRL LAT/REL M/S System 1 AFT MRL LAT/REL M/S System 2 MID MRL RTL M/S System 1 AFT MRL RTL M/S System 2	MNB MMC2 MNB MMC4 MPM Motor System 2 FWD MRL Motor System 1 MID MRL Motor System 2 Shoulder STO/DEP M/S System 2 MID MPM STO/DEP M/S System 1 FWD MRL LAT/REL M/S System 1 MID MRL LAT/REL M/S System 2 FWD MRL RTL M/S System 1 MID MRL RTL M/S System 2	MNC MMC2 MNC MMC4 MPM Motor System 1 FWD MRL Motor System 2 AFT MRL Motor System 1 Should STO/DEP M/S System 1 FWD MPM STO/DEP M/S System 2 AFT MPM STO/DEP M/S System 2 FWD MRL LAT/REL M/S System 2 AFT MRL LAT/REL M/S System 1 FWD MRL RTL M/S System 2 AFT MRL RTL M/S System 1
<u>MNA MPC1</u> MNA MMC1 MNA MMC3 PRI Power To Arm Heater System 1 MID MRL Motor System 1 AFT MRL Motor System 2 FWD MPM STO/DEP M/S System 1 MID MPM STO/DEP M/S System 2 AFT MPM STO/DEP M/S System 1 MID MRL LAT/REL M/S System 1 AFT MRL LAT/REL M/S System 2 MID MRL RTL M/S System 1 AFT MRL RTL M/S System 2	<u>MNB MPC2</u> MNB MMC2 MNB MMC4 B/U Power To Arm Heater System 2 MPM Motor System 2 FWD MRL Motor System 1 MID MRL Motor System 2 MID MPM STO/DEP M/S System 1 Shoulder STO/DEP M/S System 2 FWD MRL LAT/REL M/S System 1 MID MRL LAT/REL M/S System 2 FWD MRL RTL M/S System 1 MID MRL RTL M/S System 2	<u>MNC MPC 3</u> MNC MMC2 MNC MMC4 MPM Motor System 1 FWD MRL Motor System 2 AFT MRL Motor System 1 Shoulder STO/DEP M/S System 1 FWD MPM STO/DEP M/S System 2 AFT MPM STO/DEP M/S System 2 FWD MRL LAT/REL M/S System 2 AFT MRL LAT/REL M/S System 1 FWD MRL RTL M/S System 2 AFT MRL RTL M/S System 1
<u>MNA MCC1</u> MID MRL Motor System 1 MID MPM STO/DEP M/S System 2 MID MRL LAT/REL M/S System 1 MID MRL RTL M/S System 1	<u>MNB MMC2</u> MPM Motor System 2 FWD MRL Motor System 1 MID MPM STO/DEP M/S System 1 FWD MRL LAT/REL M/S System 1 FWD MRL RTL M/S System 1	<u>MNC MMC2</u> AFT MRL Motor System 1 Shoulder STO/DEP M/S System 1 FWD MPM STO/DEP M/S System 2 AFT MRL LAT/REL M/S System 1 AFT MRL RTL M/S System 1

100

Table 6-6.- Concluded.

<p align="center"><u>MNA MCC3</u></p> <p>AFT MRL Motor System 2 FWD MPM STO/DEP M/S System 1 AFT MPM STO/DEP M/S System 1 AFT MRL LAT/REL M/S System 2 AFT MRL RTL M/S System 2</p>	<p align="center"><u>MNB MMC4</u></p> <p>MID MRL Motor System 2 Shoulder STO/DEP M/S System 2 MID MRL LAT/REL M/S System 2 MID MRL RTL M/S System 2</p>	<p align="center"><u>MNC MMC4</u></p> <p>MPM Motor System 1 FWD MRL Motor System 2 AFT MPM STO/DEP M/S System 2 FWD MRL LAT/REL M/S System 2 FWD MRL RTL M/S System 2</p>
<p align="center"><u>MNA FPC1</u></p> <p>MCIU</p>	<p align="center"><u>MNB 015&A8</u></p> <p>B/U Power to Arm Heater System 2</p>	<p align="center"><u>MNC ML86B</u></p> <p>Guillotine System B Jettison System B</p>
<p align="center"><u>MNA 014&A8</u></p> <p>MCIU PRI Power To Arm Heater System 1</p>	<p align="center"><u>MNB ML86B</u></p> <p>MRL Deadface Relays Guillotine System A Jettison System A</p>	

101

6.2 DPS

From earlier discussions of the SM GPC and its relationship to the PDRS, one can quickly determine that its loss or unavailability would restrict the RMS operation to the direct drive and backup modes of operation. Several DPS components must work properly in order to have an SM GPC/MCIU combination available for PDRS use. Upon reaching orbit, the crew loads one of the GPCs with SM OPS 2 software. This software is retrieved from a MMU (there are two for redundancy) via MMU buses. The crew then reassigns the launch data bus 1 from a GNC GPC/MEC configuration (ascent/entry requirement) to the SM GPC. The LDB1 is the bidirectional serial data bus that connects the MIA at the SM GPC with the MIA at the MCIU. LDB1 is the only data bus available for this use.

The arm operator initiates the RMS software routines resident in the SM OPS 2 by keying SPEC 94 PRO on the SM CRT/keyboard; he requests data I/O activity between the

SM GPC and MCIU by keying ITEM 5 EXEC on the SPEC 94 display. He again relies on the MMU and associated data buses when calling the roll-in display SPEC 96.

Depending on the DPS component loss or the nature of its degradation, the arm operator is faced with failure effects ranging from a limitation of visibility into the system, to complete loss of computer support.

On the other side of the coin, the GPC can provide visibility into the PDRS to compensate for certain panel A8 D&C failures. If the illuminated displays or EE talkbacks are not working (MCIU output to D&C data bus bad, lamps or sticks inoperative, AC1ØA lost, etc.) the arm operator can look at memory locations in the SM GPC to see the EE microswitch status, joint angle values and mode indication. The addresses for these locations are listed in the REF DATA book in the FDF. Table 6-7 represents an example of the page as it appears in the 51-L REF DATA book.

Table 6-7.- REF DATA memory locations.

NAME	ITEM 26		ADDRESS ID		DESCRIPTION/NOTES ('ACTUAL' = WXYZ)
	XXX	UNITS	OPS 2	OPS 3	
IMU HARDWARE BITE SOFTWARE BITE	N/A ↓	N/A ↓			TABLE 1 (FS 4-6) TABLE 2 (FS 4-6)
OMS QTY L OXID FU R OXID FU	100 ↓	↓		3E89 3E8A 3EC0 3EC1	*TO CONVERT QTY TO PERCENT DIVIDE BY 320
PDRS					
EE TALKBACKS EXTEND RIGID DERIGID OPEN CLOSE CAPTURE	N/A ↓	N/A ↓	DB34		Y 8,9,A,B,C,D,E,F 2,3,6,7,A,B,E,F Z 4,5,6,7,C,D,E,F Y 1,3,5,7,9,B,D,F Z 8,9,A,B,C,D,E,F Y 4,5,6,7,C,D,E,F
JOINT ANGLES SY SP EP WP WY WR	200 ↓	deg ↓		CE4E CE50 CE52 CE54 CE56 CE58	* * * * *

103

Table 6-7.- Concluded.

NAME	ITEM 26		ADDRESS ID		DESCRIPTION/NOTES ('ACTUAL' = WXYZ)
	XXX	UNITS	OPS 2	OPS 3	
MODE INDICATORS	N/A	N/A			'ACTUAL' = DISCRETE SET WXYZ IF VALUE =
AUTO 1	↓	↓	D534		X 1,3,5,7,9,B,D,E
2					Y 8,9,A,B,C,D,E,F
3			4,5,6,7,C,D,E,F		
4			2,3,6,7,A,B,E,F		
OPR CMD	↓	↓	D536		X 2,3,6,7,A,B,E,F
TEST				Y 1,3,5,7,9,B,D,F	
ORB UNLD				1,3,5,7,9,B,D,F	
EE				Z 8,9,A,B,C,D,E,F	
ORB LOADED	↓	↓	D534		4,5,6,7,C,D,E,F
PAYLOAD					Z 4,5,6,7,C,D,E,F
SINGLE					
RCS QTY	200	%	CC34	C7EC	USE 'ADDRESS ID' SHOWN PLUS 'SEQ ID' (ITEM 24) QTYs WILL BE IN ORDER SHOWN AT LEFT
R OXID	↓	↓	↓	↓	
FU					
L OXID					
FU					
R OXID					TABLE 3 (FS 4-7) TABLE 4 (FS 4-8) SWITCH CONTACTS
FU					
SWITCHES/PBIs					
'GREEN DOT'					
SWITCHES					
ALL OTHER					
SWITCHES					

104

6.3 RCS

The relationship of RCS and PDRS is not defined in terms of one needing the other for operational support. It is defined in terms of certain operational constraints imposed on one or the other. For example, when the arm is in use, the flight rules and one's prudent nature would inhibit the positioning of it within certain specified distances of an RCS thruster.

Under certain PDRS use conditions, the dynamic loads induced by the rotational and translational acceleration capabilities of the PRCS should be avoided. When the arm is in a reach limit or singularity condition, or is grappled to an unberthed payload, a PRCS-induced dynamic load could put an unwanted stress on the joint that has limited movement or on the Orbiter longeron. When the arm is in test mode, the brakes are off and the current attenuation to all joint motors is 15/15 (no current available). Under this condition, PRCS use should be avoided whether the arm is loaded or unloaded, because the arm is not held in place. VRCS can be used when in test mode but only if the arm is unloaded; VRCS can be used under all other arm conditions with most payloads.

If VRCS is not available for use, the crew should ensure that Orbiter attitude control is in free drift under the conditions mentioned above. It was mentioned earlier that the relationship of PDRS to other Orbiter systems is not always obvious. An example of this is a total loss of the flight critical MDM FF3. Although this is a DPS failure and although the PDRS has nothing to do with FF3, the arm operator must realize the PDRS operation is affected because of the indirect relationship through RCS/PDRS flight rules. Loss of FF3 means a loss of VRCS; hence the crew must alternate Orbiter control between PRCS and free drift during PDRS operations.

6.4 OI

Most of the data from the ABE and MCIU that goes to the SM GPC does so via LDB1. However, some of the D&C switch positions, all of the MPM/MRL microswitch positions, and the PIC voltages of the arm jettison system go to the OI subsystem (DSC and MDM) first and then to the SM GPC via the PCMMU. The GPC displays some of it on SPEC 94. It blocks all of the data into an SM GPC downlist format and makes it available to the PCMMU for downlink. How much of it is downlinked depends on the TFL and bit rate.

If a DSC fails, all of the data it normally handles will suddenly appear as zeroes. If an MDM fails, all of the data it normally handles will become static. The arm operator must always be aware of any indication of OI failure in order to avoid a misunderstanding of the data displayed.

Table 6-8 lists the PDRS-related telemetry parameters with the OI MDM and DSC that handles them. The parameters that are not simulated (starboard RMS, test values, etc.) are not included.

Table 6-8.- RMS, MDM and DSC list. a

<u>OI MDM OF1</u>	
V54X0812E	FWD MPM DEPLOY M/S SYS 1
V54X0816E	AFT MPM DEPLOY M/S SYS 1
V54X0822E	FWD MPM STOW M/S SYS 1
V54X0826E	AFT MPM STOW M/S SYS 1
V54X0845E	AFT MRL RTL M/S SYS 2
V54X0865E	AFT MRL RELEASE M/S SYS 2
V54X0875	AFT MRL RELEASE M/S SYS 2
V76V7307A	SHOULDER JETTISON PIC VOLTS SYS A
V76V7331A	SHOULDER GUILLOTINE PIC VOLTS SYS A
V76V7341A	FWD MPM JETTISON PIC VOLTS SYS A
V76V7348A	FWD MPM GUILLOTINE PIC VOLTS SYS A
V76V7358A	MID MPM JETTISON PIC VOLTS SYS A
V76V7365A	MID MPM GUILLOTINE PIC VOLTS SYS A
V76V7375A	AFT MPM JETTISON PIC VOLTS SYS A
V76V7382A	AFT MPM GUILLOTINE PIC VOLTS SYS A
<u>OI MDM OF2 - NONE</u>	
<u>OI MDM OF3</u>	
V76V7308A	SHOULDER JETTISON PIC VOLTS SYS B
V76V7332A	SHOULDER GUILLOTINE PIC VOLTS SYS B
V76V7342A	FWD MPM JETTISON PIC VOLTS SYS B
V76V7349A	FWD MPM GUILLOTINE PIC VOLTS SYS B
V76V7359A	MID MPM JETTISON PIC VOLTS SYS B
V76V7366A	MID MPM GUILLOTINE PIC VOLTS SYS B
V76V7376A	AFT MPM JETTISON PIC VOLTS SYS B
V76V7383A	AFT MPM GUILLOTINE PIC VOLTS SYS B

^a Note: Measurements not used in training (STBD RMS, test parameters, etc.) are not included).

Table 6-8.- Continued. a

<u>OI MDM OF4</u>	
V54S0600E	PRI POWER MN A
V54S0601E	B/U POWER MN B
V54S0760E	HEATER POWER AUTO 1
V54S0818E	MPM STOW COMMAND
V54S0830E	MRL LATCH COMMAND
V54X0815E	MID MPM DEPLOY M/S SYS 2
V54X0825E	MID MPM STOW M/S SYS 2
V54X0842E	MID MRL RTL M/S SYS 1
V54X0862E	MID MRL LATCH M/S SYS 1
V54X0872E	MID MRL RELEASE M/S SYS 1
V76S7210E	GUILLOTINE ARM COMMAND SYS A
V76S7301E	JETTISON ARM COMMAND SYS A
<u>OI MDM OA1</u>	
V54X0814E	MID MPM DEPLOY M/S SYS 1
V54X0824E	MID MPM STOW M/S SYS 1
V54X0843E	MID MRL RTL M/S SYS 2
V54X0863E	MID MRL LATCH M/S SYS 2
V54X0873E	MID MRL RELEASE M/S SYS 2
<u>OI MDM OA2</u>	
V54X0810E	SHOULDER MPM DEPLOY M/S SYS 1
V54X0811E	SHOULDER MPM DEPLOY M/S SYS 2
V54X0820E	SHOULDER MPM STOW M/S SYS 1
V54X0821E	SHOULDER MPM STOW M/S SYS 2
V54X0840E	FWD MRL RTLS M/S SYS 1
V54X0841E	FWD MRL RTLS M/S SYS 2
V54X0860E	FWD MRL LATCH M/S SYS 1
V54X0861E	FWD MRL LATCH M/S SYS 2
V54X0870E	FWD MRL RELEASE M/S SYS 1
V54X0871E	FWD MRL RELEASE M/S SYS 2

^a Note: Measurements not used in training (STBD RMS, test parameters, etc.) are not included).

Table 6-8.- Continued. a

<u>OI MDM OA3</u>	
V54X0813E	FWD MPM DEPLOY M/S SYS 2
V54X0817E	AFT MPM DEPLOY M/S SYS 2
V54X0823E	FWD MPM STOW M/S SYS 2
V54X0827E	AFT MPM STOW M/S SYS 2
V54X0844E	AFT MRL RTL M/S SYS 1
V54X0864E	AFT MRL LATCH M/S SYS 1
V54X0874E	AFT MRL RELEASE M/S SYS 1
<u>OI DSC OF1</u>	
V76V7307A	SHOULDER JETTISON PIC VOLTS SYS A
V76V7331A	SHOULDER GUILLOTINE PIC VOLTS SYS A
V76V7341A	FWD MPM JETTISON PIC VOLTS SYS A
V76V7348A	FWD MPM GUILLOTINE PIC VOLTS SYS A
V76V7358A	MID MPM JETTISON PIC VOLTS SYS A
V76V7365A	MID MPM GUILLOTINE PIC VOLTS SYS A
V76V7375A	AFT MPM JETTISON PIC VOLTS SYS A
V76V7382A	AFT MPM GUILLOTINE PIC VOLTS SYS A
<u>OI DSC OF2 - None</u>	
<u>OI DSC OF3</u>	
V76V7308A	SHOULDER JETTISON PIC VOLTS SYS B
V76V7332A	SHOULDER GUILLOTINE PIC VOLTS SYS B
V76V7342A	FWD MPM JETTISON PIC VOLTS SYS B
V76V7349A	FWD MPM GUILLOTINE PIC VOLTS SYS B
V76V7359A	MID MPM JETTISON PIC VOLTS SYS B
V76V7366A	MID MPM GUILLOTINE PIC VOLTS SYS B
V76V7376A	AFT MPM JETTISON PIC VOLTS SYS B
V76V7383A	AFT MPM GUILLOTINE PIC VOLTS SYS B

^a Note: Measurements not used in training (STBD RMS, test parameters, etc.) are not included).

Table 6-8.- Concluded. a

<u>OI DSC OF4 - None</u>
<u>OI DSC OA1 - None</u>
<u>OI DSC OA2 - None</u>
<u>OI DSC OA3 - None</u>
<u>OI DSC OL1 - None</u>
<u>OI DSC OL2 - None</u>
<u>OI DSC OM1 - None</u>
<u>OI DSC OM2 - None</u>
<u>OI DSC OR1 - None</u>
<u>OI DSC OR2 - None</u>

^a Note: Measurements not used in training (STBD RMS, test parameters, etc.) are not included).

6.5 CCTV

The CCTV system does not have much of a direct effect on the PDRS. An overheating camera could possibly generate enough heat to be detected by the thermistors and an unstowable elbow camera could conceivably force an arm jettison prior to PLBD closure.

Most of the effects of CCTV failures apply to the arm operator and his ability to carry out the planned activity. The criticality rating of a monitor, multiplex electronics or camera loss is mission dependent and varies widely. The CCTV system is designed for redundancy, but the loss of a keel camera needed for berthing certain payloads or the loss of a wrist camera needed for grappling certain payloads could cause the task to become difficult or even impossible.

The use of mirrors positioned strategically in the bay has been considered as a possible enhancement of CCTV capabilities. This has met with little enthusiasm, however, since it introduces the complexity of additional reflected heat and light. In some cases of camera loss, an EVA crewmember could provide the feedback necessary for completion of arm activity.

While training for a mission, an arm operator should endeavor to investigate all possible CCTV configurations, including those of limited camera and monitor availability. This will allow him to develop the optimum techniques required under all CCTV conditions.

6.6 Questions

1. What buses are required to provide power to the MCIU?
2. How is the connection of MNB MMC2 to MNB MPC2 made?
3. After deploying the arm, the operator sees an indication on SPEC 94 that the system 2 shoulder stowed microswitch is still closed. What can he do to recover use of the system 2 motor to support MPM stowing?
4. The system 1 motor for the aft MRL develops an internal short to ground. What effect does this have on the EPS when the RETENTION LATCHES switch is used and how can that effect be avoided?
5. If MNC MMC4 is lost, what effect does it have on the MRL R-T-L talkback operation?
6. What effect does the loss of the MNB 015 & A8 bus have on PDRS?
7. The crew determines that AC1ØA is lost. What can they do to compensate for the loss of the illuminated displays on panel A8?
8. What rules govern the use of VRCS during arm operations?
9. When the arm operator powers up the arm, it responds as expected, but the SPEC 94 indication of RMS PWR does not change. What is the most plausible explanation for this loss of status indication?

6.7 Answers

1. MNA DA1 provides power to the MNA FPC1 bus and MNA 014 & A8 bus. MNA FPC1 provides load voltage to the MCIU whenever the RMS PWR switch is placed in the PRI position. The switching control power necessary for this action is provided by MNA 014 & A8.
2. Voltage provided by control bus BC3 closes the RPC relay that connects MNB MMC2 to MNB MPC2.
3. Power available to the logic gate through the system 2 shoulder stowed microswitch must be removed to allow the K22 stow relay to close. This can be accomplished by placing the MCA Logic MNB MID4 switch to the OFF position.
4. When the system 1 motor for the aft MRL shorts to ground during use of the RETENTION LATCHES switch, it produces a high current on AC3. If the ac bus sensor is in auto trip, the inverter will disconnect from AC3. To avoid this, the operator can remove power to MNC MMC2 by placing the MCA LOGIC MNC MID2 switch to the OFF position.
5. The loss of MNC MMC4 has no effect on MRL R-T-L talkback operation. Its loss does cause the system 2 forward MRL R-T-L microswitch status to go to zero, but the talkbacks respond to the system 1 microswitches only.
6. Loss of the MNB 015 & A8 bus would preclude the use of backup and heater system 2.
7. The arm operator can compensate for the loss of the joint angle display and mode lights on panel A8 by monitoring certain SM GPC memory locations. The addresses for these locations are listed in the REF DATA book. The breakout box is not used for AC.
8. VRCS can be used during all arm operations except when the arm is simultaneously grappled to an unberthed payload and in test mode.
9. If SPEC 94 does not reflect a change of power status for the arm when other indications confirm it, the arm operator could reasonably suspect a failure of OI MDM OF4.

Appendix A: Abbreviations and Acronyms

ABE	arm based electronics	EXEC	execute
ac	alternating current	F	Fahrenheit
Amp	ampere	FDF	flight data file
BDA	backup drive amplifier	FF	flight forward (critical MDM)
BITE	built-in test equipment	FPC	forward power controller
BSR	BITE status register	GPC	general purpose computer
B/U	backup	HC	hand controller
CCTV	closed circuit television	H/W	hardware
CK	check	I	initialization
CKT	circuit	IC	inter computer
CNTL	control	ICF	interface control function
COMM	communication	ID	identification
CONT	control	IFM	inflight maintenance
CPU	central processing unit	I/O	input/output
CRT	cathode ray tube	JPC	joint power conditioner
C/W	caution and warning	LDB	launch data bus
D	display	LED	light emitting diode
D&C	display and control	LIM	limit
dc	direct current	LRU	line replaceable unit
DERIG	derigidize	MADC	multiplexing analog to digital converter
DPS	data processing system	MCA	motor control assembly
DSC	dedicated signal conditioner	MCIU	manipulator controller interface unit
EE	end effector	MCPC	MCIU power conditioner
EEEU	end effector electronic unit	MDA	motor drive amplifier
EFF	effector	MDM	multiplexer/demultiplexer
EMF	electromotive force	MIA	multiplexer interface adapter
EOB	end of block	MMC	mid motor controller
EP	elbow pitch	MMU	mass memory unit
EPS	electrical power system		
ERR	error		
EVA	extravehicular activity		

MN	main
MPC	mid power controller
MPM	manipulator positioning mechanism
MRL	manipulator retention latch
MS	microsecond
M/S	microswitch
MSEC	microsecond
NAND	not AND (logic gate)
NSI	NASA standard initiator
OI	operational instrumentation
OPS	operations
OR	To combine via OR logic gate
P	pitch
PCMMU	pulse code master measurement unit
P/L	payload
PLB	payload bay
PLBD	payload bay door
PLL	phase lock loop
POR	power on reset
POS	position
PRCS	primary reaction control system
PRD	payload retention device
PRO	proceed
PWM	pulse width modulator
PWR	power
R	roll
RAD	radian
RAM	random access memory
RCH	reach
RCS	reaction control system
REF	reference
REL	release
RIP	receive in progress
RMS	remote manipulator system
ROM	read only memory
RPC	remote power controller

RTL	ready to latch
SCU	signal conditioning unit
SEQ	sequential
SHMF	systems health monitor function
SING	singularity
SM	systems management
SP	shoulder pitch
SPA	servo power amplifier
SPEC	special (display)
STBD	starboard
SY	shoulder yaw
SYNC	synchronize
T	temperature
TACH	tachometer
T/B	talkback
TE	tachometer electronics
TEMP	temperature
TFL	telemetry format load
TIP	transmit in progress
TW	test word
Vac	voltage alternating current
VCO	voltage controlled oscillator
Vdc	voltage direct current
VRCS	vernier reaction control system
WP	wrist pitch
WR	wrist roll
WY	wrist yaw

112 END