

Space Program Operations Contract

Controllers Workbook CONT 21002

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Final Version

This document has been reviewed and updated. No subsequent updates to this document are anticipated or required due to the approaching shuttle program closure.

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**Controllers Workbook
CONT 21002**

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PREFACE

The content of this document was provided by the Control/Propulsion Department, Space Flight Training Division, Mission Operations Directorate (MOD), Lyndon B. Johnson Space Center (JSC), National Aeronautics and Space Administration (NASA). Technical documentation support was provided by Integrated Documentation Services (IDS). Any questions concerning this workbook or any recommendations should be directed to the book manager.

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If this workbook is being read as part of a formal syllabus, the reader should complete the training materials evaluation form at the end of the document. The evaluation form does not need to be signed.

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1.0 OVERVIEW

1.1 OBJECTIVES

After completing this workbook, the student should be able to do the following:

- Describe the purpose, location, and flight-phase availability of each controller.
- Describe the power sources for each controller.
- Describe the Primary Avionics Software System (PASS) and Backup Flight System (BFS) software processing and Redundancy Management (RM) for each controller.
- Describe the effects of other Flight Control System (FCS) switches on controller functions.

1.2 CONTROLLER PURPOSE

The Rotational Hand Controller (RHC) controls the orbiter roll, pitch, and yaw movements during ascent by sending rate commands to the solid rocket boosters, to the main engines' thrust vector control, and to the Orbital Maneuvering System (OMS), and by commanding jet firings of the Reaction Control System (RCS). The RHC also controls movement on orbit with the OMS and RCS. It controls movement during entry with RCS and aerodynamic control surfaces.

The Translational Hand Controller (THC) controls the vehicle vertical, lateral, and longitudinal movements by firing the RCS jets during insertion into orbit, on orbit, and during deorbit operations.

The combined Speedbrake and Thrust Controller (SBTC) allows manual control of the speedbrake during entry and of main engine thrust during ascent. (Only the right SBTC, the pilot's, is active during ascent.)

The Rudder Pedal Transducer Assembly (RPTA) outputs rudder pedal commands for rudder control during landing and rollout.

1.3 CONTROLLER LOCATIONS

1.3.1 Forward Stations

The forward station controllers are illustrated in Figure 1-1. As shown, both the commander's and the pilot's stations have an RHC, an SBTC, and a set of rudder pedals connected to an RPTA. Only the commander has a THC in the forward station. The RHC is offset slightly from the vehicle body axis. To suit the operator, it can be adjusted 5 inches in the vertical axis and 20° in the pitch axis. The rudder pedals can be adjusted 3.25 inches forward or aft from the neutral position.

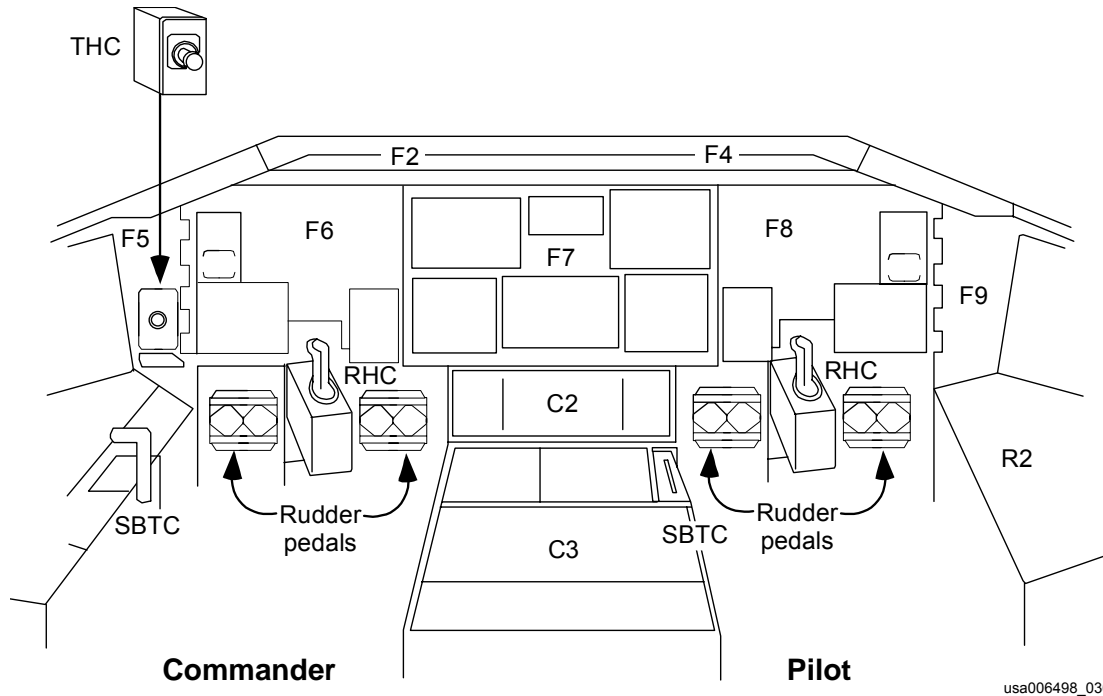


Figure 1-1. Forward station controllers

1.3.2 Aft Station

The aft station has only an RHC and a THC (Figure 1-2).

1.4 CONTROLLER AVAILABILITY

Operational Sequences (OPS) and associated Major Modes (MMs) corresponding with certain phases of flight will be used throughout this workbook. The controller availability matrix (Figure 1-3) illustrates the MMs, in which the various controllers can supply manual inputs or signals to the FCS to actually control the vehicle. The shaded area in an MM box indicates that the software for that controller is up and running during that MM.

Only the right SBTC is available during MMs 102 and 103 of OPS 1 and MM 601 of OPS 6 for manual throttling. Both left and right SBTCs are available in MM 304 and 305 during OPS 3 and in MMs 602 and 603 during OPS 6 for manual speedbrake control.

The aft station controllers are available only during OPS 2 and OPS 8 for on-orbit and checkout operations.

During MM 601, the left THC is available for a manual separation from the external tank.

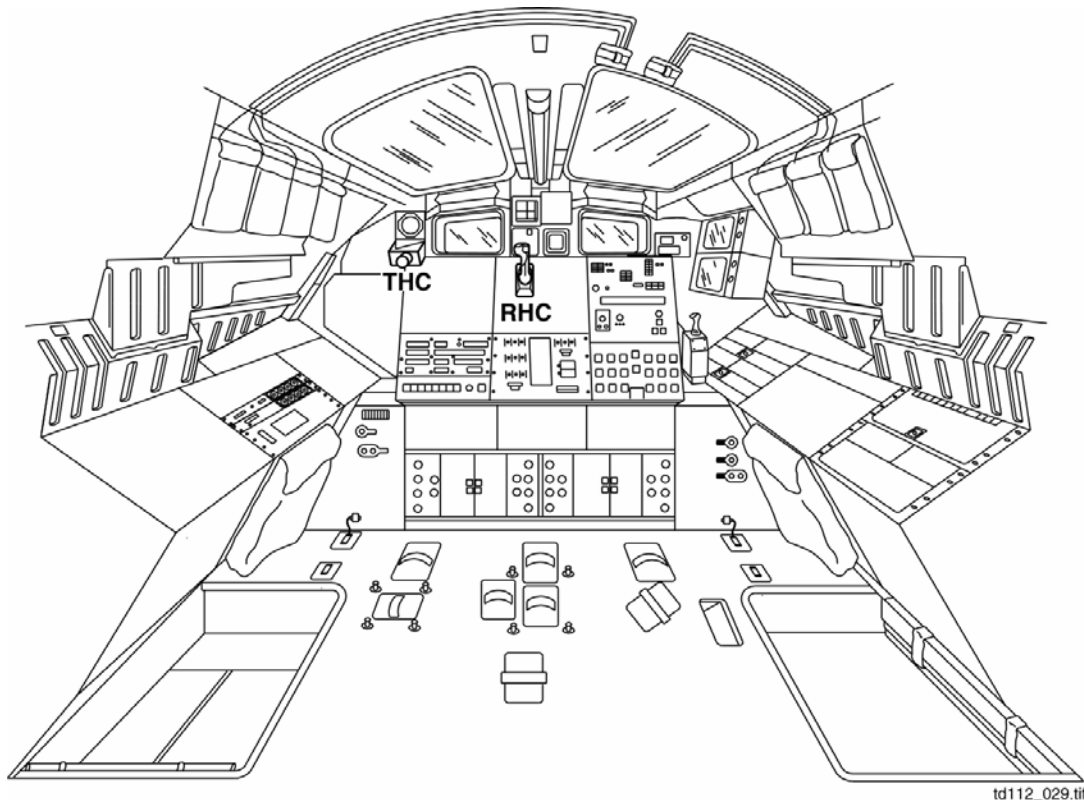


Figure 1-2. Aft station controllers

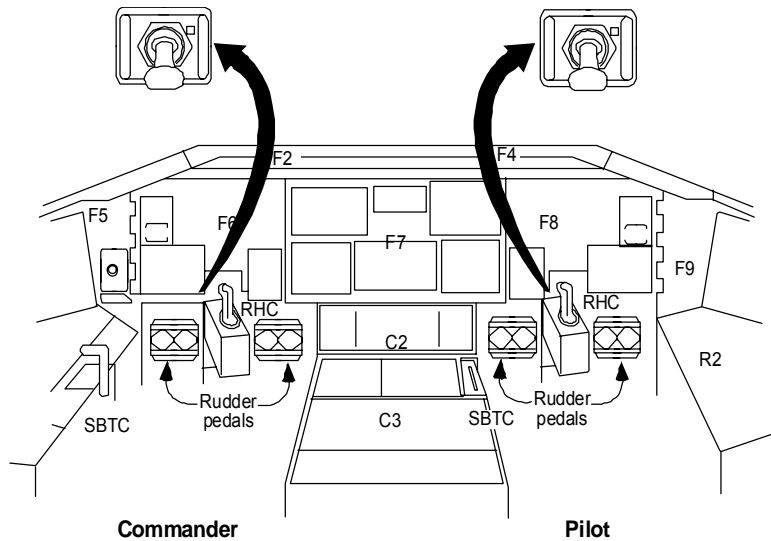
MM/OPS	101	102	103	104	105	106	201	OPS 8	202	301	302	303	304	305	MM	601	602	603
Pilot and commander RHC 3-axis command capability															Pilot and commander RHC 3-axis command capability			
Pilot and commander aft RHC 3-axis															Pilot and commander RHC 2-axis			
Pilot and commander, RHC 2-axis															THC (forward) (post-MECO only)			
THC forward and aft															SBTC right-hand throttle cont			
THC forward only															SBTC right-hand and left-hand speedbrake			
SBTC right-hand throttle cont															RPTA			
SBTC right-hand and left-hand speedbrake															Body flap			
RPTA																		
Body flap																		

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Figure 1-3. Controller availability matrix

1.5 CONTROLLER POWER SOURCES

Each station has a flight controller power switch that controls the power to all the controllers in that station. The flight controller power switches are found on forward Panels F7 and F8 and aft Panel A6U (Figure 1-4 and Figure 1-5).



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Figure 1-4. Flight controller power switches (forward station)

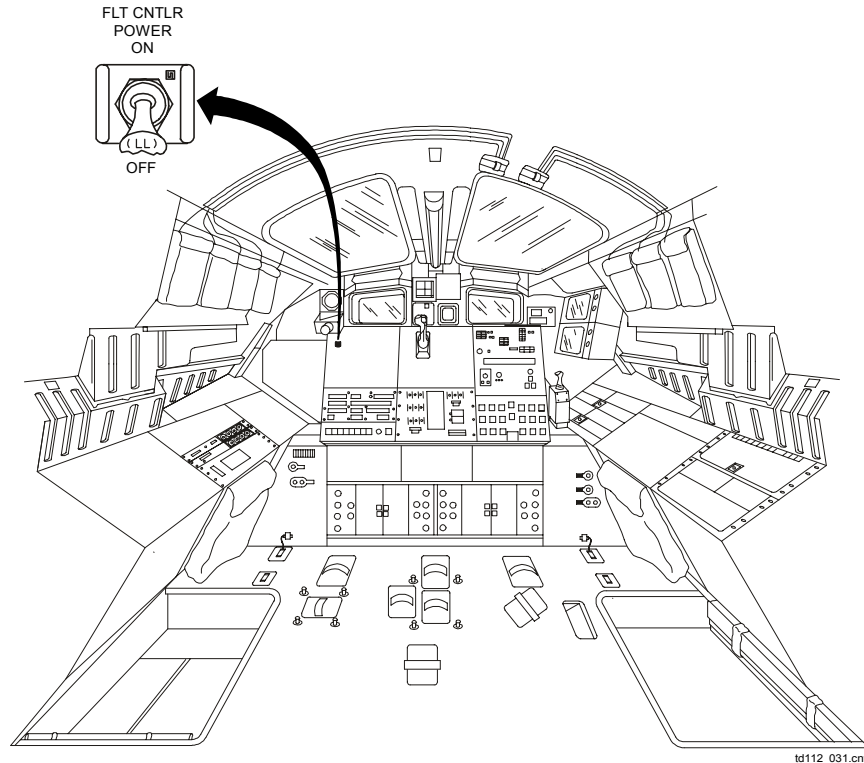


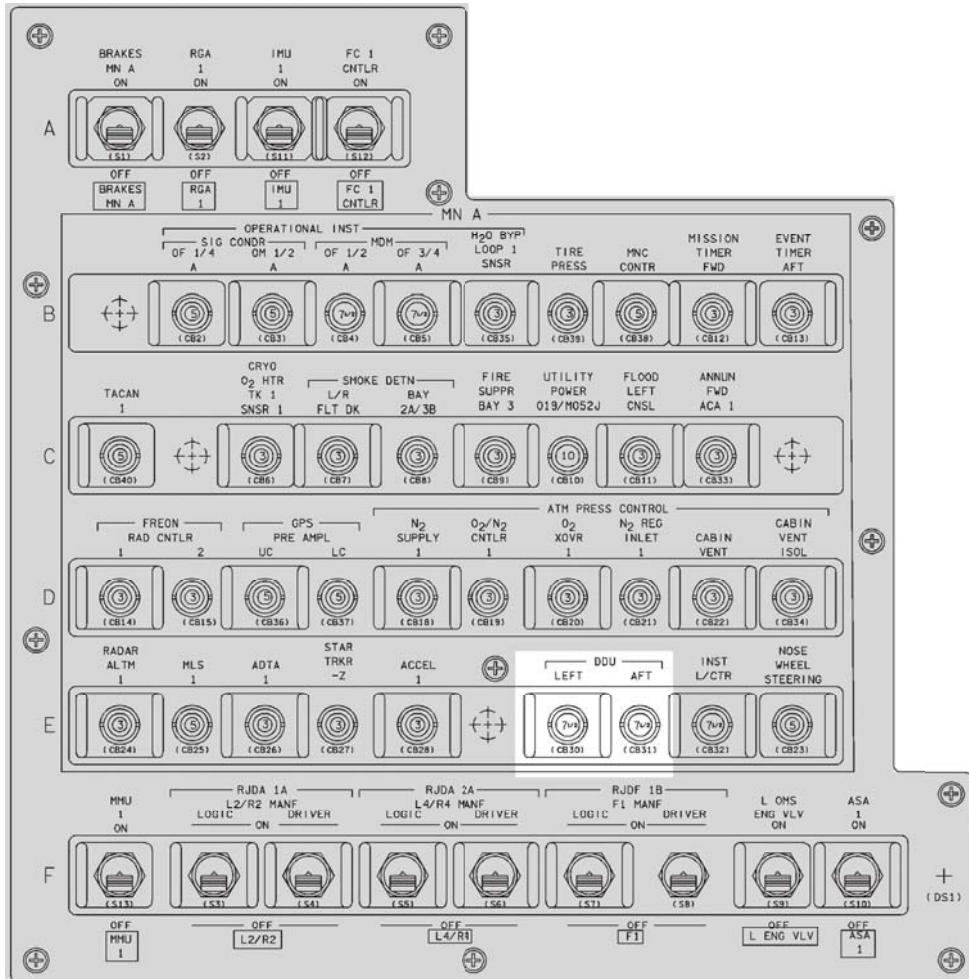
Figure 1-5. Flight controller power switches (aft station)

Each station has an associated Device Driver Unit (DDU) that supplies power to all the controllers at that station. Each DDU receives its power from two main power buses; thus, the DDU remains powered even after the loss of one main power bus. Each DDU contains three power supplies - A, B, and C - which supply power to channels 1, 2, and 3 in each controller. The three channels in each controller are redundant; that is, the controller can operate with only one channel selected.

The following matrix indicates which main power buses are associated with which DDUs.

	Main power buses (MN)
Left DDU (commander's)	A and B
Right DDU (pilot's)	B and C
Aft DDU	A and C

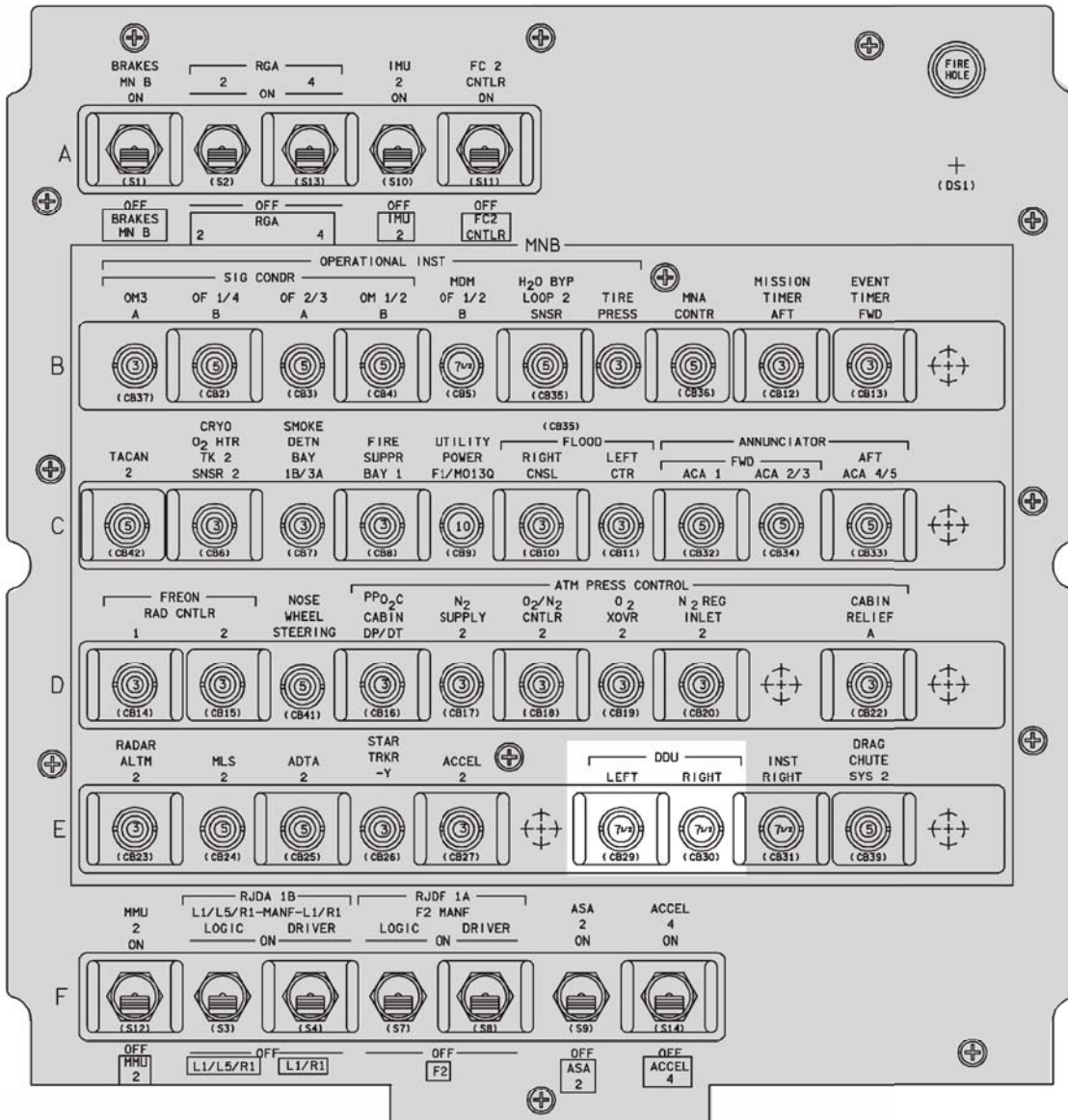
The circuit breakers associated with these DDUs are located on overhead Panel (PNL) 014 (Figure 1-6), PNL 015 (Figure 1-7), and PNL 016 (Figure 1-8).



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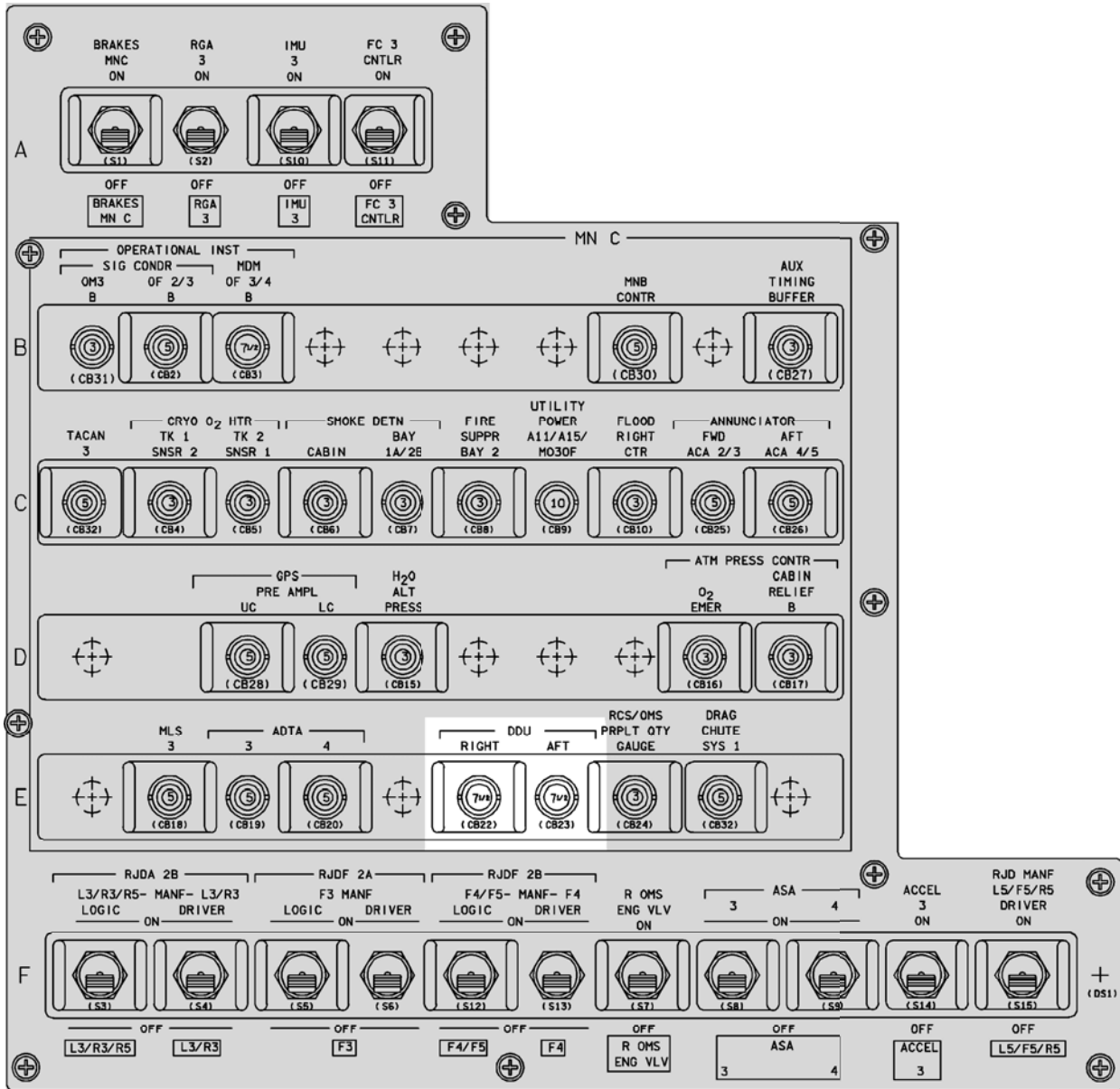
TD1120106.PNL1

Figure 1-6. DDU-associated circuit breakers on Panel 014



TD1120107, PNL 1

Figure 1-7. DDU-associated circuit breakers on Panel 015



TD112010B. PNLs 1

Figure 1-8. DDU-associated circuit breakers on Panel 016

1.6 SIGNAL FLOW

Commands or signals coming from each controller pass over Flight-Forward (FF) Multiplexer/Demultiplexer (MDM) channels to the FCS in the General Purpose Computer (GPC). The control signals passing from the flight controller to the MDMs are on triply redundant channels. As an example, pitch, roll, and yaw command channel A goes to MDM FF 1 from the left RHC. Pitch, roll, and yaw command channel B goes to MDM FF 2, and pitch, roll, and yaw command channel C goes to MDM FF 3. (Figure 1-9)

All controllers for a given station have the same channels assigned to the same MDMs. For instance, the signals on channels A, B, and C of each commander's controllers (L RHC, L THC, L SBTC, and L RPTA), are sent over MDMs FF 1, 2, and 3, respectively. As Table 1-1 illustrates, the controllers for the left and aft stations follow the same pattern of channelization, but the right station controllers follow a different pattern. This arrangement provides redundancy for the commander's (left station) and pilot's (right station) controller signals. For example, if FF 1 is lost, the channel A controller signals for the left and aft stations will be missing, but the right station will be unaffected because none of the right station controller signals are sent over FF 1.

Table 1-1. Controller channelization

FF MDM	1	2	3	4
L RHC channels	A	B	C	
R RHC channels		A	B	C
A RHC channels	A	B (P,Y)*	C	B (R)*
L RPTA channels	A	B	C	
R RPTA channels		A	B	C
L SBTC channels	A	B	C	
R SBTC channels		A	B	C
L THC channels	A	B	C	
A THC channels	A	B	C	

* The AFT RHC Pitch and Yaw axes are channelized thru FF2, but Roll goes thru FF4.

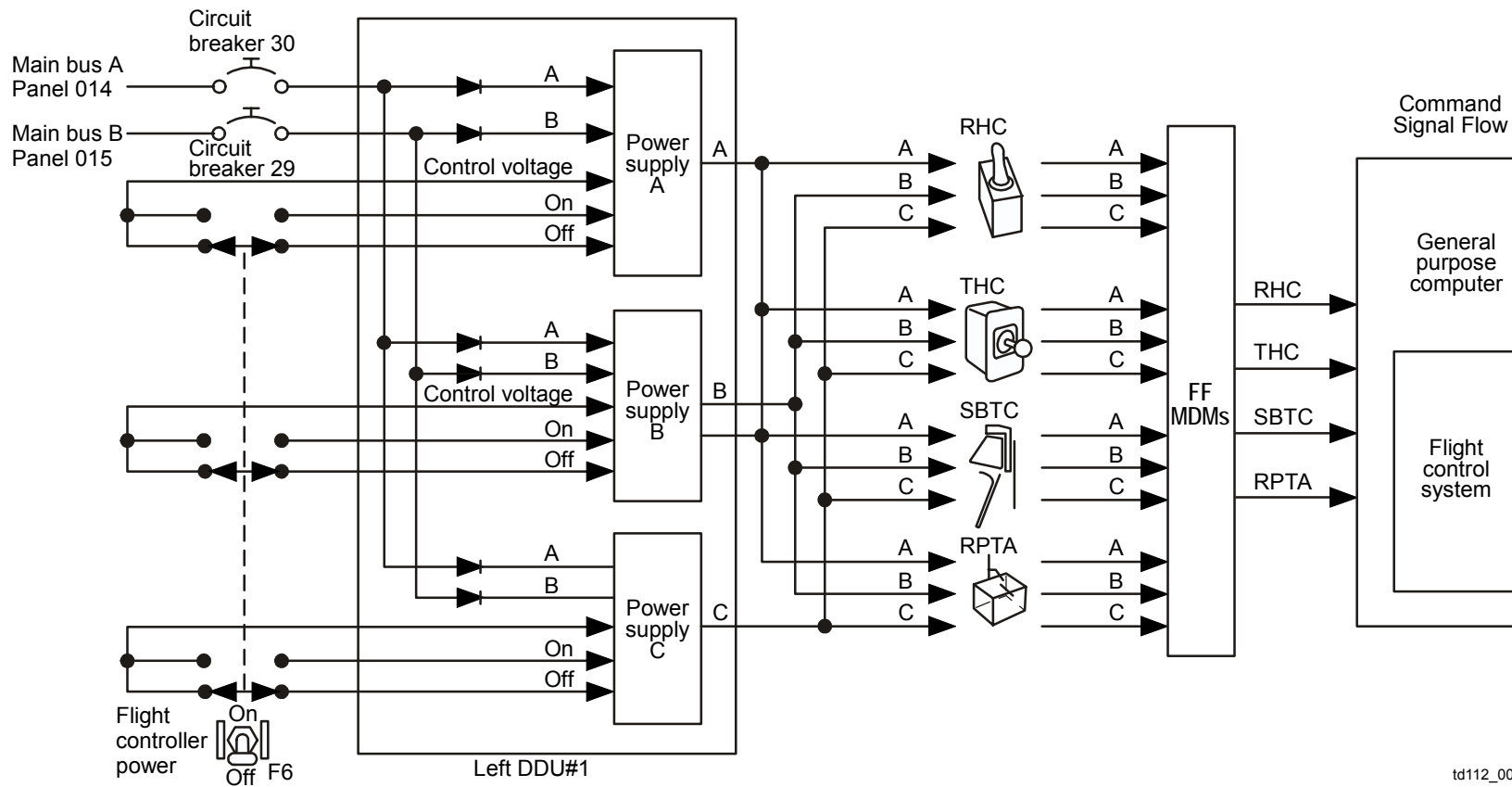


Figure 1-9. Flight controller power distribution - commander

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1.7 QUESTIONS


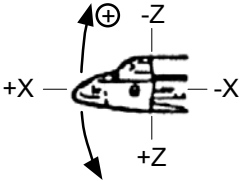
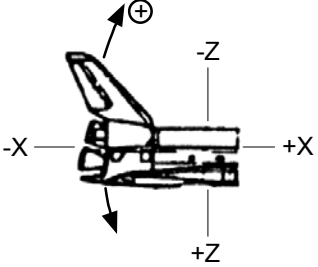
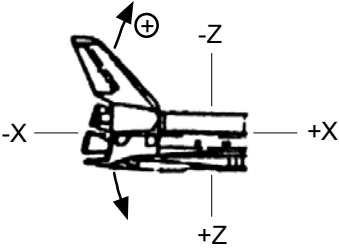
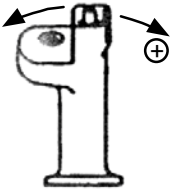
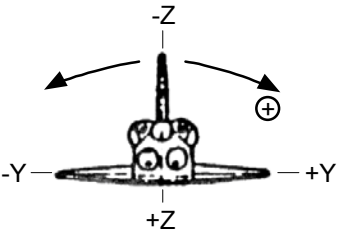
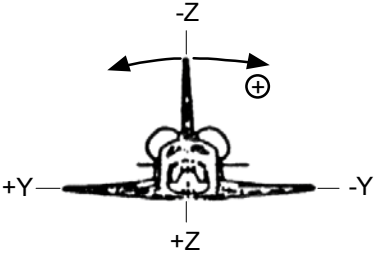
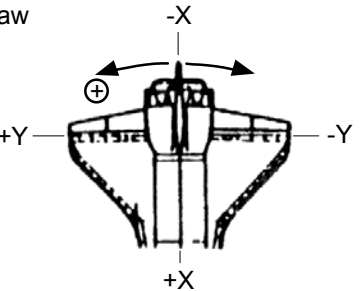
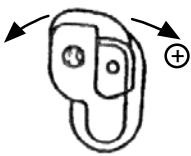
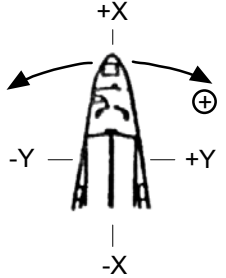
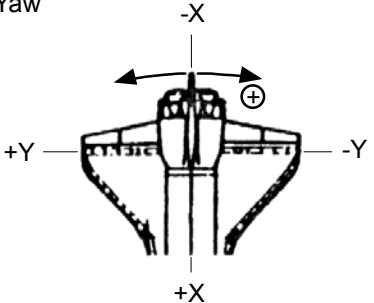
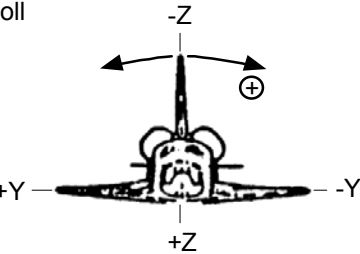
1. During ascent, which controller can be used to manually control main engine thrust?
2. Explain the functions of the THC.
3. What effect would the loss of main bus A have on the pilot's controllers?
4. In what way would the loss of MDM FF 2 affect the pilot's station?

2.0 ROTATIONAL HAND CONTROLLER

2.1 ROTATIONAL HAND CONTROLLER USE

2.1.1 Forward RHC Use

The RHC frame of reference used by the commander and pilot is the standard reference system used for the FCS. Depicted in Figure 2-1 are the positive (+) deflections of the RHCs by axis and the corresponding orbiter movements.

RHC use	Forward RHC use - Commander and pilot	Aft line-of-sight reference Aft RHC use Sense switch -X	Overhead line-of-sight reference Aft RHC use Sense switch -Z
	<p>Pitch</p> 	<p>Pitch</p> 	<p>Pitch</p> 
	<p>Roll</p> 	<p>Roll</p> 	<p>Yaw</p> 
	<p>Yaw</p> 	<p>Yaw</p> 	<p>Roll</p>  <p>Visualize RHC mounted on same plane as -X windows</p>

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Figure 2-1. Positive deflections of the RHC by axis

2.1.2 Aft Station Control

The aft station has two sets of windows (Figure 2-2) so that the crew can look along the -X or the -Z axis of the orbiter. Since there is only one set of aft station controllers, an RHC and a THC, a visual control reference must be established on the basis of the crewmembers' line of sight. This is accomplished with the aft sense switch on Panel A6U (Figure 2-3). The -Z position of the switch selects the line of sight reference about the -Z axis (overhead windows), and the -X position selects the line of sight reference about the -X axis (aft windows).

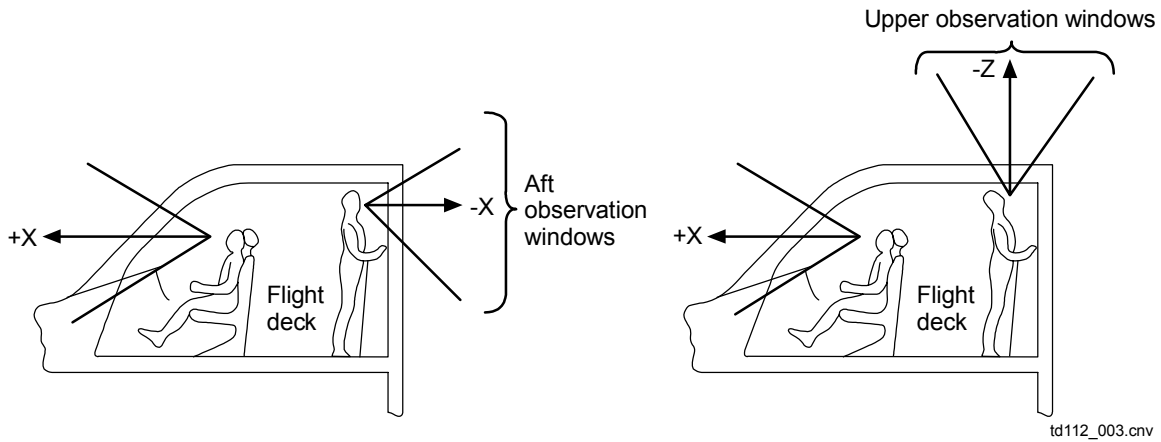


Figure 2-2. Aft station windows

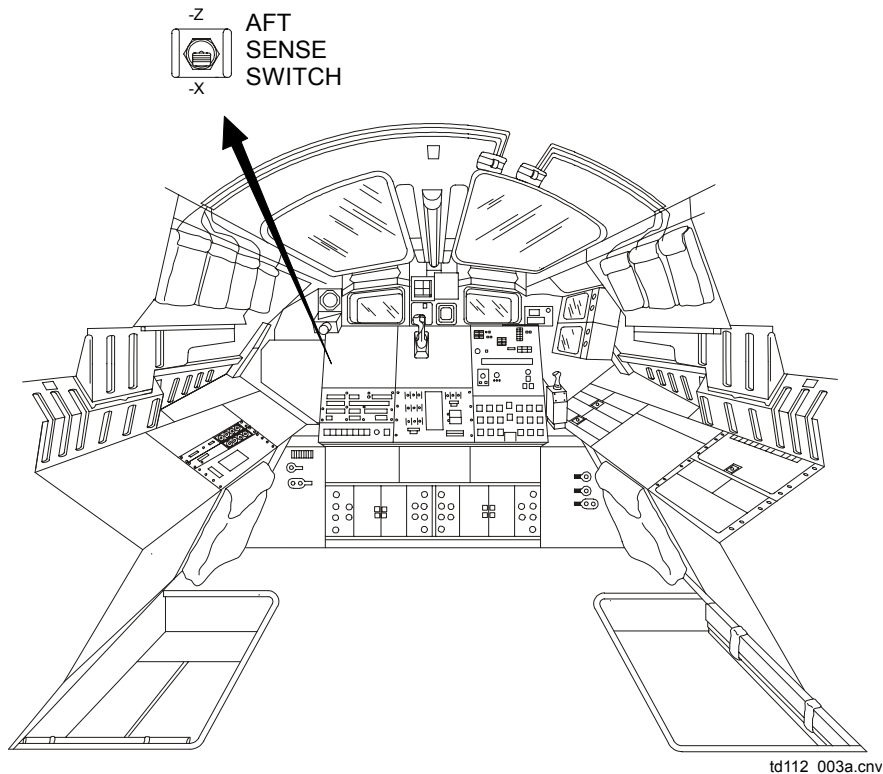


Figure 2-3. Aft sense switch

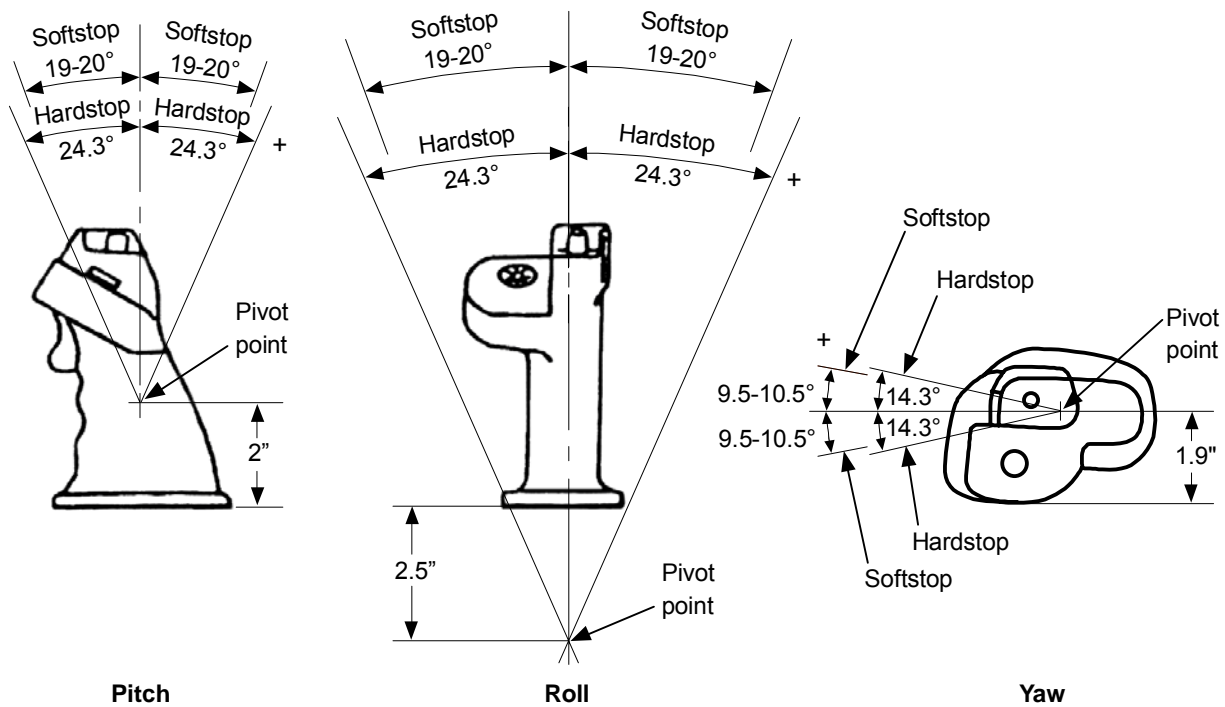
2.2 HARDWARE

2.2.1 RHC Mechanical Limits

As illustrated in Figure 2-4, an RHC mechanical hardstop (the maximum deflection that can be obtained in an axis) occurs at $\pm 24.3^\circ$ in the pitch and roll axes, and at $\pm 14.3^\circ$ in the yaw axis. A built-in resistance (softstop) occurs before the hardstop, at $\pm 19^\circ$ to $\pm 20^\circ$ in the pitch and roll axes, and at $\pm 9.5^\circ$ to $\pm 10.5^\circ$ in the yaw axis.

2.2.2 RHC Stick Forces

The static torque, or force, required to deflect the RHC varies by axis and also differs between the forward RHCs and the aft RHCs.



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Figure 2-4. RHC mechanical limits

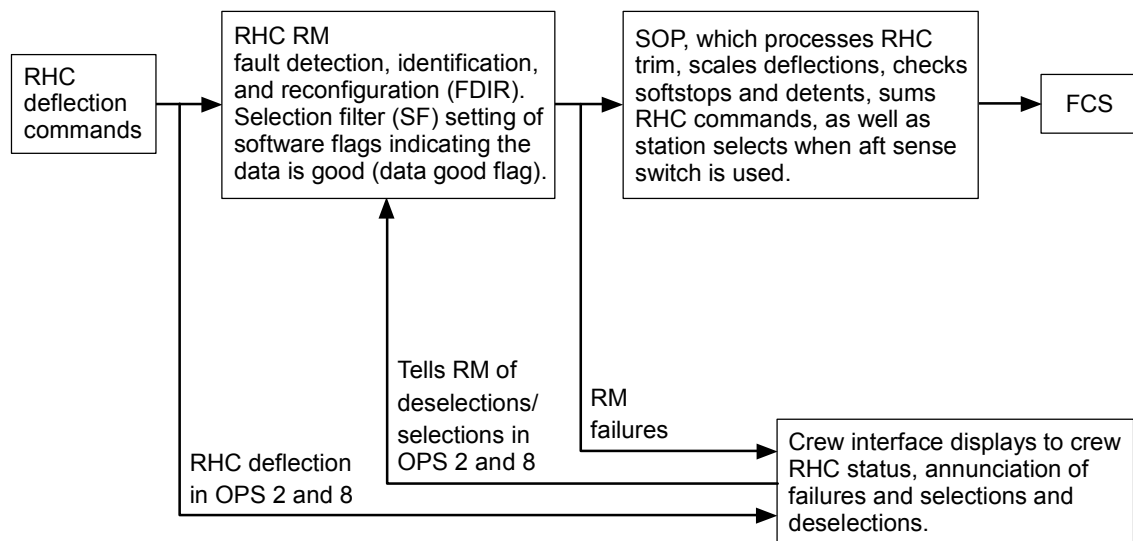
2.3 SOFTWARE

Deflection signals from each RHC undergo software processing before being displayed to the crew or being incorporated into the FCS. During OPS 2 and 8, redundant RHC signals can be seen on crew displays before being processed by the RM software. As illustrated in Figure 2-5, the normal software flow from the RHCs to the FCS is through RM and a Subsystem Operating Program (SOP).

2.3.1 Nominal and Abort Timeline

For a nominal mission, the crew has manual control of the RHC during every MM except terminal countdown (MM 101). During ascent and transitional flight (MMs 102 - 106, and 301 - 303), the commander's and pilot's RHCs have three-axis (roll, pitch, and yaw) control. For orbital flight, any of the three stations can input three-axis control commands to the FCS. During entry and landing (MMs 304 - 305), the commander's and pilot's RHCs have two-axis (roll and pitch only) capability. Yaw (sideslip) is controlled by the Aerojet Digital Autopilot (DAP). Roll, pitch, and yaw aerosurface deflection trim is controlled via the panel trim switches, while roll and pitch vehicle rate trim is controlled with the trim switches on the RHC. The aft sense switch indicates to the software how the aft RHC should be transformed.

For a Return-To-Launch Site (RTLS) abort, both the commander's and pilot's RHC have three-axis capability during MM 601, and roll and pitch capability during MM 602 and MM 603.

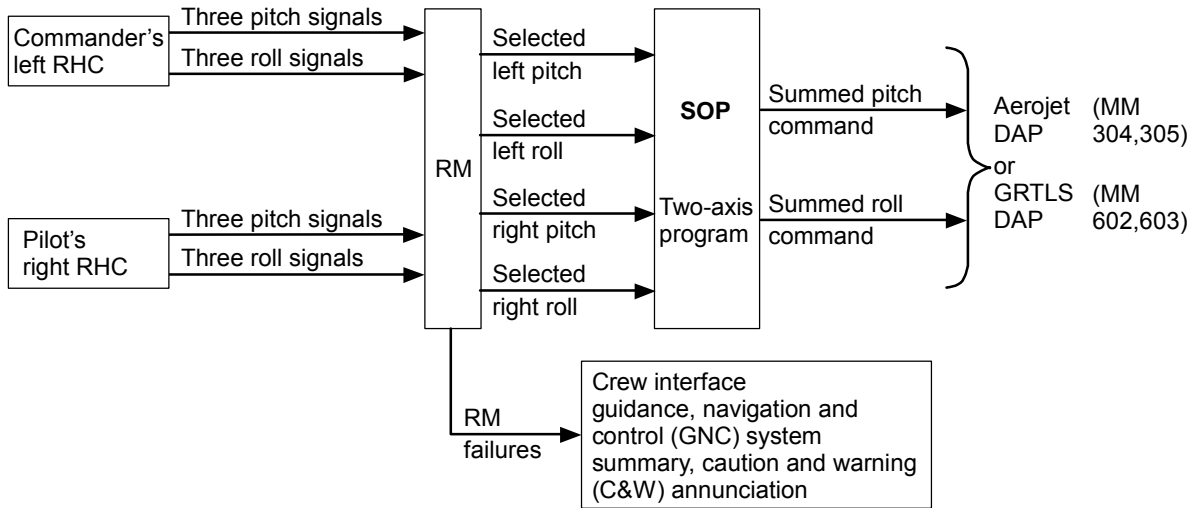


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Figure 2-5. Rotational hand controller software overview

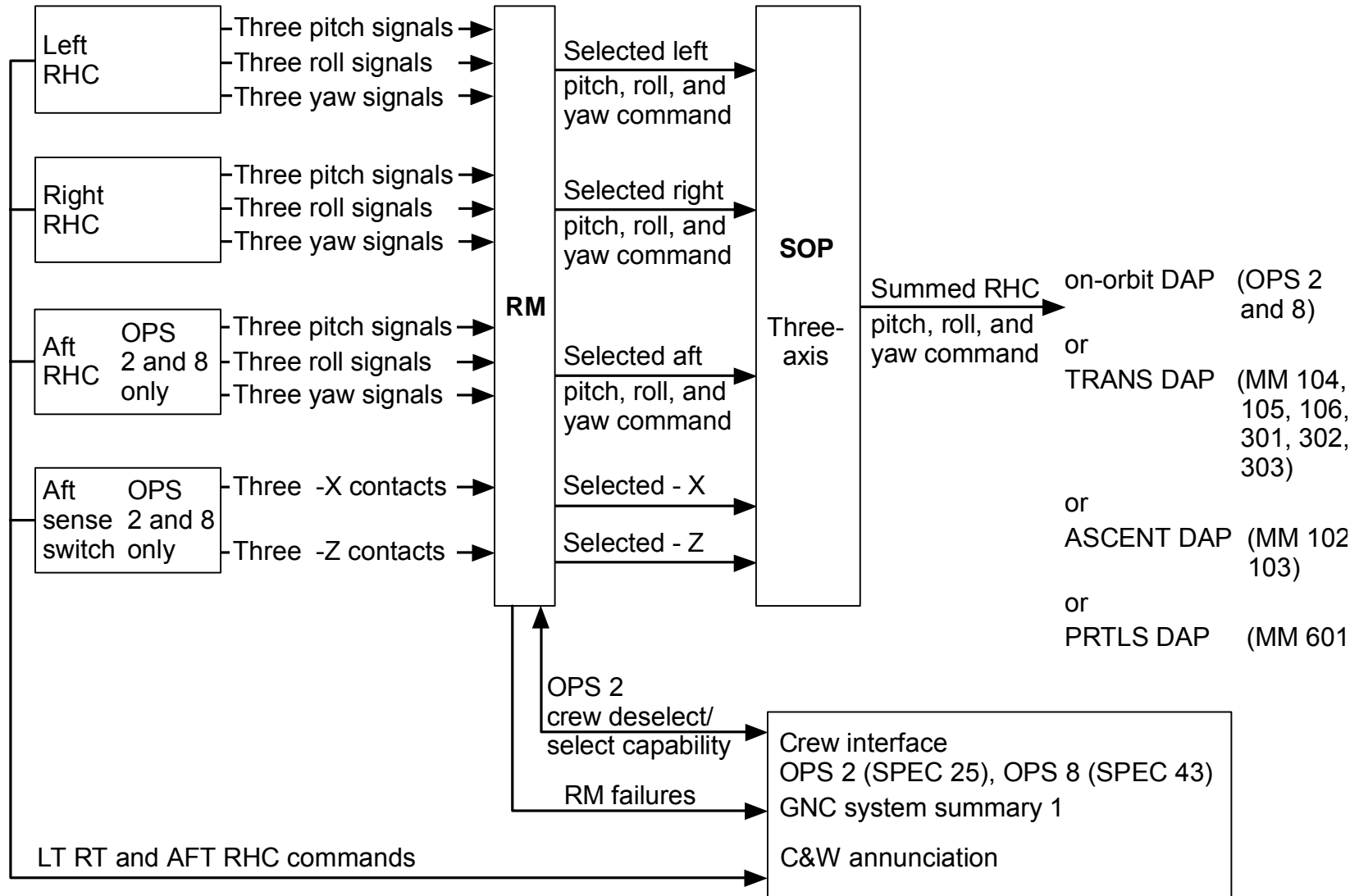
2.3.2 RHC Programs

RHC software data flow for all axis programs is triply redundant. In the two-axis program, roll and pitch signals come from the commander's (left) or pilot's (right) RHC (Figure 2-6). The redundant signals go through an RM process and then to the SOP, before being passed to the Aerojet DAP. In the three-axis program, yaw signals also come from the commander's and pilot's RHCs (Figure 2-7). In the orbit three-axis program the aft station signals, aft sense switch indication, and crew deselection/reselection capability via keyboard item entry are also added (Figure 2-7).



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Figure 2-6. RHC software data flow, two axis program



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Figure 2-7. RHC software data flow, three-axis program

2.3.3 RHC Subsystem Operating Program

The two- and three-axis RHC SOPs perform several major functions. First, the RHC voltage output is converted to degrees. Next, Data Good (DG) flags for each axis on each RHC, sent by RM, are checked. If any DG flag on an RHC is false (bad) then all output commands from that RHC are set to zero. If the DG flags are set to true (good), then a breakout deadband (1.25° in roll, 1.15° in pitch, and 0.65° in yaw) is checked to allow for stick play.

When an RHC signal exceeds an axis-specific detent limit, the SOP generates a discrete signal which takes the DAP from automatic mode (AUTO) to Control Stick Steering (CSS). This method of manual takeover is referred to as “hot stick” downmoding. Hot stick downmode is not available during the Ascent DAP, where a CSS Pushbutton Indicator (PBI) must be depressed for manual inputs to be implemented in the FCS. Additionally, any change from AUTO to CSS during ascent will occur in all axes.

While in transitional or orbital DAP, the RHC SOP generates an additional discrete when an RHC axis exceeds the softstop. This will change the RHC mode to an acceleration command if the RHC deflection exceeds the softstop in a particular axis. Such a change affects the RCS jet firings, it has no affect on the OMS.

Finally, the RHC SOP algebraically sums any RHC inputs from all RHCs to generate manual roll, pitch, and (if three-axis) yaw commands

2.4 CREW DISPLAYS

The crew displays discussed below are shown in Figure 2-8.

The GNC SYS SUMM 1 display (called up by entering SPEC 18 or pressing the SYS SUMM key) shows channel status indications (1, 2, and 3 for channels A, B, and C) for the left, right, and aft RHCs. (The aft RHC is not operational in OPS 1, 3, and 6.) The following status indicators will appear on the GNC SYS SUMM 1 display for the left, right, and aft RHCs:

“ ↓ ” for an RM failure (channel basis), or crew deselect

“ ? ” for RHC dilemma (channel basis) declared by RM

“M” for missing data (channel basis) from FCOS, comm fault condition

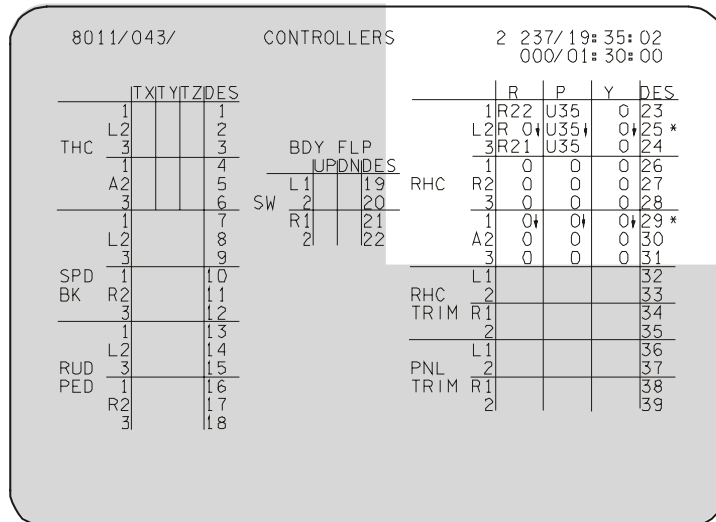
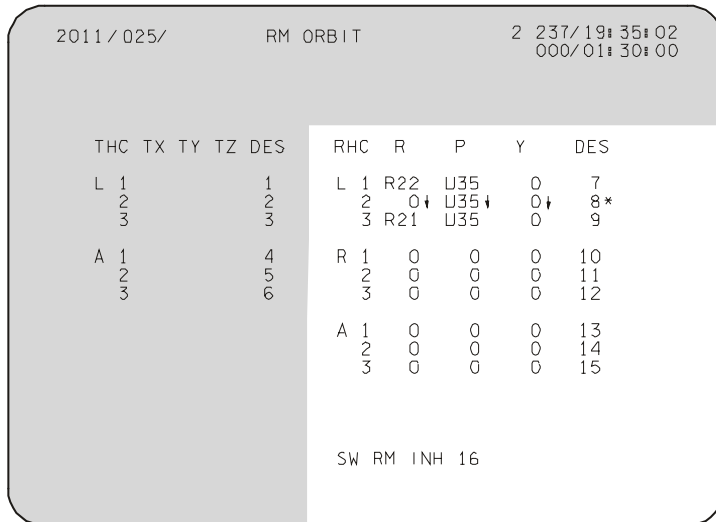
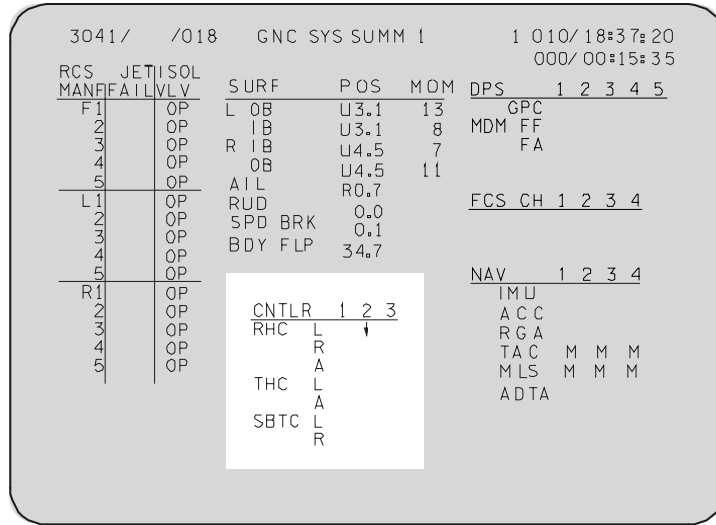
The RM ORBIT display (SPEC 25) is available in OPS 2. The triply redundant RHC commands are displayed for the left, right, and aft RHCs. Roll and yaw commands are preceded by R or L (right or left), and pitch commands are preceded by U or D (up or down). The percentage of RHC full-scale deflection is displayed on a scale from 0 to 99. The following data status indicators will appear on the RM ORBIT display for the left, right, and aft RHCs:

“ 00 ” for no sensed command or power is off

“ ↓ ” for an RM failure (channel basis), or crew deselect

“ ? ” for RHC dilemma (channel basis) declared by RM

“M” for missing data (channel basis) from FCOS, comm fault condition



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Figure 2-8. Crew displays

The crew can deselect or reselect a candidate for Selection Filter (SF) processing by entering the appropriate item number and pressing the EXEC key. An asterisk (*) appears for the deselected candidate in the Deselect (DES) column.

Entering Item 16 SW RM INH (switch RM inhibit) inhibits or enables the GN&C Switch (SW) contact RM. An asterisk is displayed after the item number when the inhibit is in force.

The CONTROLLERS display (SPEC 43) is available in OPS 8. It works the same way the RM ORBIT display does (except that it has no SW RM INH item).

2.5 QUESTIONS

1. Define RHC hardstop.
2. What is the purpose of the aft sense switch with regard to the RHC?
3. Three-axis RHC capability is possible for all flight phases except in later MMs of OPS 3 and 6. Therefore, during an RTLS abort, three-axis RHC capability is possible only for which MM?
4. If a crewmember desires CSS on ascent, what is the procedure for achieving it?

3.0 TRANSLATIONAL HAND CONTROLLER

3.1 TRANSLATIONAL HAND CONTROLLER USE

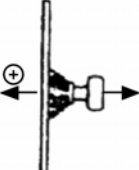
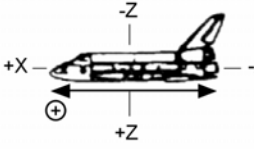
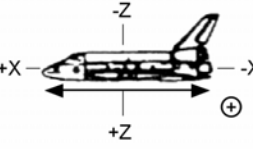
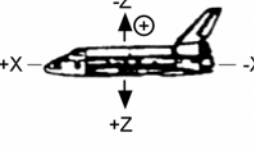
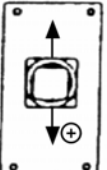
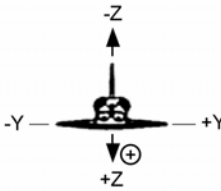
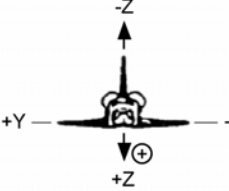
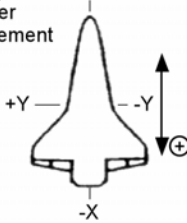
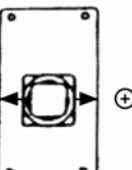
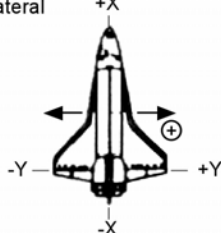
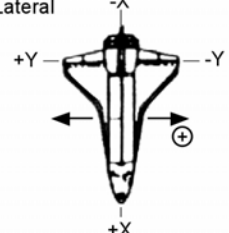
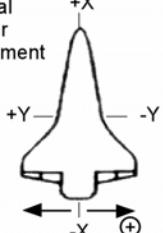
3.1.1 Forward Line of Sight THC Reference

The forward line of sight THC reference used by the commander is the standard reference used for the FCS. Figure 3-1 illustrates the positive deflections of the THC by axis and the corresponding orbiter movement.

3.1.2 Aft THC Use

The aft and overhead windows allow the aft crew to look along the $-X$ or $-Z$ axis of the orbiter while operating the THC. The aft sense switch must be in the proper position ($-X$ for aft windows and $-Z$ for overhead windows) in order for the aft THC commands to be correctly transformed to give the desired orbiter movement.

Note: To use the rear THC, push the THC in the direction of desired vehicle movement. In the overhead $-Z$ aft position, visualize the THC mounted on the same plane as the $-Z$ window.

All commands to the flight control system are sent in this reference	Forward line-of-sight reference THC use commander	Aft line-of-sight reference; aft THC use sense switch $-X$	Overhead line-of-sight reference; aft THC use sense switch $-Z$
Longitudinal THC movement 	Longitudinal 	Longitudinal 	Vertical orbiter movement 
Vertical THC movement 	Vertical 	Vertical 	Longitudinal orbiter movement 
Lateral THC movement 	Lateral 	Lateral 	Lateral orbiter movement 

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Figure 3-1. Positive deflections of the THC

3.2 THC HARDWARE

3.2.1 THC Mechanical Limits

During orbit insertion, on-orbit, and deorbit operations, crewmembers use the THC to control the vehicle vertical, lateral, and longitudinal movement with RCS jets. The normal displacement of the THC is 0.5 inch from the center null position in both directions along each of the three THC axes, respectively.

3.2.2 THC Forces

A force of 2 pounds is required to deflect either THC 0.5 inch in each axis. The output of the THC is a voltage level of either 0 or 5 volts in each axis. A displacement of 0.35 inch to 0.5 inch will cause the 5-volt output. The THC is illustrated in Figure 3-2.

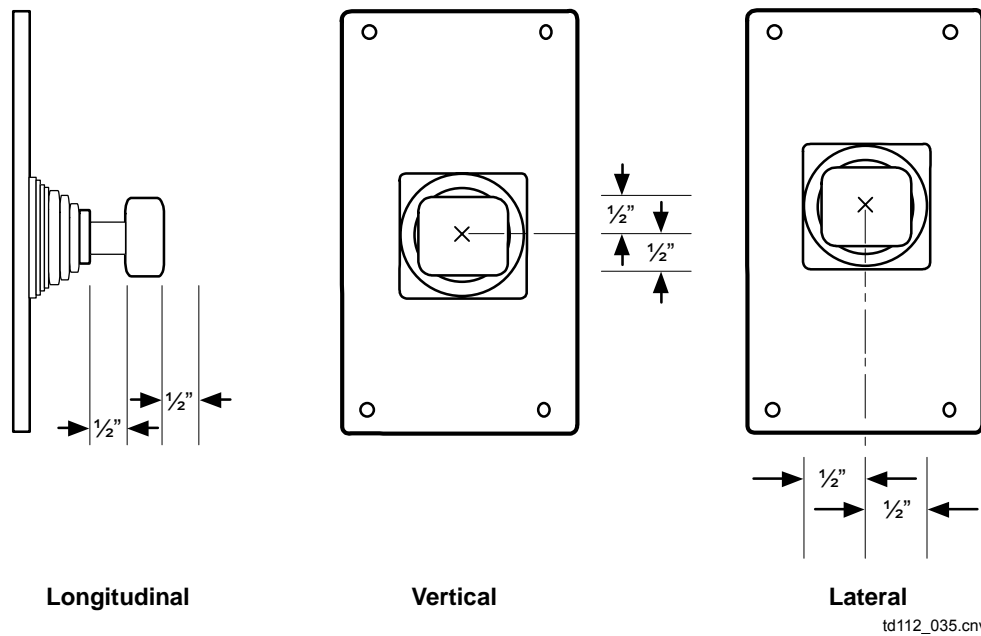
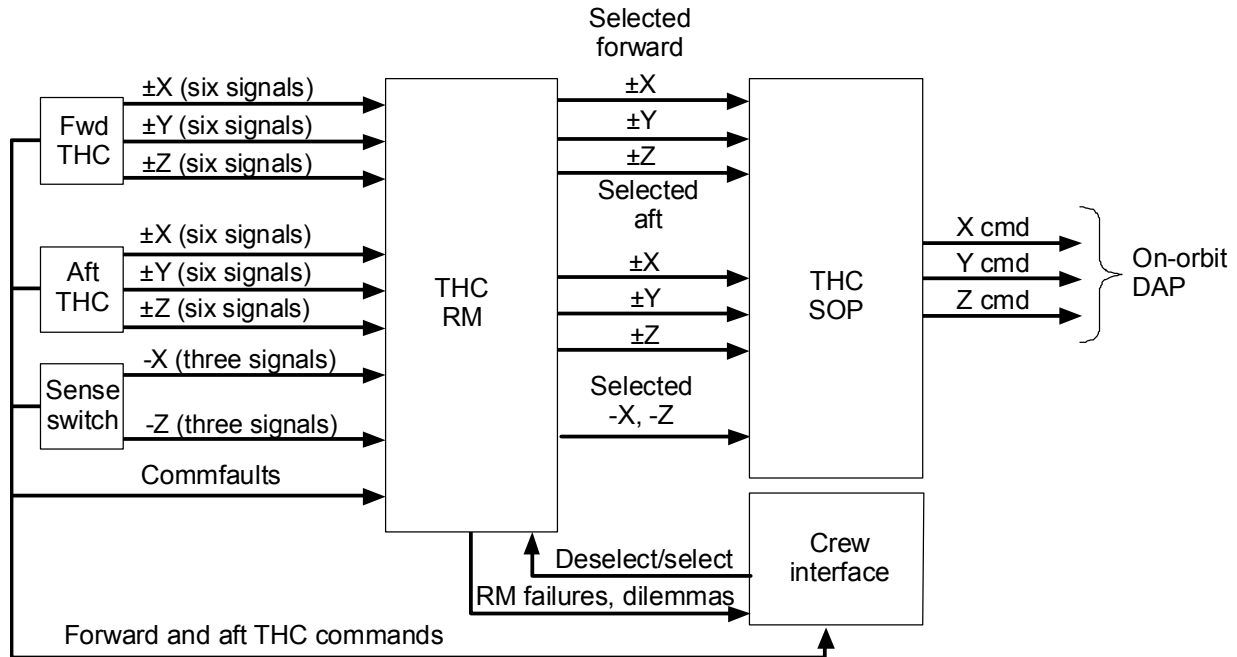


Figure 3-2. THC

3.3 THC SOFTWARE

The THC has six positions; a positive and negative position for each of the three axes. Each position has three contacts, similar to a three-contact switch. As illustrated in Figure 3-3, the redundant signals from the forward and aft THCs go through an RM process and then to a SOP, before being passed to the FCS (on-orbit DAP). Failures and dilemma conditions from RM go to the crew interfaces. The crew has deselection/reselection capability of THC signals via keyboard item entries on SPEC 25 or SPEC 43 during OPS 2 and OPS 8.



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Figure 3-3. THC software data flow

3.3.1 Nominal and Abort Timelines

The forward THC is available for use in all three vehicle axes, in MMs 103, 104, 105, 106, 201, 202, 801, 301, 302, and 303. During RTLS aborts, the forward THC is available in MM 601. The aft THC is available for use only in OPS 2 and OPS 8. Failures and dilemma conditions from RM go to the crew interfaces. The crew has deselection/reselection capability of THC signals via keyboard item entry during OPS 2 and OPS 8.

3.3.2 THC Software Operating Program

The THC SOP monitors the sense switch position and transforms the aft station THC commands, from the -X or -Z sense to the forward station sense. If a forward THC positive signal or a transformed aft THC positive signal is present, the THC SOP generates a positive signal. If a forward THC negative signal or a transformed aft THC negative signal is present, it generates a negative signal. When both crew stations generate conflicting translation commands, the output translation command is zero.

3.4 CREW DISPLAYS

3.4.1 GNC System Summary Display (OPS 2, 8, and 3)

During OPS 2, 8, and 3, THC failures and dilemmas will trigger the SM alert light and tone and the fault message: SBTC/THC L (A) (aft THC is annunciated in OPS 2 and OPS 8 only, no THC annunciation occurs in OPS 1). The displays discussed in this section can be found in Figure 3-4.

The GNC SYS SUMM1 display shows channel status indications (1, 2, and 3 for channels A, B, and C) for the left and aft THCs. There are no crew controls for this display. The following status indicators will appear on the GNC SYS SUMM 1 display for the left and aft THCs:

“ ↓ ” for an RM failure (channel basis), or crew deselect

“ ? ” for THC dilemma (channel basis) declared by RM

“M” for missing data (channel basis) from FCOS, comm fault condition

3.4.2 RM ORBIT Display (OPS 2 Only)

The RM ORBIT display shows the triply redundant THC commands for the left and aft THC. THC x, y, and z commands are preceded by a “+” or a “-“ as referenced to each axis.

The following data status indicators will appear on the RM ORBIT display for the left and aft THCs:

Blank: No sensed THC Command (CMD) for the transducer

“ ↓ ” for THC failure (parameter basis), or crew deselection (three in a row)

“ ? ” for the THC dilemma (parameter basis) declared by RM

“M” for missing data (channel basis) from the FCOS, comm fault condition

The crew can deselect or reselect a candidate for Selection Filter (SF) processing by entering the appropriate item number and pressing the EXEC key. An asterisk (*) appears for the deselected candidate in the DES column.

The current Selection Filter (SF) status is maintained across MM and OPS transitions.

3.4.3 CONTROLLERS Display (OPS 8)

The CONTROLLERS display works the same way as the RM ORBIT display for the left and aft THC. Figure 3-4 illustrates an example of an RM-sensed failure of channel 3 of the + X THC axis position of the aft THC.

A second failure (a disagreement between channels 1 and 2 of the + X position of the aft THC) appears as a dilemma (two question marks) on SPEC 25 and SPEC43.

A third failure in the form of a comm fault (missing data) on channel 2 (all axes) would be displayed as "M."

An example of all the channels of the left THC deselected by the crew for checkout purposes would appear as nine down arrows and three asterisks in the DES column.

3041/ /018 GNC SYS SUMM 1 1 010/18:37:20
000/00:15:35

RCS MANF	JET	ISOL	SURF	POS	MOM	DPS	1	2	3	4	5
F1		OP	L OB	U3.1	13	GPC					
2		OP	IB	U3.1	8	MDM	FF				
3		OP	R IB	U4.5	7	FA					
4		OP	OB	U4.5	11						
5		OP	AIL	RO.7							
L1		OP	RUD			FCS	CH	1	2	3	4
2		OP	SPD BRK	0.0							
3		OP	BDY FLP	0.1							
4		OP		34.7							
5		OP				NAV	1	2	3	4	
R1		OP				IMU					
2		OP				ACC					
3		OP				RG A					
4		OP				TAC	M	M	M		
5		OP				MLS	M	M	M		

CNTLR	1	2	3
RHC	L		
	R		
	A		
THC	L	?	?
	A		
SBTC	L		
	R		

2011/025/ RM ORBIT 1 010/18:37:20
000/00:15:35

THC	TX	TY	TZ	DES	RHC	R	P	Y	DES
L	1			1	L	1	0	0	7
	2			2		2	0	0	8
	3			3		3	0	0	9
A	1	?		4	R	1	0	0	10
	2	+?		5		2	0	0	11
	3	+↓		6		3	0	0	12
					A	1	0	0	13
						2	0	0	14
						3	0	0	15

SW RM INH 16

8011/043/ CONTROLLERS 2 237/19:35:02
000/01:30:00

THC	TX	TY	TZ	DES	RHC	R	P	Y	DES
1				1	1	R22	U35	0	23
L2				2	L2	R21	U35	0	24
3				3	3	R2↑	U35↑	0↑	25 *
1	?			4					26
A2+?				5	L1*				19
3+↓				6	2*				20
1		65		7	R1				21
L2		65		8	2				22
3		65		9					
1				10	L1				32
R2				11	RHC				33 *
3				12	TRIM	R1			34
1		0		13	2				35
L2		P24		14	L1	R	U	L	36
3		0		15	PNL		D		37
1				16	TRIM	R1			38
R2		L25		17	2				39 *
3				18					

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Figure 3-4. Crew displays during OPS 2, 3, and 8

3.5 QUESTIONS

1. Why is the aft sense switch important for aft THC use?
2. If the commander and aft crew generate conflicting THC commands, what will the resultant translation output command be?
3. How can a crewmember confirm a THC failure after failure annunciation?

4.0 SPEEDBRAKE/THRUST CONTROLLER

4.1 SPEEDBRAKE/THRUST CONTROLLER USE

4.1.1 Manual Throttling During Ascent

The SBTC lever is illustrated in Figure 4-1. When the SBTC lever is rotated backwards to the stop, the throttle setting of the Space Shuttle Main Engines (SSMEs) is commanded to minimum percentage. The lever positioned at the forward stop commands maximum percent throttle setting of the SSMEs. These max/min throttle settings are dependent on guidance I-loads for each particular flight. I-loads are initial software loads of various parameters put into a system before a flight, and are usually not changed. By using the SBTC during ascent, the SSME thrust is controlled manually.

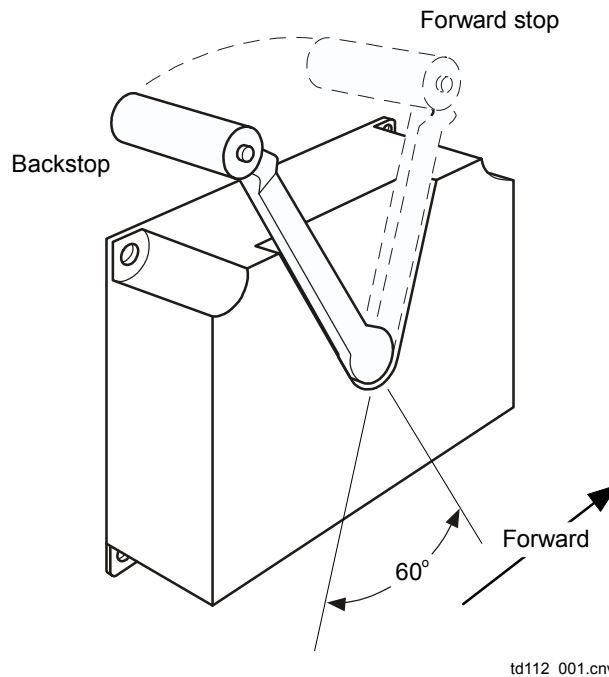


Figure 4-1. Speedbrake/thrust controller

4.1.2 Speedbrake Control During Entry

The speedbrake is commanded fully open when the SBTC lever is positioned at the backstop, and is commanded closed at the forward stop. During early entry, the vehicle pitching moment is affected by opening and closing the speedbrake. Later in the entry, the speedbrake is used to help control the vehicle speed/energy by modulating the position of the speedbrake, either open or closed.

4.2 HARDWARE

4.2.1 SBTC Takeover Switch

The SBTC takeover SW, illustrated in Figure 4-2, is a momentary pushbutton used to gain manual throttling control for the *right* SBTC only or to gain or transfer manual speedbrake control of either SBTC (Figure 4-2).

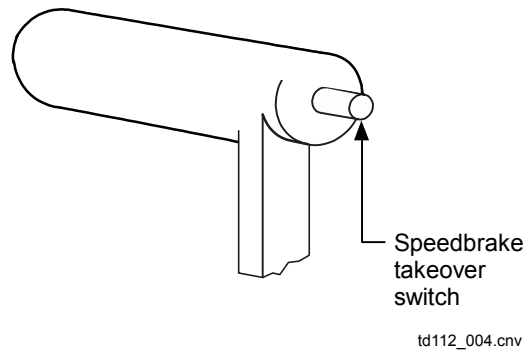
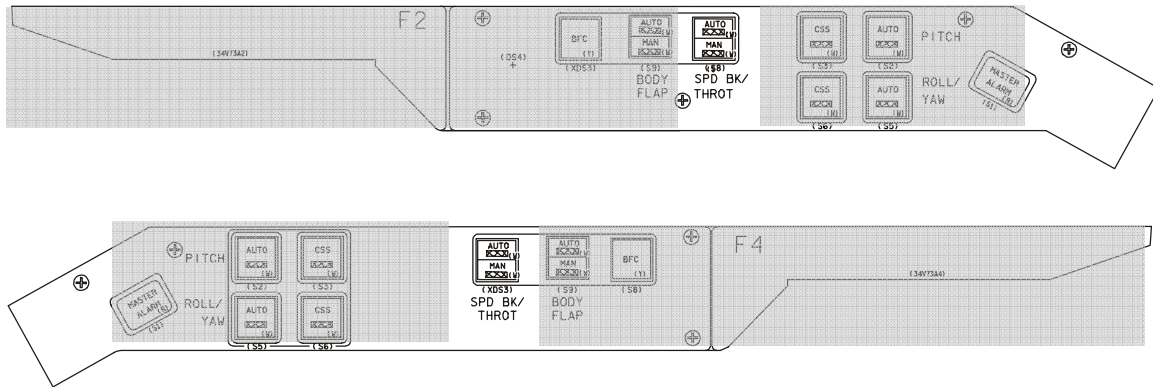


Figure 4-2. Speedbrake takeover switch

4.2.2 Manual Speedbrake Control

The speedbrake is typically under automatic control. The top half of both SPD BK/THROT PBIs (AUTO) will be illuminated. Either SBTC can be enabled for manual speedbrake control as follows:

Depress the SBTC takeover switch. If the commander depresses the SBTC takeover switch the bottom half (Manual - MAN) of the commander's PBI will illuminate (Panel F2) and the pilot's PBI will extinguish (Panel F4). Similarly, if the pilot takes control, the bottom half (MAN) of the pilot's PBI will illuminate and the commander's PBI will extinguish. Only one person can have manual control of the speedbrake at a time. The person who depressed the SBTC takeover switch last has manual control. To place the speedbrake back under software control, either PBI can be depressed. The top half (AUTO) of both PBIs will illuminate (Figure 4-3).



TD1120402, PNL 1

Figure 4-3. Manual speedbrake control

4.2.3 Manual Throttling

Engine throttling is usually under automatic control. The top half of both SPD BK/THROT PBIs (AUTO) will be illuminated. Only the right SBTC can be enabled for manual throttle control as follows:

Depress and hold the takeover switch on the right SBTC. Both AUTO PBI lights will extinguish. With the takeover switch depressed, the computer throttle command is “frozen” at its current value. While depressing the takeover switch, move the SBTC to match the frozen computer command. Manual control is established when the match is achieved within 4 percent. When the match is achieved, the SPD BK/THROT MAN PBI light on the pilot’s side of the cockpit illuminates. The takeover switch may then be released. If the takeover switch is released before a match is achieved, the system reverts to computer-generated (auto) commands.

Note that when the takeover switch is depressed, the upper left field of the ascent/entry primary flight display (A/E PFD) will also display “Throt: Man” with a yellow box outlining the field (Figure 4-4). However, this does not indicate that manual control has been achieved yet.

When under manual throttle control, depressing either or both auto PBIs shall cause the system to revert to the auto mode, extinguishing the pilot’s MAN light, and illuminating both AUTO PBI lights.

Transferring back to auto during an RTLS abort leaves the throttle at the last commanded manual setting. Fine mass control will only occur if transfer back to auto throttles is completed pre-powered pitch around.



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Figure 4-4. Manual throttle control

4.3 SOFTWARE

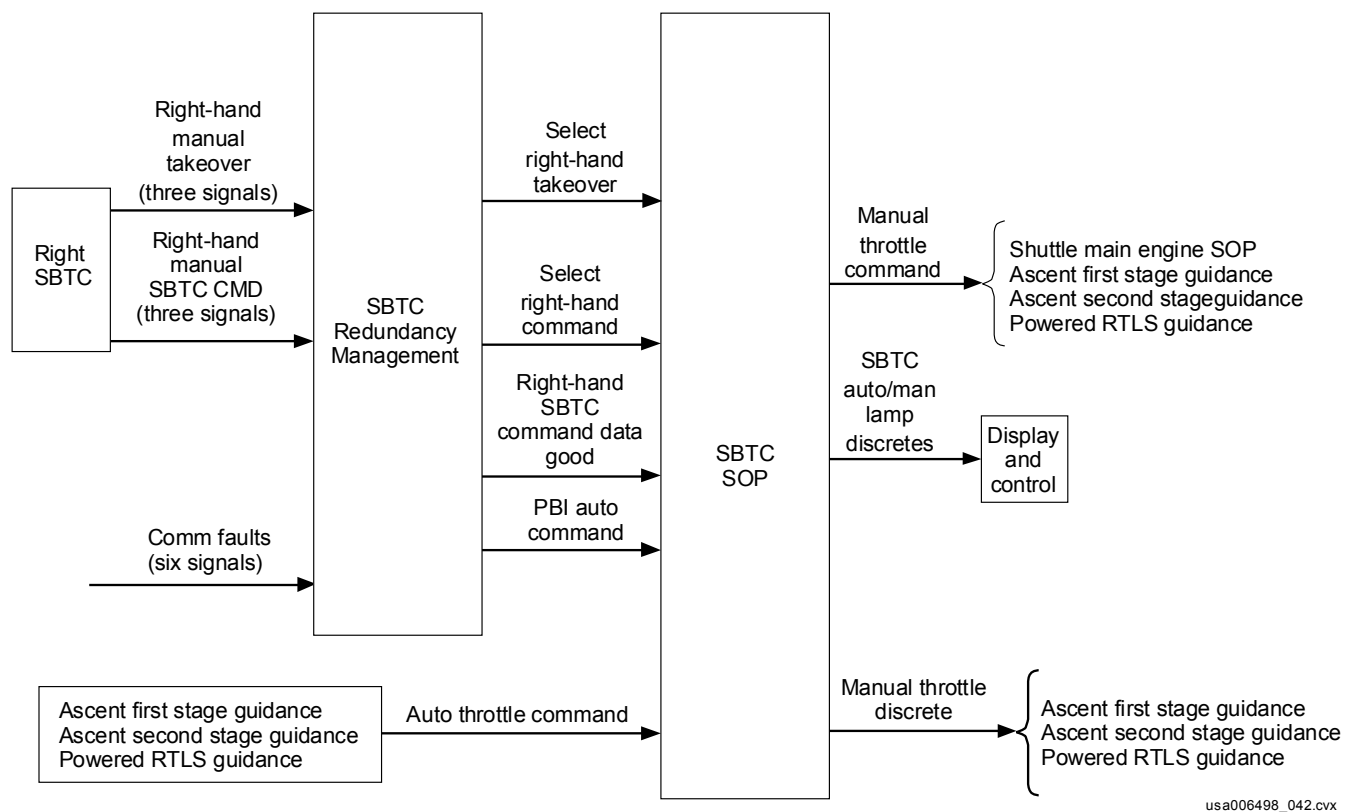
4.3.1 Nominal and Abort Timeline

During MMs 102, 103, and 601, the pilot can perform manual throttling of the main engines. As illustrated in Figure 4-5, the selected right-hand manual takeover, manual throttle command, DG indicator, and AUTO PBI command are output by RM to the SBTC SOP. When the SOP receives the manual takeover indicator, the manual throttle DISC (discrete) is output to guidance, causing the guidance-generated auto throttle command to be “frozen.” A comparison of the auto throttle command from guidance and the pilot’s manual throttle command is performed in the SOP, and when a match within 4 percent tolerance is made, manual control is established and the manual

throttle command is output by the SOP. The SOP also controls the lighting of the SPD BK/THROT PBI lamps.

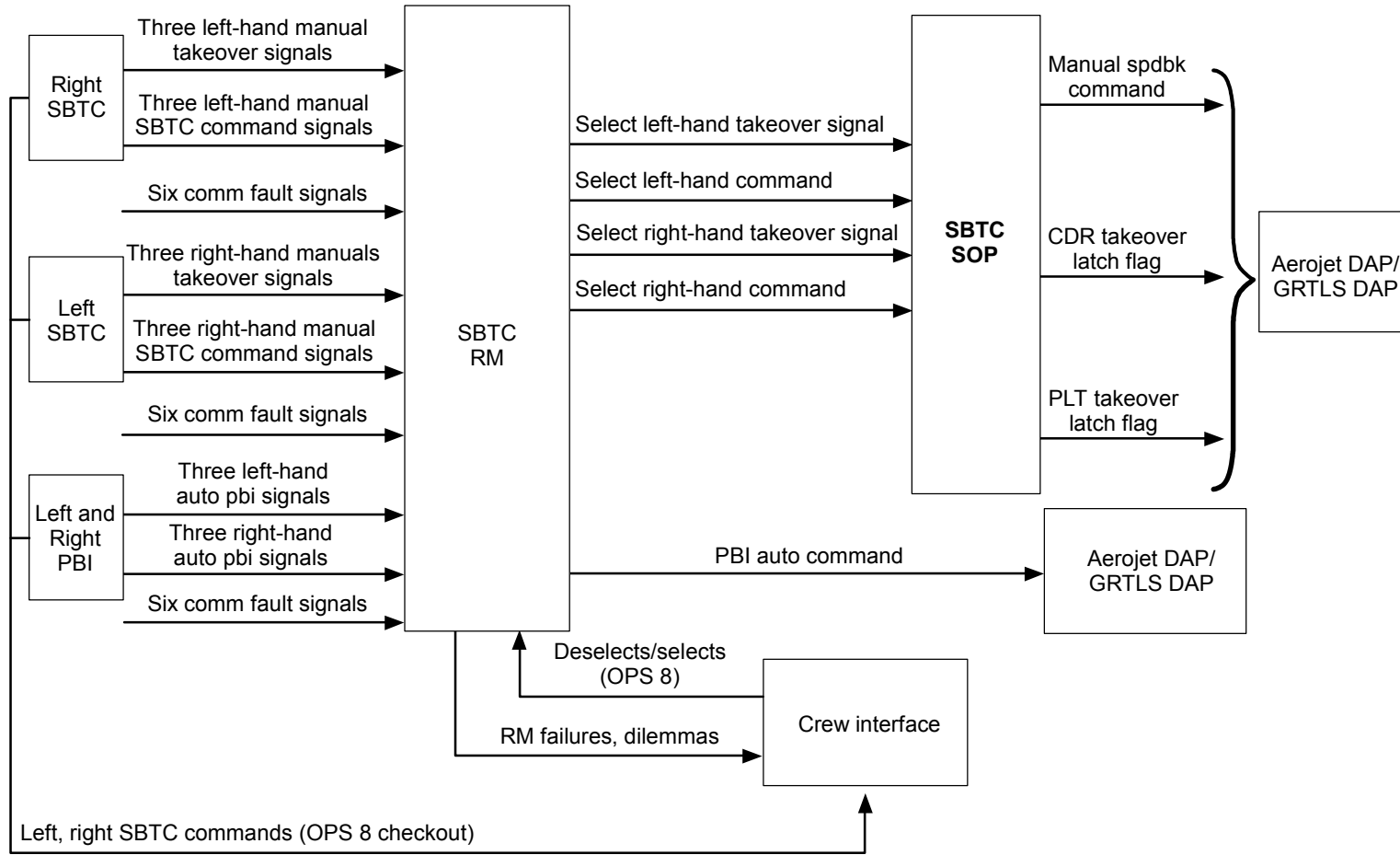
During MMs 304, 305, 602, and 603, the pilot or commander can manually control the speedbrake. The software flow for manual speedbrake control is illustrated in Figure 4-6. RM processes the takeovers and the manual commands from the SBTCs, as well as the AUTO PBIs. The SBTC SOP performs station selection of the manual SBTC commands for output to the autopilot. The autopilot handles the lighting of the SPD BK/THROT PBI lamps.

The crew has channel deselection/reselection capability for signals from both SBTCs in OPS 8 for system checkout purposes.



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Figure 4-5. SBTC Manual Throttle Processing



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Figure 4-6. SBTC Manual Speedbrake Processing

4.4 SBTC SOP

The SBTC SOP performs five functions.

1. It converts the selected manual speedbrake command from volts to degrees for flight control.
2. It performs station selection for manual speedbrake commands during OPS 3 and OPS 6, which means
 - The output command is chosen from the crewmember who last depressed the takeover switch.
 - If the command selected for output has a bad “DG” flag, then the output command will be held to the value of the last output command.
 - If both crew stations generate simultaneous takeover commands, the commander will have precedence.
3. The SBTC SOP also provides takeover latch flags for flight control (OPS 3 and OPS 6) to identify the crewmember presently in manual control. This allows the correct PBI (bottom half) to be illuminated.
4. It converts the compensated manual throttle command to a manual throttle setting in percent for guidance.
5. It provides auto and manual flags to illuminate the SBTC PBIs in MM 102, 103, and 601.

4.5 SBTC CREW DISPLAYS

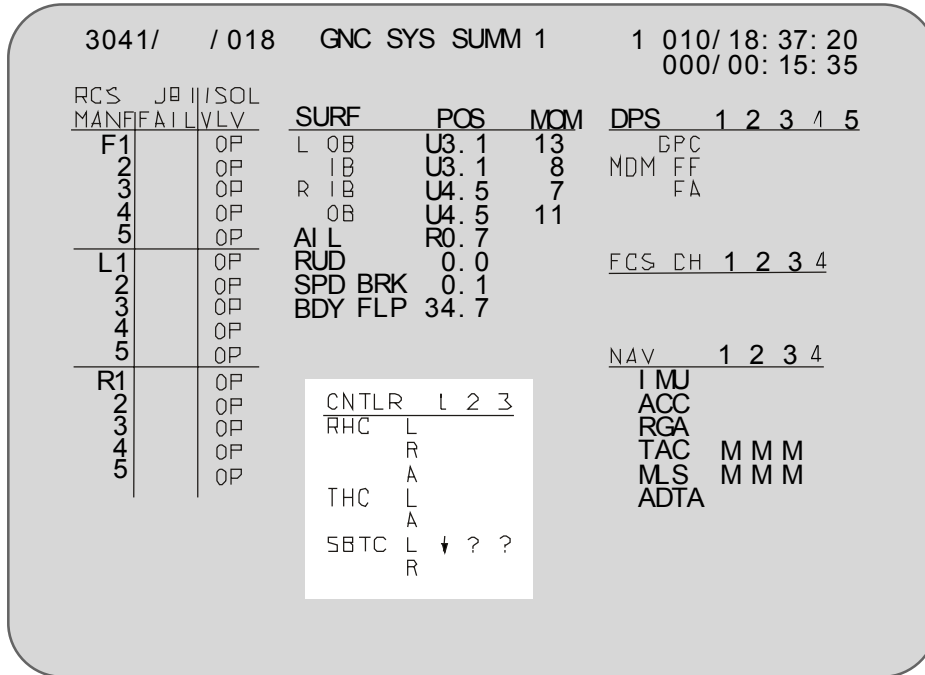
The GNC SYS SUM 1 displays SBTC statuses for RM-declared failures, dilemmas, and commfaults in OPS 3 and OPS 6 only. Figure 4-7 indicates a failure on channel 1 of the left SBTC and a dilemma for channels 2 and 3.

“↓” for an RM failure (channel basis)

“?” for SBTC dilemma (channel basis) declared by RM

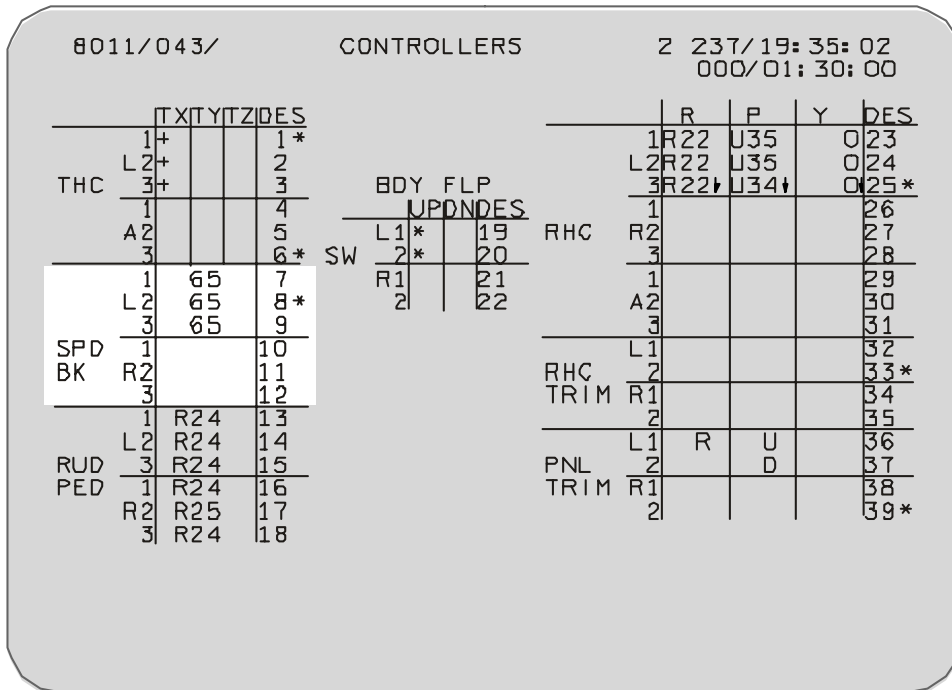
“M” for missing data (channel basis) from FCOS, comm fault condition

The CONTROLLERS display is available in OPS 8 for displaying left and right SBTC commands. The triply redundant commands are displayed in percent of speedbrake extension. The crew has channel deselection capability for each SBTC. Figure 4-8 indicates that the left SBTC lever is deflected to command 65 percent of speedbrake extension.



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Figure 4-7. GNC SYS SUMM 1 display, OPS 3 and 6



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Figure 4-8. CONTROLLERS display, OPS 8

4.6 QUESTIONS

1. How is manual control of the main engine throttling gained?
2. How is manual control of the speedbrake gained?
3. During entry, an SBTC lever placed at the forward stop commands the speedbrake to what position?
4. How can the crew deselect a bad SBTC channel?

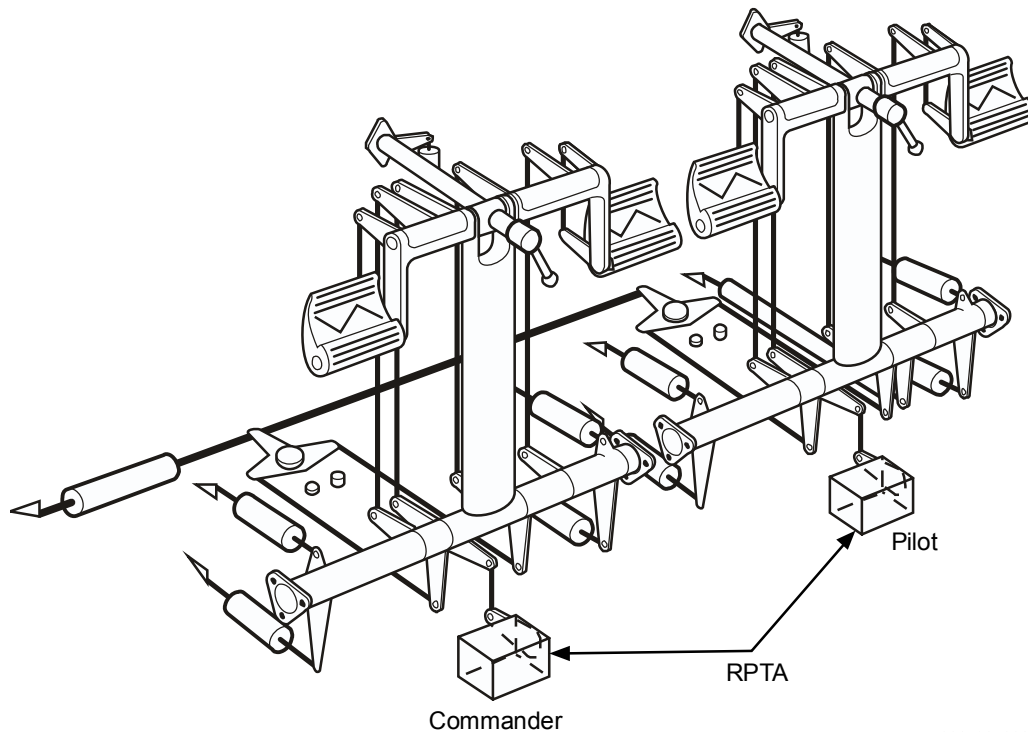
5.0 RUDDER PEDAL TRANSDUCER ASSEMBLY

5.1 RUDDER PEDAL TRANSDUCER ASSEMBLY USE

The RPTA consists of a black box with a set of triply redundant transducers and a mechanical input arm. They generate an electrical signal output for a set of conventional rudder pedals controlling the position of the rudder for manual yaw control. The commander and pilot's RPTAs are mechanically linked. The compensated signal with the largest magnitude is selected as the yaw command.

The rudder pedal position adjustment range is 3.25 inches maximum forward or aft from the neutral position in 0.81-inch increments (nine positions). The breakout force is 10 pounds. To depress a pedal to its maximum forward or aft position requires a pedal force of 70 pounds.

The RPTA is illustrated in Figure 5-1.



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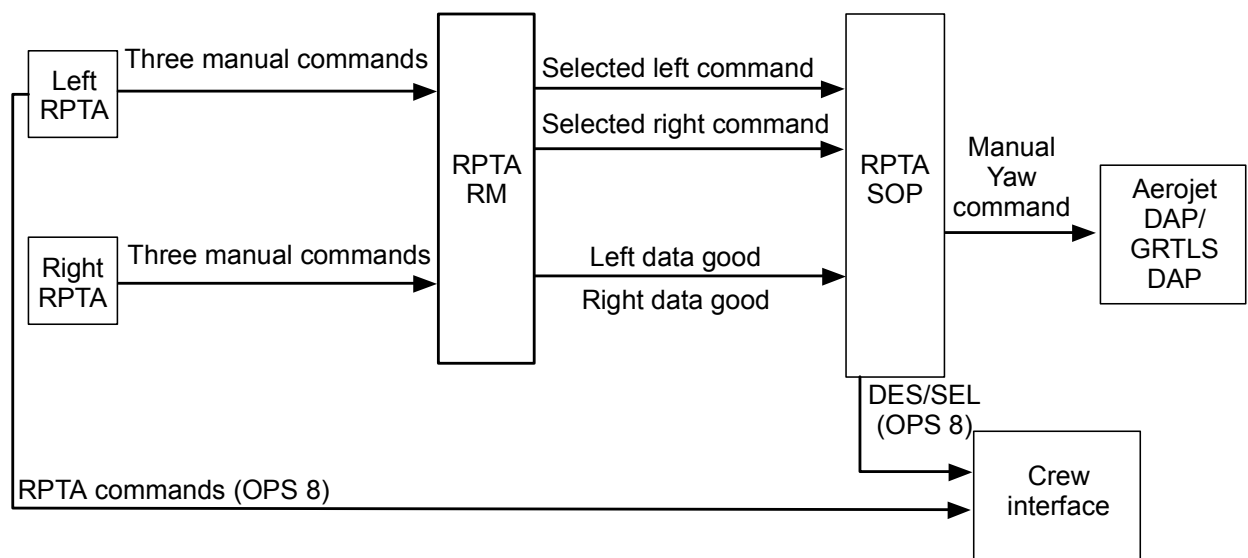
Figure 5-1. RPTA

5.2 RPTA SOFTWARE

Triply redundant signals from each RPTA undergo software processing before being incorporated into the FCS (Figure 5-2). The nominal flow from the RPTAs is through RM and the RPTA SOP. During OPS 8, the crew may view the redundant rudder pedal software commands and deselect any failed RPTA channel (Figure 5-3.)

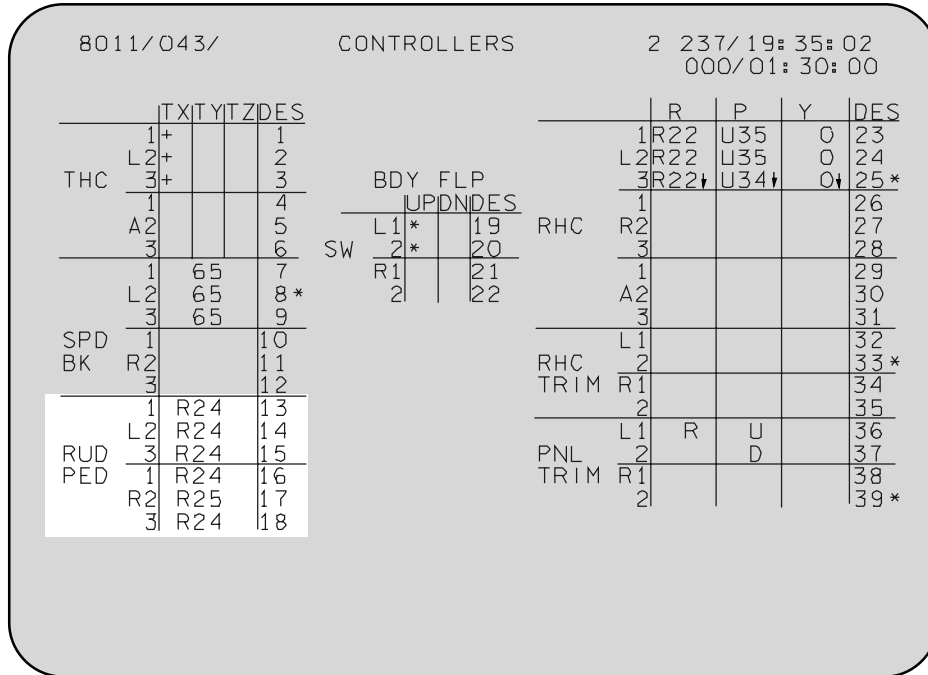
5.2.1 Nominal and Abort Timelines

Nominal and abort operations available for the RPTAs are MMs 304, 305, 602, and 603. The rudder pedals are active below M=5 if roll/yaw CSS is selected. Although RM runs in the above MMs, no fault message is annunciated for RPTA failures.



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Figure 5-2. RPTA software data flow



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Figure 5-3. CONTROLLERS display, OPS 8

5.3 RPTA SOP

The RPTA SOP converts selected transducer commands from volts to degrees. It performs station selection by selecting either the right or left RPTA signal, provided that the associated DG flag is true (data is good) and the command has the largest magnitude of the two. If both DG flags are not true (data is bad), the selected signal shall be set to zero.

The RPTA SOP also applies a breakout deadband of $\pm 1.125^\circ$ to the station-selected command.

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5.4 QUESTIONS

1. The RPTA generates an electrical signal output for which set of rudder pedals?
2. Which set of rudder pedals has priority and why?
3. The right or left RPTA signal is output to flight control, provided that what conditions exist?

6.0 SWITCHES

6.1 OVERVIEW

This section provides general information, rather than material for self-instruction. The name of each flight control switch is presented, along with its picture, panel location, purpose, and use. The crew checkout capabilities and the displays associated with each switch are also included.

6.2 BODY FLAP SWITCHES

The dually redundant Body Flap (BF) switches (Panels L2 and C3) are used for manual BF slew commands when the BF control mode is manual. (Figure 6-1) When the switch is in the UP position, the BF will rotate upward, and when the switch is in the down position, the BF will rotate downward.

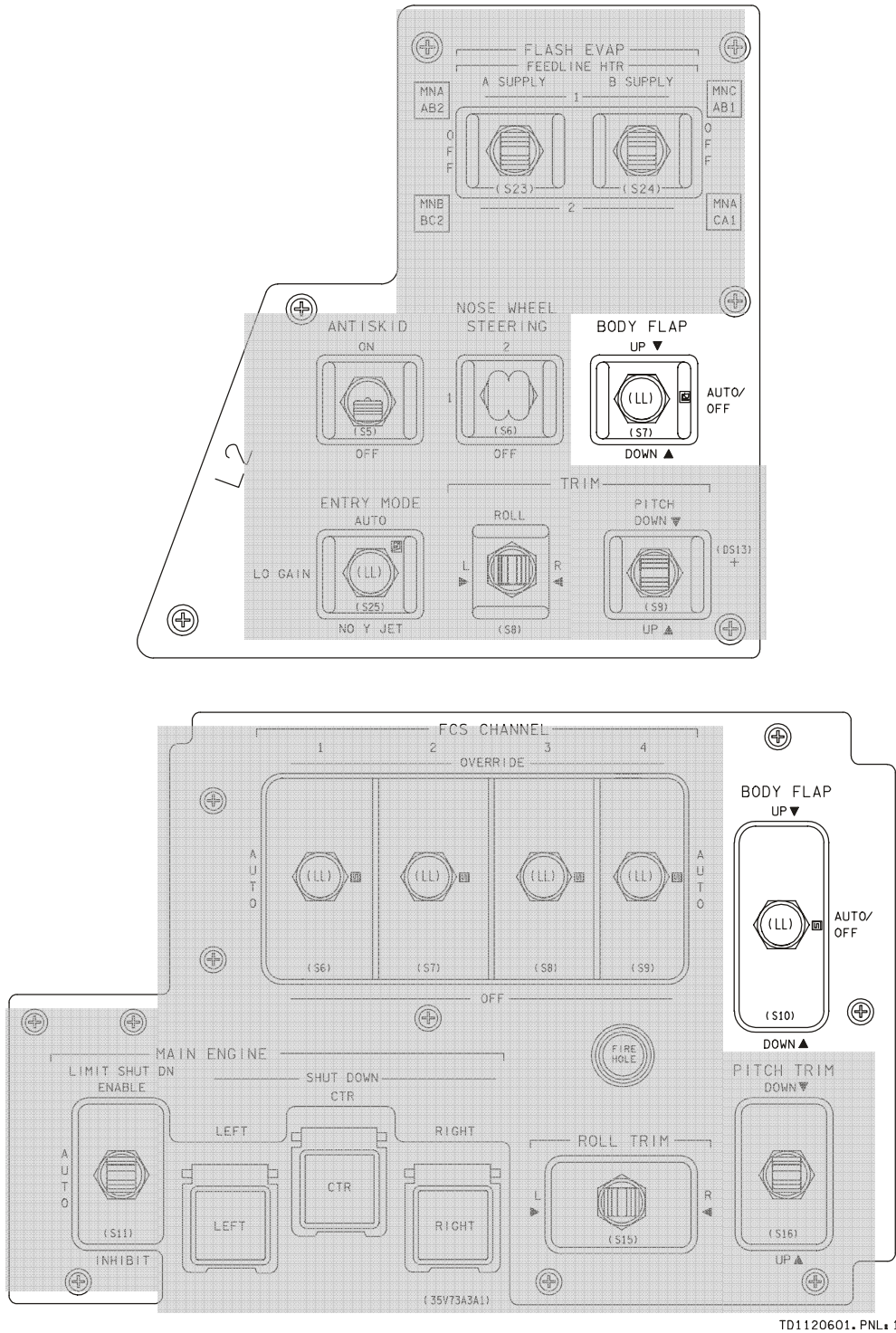
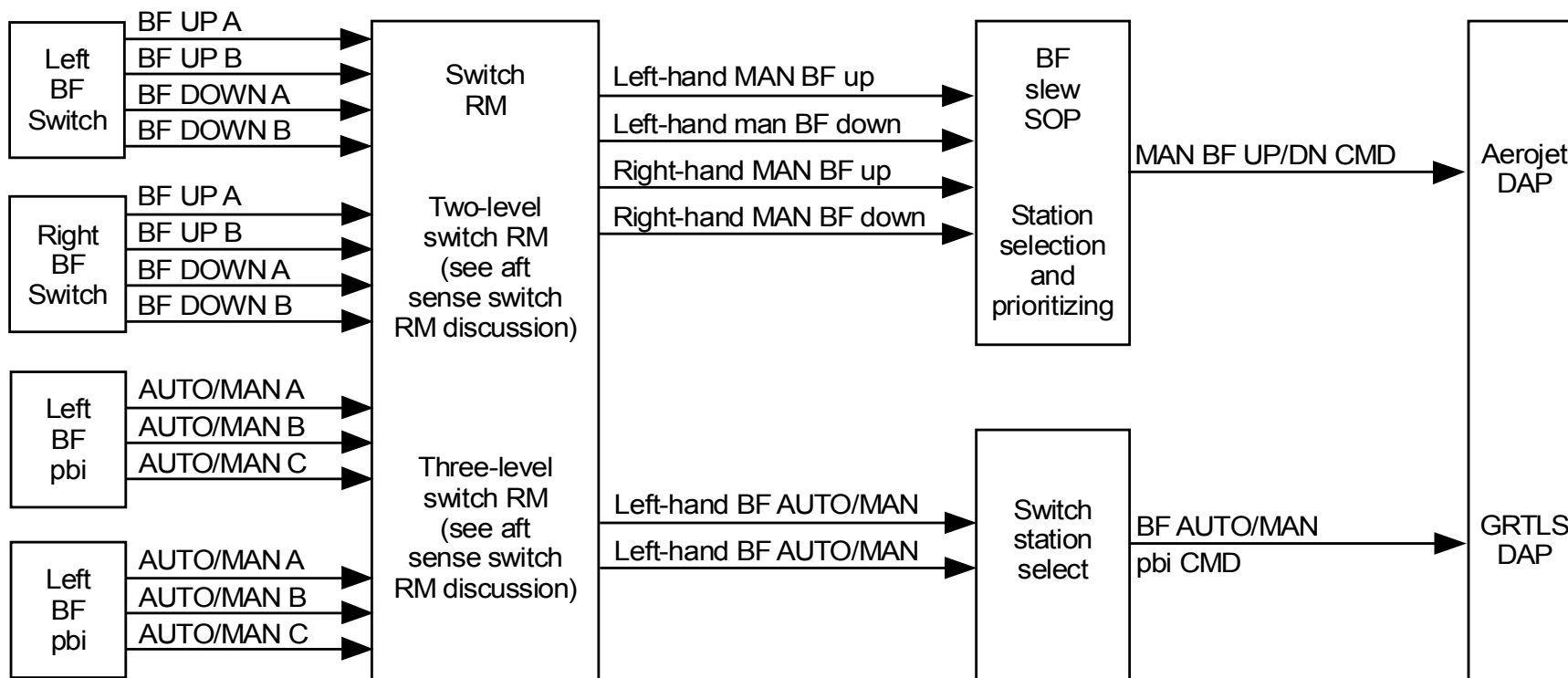


Figure 6-1. Body flap switches, Panels L2 and C3

6.2.1 Body Flap Control Logic

During manual BF Slew command processing (BF SLEW SOP), a manual BF UP command is generated for flight control if a left BF UP command or a right body flap UP command is present. A manual body flap DOWN command is generated for flight control if a left BF DOWN command or a right BF DOWN command is present. (Figure 6-2) When both crew stations generate conflicting commands, a BF UP command shall be output to flight control, as UP has priority.

The BF is typically under automatic control with both BODY FLAP PBIs indicating AUTO. To place the BF under manual control, either of the BODY FLAP PBIs can be depressed. The AUTO will extinguish and both Manual (MAN) lights will illuminate. To go back to automatic software control, either of the BODY FLAP PBIs can be depressed. The BF control mode will then change from manual to auto, the MAN lights will extinguish, and both AUTO PBIs will illuminate.



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Figure 6-2. Body flap control logic

6.2.2 Body Flap Switch Checkout - OPS 8

The contacts of the BF switches can be checked out by using the CONTROLLERS display in OPS 8 (Figure 6-3). An up or down BF switch position is shown as “*” for each contact of the left and right BF switches. The crew has deselect capability for a failed switch contact.

6.2.3 Body Flap Pushbutton Indicator

The BF PBI is triply redundant. When depressed, it changes the BF control mode from manual to automatic, or from automatic to manual. (Figure 6-4)

6.3 CSS INDICATORS

Pitch and roll/yaw FCS mode PBIs are triply redundant. During ascent, depressing any of the four CSS PBIs will mode flight control to augmented manual in all axes. All four CSS PBI lights will light and all four AUTO lights will extinguish. During entry, depressing a CSS PBI will mode flight control to augmented manual in the corresponding axis. Both CSS lights will light, and both AUTO lights will extinguish in the corresponding axis.

During ascent, depressing any of the four AUTO PBIs will mode flight control to automatic in all axes. All four AUTO PBIs will light and all four CSS lights will extinguish.

During entry, depressing an AUTO PBI will mode flight control to automatic in that axis. Both AUTO lights will light and both CSS lights for that axis will extinguish. FCS mode PBIs are shown in Figure 6-5.

During OPS 8, a light check can be performed with the FCS dedicated checkout display, FCS/Dedicated (DED) DIS Checkout (C/O), illustrated in Figure 6-5. These lights include the event sequence, FCS mode speedbrake, and body flap AUTO/MAN lights (13 lights for each side on F2 and F4). An item 7 EXEC turns the lights on simultaneously, and an item 8 EXEC turns the lights off.

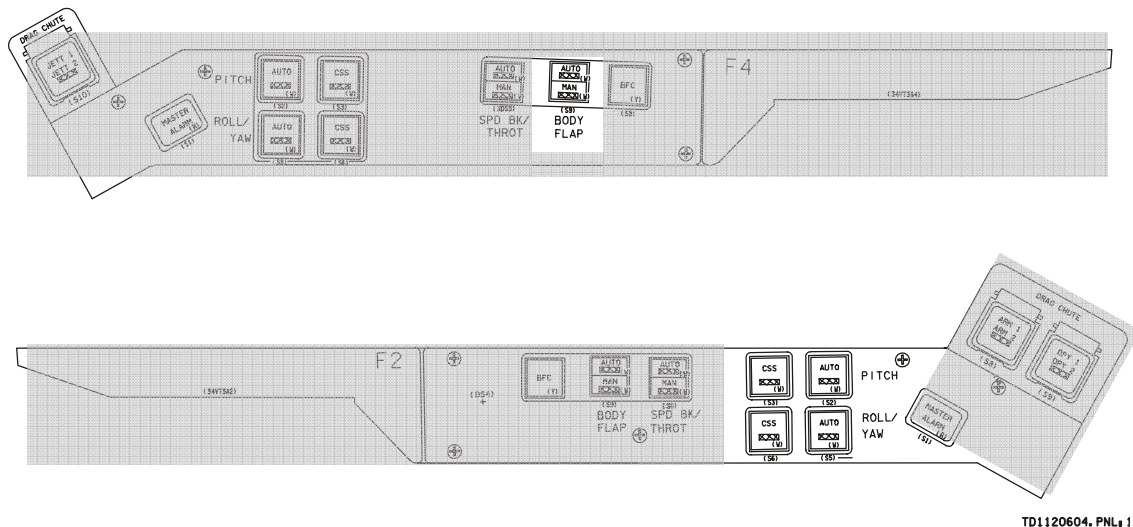
8011/043/		CONTROLLERS		2 237/19: 35: 02		000/01: 30: 00	
		T	X	Y	Z	D	E
		1				1	
		L2				2	
THC		3				3	
		1				4	
		A2				5	
		3				6	
		1	65			7	
		L2	65			8	
		3	65			9	
SPD		1				10	
BK	R2					11	
	3					12	
		1	D			13	
		L2	P24			14	
		3	0			15	
RUD		1				16	
PED	R2		L25			17	
	3					18	

BDY FLP		UPDNDES	
L1	*	L9	
R1	*	R21	
2	*	20	
2		22	

	R	P	Y	DES
	1 R22	U35	0	23
	L2 R21	U35	0	24
	3 R21	U35	0	25 *
RHC	1			26
	R2			27
	3			28
	1			29
	A2			30
	3			31
	L1			32
RHC	2			33 *
TRIM	R1			34
	2			35
	L1	R	U	L
PNL	2		D	
TRIM	R1			38
	2			39 *

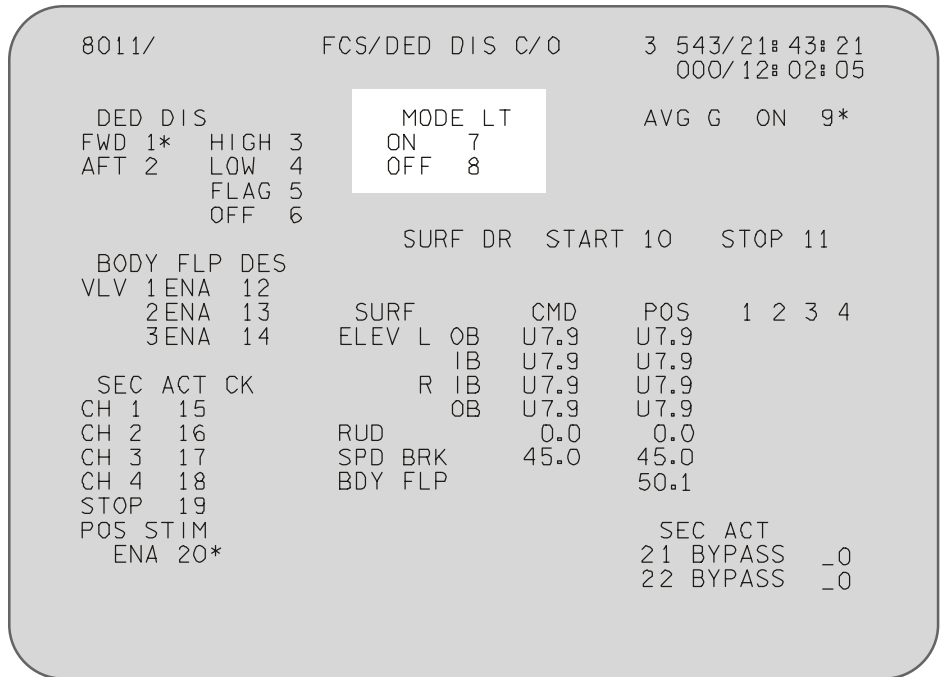
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Figure 6-3. BF switch checkout



TD1120604.PNL:1

Figure 6-4. Flight control system PBI



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Figure 6-5. FCS/DED display checkout, OPS 8

6.4 FCS MODE SWITCHES

During OPS 8 on SPEC 42, an "*" under AUTO or CSS for Pitch (P) and Roll/Yaw (R/Y), Auto (AUT) or Manual (MAN) for speedbrake, and AUTO for BF indicates the contact is in that position. An "M" denotes missing data (comm fault condition). Blank denotes okay. The item XX EXEC alternately deselected and reselects a contact for SF processing (deselect status carried over to OPS 3). Deselection causes an entire set of contacts for all FCS mode switches to be deselected. An asterisk (*) appears for the deselected state in the DES column. (Figure 6-6)

8011/042/		SWITCH/SURF				2 237/19: 35:02 000/01: 30:00							
FCS CH		OR	IDE	DES		OR	IDE	DES					
	1	1		1	3	1		7					
	2			2				8					
	3			3				9					
	2	1		4	4	1		10					
	2			5				11					
	3		6		2		12						
FCS MODE	L	P		R/Y		SPD BRK	BDY FLP	DES					
		AUT	CSS	AUT	CSS	AUT	MAN						
	R						*	16					
							*	17					
							*	18					
SURF		L	OB	L	IB	R	IB	R	OB	RUD	SPD BRK	BDY FLP	
	1	U	3.0	U	3.0	U	3.0	U	3.1	1.1	71	4	19
	2	U	3.1	U	3.0	U	3.0	U	3.1	1.0	71	4	20
	3	U	3.1	U	2.9	U	2.9	U	3.1	1.0	71	4	21
	4	U	3.0	U	3.0	U	3.0	U	3.1	1.1	71	4	22

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Figure 6-6. SWITCH/SURF display

6.5 ENTRY MODE SWITCH

The entry mode switch is quadruply redundant and found on Panel L2. (Figure 6-7) During entry (MMs 304, 305, 602, and 603), positioning the switch to LO GAIN will reduce the pitch, roll, and yaw command gain by half in the DAP. During entry, the NO YAW JET position of the entry mode switch deactivates the yaw jets and causes the ailerons and/or rudder (when enabled) to be used to control sideslip.

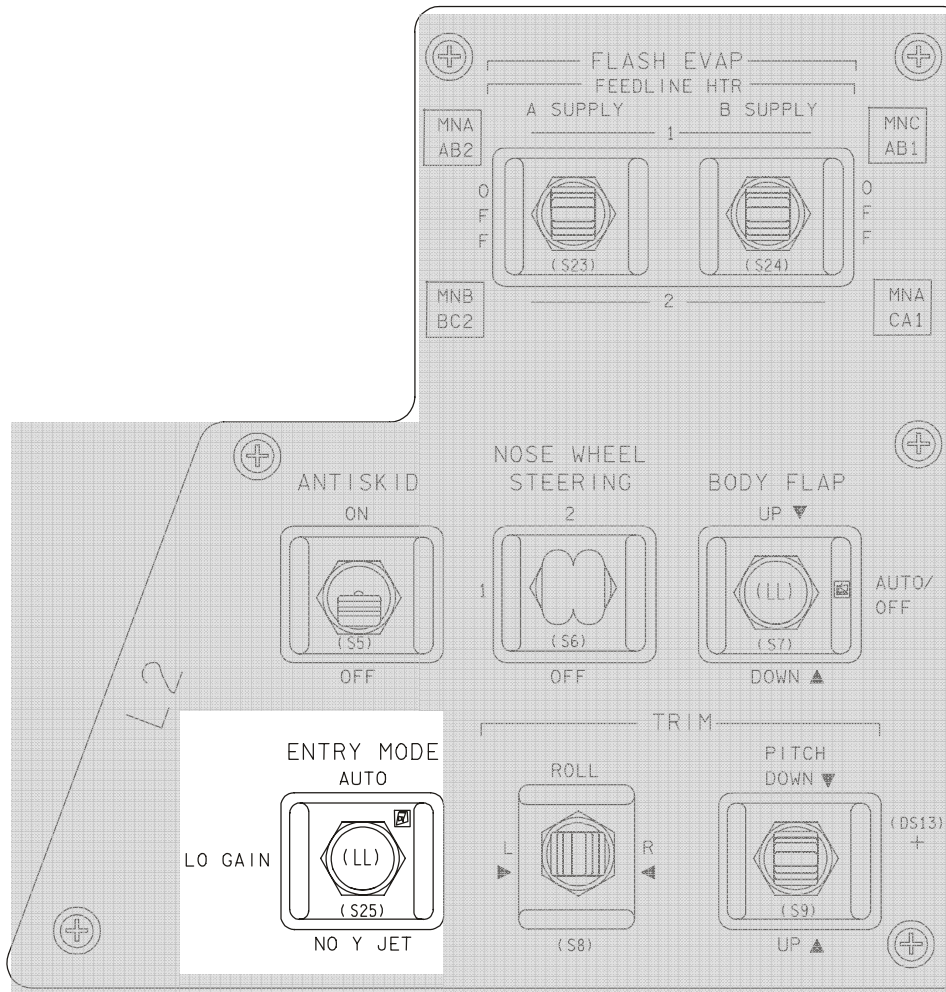


Figure 6-7. Entry mode switch, Panel L2

The contacts of the entry mode switch can be checked out by means of the SWITCHES display in OPS 8. For each switch contact, an asterisk will be displayed on the SWITCHES display (Figure 6-8) to indicate that the contact closed position has been sensed (contact 2 of low gain). An "M" will be displayed if the signal data are missing for any of the contacts (contact 3 of Low Gain and NO Y/J). Item entries 1 through 4 allow crew deselection or reselection of a particular set of switch contacts as candidates for switch RM. An asterisk will be displayed next to the item number to indicate deselection, and will be blank when the contacts are selected for use by RM.

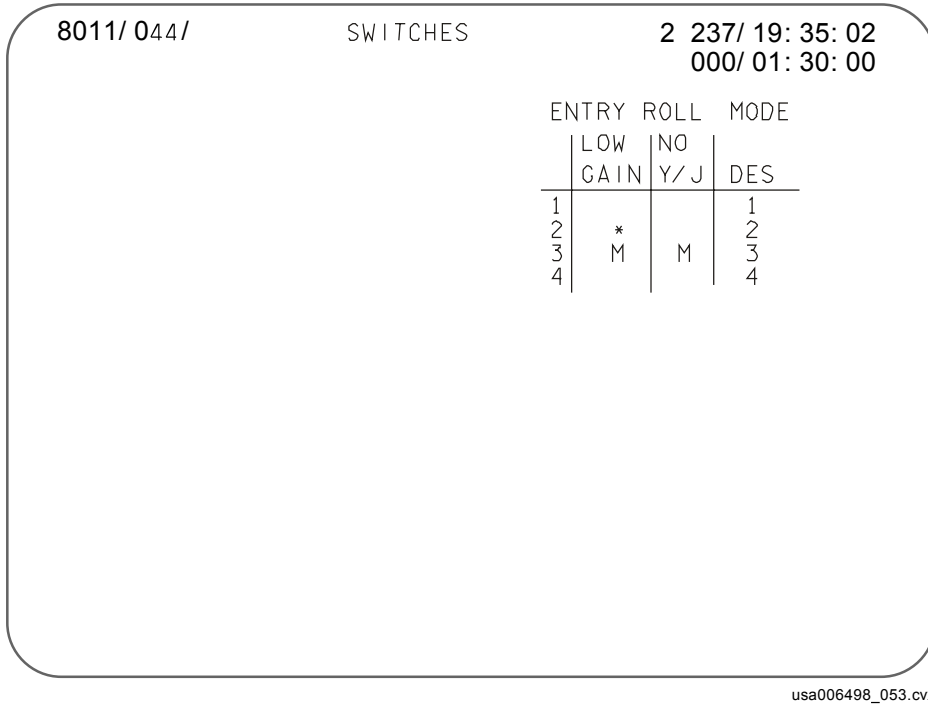


Figure 6-8. SWITCHES display, OPS 8

6.6 COMMANDER AND PILOT BACKUP FLIGHT CONTROL ENGAGE PBIs

The BFS is engaged by depressing the red BFS button located on either the commander’s or pilot’s RHC.

A Backup Flight Control (BFC) light indicates that the BFS has been engaged. (Figure 6-9)

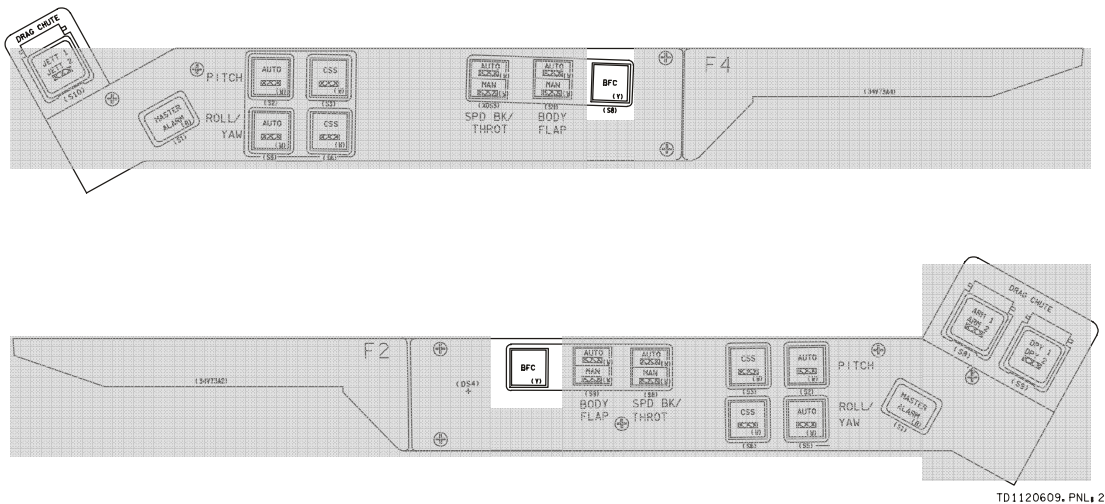


Figure 6-9. BFS engage switch

6.7 ABORT MODE SWITCH

The abort mode switch (Figure 6-10) is triply redundant. It initiates an RTLS, an Abort-To-Orbit (ATO), or a Transoceanic Abort Landing (TAL) abort mode when placed in the desired position with the ABORT PBI depressed.

The ABORT PBI light is driven by ground command over the GPC 5 backup computer-payload MDMs 1 and 2. The light is used as an annunciator for the crew and depends on the time and type of failure. (Illumination of the light is *not* an indication that the selected abort mode has been implemented, but it is for crew awareness.)

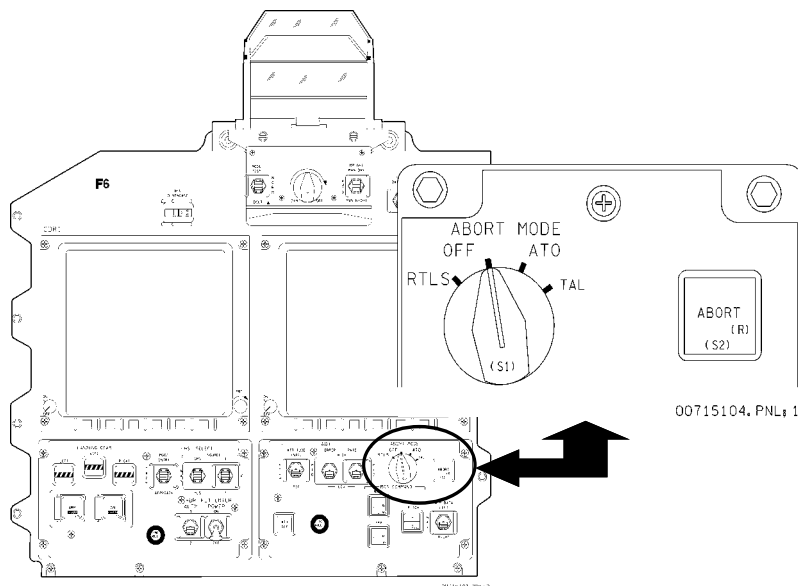


Figure 6-10. Abort mode switch, Panel F6

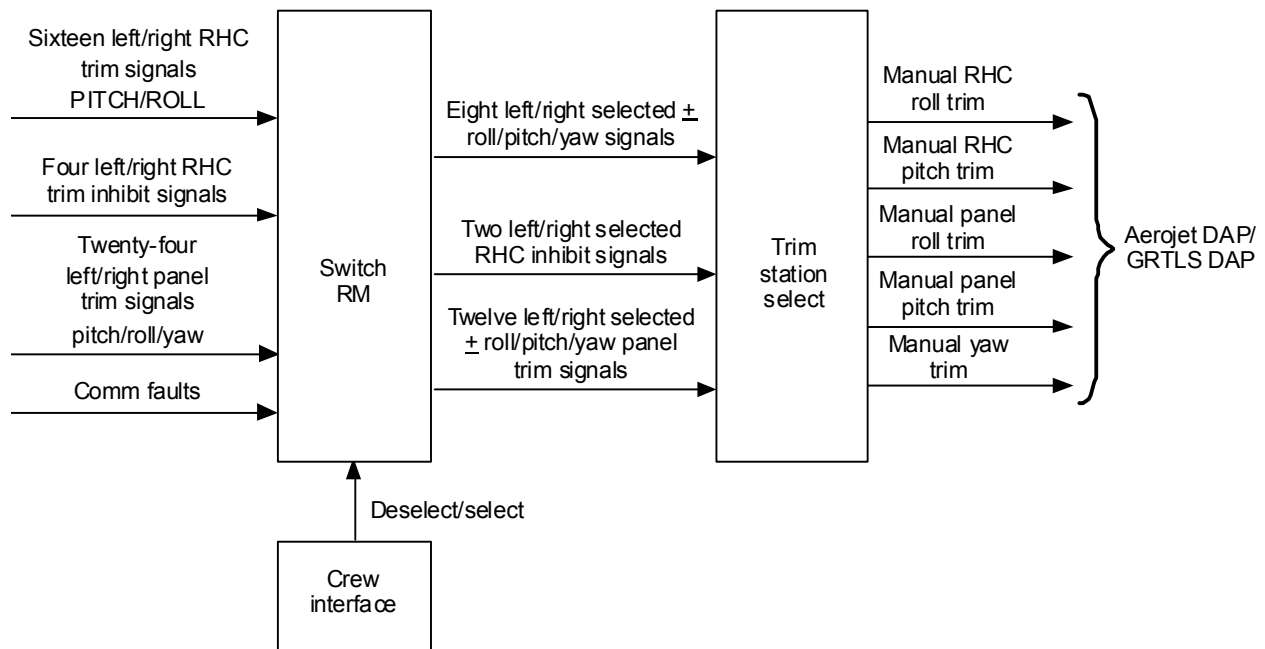
6.8 TRIM SWITCHES

6.8.1 Trim Switch Station Select

Panel trim switch software data flow is illustrated in Figure 6-11 and commands pitch, roll, and yaw aerosurface deflection rates. Trim switch software is available in MMs 304, 305, 602, and 603.

When the trim inhibit signal is absent for a crew station, the selected trim signals from that station are enabled. A resultant positive pitch, roll, or yaw trim signal is generated if a selected left positive trim signal or a selected right positive trim signal is present. A resultant negative pitch, roll, or yaw trim signal is generated if a selected left negative trim signal or a selected right negative trim signal is present.

When both crew stations generate conflicting trim commands in an axis (e.g., if the commander generates a positive pitch trim and the pilot generates a negative pitch trim simultaneously), the resultant trim command in that axis is zero.



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Figure 6-11. Trim switch software data flow

RHC trim switches command vehicle pitch and roll rate with the corresponding FCS mode in CSS (pitch or roll). A resultant positive pitch or roll trim signal is generated if an enabled left positive trim signal or an enabled right positive trim signal is present. A resultant negative pitch or roll trim signal is generated if an enabled left negative trim signal or an enabled right negative trim signal is present. RHC trims are generated by moving one of the dually redundant RHC trim switches. Constant vehicle rates can be commanded about the body pitch and roll axes. Each RHC has a trim switch, but only the commanders and pilots have vehicle trim capability.

6.8.2 RHC/PNL Trim Enable/Inhibit Switch

Trim enable switches for both the commander and pilot are illustrated in Figure 6-12. The dually redundant RHC/panel trim enable/inhibit switches on Panel F3 provide signals to the GPCs, disallowing software execution of the associated RHC and panel trim input when in the inhibit position. The enable position is not wired to the GPCs, so trimming is allowed to take place with the corresponding FCS mode in CSS (pitch or roll). The dually redundant trim panel ON/OFF switches on Panel F3 provides power to the associated roll, pitch, and yaw panel trim switches when in the ON position. The dually redundant roll, pitch, and yaw panel trim switches on Panels C3 and L2 command an aerosurface deflection.

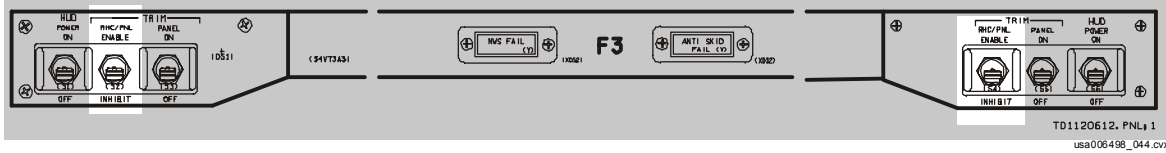


Figure 6-12. RHC trim enable switches

After Weight On Wheels (WOW) is set, PASS software ignores the position of the RHC/PNL switch and honors negative pitch commands from the left or right RHC beep trim. This allows the RHC/PNL switch to remain in the INHIBIT position throughout entry, while preserving the use of beep trim derotation.

During OPS 8, RHC and panel trim status can be checked on the CONTROLLERS display (Figure 6-13). Crew controls consist of item XX EXEC, which alternately deselects and reselects a candidate for RM processing. An asterisk (*) appears for the deselected state in the DES column. Data status indicators are “M” for missing data, and blank for no sensed command. RHC trim status indicators use only R and P columns (R-right roll trim, L-left roll trim, U-up pitch trim, and D-down pitch trim). Panel trim status indicators use R, P, and Y columns (R-right roll/yaw trim, L-left roll/yaw trim, U-up pitch trim, and D-down pitch trim).

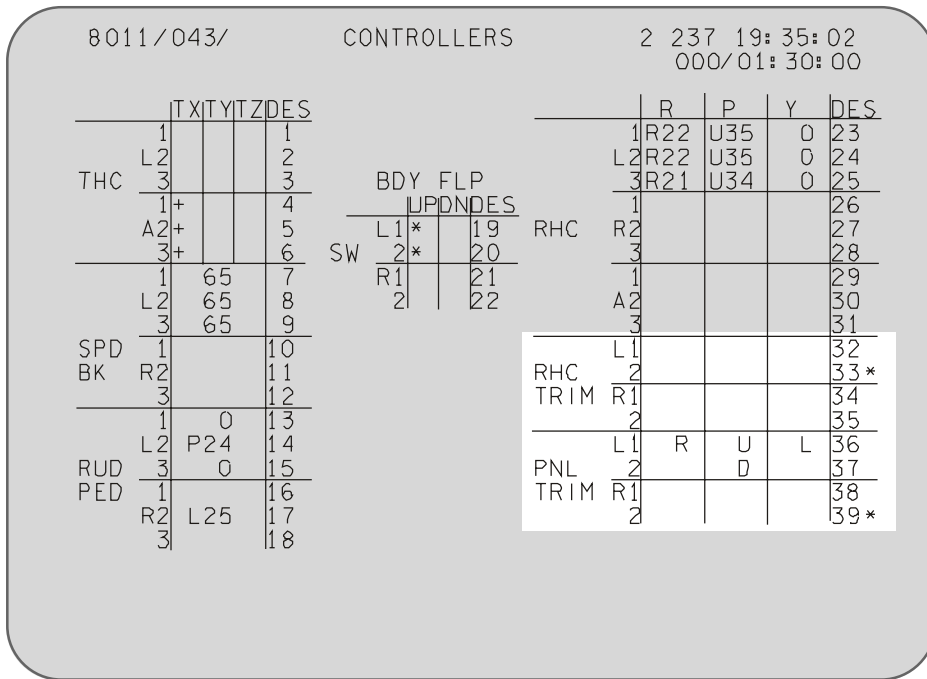


Figure 6-13. CONTROLLERS display, OPS 8

6.9 CHANNEL SWITCHES

The triply redundant FCS channel switches are located on Panel C3 (Figure 6-14). The OVERRIDE position is hardwired to the GPCs and provides the capability to reset a

channel that has been bypassed by the fault detection logic. OVERRIDE and AUTO allow power to flow to the Aerosurface Amplifier (ASA) and Ascent Thrust Vector Control (ATVC) switches. Moving the switch to OFF removes power from the ASA and ATVC switches, thus powering down the respective ASA and ATVC.

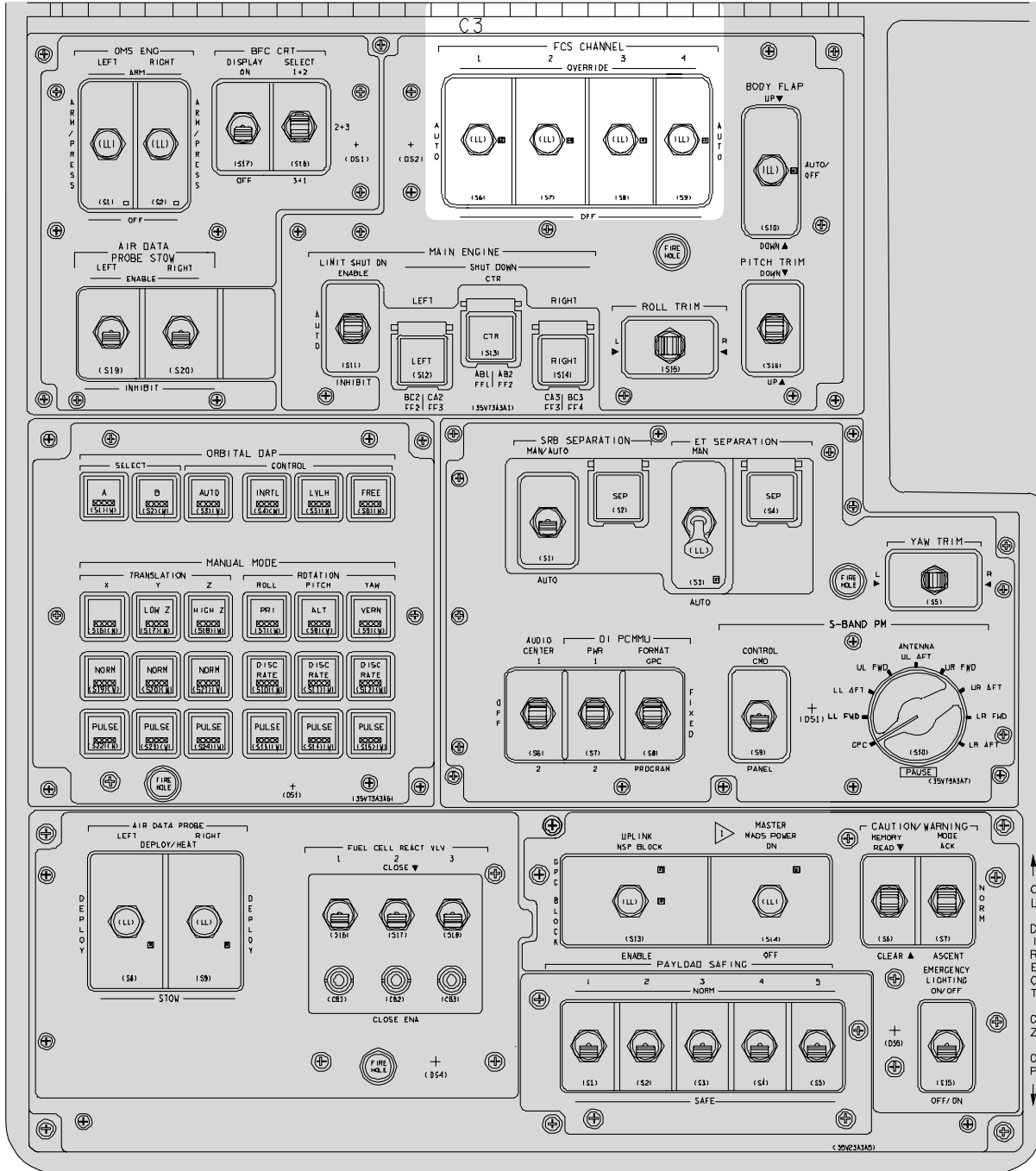


Figure 6-14. FCS channel switches, Panel C3

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6.10 SENSE SWITCH

The aft sense switch, located on Panel A6U, is triply redundant. (Figure 6-15) As mentioned previously, the sense switch is used to mode the aft RHC, THC, and the Attitude Display Indicator (ADI) to correspond to the operator's viewing direction.

6.10.1 Aft Sense Switch Default Position

The default position for the aft sense switch is the -Z position of the switch. If *both* positions (-X and -Z) are indicated, the -Z default position will be output by RM and a class 3 annunciation (SM alert light on F7, tone, and a default message) will occur. If *neither* position (-X or -Z) is indicated, the -Z default position will be output by RM, and a class 3 annunciation will occur.

The orbit three-axis RHC SOP transforms the aft RHC outputs based on the sense switch position prior to any station selection.

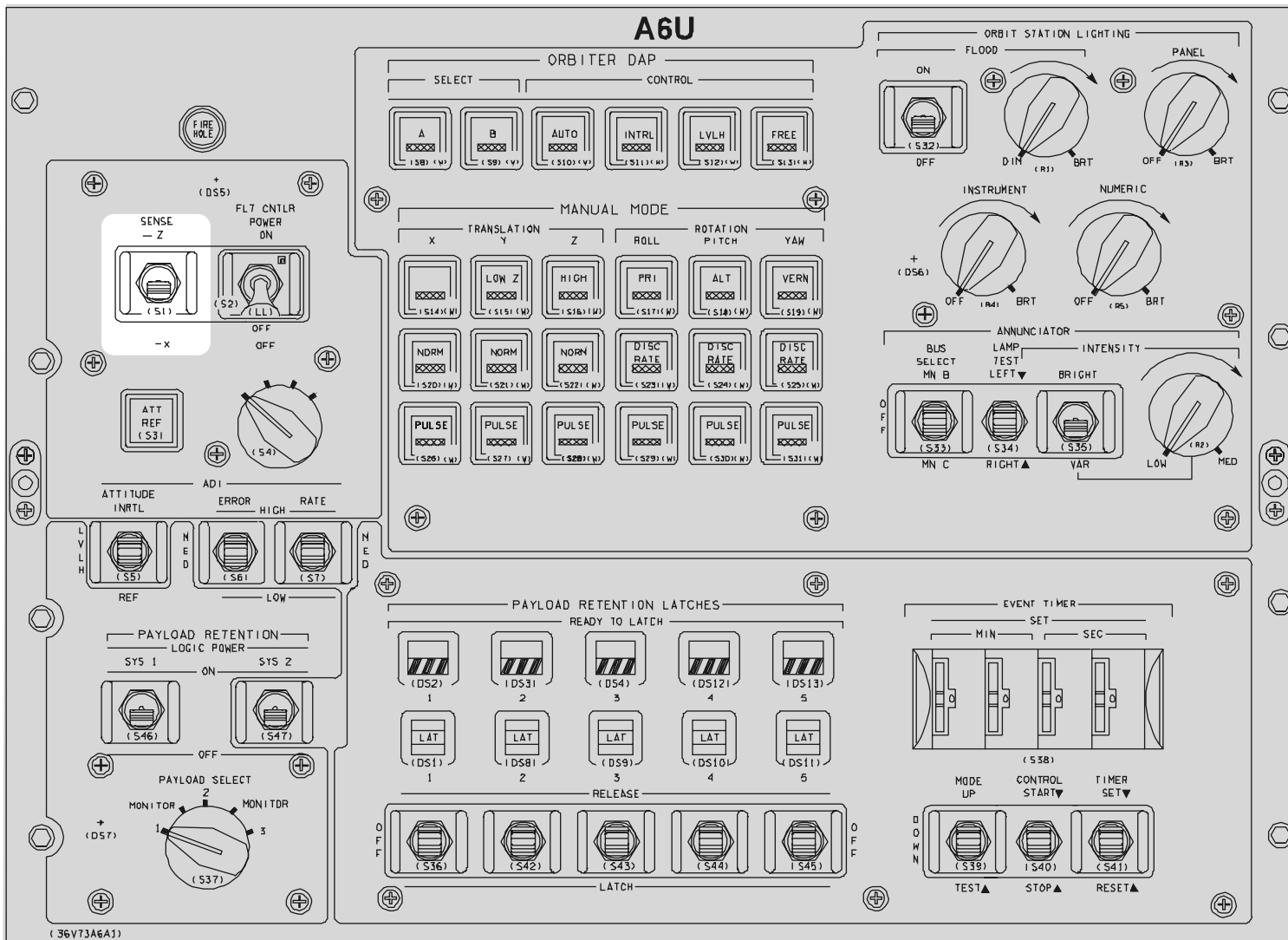
6.11 ORBITAL DAP/TRANSLATION/ROTATION SWITCHES

6.11.1 Orbital DAP/Translation/Rotation Switch Processing

The orbital DAP PBIs are processed in the following way. Station selection is made when there is presence of a forward station or its corresponding aft station PBI discrete, causing that PBI indication to be input to flight control.

The PBI is illuminated when the mode is implemented in the FCS.

Orbital DAP control and select PBIs are triply redundant. The orbital DAP select PBIs are used on orbit in the following manner. Depressing SELECT A implements DAP load A settings for the on-orbit DAP gains. SELECT A lights (forward and aft) are illuminated, and SELECT B lights are extinguished. Depressing SELECT B implements DAP load B settings for the on-orbit DAP gains. SELECT B lights (forward and aft) are illuminated, and SELECT A lights are extinguished. DAP A and B PBIs are, therefore, mutually exclusive. The DAP A and B configurations are defined on the OPS 2 and OPS 8 DAP configuration spec function.



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Figure 6-15. Aft sense switch, Panel A6

Orbital DAP control PBIs, used for transition and on orbit, function as follows.

Depressing CONTROL AUTO modes the DAP (transition and on orbit) to an automatic mode. AUTO lights (forward and aft) are illuminated, and other CONTROL lights are extinguished. Depressing CONTROL INRTL modes the DAP (transition and on orbit) to a manual inertial mode, with automatic inertial attitude hold when no RHC input is made and DISC RATE rotation PBIs are illuminated. AUTO, INRTL, LVLH, and FREE PBIs are all mutually exclusive. This mode is also initiated by deflecting the RHC out of detent while operating in the automatic mode. The manual PBIs will illuminate and the auto PBIs will extinguish. The CONTROL LVLH PBI invokes the same control mode, except that a Local Vertical/Local Horizontal (LVLH) attitude hold will be in effect.

In OPS 2 and OPS 8 only, the CONTROL FREE PBI modes the DAP to free drift; that is, no attitude hold or automatic maneuvers are supported.

Depressing PRI enables the primary RCS jets for rotational control using a table-lookup scheme and firings and disables the vernier jets. NORM lights are illuminated (forward and aft), and VERN lights are extinguished.

Depressing VERN enables the vernier RCS jets for rotational control and disables the primary jets. VERN lights are illuminated (forward and aft), and NORM lights are extinguished. PRI, ALT, and VERN PBIs are all mutually exclusive.

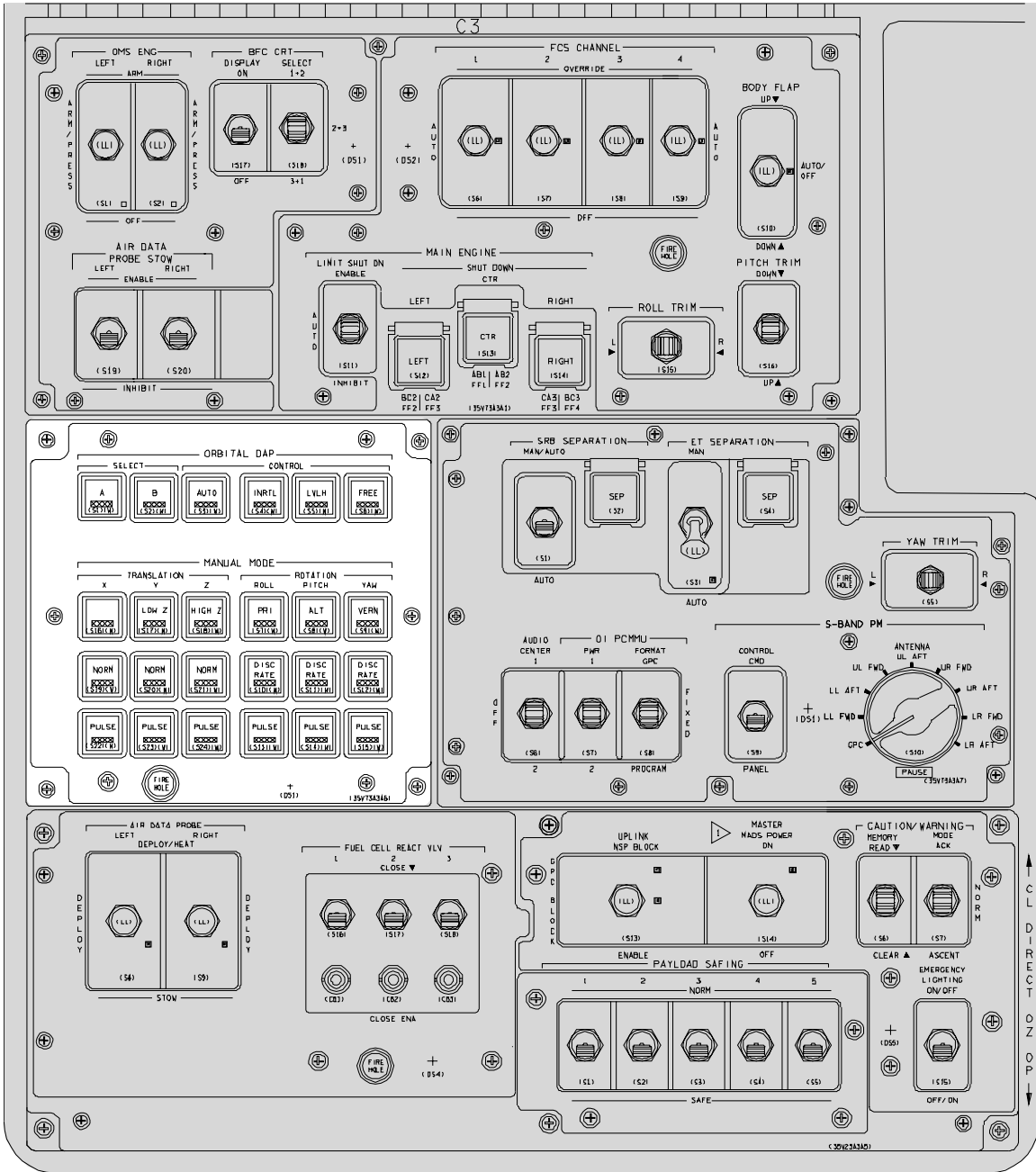
RCS JETS ALT enables the use of primary jets, but in an alternate selection scheme that is more propellant efficient and imparts smaller structural loads on the vehicle.

To ensure PBI prioritizing, simultaneous, conflicting commands will be treated as follows: DAP load A has priority over DAP load B; INRTL has priority over AUTO, which has priority over FREE, which has priority over LVLH; and primary RCS has priority over vernier RCS, which has priority over alternate.

6.12 MANUAL MODE PBIs

The manual mode PBIs are illustrated in Figure 6-16. Manual mode (translation/rotation) PBIs are dually redundant. Manual mode rotation PBIs are used on orbit and during trans-DAP operation.

The RCS rotation mode is selected on an axis-by-axis basis. Mixing of modes is allowed. Depressing Discrete (DISC) rate for an axis causes the appropriate primary or vernier thrusters to fire to attain a predetermined rotational rate in that axis, while the RHC is out of detent. When the RHC is returned to detent, the rate is nulled and a new attitude hold is established.



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Figure 6-16. Orbital DAP and manual mode PBIs

The DISC RATE PBIs are illuminated (forward and aft) and the PULSE PBIs are extinguished for the applicable axis.

Depressing PULSE for an axis causes the appropriate primary or vernier thrusters to fire for preset increments (degrees per second) in response to each deflection of the RHC in that axis. No further firing occurs until the RHC is returned to detent and deflected again, allowing attitude to drift freely. The PULSE PBIs are illuminated (forward and aft) and the DISC RATE PBIs are extinguished for the applicable axis.

Whether in DISC RATE or PULSE, when the RHC is deflected beyond the soft stop, the ACCEL mode is invoked in that axis, in which jets fire continuously until the RHC is returned to inside the softstop.

Manual mode translation PBIs are also used on orbit. Mixed modes are permitted on an axis-by-axis basis.

Depressing HIGH Z for the Z-axis causes all primary +Z thrusters (up firing jets) to be fired as long as the THC is held out of detent in that axis. The HIGH Z PBIs are illuminated (forward and aft) and the LOW Z, Z NORM, and Z PULSE PBIs are extinguished. Depressing LOW Z causes $\pm X$ jets to be fired, giving a small upward component for + Z translation only for as long as the THC is held out of detent, and preventing any up-firing jets from being commanded for rotational control. The LOW Z PBIs are illuminated (forward and aft) and the Z HIGH PBI is extinguished, making them mutually exclusive. The LOW Z can be toggled to allow selection of LOW Z/NORM or LOW Z/PULSE modes.

Depressing NORM for an axis causes the appropriate primary thrusters in that axis to be fired for as long as the THC is held out of detent. The NORM PBIs (forward and aft) are illuminated and the PULSE and Z HIGH PBIs are extinguished for the applicable axis.

Depressing PULSE for an axis causes the appropriate primary thrusters in that axis to be fired for a preset increment (feet per second) in response to each deflection of the THC. No further firing occurs until the THC is returned to detent and deflected again. The PULSE PBIs (forward and aft) are illuminated and the NORM or Z HIGH PBIs are extinguished for the applicable axis.

To ensure PBI prioritizing, simultaneous, conflicting commands will be treated as follows: for the X, Y axes, NORM has priority over PULSE. For the Z-axis, HIGH has priority over LOW, and NORM has priority over PULSE, which has priority over HIGH. For rotation, DISC RATE has priority over PULSE.

The DAP is initialized in OPS 2, with DAP load A for SELECT, AUTO control, PRI jets, DISC RATE rotational submode, and PULSE translation submode.

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6.13 QUESTIONS

1. When there are conflicting body flap slew commands, which command has priority?
2. To change the body flap mode from automatic to manual, or from manual to automatic, which body flap AUTO/MAN PBI must be depressed?
3. During entry, how can a crewmember deactivate yaw jets and cause the ailerons and/or rudder to be used to control sideslip?
4. What must be done in order for the abort mode switch to initiate an RTLS, AOA, or ATO after being placed in the desired position?
5. In a given axis, which crew position, commander or pilot, has trim priority?
6. For the trim switches to be used by the software, the associated trim enable/inhibit switches must be in which position?
7. Which position of the FCS channel switches is hardwired to the GPCs?
8. If both *or* neither position (-X or -Z) is indicated for the aft sense switch, what is the assumed switch position?
9. What is the function of the DAP LVLH PBI?
10. Is a manual mode rotation roll DISC, pitch DISC, yaw PULSE PBI configuration allowed?

7.0 BACKUP FLIGHT SYSTEM CONTROLLERS

This section discusses the controller differences when in the BFS.

7.1 RHC (COMMANDER AND PILOT)

There is no manual control during powered flight ascent. Detent processing (hot stick) is only for trans-DAP (no on-orbit DAP and no AUTO during entry-only CSS). RM processing includes only midvalue-select SF. There is no Fault Detection, Identification, and Reconfiguration (FDIR) or downmoding for comm faults. There is no DG test.

7.2 FORWARD THC AND SWITCH PROCESSING

The forward THC operates with three contacts for each direction ($\pm x$, $\pm y$, $\pm z$). The output from the THC is a discrete signal. Therefore, it is processed like a switch in selection filter. Selection filtering for the forward THC and switches will be performed as follows. For the forward THC and three contact switches, output is the majority vote. For two contact switches, output is the logical AND of both inputs. For one contact switches, output is the same as the input. There is no FDIR, comm fault recognition, or crew deselection capability in the BFS software, therefore, selection filter can not downmode. Commander and pilot requests will be based on the last selected.

7.3 RPTA (COMMANDER)

The BFS processes left crew station RPTA signals only; however, because the rudder pedals on both sides are mechanically linked, either the commander's or pilot's rudder pedals will be processed. RM processing includes only a midvalue select SF. There is no FDIR or downmoding for comm faults during BFS or any DG test.

7.4 SBTC

Manual throttling during ascent is not possible if the BFS is engaged. The speedbrake is also controlled automatically during entry to an altitude of 2000 ft. Below 2000 ft., the speedbrake must be moved manually. RM processing includes only a midvalue select SF. There is no FDIR or downmoding for comm faults or any DG test.

8.0 REDUNDANCY MANAGEMENT

8.1 OVERVIEW

Controller RM receives triply redundant signals from each controller and provides the controller software operating program with the RM-selected signal. As an example, RM receives the following individual controller signals:

- Left, right, and aft RHC pitch command channels 1, 2, and 3
- Left, right, and aft RHC roll command channels 1, 2, and 3
- Left, right, and aft RHC yaw command channels 1, 2, and 3
- Left and right SBTC speedbrake or thrust control command channels 1, 2, and 3
- Left and right RPTA rudder movement command channels 1, 2, and 3

Each channel 1 command, whether RHC pitch, roll, and yaw channel 1 or SBTC and RPTA control command, comes from a channel 1 transducer within the specific controller. SF and FDIR processes are done on these transducers. The FDIR detects data which is out of tolerance, identifies the faulty unit, and may make the data from the faulty unit unavailable to the SF. For the RHCs, processes are done on the three transducers for each RHC axis (as an example, the pitch channel 1, roll channel 1, and yaw channel 1 transducers of the left RHC). The SBTC and RPTA do not have multiple axes; therefore, the channel 1 transducer has only one channel 1 command for RM to use.

Controllers are downmoded on a transducer or channel basis or like numbered channels in the multiple RHC axis case. Dilemmas are not resolved because there is no Built-In Test Equipment (BITE). There is a DG flag.

8.1.1 Three Good Signals (Nominal Case)

The middle-value signal is selected by the SF for output to the SOP. For the three-level RM, the DG indicator is always set good. The FDIR subtracts pairs of signals and compares the results to an I-load limit. A signal is declared failed by the FDIR if it differs from the other two signals by more than the I-load limit and the failure counter has reached its limit of three.

8.1.2 First Failure (Two Good Signals)

When a signal is declared failed by the FDIR, it is deselected from the SF and the FDIR. Fault annunciation occurs for failed RHC and SBTC signals. (For an RHC, a failure in one axis causes the comparable channel signals in the other axis of that RHC to be deselected from the SF and FDIR). RM is downmoded to level 2 and the two signals are averaged and output to the SOP. The DG test is implemented by subtracting the two signals and comparing the results with an I-load limit. The DG flag is set "good" if the DG limit is not exceeded. The FDIR continues to subtract the two signals and compare the results to an I-load limit.

8.1.3 Second Failure (One Good Signal)

A second failure caused by a bad signal will not cause RM to downmode, but will result in the SF averaging the remaining good signal with the bad signal for output to the SOP. However, if the DG limit is exceeded, a dilemma will result and the DG flag will be set bad. These DG limits are presently 4.51° in pitch and roll and 2.7° in yaw for the RHCs. All signals from that controller will be set to zero by the SOP. Fault annunciation occurs for RHC and SBTC dilemma conditions, but not for RPTA. The FDIR must count three consecutive miscomparisons before the crew annunciation is implemented. Therefore, the DG flag will go bad before annunciation occurs, since one miscompare triggers the DG bad indication. The DG flag is not latched, so it is possible for it to reset to "good."

8.1.4 Third Failure (No Good Signals)

The SF DG flag is set bad and there is no FDIR processing. SOP sends zeros to the FCS.

8.1.5 First Failure (Comm Fault)

Communication faults also cause failures. The FDIR and SF are downmoded in this case by the FCOS. The indication of a comm fault on a display is an "M" (missing data). A comm fault occurs when input data from GNC hardware going to each of the GPCs are found by the FCOS to contain errors, not to have arrived in the prescribed amount of time, or not to have arrived at all. A comm fault flag is set to advise GNC software that a fault has occurred and that the expected data are missing.

The first failure by a comm fault causes an "M" to appear on the GNC SYS SUMM 1 display for the channel on which there are no data. Crew annunciation (in the form of "M" for comm fault or missing data, "↓" for an upper or lower limit being met or exceeded or a system failure, and "?" for a dilemma) is the same for all programs. Caution and Warning (C&W) annunciations are covered in the Caution and Warning 21002 manual.

Channel commands declared missing by FCOS, SF, and FDIR are downmoded to level 2. SF outputs the average of the two remaining signals. A DG test is implemented for each channel as in the second failure case. If a result exceeds the limit three consecutive times, FDIR declares a dilemma. If the comm fault no longer exists, FDIR and SF upmode to level 3 and FDIR resumes fail count. The failure counter is not affected by comm faults.

8.1.6 Second Failure (Comm Fault)

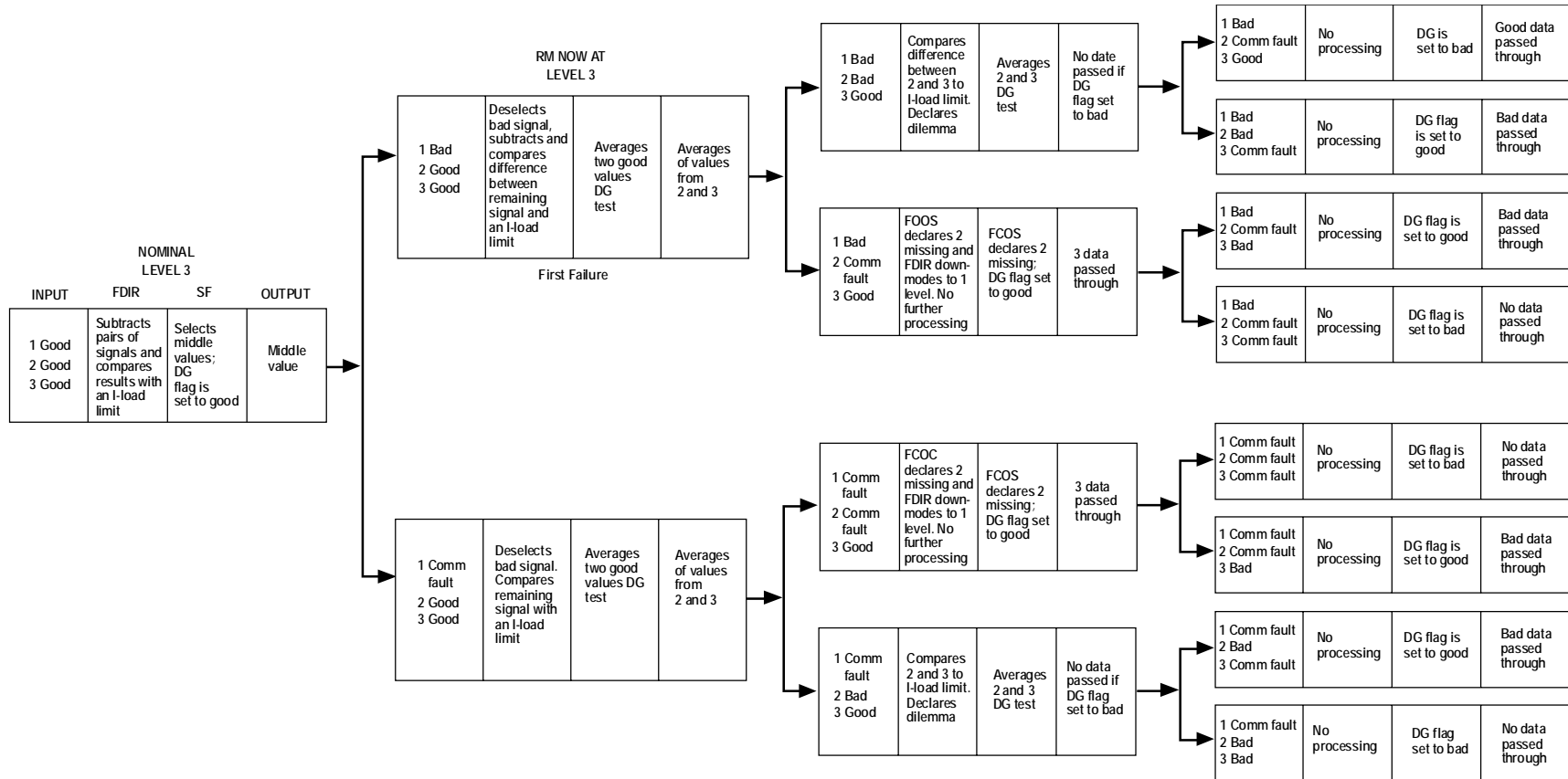
A second failure caused by a comm fault will result in the downmoding of the SF and the FDIR to level 1. The remaining signal (good or bad) is passed through RM with no processing. The DG flag is set good for the level 1 RM. If the comm fault clears, RM will upmode to level 2.

8.1.7 Third Failure (Comm Fault)

A third failure by a comm fault downmodes the SF and FDIR to level 0. The DG flag is set bad. The SOP sends zeros to the FCS for the controller output. If the comm fault clears, RM upmodes to level 1.

A third failure caused by the remaining signals failing when the second failure was a comm fault will not affect RM. The bad signal is passed through RM with no processing. The DG flag is set good, but bad data will be passed to flight control.

Figure 8-1 is a diagram showing RM downmoding.



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Figure 8-1. RM downmoding

8.2 RHC RM

RHC RM is performed on both the left and right RHCs during OPS1, OPS 2, OPS 3, and OPS 6. The aft RHC is added to RM processing during OPS 2. All signals from the RHCs are triply redundant.

During MM 102 - MM106 and MM 601, all three axis are processed through RM which consists of selection filter only. There is no RHC FDIR. FDIR is performed by the flight controllers in the Mission Control Center at these times. The same is true during MM 602 and MM 603, but only the pitch and roll axes are processed. Selection filtering is downmoded only by comm faults. A failure resulting from disagreeing data will go undetected by RM.

During MM 201 and MM 202, the three axis RM processing includes FDIR and selection filter for all three RHCs. Once the transition to OPS 3 occurs, the aft RHC is no longer processed. Three axis RM processing continues from MM 301 - MM 303. During MM 304 - MM 305, two axis RM processing is performed for the roll and pitch signals from the left and right RHCs.

8.3 SBTC RM

SBTC RM is performed simultaneously but separately on both left and right SBTCs. In MM 304, 305, 602, and 603, RM is performed for speedbrake control; in MM 102, 103, and 601, RM is performed for throttle control. RM for SBTC commands is the same as for RHC commands. SBTC FDIR is available in OPS 3 only, and the SF is downmoded only by comm faults in OPS 1 or OPS 6. The SBTC signals are triply redundant.

The SBTC takeover switch is triply redundant and is used to gain or transfer manual speedbrake control, or to gain manual throttling control for the right SBTC only. Since the SBTC takeover switch is a three-contact, two-position switch, it has the same RM cases as the aft sense switch. There is no RM annunciation for the takeover switch.

The speedbrake/throttle (SPD BK/THROT) PBI is triply redundant and, when depressed, provides an indication to place the speedbrake or throttling function under software control. An illuminated AUTO light indicates that speedbrake control or engine throttling is under software control. An illuminated MAN light (left or right, but not both) indicates that speedbrake or engine throttling is under manual control of the corresponding crewmember. Like the SBTC takeover switch, the SPD BK/THROT PBI has the same RM cases as the aft sense switch.

8.4 RPTA RM

RPTA RM is performed simultaneously but separately on both the left and the right side RPTAs. RM for RPTA commands is also the same as for RHC commands. Downmoding of SF is by comm faults in OPS 6. There is no FDIR during OPS 6. There is no FDIR annunciation for RPTA failures. The RPTA signals are triply redundant.

8.5 THC RM

THC RM is performed on the six positions of the forward and aft THCs during OPS 2 and OPS 8 and on the forward THC during OPS 1 and OPS 3. Each position (+X, -X, +Y, -Y, +Z, -Z) has three contacts and is analogous to a three-contact switch. THC RM is performed on the switch contacts, which is a discrete RM scheme. THC failures are annunciated for the crew.

8.6 GNC SWITCH RM

Switch RM monitors switch contacts and determine the outputs for certain switch positions. These are discrete RM systems.

The SF for discrete data differs from the RHC, RPTA, and SBTC analog data selection system. The method of selection is different. There is no DG flag since there are no tracking tests, and downmoding is on a switch-position (not the entire switch) basis.

However, certain features of the discrete data selection are similar to the concepts discussed for the controllers' data selection. These features include downmoding for comm fault, failure, or crew deselection; upmoding for software reinitialization of comm fault flags or selection from acceptable candidates.

When considering an individual switch, a selection is made from candidate contacts for each position of the switch. To be a candidate, a switch contact must

- Not have a comm fault flag set
- Not be declared failed by FDIR
- Not be deselected manually by the crew

The discrete output for a closed switch is 1, and for an open switch is 0. In this discussion, consider a 1 and 0 for contacts closed and open.

8.6.1 Three Contacts Available

The SF output is the majority vote of the three contacts; that is, two of the three contacts must be closed (made) for the switch to be in the monitored position. A 1 is output; otherwise, 0 is output. The FDIR compares all three contacts and declares a contact failed if it differs from the other two contacts for three consecutive FDIR cycles. A failed contact is deselected from the SF and the FDIR, and thus downmodes RM to the two-contact level. There is no annunciation of the failure to the crew. Downmoding is on a switch-position contact basis.

8.6.2 Two Contacts Available

Both contacts must be closed (made) for the SF output to indicate that the switch is in the monitored position. The selected value is the logical AND of the two contacts. In order for a 1 to be output, both contacts must be 1. The FDIR compares the two contacts and declares a dilemma if they miscompare (one closed and one open) for three consecutive FDIR cycles. Generally, there is no annunciation to the crew of this situation. FDIR cannot resolve the dilemma.

8.6.3 One Contact Available

The SF output is the same as the single contact input for the monitored position. The value of the only contact 1 or 0 is output. There is no FDIR processing at the 1 contact level.

Comm faults downmode the SF and FDIR for as long as the comm fault is present. If the comm fault goes away, the SF and FDIR upmode to the next higher level.

The matrix in Figure 8-2 shows the channelization summary for the control switches.

Control/ Channel 1234	Switch/PBI name	Panel NO/LOCH	Electrical control bus	FF MDM 1234
XXX	Abort mode switch	F6	AB 1, BC1, CA1	XXX
XX	Body flap switch	L2	AB1, BC1	XX
XX	Body flap switch	C3	BC2, CA2	XX
XXX	Body flap mode switch	F2	AB1, BC1, CA1	XXX
XXX	Body flap mode switch	F4	BC2, CA2, BC3	XXX
XXXX	Entry mode switch	L2	AB1, BC1, CA1, BC2	XXXX
XXX	FCS channel 1	C3	BC1, AB1, CA1	XXX
XXX	FCS channel 2	C3	BC2M, CA3M, BC3	XXX
XXX	FCS channel 3	C3	CA1, AB2, BC1	XX X
XXX	FCS channel 4	C3	AB3, CA2, AB2	X XX
XXX	FCS mode, pitch	F2	AB1, BC1, CA1	XXX
XXX	FCS mode, roll/yaw	F2	AB1, BC1, CA1	XXX
XXX	FCS mode, pitch	F4	BC2, CA2, BC3	XXX
XXX	FCS mode, roll/yaw	F4	BC2, CA2, BC3	XXX
XX	Manual mode trans X, Y, Z	C3	AB3, BC3	XX
XX	Manual mode rot X, Y, Z	C3	AB3, BC3	XX
XX	Manual mode trans X, Y, Z	A6	CA2, BC2	XX
XXX	Orbit DAP select	C3	AB3, BC3, CA3	XXX
XXX	Orbit DAP control	C3	AB3, BC3, CA3	XXX
XXX	Orbit DAP RCS jets	C3	AB3, BC3	XX
XXX	Orbit DAP select	A6	CA2, BC2, AB2	X XX
XXX	Orbit DAP control	A6	CA2, BC2, AB2	X XX
XXX	Orbit DAP RCS jets	A6	CA2, BC2	XX
XX	Panel trim	F3	AB1, BC1	XX
XX	Panel trim	F3	CA2, BC2	XX
XX	Pitch trim	L2	AB1, BC1	XX
XX	Pitch trim	C3	CA2, BC2	XX
XX	RHC trim enable	F3	AB1, BC1	XX
XX	RHC trim enable	F3	CA2, BC2	XX
XX	RHC trim, left	LT trim BT	MN A&B, A&B	XX
XX	RHC trim, right	RT trim BT	MN B&C, B&C	XX
XX	Roll trim	L2	AB1, BC1	XX
XX	Roll trim	C3	CA2, BC2	XX
XXX	SBTC mode SW	F2	AB1, BC1, CA1	XXX
XXX	SBTC mode SW	F4	BC2, CA2, BC3	XXX
XXX	SBTC left takeover SW	L/SBTC	MN A&B, A&B, A&B	XXX
XXX	SBTC right takeover SW	R/SBTC	MN B&C, B&C, B&C	XXX
XXX	Sense switch	A6	AB2, BC2, CA2	XXX
XX	Yaw trim	L2	AB1, BC1	XX
XX	Yaw trim	C3	CA2, BC2	XX

Figure 8-2. Channelization summary for the control switches

8.7 QUESTIONS

1. For the nominal case, RM selects which signals from the triply redundant RHC signals to output to the RHC SOP?
2. For an RHC signal to be declared failed by RM, it must differ from which other two signals by more than a predefined tolerance for three consecutive counts?
3. At the 2-level, the values of the remaining two RHC signals are_____.
4. If the DG limit is exceeded by a single channel in an RHC axis, outputs from all axes on that channel of the RHC are sent to the FCS as _____.
5. What action is recommended if a dilemma condition exists for an RHC in dynamic flight (for example, entry)?
6. Triply redundant signals from the RHCs first undergo redundancy management software processing, which is made up of which two processors?
7. The THC has six positions, and each position can be compared to a three-contact switch. Therefore, THC RM is identical to that of which switch?

APPENDIX A ACRONYMS AND ABBREVIATIONS

ADI	Altitude Display Indicator
A/E PFD	Ascent/Entry Primary Flight Display
AOA	Abort Once Around
ASA	Aerosurface Amplifier
ATO	Abort-To-Orbit
ATVC	Ascent Thrust Vector Control
AUT	Auto
BF	Body Flap
BFC	Backup Flight Control
BFS	Backup Flight System
BITE	Built-In Test Equipment
C&W	Caution and Warning
C/O	Checkout
CMD	Command
CSS	Control Stick Steering
DAP	Digital Autopilot
DDU	Device Driver Unit
DED	Dedicated
DES	Deselect
DG	Data Good
DISC	Discrete
FCOS	Flight Control Operating System
FCS	Flight Control System
FDIR	Fault Detection, Identification, and Reconfiguration
FF	Flight Forward
FSSR	Functional Subsystem Software Requirements
GNC	Guidance, Navigation, and Control
GPC	General Purpose Computer
JSC	Johnson Space Center
LVLH	Local Vertical/Local Horizontal
MAN	Manual
MDM	Multiplexer/Demultiplexer
MM	Major Mode
MOD	Mission Operations Directorate

NASA	National Aeronautics and Space Administration
OMS	Orbital Maneuvering System
OPS	Operational Sequence
P	Pitch
PASS	Primary Avionics Software System
PBI	Pushbutton Indicator
PNL	Panel
R/Y	Roll/Yaw
RCS	Reaction Control System
RHC	Rotational Hand Controller
RM	Redundancy Management
RPTA	Rudder Pedal Transducer Assembly
RTLS	Return-To-Launch Site (abort)
SBTC	Speedbrake and Thrust Controller
SF	Selection Filter
SM	Systems Management
SOP	Subsystem Operating Program
SSME	Space Shuttle Main Engine
SW	Switch
TAL	Transoceanic Abort Landing
THC	Translational Hand Controller

APPENDIX B ANSWERS

SECTION 1.0

1. The speedbrake/thrust controller is the controller that is used to manually control main engine thrust during ascent.
2. The Translational Hand Controller controls the orbiter translation along the vertical, lateral, and longitudinal axes.
3. A loss of main bus A would have no effect on the pilot's DDU, because it is powered by main buses B and C.
4. The loss of MDM FF 2 would cause the loss of all channel 1 signals to the pilot's controllers.

SECTION 2.0

1. The RHC hardstop is the maximum deflection possible in an RHC axis.
2. The purpose of the aft sense switch with regard to the RHC is to establish a control reference based on the crewmembers' line of sight.
3. During an RTLS abort, three-axis RHC capability is possible only for MM 601.
4. To achieve CSS during ascent, either the pitch or roll/yaw CSS PBI must be depressed. Hot sitck down mode is not available during ascent.

SECTION 3.0

1. The aft sense switch is important for aft THC use because it must be in the proper position for the aft THC commands to be correctly transformed to give the desired orbiter movement.
2. If the commander and aft crew generate conflicting THC commands, the resultant translation output command will be zero.
3. A crewmember can confirm a THC failure after failure annunciation by the down arrow that can be seen on the RM ORBIT, GNC SYS SUMM 1, and CONTROLLERS displays.

SECTION 4.0

1. Manual control of the main engine throttling is gained by using the Pilot's SBTC takeover switch and matching auto throttling within 4 percent.
2. Manual control of the speedbrake is gained by momentarily depressing the SBTC takeover switch.
3. During entry, an SBTC lever placed at the forward stop commands the speedbrake to closed.
4. The crew can deselect a bad SBTC channel by using the CONTROLLERS display during OPS 8.

SECTION 5.0

1. The RPTA generates an electrical signal output for each set of rudder pedals.
2. The set of rudder pedals that has priority is the compensated signal with the largest magnitude, because the commander and pilot's RPTAs are mechanically linked together.
3. The right or left RPTA signal is output to flight control, provided that the data good flag is true and its magnitude is the larger of the two, the flight controller power is on, roll/yaw is in CSS, and Mach < 5.

SECTION 6.0

1. When there are conflicting body flap slew commands, the UP command has priority.
2. To change the body flap mode from automatic to manual or from manual to automatic, either body flap AUTO/MAN PBIs must be depressed.
3. During entry, a crewmember can deactivate yaw jets and cause the ailerons and/or rudder to be used to control sideslip by using the NO YAW JET position of the Entry Mode switch.
4. In order for the abort mode switch to initiate an RTLS, AOA, or ATO after being placed in the desired position, the abort PBI must be depressed.
5. In a given axis, neither the commander nor the pilot has trim priority, because conflicting trim commands in an axis result in zero trim commands.
6. For the trim switches to be used by the software, the associated trim enable/inhibit switches must be in the enable position.
7. Only the OVERRIDE position of the FCS channel switches is hardwired to the GPCs.

8. If both *or* neither position (-X or -Z) is indicated for the aft sense switch, -Z is the assumed default position.
9. The function of the DAP LVLH PBI is to mode the on-orbit DAP to manual LVLH mode. With rotation in DISC rate for all three axes and RHC in detent, LVLH hold will be maintained.
10. A manual mode rotation roll DISC, pitch DISC, yaw PULSE PBI configuration is allowed; mixed modes are permitted on an axis-by-axis basis.

SECTION 8.0

1. For the nominal case, RM selects the middle-value signals from the triply redundant RHC signals to output to the RHC SOP.
2. For an RHC signal to be declared failed by RM, it must differ from the other two signals in the same axis by more than a predefined tolerance for three consecutive counts.
3. At level-2, the values of the remaining two RHC signals are averaged.
4. If the DG limit is exceeded in an RHC axis, outputs from all axes of the RHC are sent to the FCS as zeros.
5. The crewmembers should turn the flight controller power switch OFF for the specific controller if a dilemma condition exists for an RHC in dynamic flight (for example, entry).
6. Triply redundant signals from the RHCs first undergo redundancy management software processing, which is made up of an SF and an FDIR processor.
7. The THC has six positions, and each position can be compared to a three-contact switch. Therefore, THC RM is identical to any three contact switch.

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- b. *The lesson objectives are clearly defined.*
- c. *The lesson effectively teaches skills and information.*
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Strongly
Agree

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2. How satisfying is the content of this lesson?

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Strongly
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Strongly
Agree

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Strongly
Disagree

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