

Space Program Operations Contract

Main Propulsion System Thrust Vector Control Workbook

MPS TVC 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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**Main Propulsion System
Thrust Vector Control Workbook**

MPS TVC 21002

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PREFACE

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1.0 INTRODUCTION

1.1 OBJECTIVES

Upon completion of this section, the student should be able to

- Recognize the command flow path of the Main Propulsion System (MPS) Ascent Thrust Vector Control (ATVC) subsystem
- Recognize the components that make up the MPS ATVC and their location
- Recognize and locate the crew inputs (in general terms) to the MPS ATVC
- Recognize the displays associated with the MPS ATVC

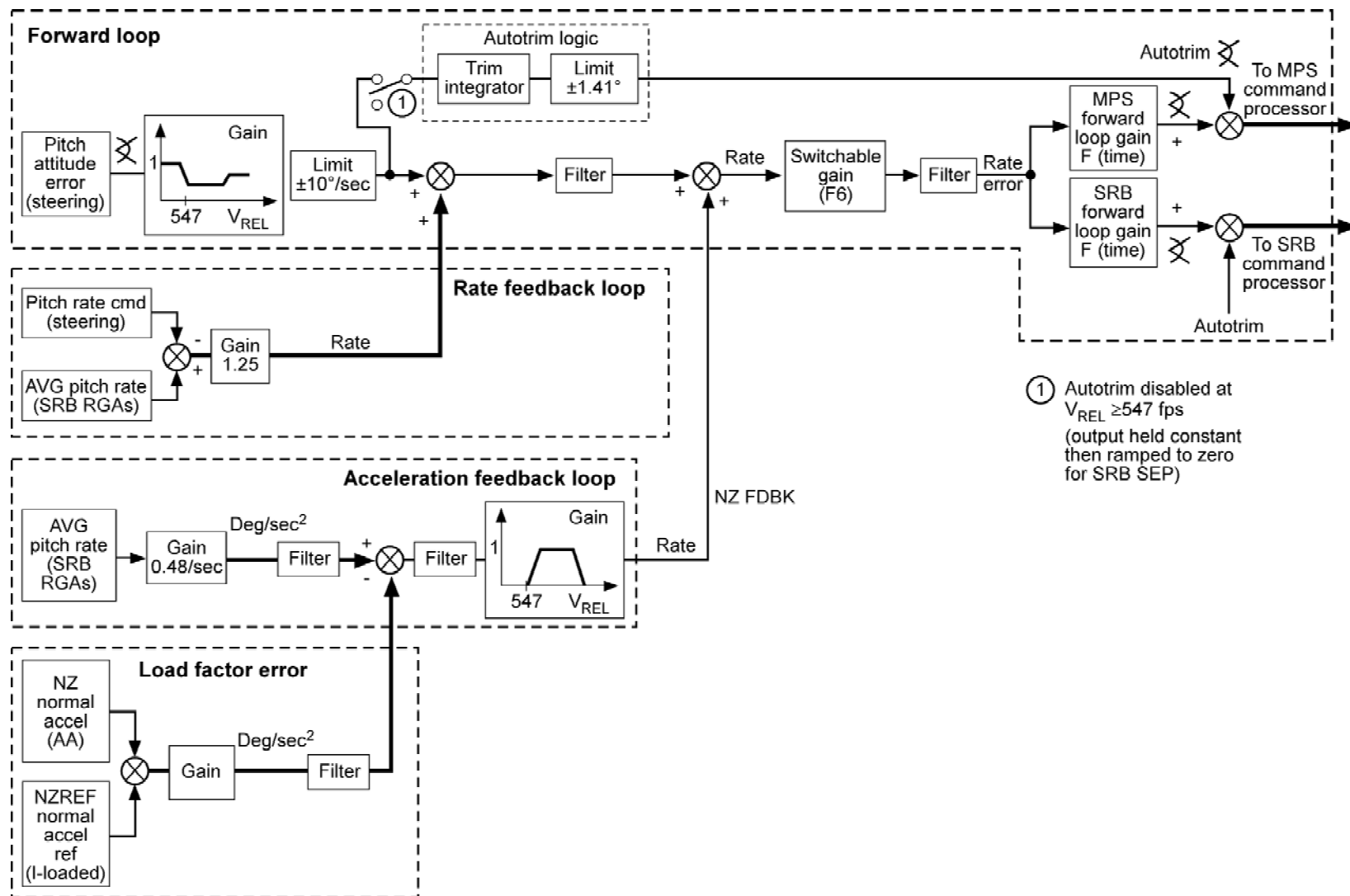
1.2 PURPOSE

The ATVC is the subsystem that provides control of the MPS and the Solid Rocket Booster (SRB) thrust vector during ascent.

The purpose of the ATVC is to respond to Digital Autopilot (DAP) commands to control and direct the thrust vector of the vehicle for attitude control and trajectory shaping. Unlike the aerosurface actuators, the positions of the MPS and SRB bells are not of primary concern in the flight control loop. The pointing of the vehicle thrust vector and the resultant rates and attitude of the vehicle are used to control the vehicle during ascent. Figure 1-1 shows the pitch control loop for first stage. This figure shows how the DAP transforms vehicle-sensed rates (and when applicable, accelerations) into ATVC commands. The commands to the ATVCs are a byproduct of the vehicle attitude, rates, and accelerations when applicable. The GNC ASC 21002, Guidance, Navigation, and Control Ascent Workbook, explains this in detail.

1.3 ATVC MAJOR SUBSYSTEMS

The major subsystems composing the ATVC subsystem are the MPS ATVC Command Subsystem Operating Program (CMD SOP), the SRB ATVC CMD SOP, the ATVC electrical black box, and the MPS and SRB hydraulic servoactuators.



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Figure 1-1. Pitch control loop for first stage

The MPS ATVC CMD SOP, which resides in the General Purpose Computers (GPCs), issues serial digital words to Flight-critical Aft Multiplexer/Demultiplexers (FA MDMs), which convert each received serial digital word to a respective voltage. This voltage is transformed by the ATVC black box into a command, which displaces hydraulic fluid in the MPS hydraulic servoactuators, causing the Space Shuttle Main Engines (SSMEs) to deflect. There are two hydraulic actuators per SSME: one for pitch motion and one for yaw motion. Each actuator is fastened to the orbiter thrust structure and to the powerhead of one of the three SSMEs. Each hydraulic actuator receives four redundant commands from the four ATVCs. (The ATVC is an avionics hardware package, which provides gimbal commands and fault detection for each MPS and SRB hydraulic gimbal actuator.)

1.4 SSME ATVC INTERFACE FLOW

Figure 1-2 shows the interfaces between the MPS ATVC primary subsystems and other orbiter systems (crew inputs and hydraulics). There is an interface with the SSMEs stow and dump logic that cues the crew when the main engines have stopped thrusting and completed their dump when the left and right auto Body Flap (BF) lamp is turned off. For the no-abort cases, the auto BF lamps are turned off when the SSME STOW COMPLETE flag is set. For a Transoceanic Abort Landing (TAL), the auto BF lamps are turned off when the MPS-L02_DUMP STOP flag is set.

Note that regardless of the BF lamp, the SSME is actually stowed as initiated by the MECO_CONFIRM flag (part of the External Tank Separation Sequence (ET SEP SEQ)).

The major subsystems comprising ATVC are

- Hydraulic servoactuator
- Thrust Vector Control (TVC) SOP
- ATVC avionics box

1.4.1 Command Flow

The MPS ATVC command flow starts in the GPC, where the Flight Control System (FCS) generates the ATVC position commands, and terminates at the SSME servoactuators, where the actuators gimbal the SSMEs in response to the commands. All the MPS ATVC position commands generated by the FCS are issued to the MPS ATVC CMD SOP, where they are processed and dispersed to their corresponding FA MDMs. The FA MDMs modify these linear commands and disperse them to the ATVC channel, generating equivalent command voltages for each command issued.

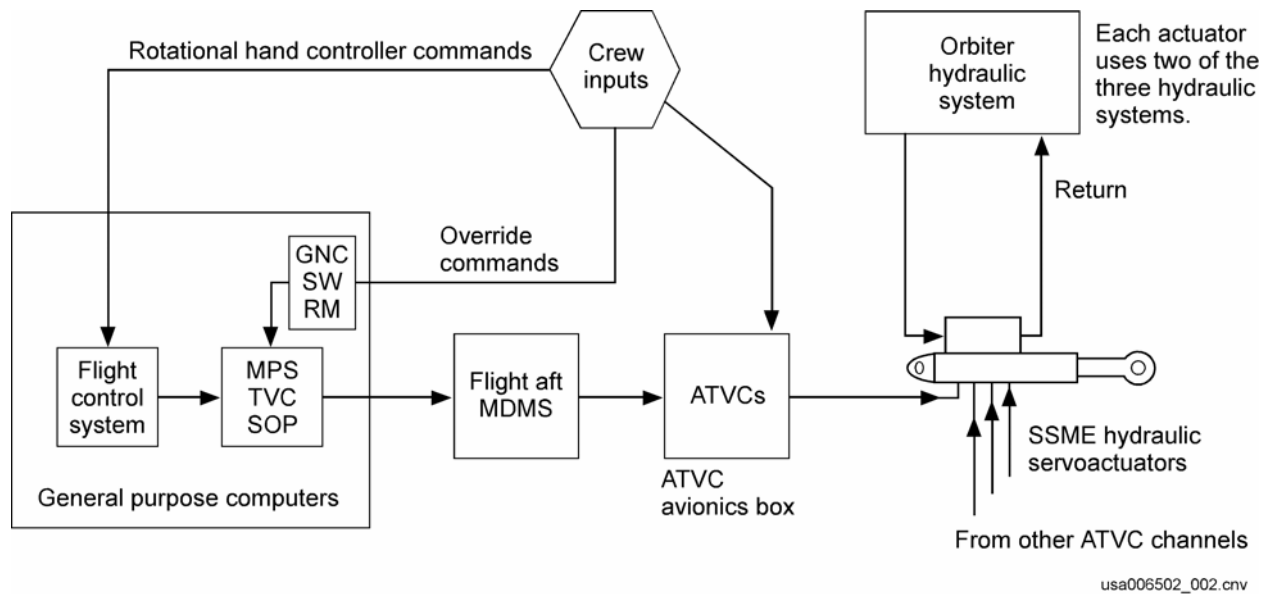


Figure 1-2. SSME TVC interface flow

These voltages are in turn sent to the servoactuators commanding the SSME hydraulic actuator to extend or retract, gimbaling the main engine to which it is fastened. A detailed discussion on the MPS ATVC primary subsystem is found in the following sections.

1.4.2 Crew Inputs

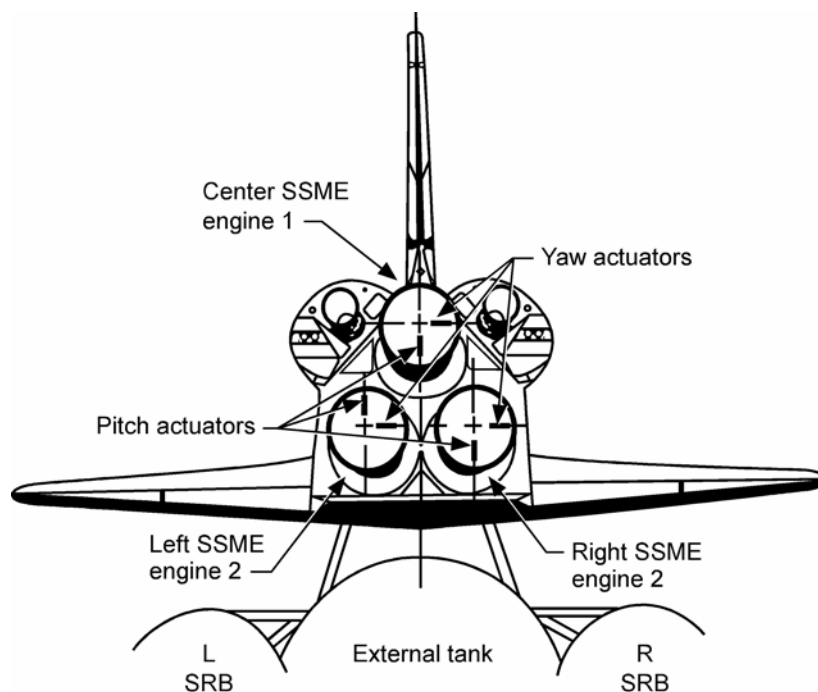
Crew inputs fall into three areas: Rotational Hand Controller (RHC) commands, override commands, and ATVC power. RHC commands are manual inputs to the FCS for flight path control. The RHC is discussed in the Controllers 21002 workbook. Override commands are the next crew input. These commands are issued to the MPS TVC SOP. These commands inhibit any ATVC channel from activating its hydraulic actuator fault detection system. The last crew input is ATVC power. ATVC electrical power is supplied to all the ATVC channels by the crew through a series of four ATVC power switches and four FCS channel monitor switches. The override command and ATVC power inputs by the crew are discussed in detail in Section 3 of this workbook.

1.4.3 Orbiter Hydraulic System

Each actuator uses two of the orbiter hydraulic systems for hydraulic pressure to generate the force necessary to gimbal the main engines. One hydraulic system is used as a primary system and one as a secondary system (standby). Hydraulic pressure is supplied to the actuator and is returned to the orbiter hydraulic supply while maintaining a working pressure of 3000 psig. Further discussion of the orbiter hydraulic interface is encountered later on in this section.

1.4.3.1 SSME Hydraulic Actuator Locations

Each SSME has two hydraulic actuators providing pitch and yaw gimbal capability. Figure 1-3 shows each actuator location in relation to the three main engines. (Note that the left SSME pitch actuator is on the upper half of the pitch axis rather than the lower half as with the other two main engines.) The actuator orientation shown was developed to stay within the amount of room in the orbiter aft thrust structure. This actually reduces the amount of piping necessary to link the actuator to the hydraulic systems, thus reducing the total orbiter weight. Each hydraulic actuator is fastened to the orbiter thrust structure and to the main combustion chamber of the corresponding SSME. The pitch actuators are mounted perpendicular to the yaw actuators and gimbal the engines in relation to their axis (pitch gimbal up or down and yaw gimbal left or right).



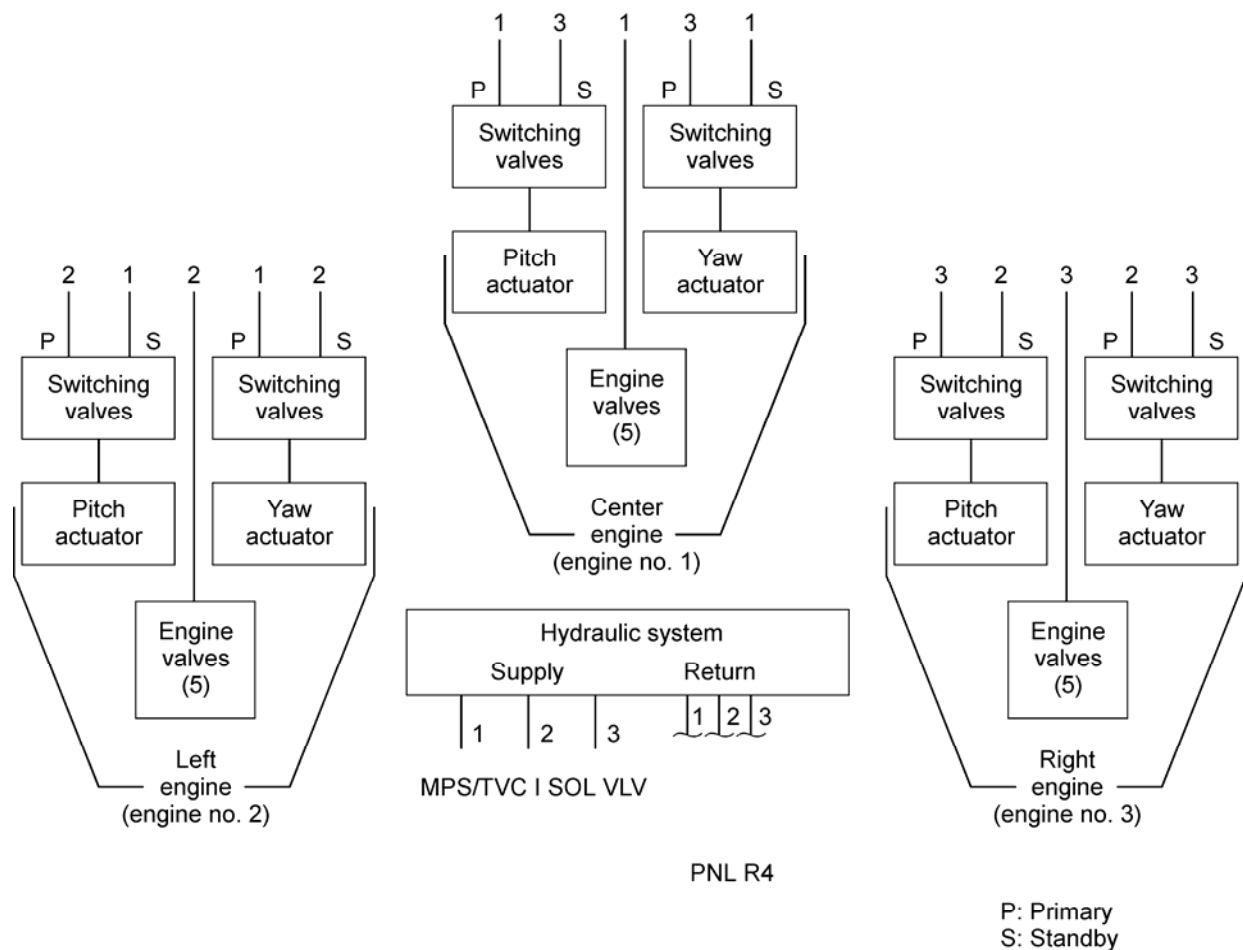
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Figure 1-3. SSME gimbal actuator locations

1.4.3.2 MPS Hydraulic System Distribution

Figure 1-2 shows that the SSME servoactuators interface with the orbiter hydraulic system and that the actuators use two of the three hydraulic systems: one as a primary system and the other as a standby system. Figure 1-4 shows the MPS ATVC hydraulic system distribution. The orbiter hydraulic supply is distributed to all six SSME ATVC actuators via three MPS/TVC isolation valves (one valve per hydraulic system). In order for the actuators to receive hydraulic pressure, these valves must be open. The valves are normally closed during on-orbit operation to prevent possible hydraulic leaks downstream of the isolation valves and to avoid unnecessary gimbaling of the main

engines from the stow position during on-orbit operation. Note that each actuator has its own hydraulic switching valve. The purpose of the switching valve is to receive hydraulic supply pressure (two of the three orbiter hydraulic supplies) and provide a single source pressure to the actuator. Each switching valve receives a primary source and a standby source. Normally the primary supply is directed to the actuator, but if the system were to fail and lose hydraulic pressure, the switching valve would automatically switch over to the standby system and the actuator would continue to function on the standby system. Note that each pitch actuator and the main engine (engine valves) employ the same hydraulic supply pressure as a primary source of hydraulic pressure (See Table 1-1). Distribution of the hydraulic systems among the actuators and engine valves was done so as to equally distribute the "hydraulic workload" among the three hydraulic systems. Figure 1-4 illustrates the MPS hydraulic system distribution.



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Figure 1-4. MPS hydraulic system distribution

Table 1-1. MPS hydraulic system distribution

Hydraulic system	Left engine			Center engine			Right engine		
	Eng. Vlv.	Pitch	Yaw	Eng. Vlv.	Pitch	Yaw	Eng. Vlv.	Pitch	Yaw
1		S1	P	P	P	S1			
2	P	P	S1					S1	P
3					S1	P	P	P	S1

P = Primary system

S1 = Standby system

Note: Each actuator has two hydraulic systems (one primary and one standby)

1.4.4 Command Flow Overview

Figure 1-5 shows a complete overview of the command flow through all the MPS ATVC subsystems. There are six MPS ATVC actuators that respond to command voltages being issued from four ATVC channels. Each ATVC channel has six MPS drivers and four SRB drivers, which have identical avionics (note ATVC 1). They convert any discrete command issued by the corresponding MDM into an equivalent command voltage and issue it to its hydraulic actuator. Note that each actuator receives four identical command voltages from four different ATVC drivers, each located in different ATVC channels. The SRB ATVC command flow is similar.

In summary

- Each GPC sends MPS ATVC commands to a given ATVC via an FA MDM.
- These commands are dispersed among six MPS drivers within each ATVC channel.
- A total of six MPS commands are sent from each ATVC channel to one servovalve on each of six SSME servoactuators.

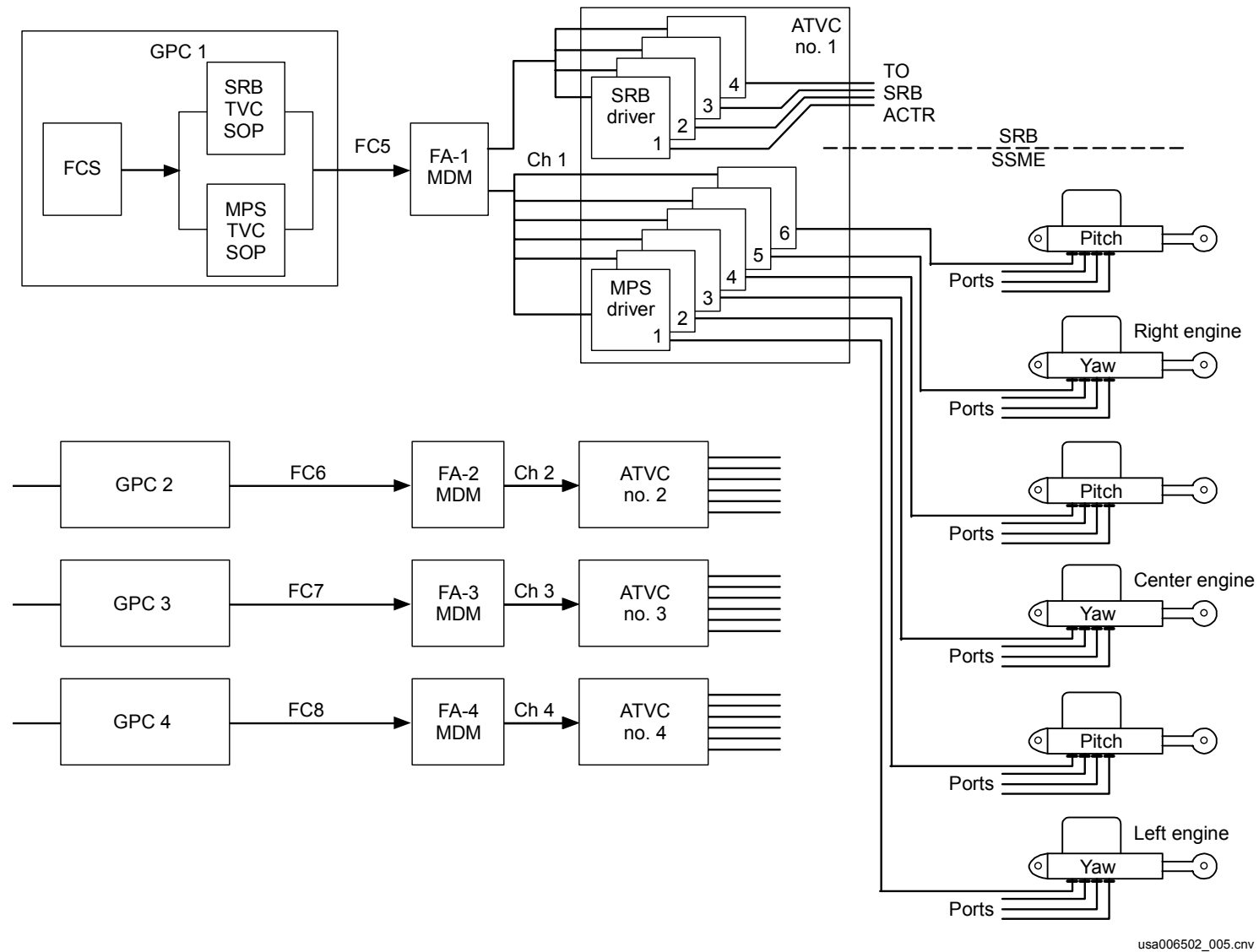
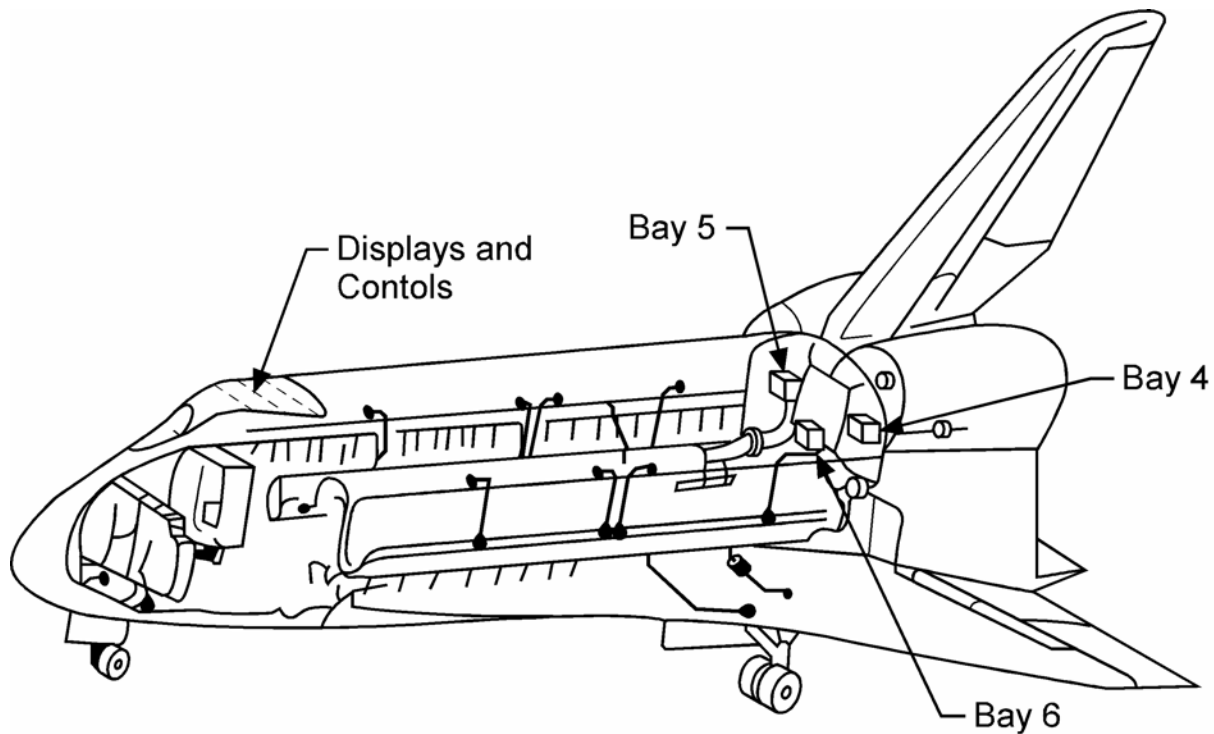


Figure 1-5. Command flow overview

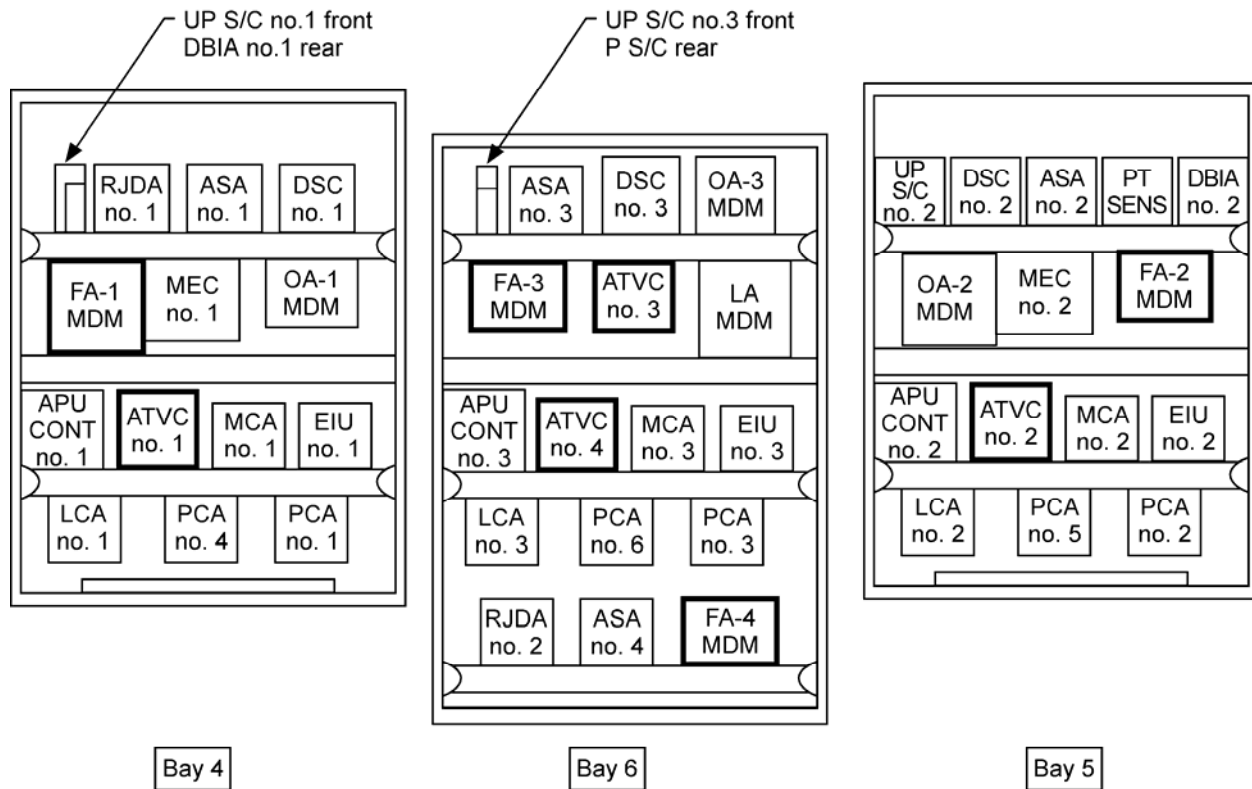
1.4.4.1 MPS ATVC Avionics Location

Figure 1-6 shows the avionics subsystems located in the three aft avionics bays. All MPS ATVC avionics subsystems are located in these three avionics bays. Figure 1-7 shows their exact locations. The FA MDMs and ATVC black boxes are outlined in heavy black outline. Each MPS ATVC avionics subsystem is cooled with coldplate cooling.



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Figure 1-6. Orbiter avionics bays



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Figure 1-7. Avionics bays 4, 5, and 6**1.4.5 SSME Actuator Operational Characteristics**

Each of the six SSME servoactuators is designed to produce linear motion to gimbal an SSME in either a pitch or a yaw axis. The servoactuators employed receive four separate position commands and convert them to an equivalent hydraulic pressure to drive a main ram that is fastened to an SSME. Figure 1-8 shows a simplified schematic of the SSME hydraulic servoactuator's general arrangement. Each actuator has a main ram assembly, which is fastened to the powerhead of an SSME. This ram assembly consists of the ram piston **1** and its shaft, which shuttles in a linear motion, either extending or retracting causing positive or negative displacement in the respective pitch or yaw axis. The ram piston, also called the primary piston, is driven by the primary hydraulic pressure differential across the ram piston. The primary pressure is being controlled by the power spool **2** displacement. The direction and amount of power spool displacement controls the direction and rate of the SSME. The power spool, in turn, is driven by the algebraic sum of the secondary delta pressures of the four servovalves **3**. The servovalve, also called second stage, receives a command from its respective ATVC and generates a secondary delta hydraulic pressure. The "health" of an actuator is reflected by the magnitude of its secondary Delta Pressures (ΔP s). Since the sum of the secondary ΔP tends towards zero and the displacement of the power spool valve is a function of the algebraic sum of the four servovalve secondary ΔP s, a secondary ΔP transducer measures the secondary delta pressure. If the measured

secondary ΔP becomes excessively high, the actuator has a problem. An isolation valve (ISOL VLV) isolates the failed servovalve from operation. In summary:

- There are four electrohydraulic servovalves [3] which receive voltage commands from their own ATVC MPS drivers and respond by converting the command voltage into an equivalent secondary hydraulic pressure.
- The sum of the secondary hydraulic pressures drives the power spools valve [2], causing the spool to generate a primary hydraulic pressure imbalance.
- The actuator ram [1] is shuttled in a linear motion (gimbaling the SSME it is fastened to) in response to the primary hydraulic pressure imbalance.
- The resistance of each servovalve is measured by a secondary ΔP transducer. This is the measurement used to isolate a servovalve failure.

A further detailed discussion of the actuator arrangement is in Section 4.

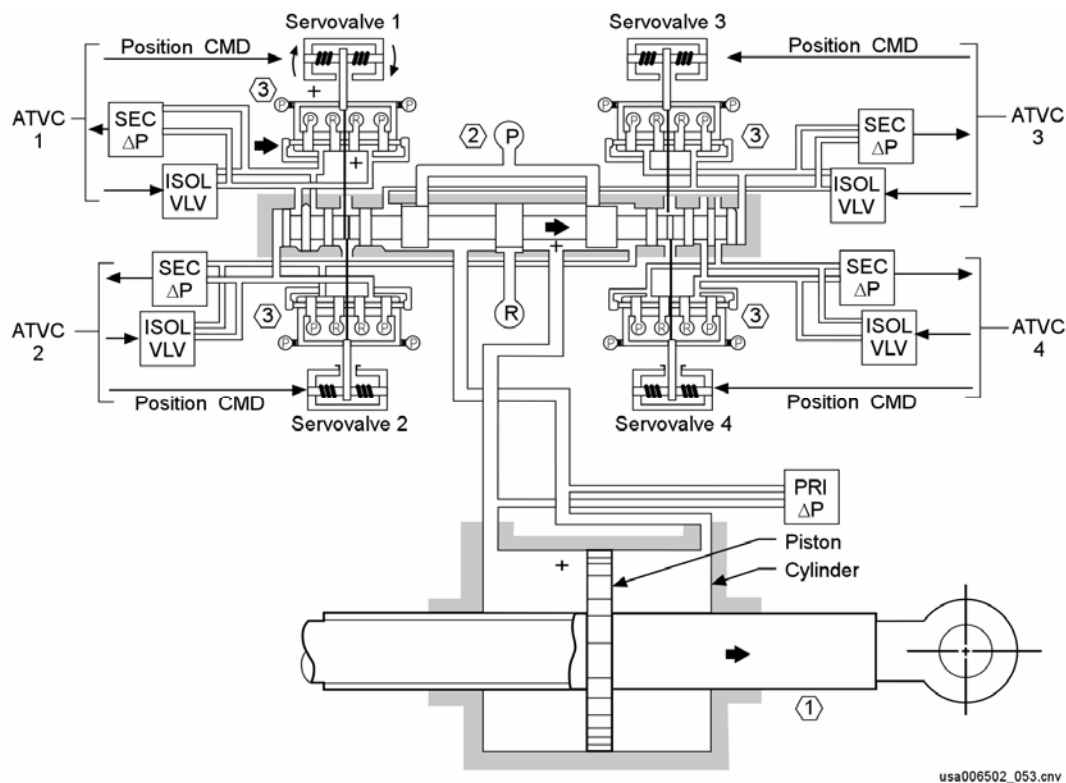
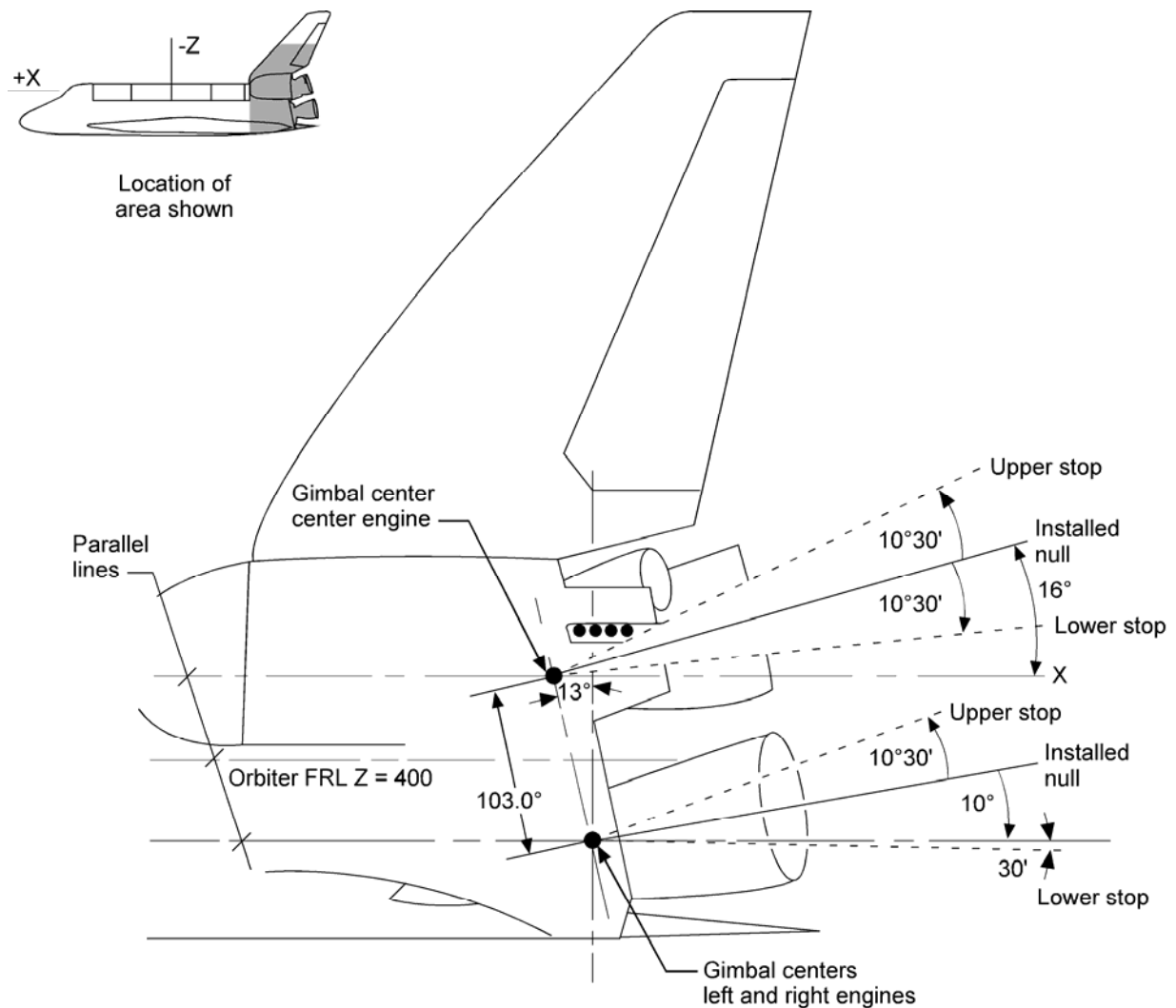


Figure 1-8. Typical actuator

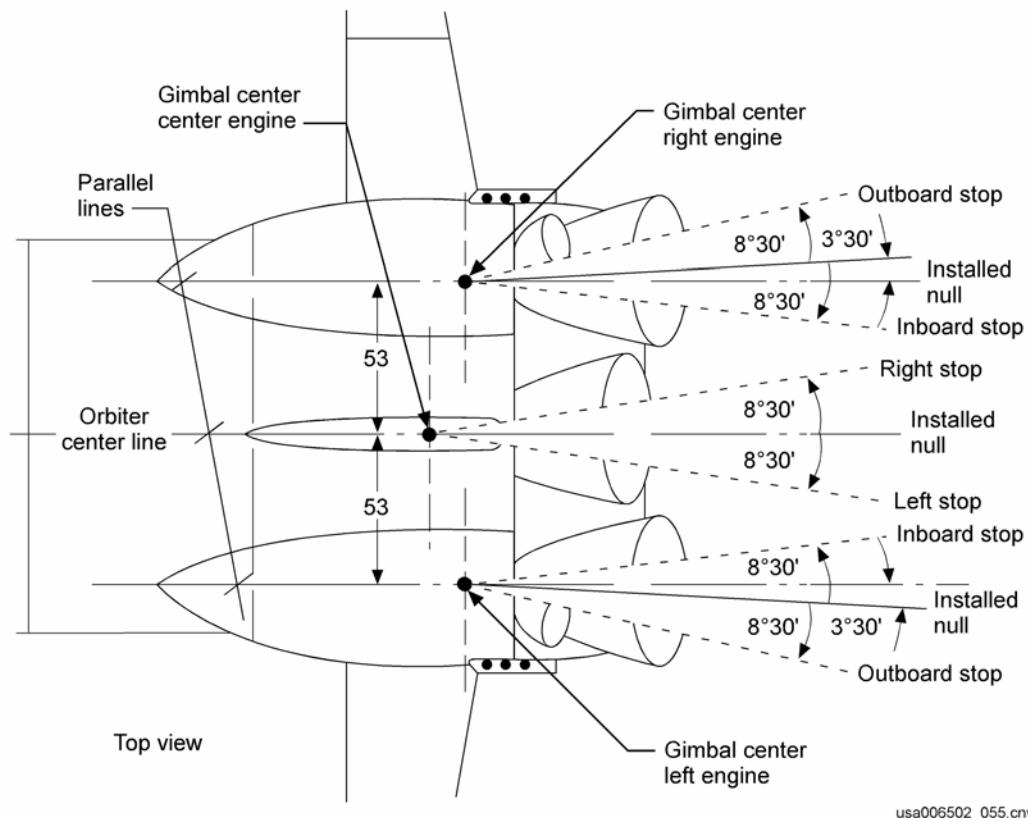
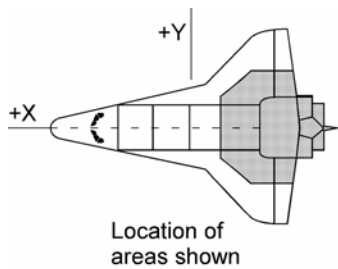
1.4.6 SSME Servoactuator Orientation

The main function of the SSME servoactuators is to change the thrust vector direction of each SSME as needed during the flight sequence of the orbiter. The three pitch actuators can gimbal the main engines up or down $10^{\circ}30'$ maximum from the installed null position (see Figure 1-9), and the yaw actuators can gimbal the main engines left or right $8^{\circ}30'$ maximum from the installed null position (see Figure 1-10). The installed null position for the left and right main engines is $10^{\circ}00'$ up from the X-axis in a -Z direction and $3^{\circ}30'$ outboard from an engine centerline parallel to the X-axis. The installed null position of the center engine is $16^{\circ}00'$ above the X-axis for pitch (see Figure 1-9). For yaw the installed null position is right on the X-axis (see Figure 1-10). When any engine is in an installed null position, it cannot have an engine-to-engine collision with the other engines.



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Figure 1-9. SSME gimbal pitch axis



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Figure 1-10. SSME gimbal yaw axis

1.4.7 SSME ATVC Controls and Displays

The following describes the controls and displays relative to the MPS ATVC.

1.4.7.1 Controls

The two sets of switches that provide crew input to the MPS ATVC system are the FCS channel monitor switches (on panel C3) and the ATVC power switches (on panel O17). The FCS monitor switches (four switches in all) provide override capability and allow power to flow to the ATVC switches. The ATVC switches (four switches in all) allow power to flow to each ATVC black box. Each ATVC black box has its own power switch, and each of the four ATVC command paths has an FCS channel monitor switch. This FCS switch is shared with the aerosurfaces (see Figure 1-11).

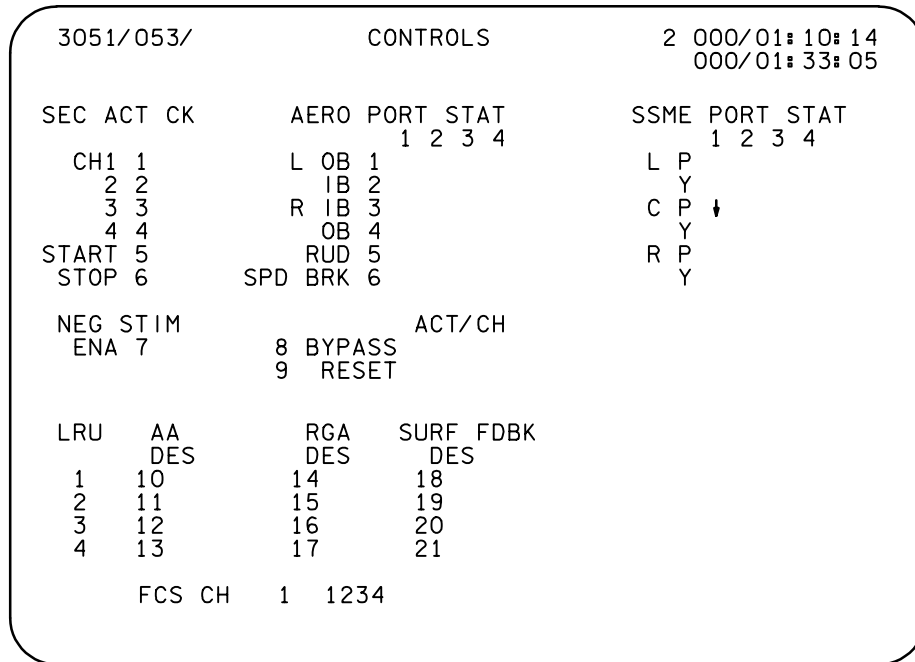


1.4.7.2 Displays

1-14

O ₂ PRESS	H ₂ PRESS	FUEL CELL REAC (R)	FUEL CELL STACK TEMP	FUEL CELL PUMP
CABIN ATM (R)	O ₂ HEATER TEMP	MAIN BUS UNDERVOLT (R)	AC VOLTAGE	AC OVERLOAD
FREON LOOP	AV BAY/ CABIN AIR	IMU	FWD RCS (R)	RCS JET
H ₂ O LOOP	RGA/ACCEL	AIR DATA (R)	LEFT RCS (R)	RIGHT RCS (R)
————	LEFT RHC (R)	RIGHT/AFT RHC (R)	LEFT OMS (R)	RIGHT OMS (R)
PAYLOAD WARNING (R)	GPC	FCS (R) SATURATION	OMS KIT	OMS TVC (R)
PAYLOAD CAUTION	PRIMARY C/W	FCS CHANNEL	MPS (R)	————
BACKUP C/W ALARM (R)	APU TEMP	APU OVERSPEED	APU UNDERSPEED	HYD PRESS

(34V73A7A2)



00650203. CRT, 3

Figure 1-14. PASS GNC Controls display (SPEC 53)

QUESTIONS

1. What is the purpose of the ATVC?
2. How many electrohydraulic servovalves are there per actuator? What kinds of commands are issued to the electrohydraulic servovalves?
3. To what position must an engine be commanded to ensure that it cannot have an engine-to-engine collision?
4. What are the three ways in which the crew can make inputs into the MPS ATVC system?
5. On which panels are the FCS channel monitor switches and the ATVC power switches?
6. What is the function of the hydraulic switching valve and on how many hydraulic supply sources does it operate?
7. Each servoactuator receives how many command voltages from the four different MPS ATVC drivers?
8. What major subsystems compose the ATVC?
9. Where does the MPS ATVC command flow start and where does it end?
10. Which two kinds of gimbal capabilities are supplied for each main engine by the two SSME actuators?
11. Each of the six SSME ATVC servoactuators is designed to
(Choose one)
 - (a) Produce rotary motion so as to gimbal an SSME in either a pitch axis or a yaw axis.
 - (b) Shuttle each of the five SSME propellant valves open or closed.
 - (c) Produce linear motion so as to gimbal an SSME in either a pitch axis or a yaw axis.
 - (d) Produce rotary motion so as to gimbal an SSME in either a rock axis or a tilt axis.

2.0 MPS ATVC COMMAND SUBSYSTEM OPERATING PROGRAM

2.1 OBJECTIVES

Upon completion of this section, the student should be familiar with

- The function of the Main Propulsion System Ascent Thrust Vector Control Command Subsystem Operating Program (MPS ATVC CMD SOP)
- The inputs and outputs relative to the MPS ATVC CMD SOP

2.2 PURPOSE

The purpose of the MPS ATVC CMD SOP is basically twofold. It receives the six actuator commands (three pitch and three yaw) from the DAP and distributes them to the FA MDMs. It also receives channel override commands and distributes them to the six MPS actuators. Figure 2-1 shows how the MPS ATVC CMD SOP distributes these commands.

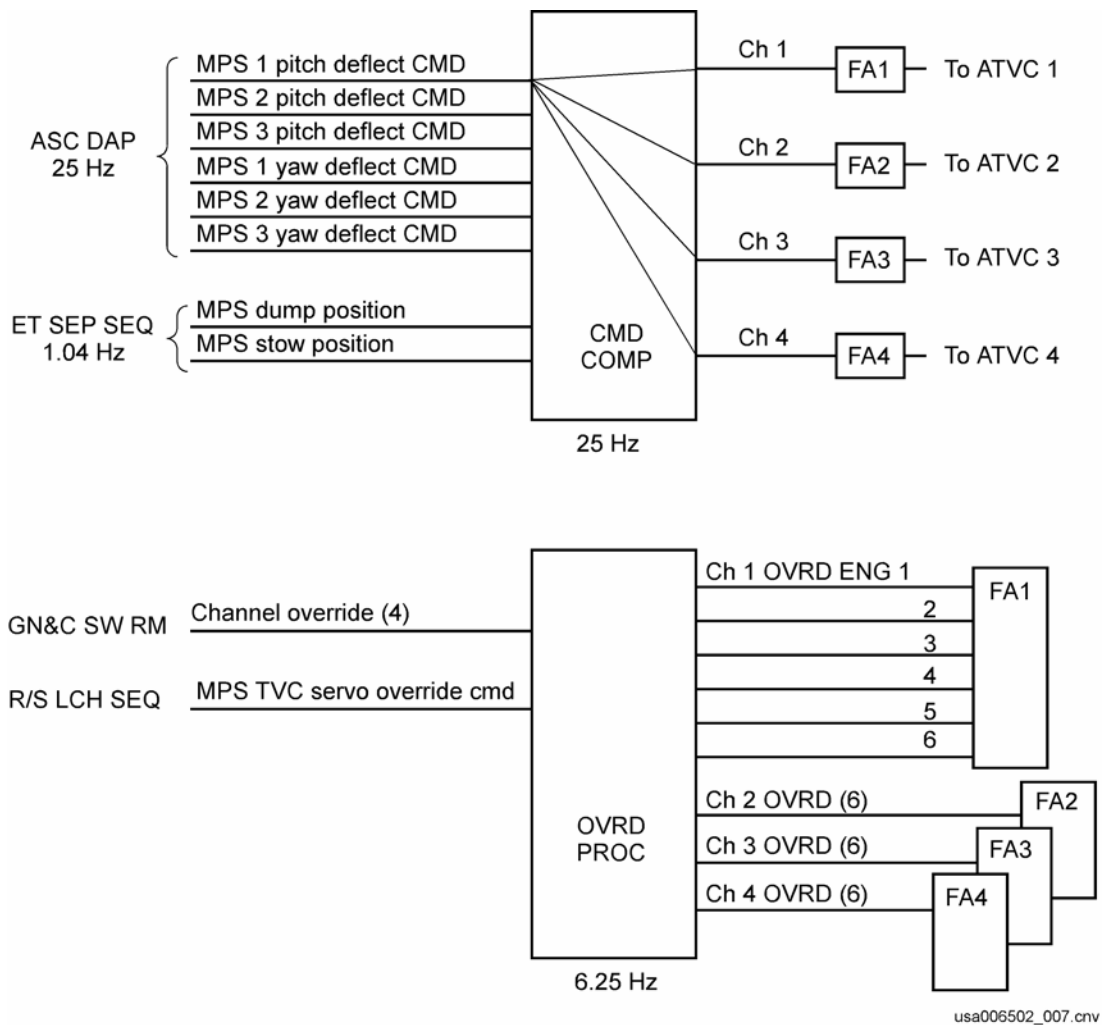
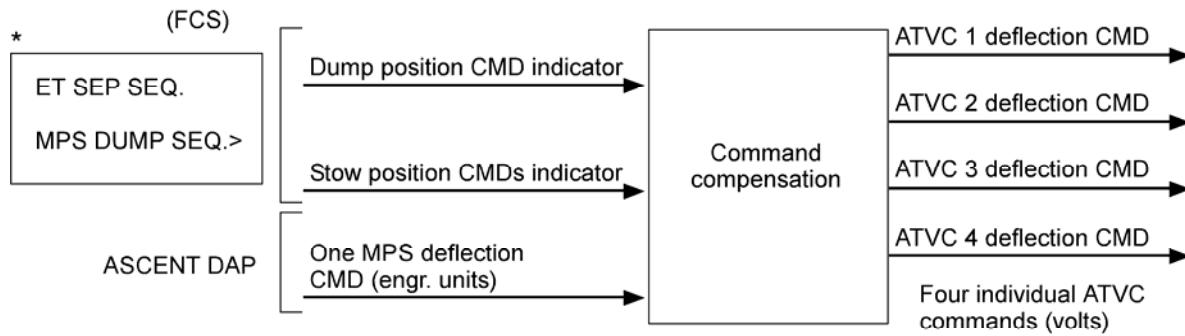


Figure 2-1. MPS TVC CMD SOP functional block diagram

2.3 MPS ATVC CMD SOP OVERVIEW

The MPS ATVC CMD SOP monitors control law main engine commands, dump commands, and stow commands. The commands for each actuator are compensated to adjust for hardware differences and are distributed to each FA MDM, forming quadruple redundant commands to each MPS actuator. Figure 2-2 shows the MPS ATVC CMD SOP overview. As discussed previously, the MPS ATVC CMD SOP is the device that transforms DAP commands to MPS actuator extend and retract commands. Another function of the MPS ATVC CMD SOP is to monitor FCS channel override requests and forced override commands from the redundant set launch sequencer. Command compensation is done at the rate of 25 Hz and override processing at the rate of 6.25 Hz.



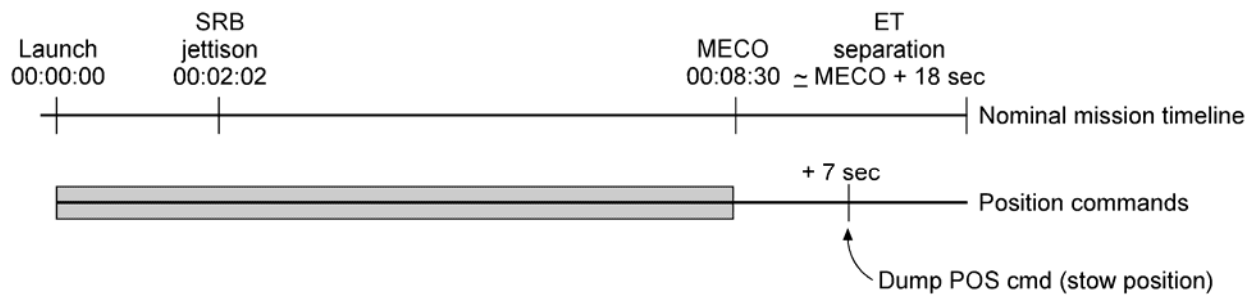
The TVC CMD SOP

- Takes one deflection command and produces four commands
- Scales the command (changes the command from engineering units to volts)
- Biases the command (corrects the command for hardware differences)

* The dump position is equal to the stow position.

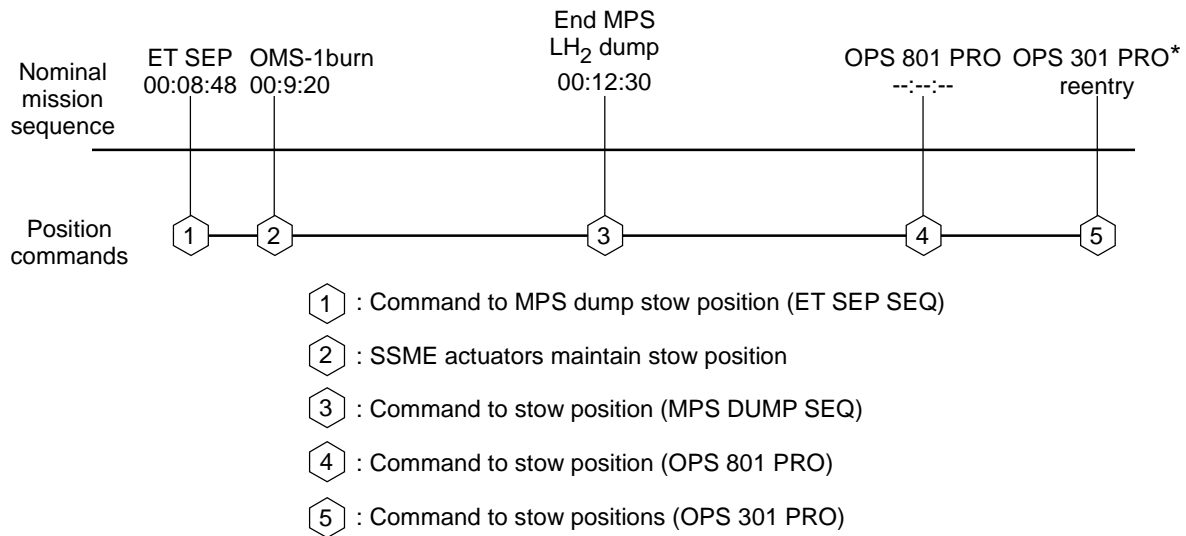
usa006502_008.cnv

Figure 2-2. Deflection command processing



usa006502_009a.cnv

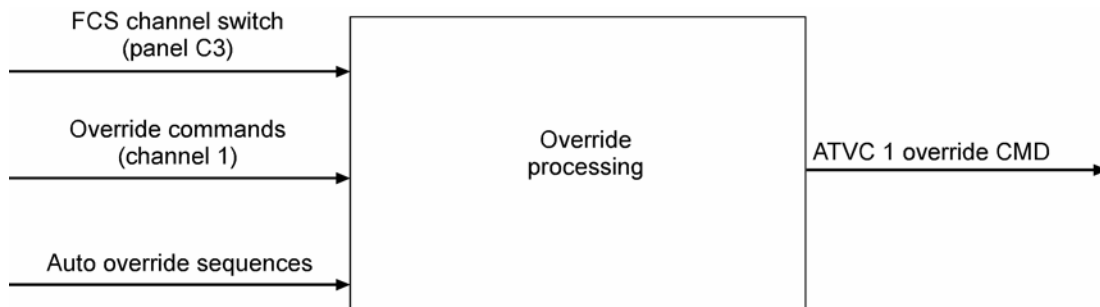
Figure 2-3. MPS TVC significant events



* **Note:** OPS transitions are covered in the DPS Hardware/Software 2102 workbook.

usa006502_009br1.cvx

Figure 2-4. MPS TVC significant events (Post-MECO)



The TVC override processor

- Receives an override command and sends it out to the ATVC channel it pertains to
- Receives override commands generated from the following:
 - FCS channel monitor switch
 - Redundant set launch sequence
 - SSME ops
 - SSME SOP

usa006502_010.cnv

Figure 2-5. MPS override command processing

2.4 SSME ATVC ACTUATOR POSITIONS

Table 2-1 shows the SSME positions during nominal flight operation as they appear in the Mission Control Center (MCC) on the Guidance, Navigation, and Control (GN&C) displays. This is the same coordinate system as the orbiter body axis. In the table the seven positions of the SSMEs ranging from the ME initial positions (OPS 101) to the rain drain positions of Major Mode (MM 901) for post landing along with the initial position check at T-3 min 10 sec are given. The pitch and yaw displacements for each main engine are about their installed null positions and are given in degrees.

Table 2-1. STS ME TVC actuator positions (deg.)

	OPS 9 to MM 101	ME ignition	Lift-off	Dump flag from ET SEP	Stow flag from ET SEP	Entry Repos.	Postlanding rain drain
ME 1 P	2.5	0.0	0.0	0.0	0.0	10	10.3
ME 1 Y	0.0	0.0	0.0	0.0	0.0	0	0.0
ME 2 P	2.5	0.0	0.0	-10.0	-10.0	0	9.7
ME 2 Y	1.5	0.0	-3.5	-3.5	-3.5	-3.5	0.0
ME 3 P	2.5	0.0	0.0	-10.0	-10.0	0	10.3
ME 3 Y	1.5	0.0	3.5	3.5	3.5	3.5	0.0

ME 1: Center engine
ME 2: Left engine
ME 3: Right engine

Questions

1. What does the acronym MPS ATVC CMD SOP stand for?
2. What is the function of the MPS ATVC SOP?
3. The pitch and yaw displacements for each main engine are about which position?
4. The purpose of the MPS ATVC CMD SOP is

(Choose one)

- (a) To process MPS rock and tilt actuator position commands, issued by the FCS, and MPS actuator override commands, issued by the crew.
- (b) To process MPS pitch and yaw actuator position commands, issued by the crew, and MPS actuator override commands, issued by the FCS.
- (c) To process MPS rock and tilt actuator position commands, issued by the crew, and MPS actuator override commands, issued by the FCS.
- (d) To distribute MPS pitch and yaw actuator position commands, received from the DAP, and MPS actuator override requests, issued by the crew.

3.0 ASCENT THRUST VECTOR CONTROL

3.1 OBJECTIVES

Upon completion of this section, the student should be able to

- Recognize the subsystems of the ATVC
- Recognize the subsystem interface with the ATVC
- Explain the possible failure modes related to the ATVC

3.2 PURPOSE

The primary functions of the ATVC are

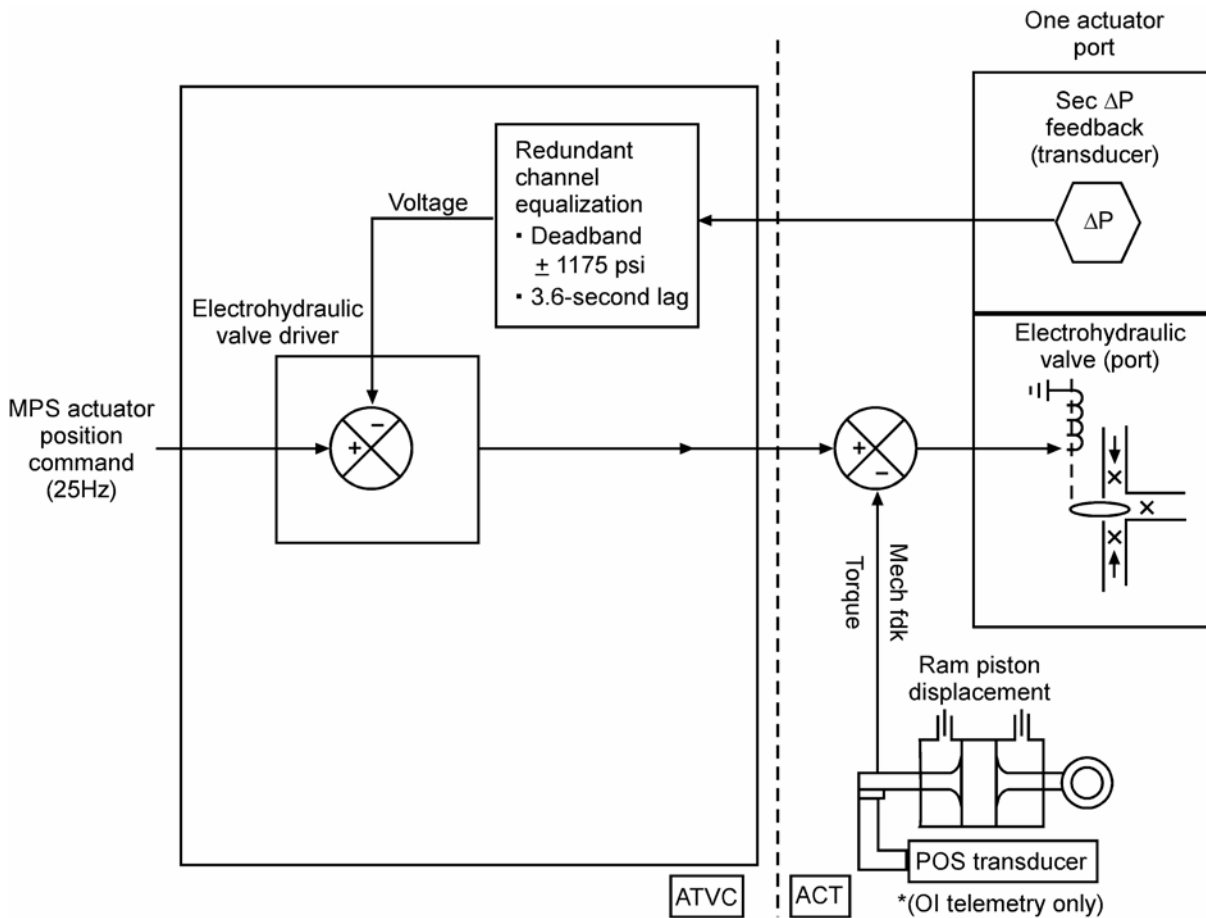
- To provide command signals to the hydraulic servoactuators
- To provide fault detection of the hydraulic servoactuators

3.3 GENERAL CHARACTERISTICS

- There are four ATVC channels per actuator.
- Each ATVC contains ten drivers, six MPS and four SRB.
- Each ATVC driver controls one port on one gimbal actuator.
- Each ATVC channel feeds its corresponding servovalve on all ten gimbal actuators (ATVC 1 feeds servovalve 1 on all 10 actuators).

3.4 ATVC COMMAND PROCESSING

Figure 3-1 shows the path for a command through one ATVC driver going to the actuator servovalve that driver controls.



usa006502_011.cnv

Figure 3-1. ATVC command processing

- The output of the MPS ATVC CMD SOP goes to the Electrohydraulic (EH) valve driver in the ATVC. The MPS ATVC CMD SOP digital word is converted to a voltage command through the aft MDM. The voltage output of the EH valve driver goes to the EH servovalve, which is an actuator port, and allows hydraulic fluid to flow to the secondary spool.
- The EH valve works in conjunction with the other three ports to effect the desired command.
- Feedback to the EH valve driver is provided by mechanical feedback and the redundant channel equalization logic.
- The equalization logic monitors the secondary ΔP . If the ΔP is greater than ± 1175 psi, then
 - A Δ voltage is applied to the actuator command through an equalization summer in the EH valve driver.
 - The Δ voltage reduces the actuator command which, in turn, reduces the ΔP .

3. Once the Δ voltage is applied, it takes 3.6 seconds for it to go away after the Δ P goes under 1175 psi.
- e. There is no crew indication of commands.

3.5 ATVC FAULT DETECTION

Figure 3-2 shows the fault detection and response performed by the ATVC.

- Secondary Δ P is monitored by the Δ P fault detection logic.
- If the secondary Δ P is greater than or equal to ± 2200 psi for 120 msec or longer, the output of the Δ P fault detection logic will turn on the isolation valve driver, energizing the isolation valve on the actuator.
- The isolation valve equalizes pressure on both sides of the hydraulic supply, thus allowing the EH valve to float and offer no resistance to changes in actuator position. This condition is called a port bypass.
- A port bypass can also occur if the ATVC power supply fails, as long as the isolation valve driver power is still good.

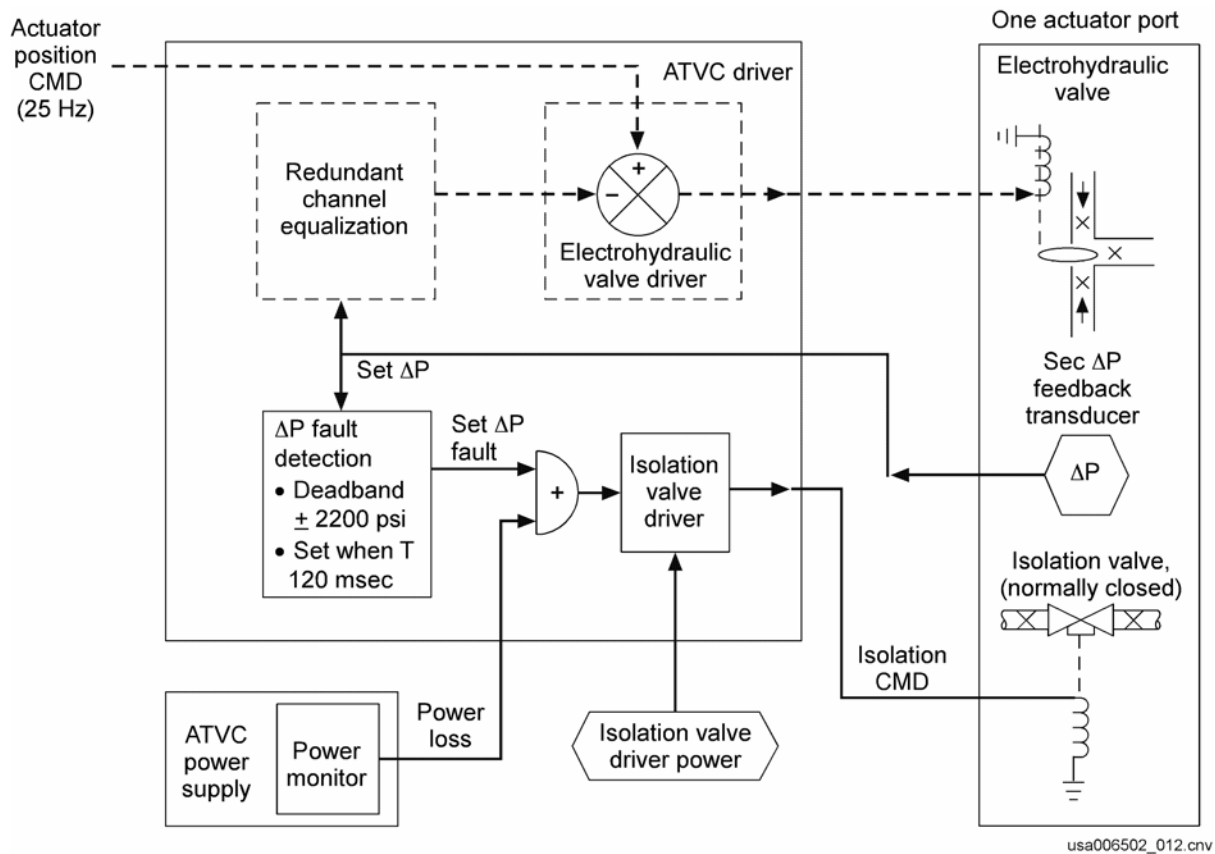


Figure 3-2. ATVC fault detection

- Port bypassing allows the remaining ports to move the power spool without causing force fights.
- If the FCS channel switch on panel C3 is in OVERRIDE, ports on that ATVC channel will not bypass due to high secondary ΔP .
- A port bypass will result in
 - A class 2 alarm
 - A backup C&W light
 - FCS Channel (CH) 1,2,3,4 CRT fault line message
 - A down arrow under the FCS channel that is bypassed on the GNC System Summary 1 display
 - A down arrow under the FCS port that is bypassed (except SRB) on the GNC Controls display

Figure 3-3 displays the panel indicator fault detection.

- Port bypassing can also be done by taking the FCS channel switch-off (SW-OFF) (ATVC SW-ON) for that ATVC channel. This step will remove the ATVC power supply directly and isolate all corresponding ports on the MPS and SRB actuators. This results in down arrows for the MPS and SRB servovalves for that ATVC channel on the GNC System Summary 1 display, and down arrows for the MPS on the GNC Controls display. This action will also result in isolation of all corresponding ports on the aerosurface for the FCS channel. This is because the FCS switch controls both the ATVC and Aerosurface Amplifier (ASA).

O ₂ PRESS	H ₂ PRESS	FUEL CELL REAC (R)	FUEL CELL STACK TEMP	FUEL CELL PUMP
CABIN ATM (R)	O ₂ HEATER TEMP	MAIN BUS UNDERVOLT (R)	AC VOLTAGE	AC OVERLOAD
FREON LOOP	AV BAY/ CABIN AIR	IMU	FWD RCS (R)	RCS JET
H ₂ O LOOP	RGA/ACCEL	AIR DATA (R)	LEFT RCS (R)	RIGHT RCS (R)
————	LEFT RHC (R)	RIGHT/AFT RHC (R)	LEFT OMS (R)	RIGHT OMS (R)
PAYLOAD WARNING (R)	GPC	FCS (R) SATURATION	OMS KIT	OMS TVC (R)
PAYLOAD CAUTION	PRIMARY C/W	FCS CHANNEL	MPS (R)	————
BACKUP C/W ALARM (R)	APU TEMP	APU OVERSPEED	APU UNDERSPEED	HYD PRESS

(34V73A7A2)

On Panel F7:

- FCS CHANNEL light
- BACKUP C/W light
- Class 2 alarm tone

00650201. PNL, 1

3051/ /018	GNC SYS SUMM 1	2 000/01:10:14 000/00:33:05
RCS JETISOL MANFFAILVLV	SURF POS MOM	DPS 1 2 3 4 5
F1 OP L OB U 0.3 0		GPC
2 OP IB U 0.3 0		MDM FF
3 OP R IB U 0.1 0		FA
4 OP OB U 0.1 0		
5	AIL 0.2	
L1 OP RUD 0.7		FCS CH 1 2 3 4
2 OP SPD BRK 25.5		↓
3 OP BDY FLP 34.4		
4 OP		NAV 1 2 3 4
5		IMU
R1 OP	CNTLR 1 2 3	ACC
2 OP	RHC L	RGA
3 OP	R R	TAC
4 OP	THC L	MLS
5	SBTC L	ADTA
	R	
FCS CH	1 1234	

**On GNC System
Summary 1 display:**

- “FCS CH1(2,3,4)” fault message
- Down Arrow under FCS channel for SSME/SRB

00650202. CRT, 2

3051/053/	CONTROLS	2 000/01:10:14 000/01:33:05
SEC ACT CK	AERO PORT STAT 1 2 3 4	SSME PORT STAT 1 2 3 4
CH1 1	L OB 1	L P
2 2	IB 2	Y
3 3	R IB 3	C P ↓
4 4	OB 4	Y
START 5	RUD 5	R P
STOP 6	SPD BRK 6	Y
NEG STIM	ACT/CH	
ENA 7	8 BYPASS	
	9 RESET	
LRU AA	RGA SURF FDBK	
DES DES DES		
1 10 14 18		
2 11 15 19		
3 12 16 20		
4 13 17 21		
FCS CH	1 1234	

On GNC Controls display:

- Down arrow for individual SSME port(s)

00650203. CRT, 3

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Figure 3-3. Panel indicators of fault detection

Figure 3-4 shows the effects of override commands.

-
- The diagram illustrates the control logic for an isolation valve. It features an 'Override monitor' with a 120-msec time delay that can 'Inhibit' the 'ΔP fault detection' block. The 'ΔP fault detection' block outputs a '(Removed) Sec ΔP fault' signal to an OR gate. The OR gate also receives input from the 'ATVC driver' and the 'Isolation valve driver'. The output of the OR gate goes to the 'Isolation valve driver', which in turn controls the 'Isolation valve' (normally closed). A 'Sec ΔP feedback transducer' provides feedback to the 'ΔP fault detection' block. The 'Isolation valve' is connected to a 'One actuator port' and a 'Power loss' signal. The 'ATVC driver' is connected to the 'Electrohydraulic valve driver' and the 'Isolation valve driver'. The 'Electrohydraulic valve driver' is connected to the 'ATVC driver' and the 'Isolation valve driver'. The 'Isolation valve driver' is connected to the 'Isolation valve' and the 'Power loss' signal. The 'Power loss' signal is connected to the 'Isolation valve' and the 'Power monitor'.

3-6

Note: Presence of an override inhibit in the ΔP fault detection logic will remove any down arrows from the GNC System Summary 1 Cathode Ray Tube (CRT) display.

- Removal of the override command will not restore an isolated EH servovalve unless the secondary ΔP is less than ± 2200 psi.

Override commands are generated by

- The Redundant Set (R/S) launch sequencer to prevent any ports bypassing during ignition transients
- The SSME SOP during the main engine shutdown phase
- The FCS channel switches, whenever a crewmember places the switch to override

Note: Placing FCS CH (1,2,3,4) SW in OVERRIDE positions causes corresponding override status for that channel.

3.7 ATVC SWITCH CONFIGURATION

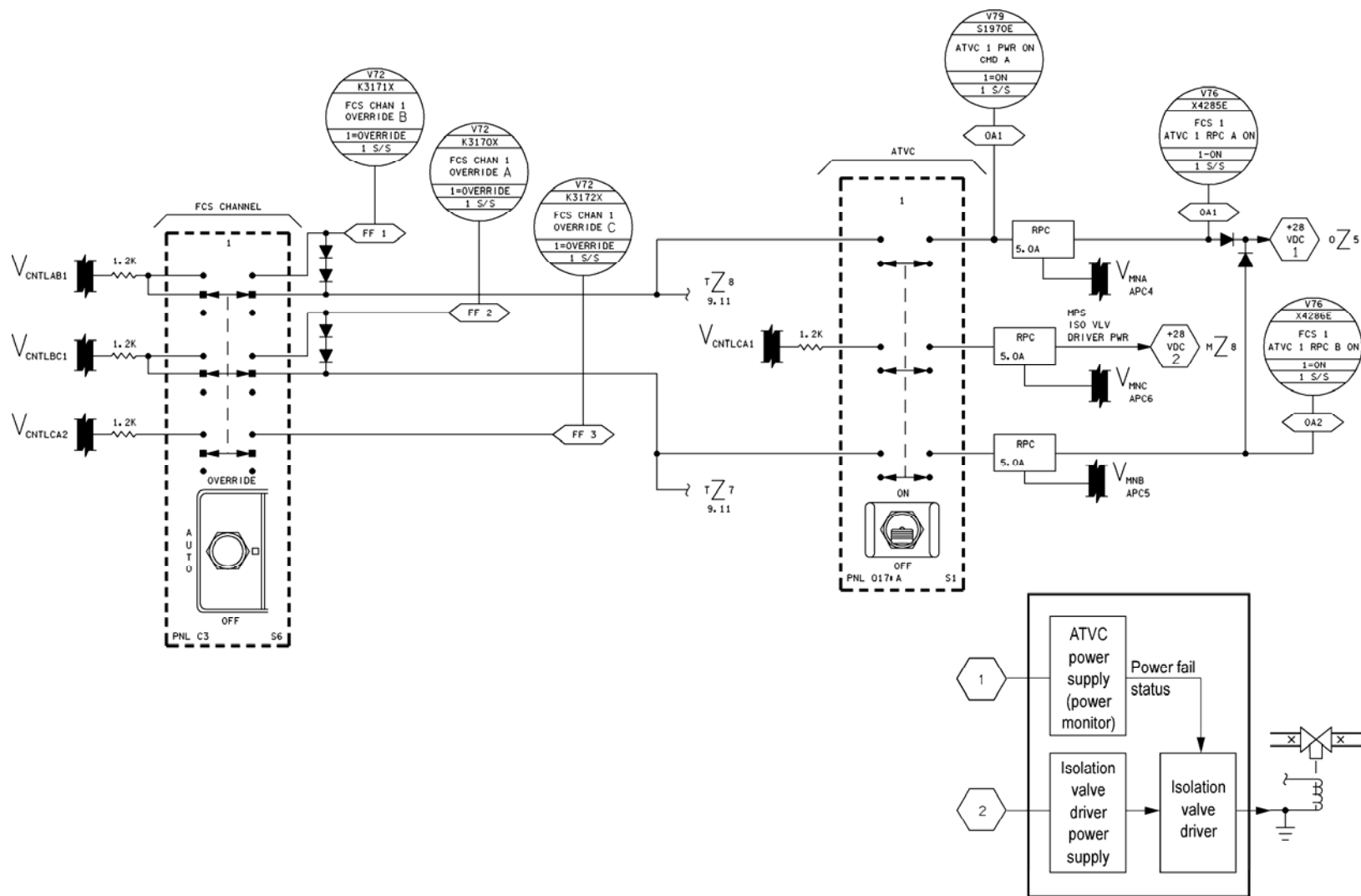
Figure 3-5 shows the ATVC switch configuration for ATVC 1. Table 3-1 gives the electrical power and MDM assignments for the four ATVCs.

3.7.1 FCS Channel SW AUTO (ATVC SW-ON)

- Control bus power is maintained to the Remote Power Controllers (RPCs), which supply power to the ATVC power supply.
- This allows the ATVC channel to isolate any port (MPS or SRB) that it contains.

3.7.2 FCS Channel SW-OVERRIDE (ATVC SW-ON)

- The override command is sent to the MPS ATVC CMD SOP via GN&C switch Redundancy Management (RM). The CMD SOP sends an override command to the ATVC inhibiting port pops for high secondary ΔP .
- ATVC power is maintained through control bus power to the RPCs, which supply power to the ATVC power supply. (Isolation valve driver power comes from RPC power through the ATVC power switch.)
- The FCS channel MPS switch overrides all ports on that ATVC channel (MPS and SRB) and also all Aerosurface Amplifier (ASA) ports on that channel.



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Figure 3-5. ATVC switch configuration

Table 3-1. FCS channel monitor switch/ATVC switch power and MDM assignments

		Control bus	Main bus	MDM
1	A B C ISOL valve	BC1 AB1 CA2 CA1	B (APC5) A (APC4) - C (APC6)	FF2 FF1 FF3 -
2	A B C ISOL valve	BC2 CA3 BC3 AB2	B (APC5) C (APC6) - A (APC4)	FF2 FF3 FF4 -
3	A B C ISOL valve	CA1 AB2 BC1 BC3	C (APC6) A (APC4) - B (APC5)	FF4 FF1 FF2 -
4	A B C ISOL valve	AB3 CA2 AB2 BC3	A (APC1) C (APC3) - B (APC2)	FF4 FF3 FF1 -

3.7.3 FCS Channel SW-OFF (ATVC SW-ON)

- This removes control power to the RPCs, which removes power from the ATVC power supply. (The isolation valve driver remains powered through an RPC controlled by the respective ATVC switch.)
- This results in the isolation of all ports on that ATVC and ASA channels (MPS, SRB, and aerosurface).

3.7.4 ATVC SW-OFF (FCS Channel Switch in Any Position)

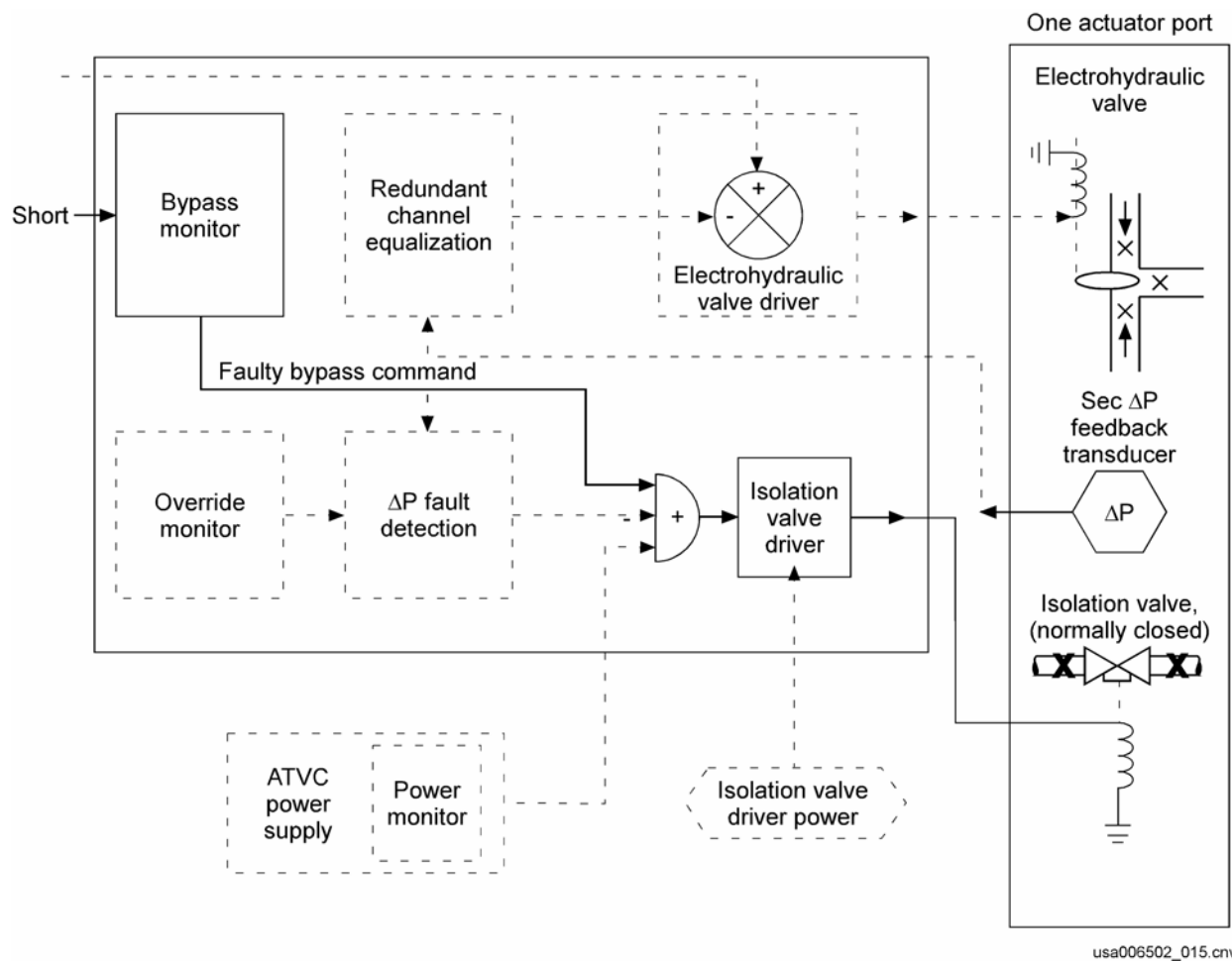
- This removes all power to the ATVC channel, which includes the isolation valve driver power.
- Also all ports in that channel (MPS and SRB) are sent a zero voltage, resulting in a force-fight when the remaining good channels are not at null.

3.8 BYPASS MONITOR SHORT

Each ATVC MPS and SRB driver has a bypass monitor that was designed to activate the isolation valve driver in response to an item entry through the keyboard by the crew. However, due to design modifications, the ability of the crew to perform an item entry relative to the bypass monitor logic is not possible. Therefore, the crew can no longer isolate any individual EH valve for MPS and SRB channels.

If an MDM were to fail, the channels wired to the bypass monitor could possibly fail. With the bypass monitor failed, an isolation command is issued to the isolation valve bypassing the port. Usually when an MDM fails, the command through the MDM is frozen, and when it differs from the remaining good channels enough to break secondary ΔP limits a bypass command is issued within the ATVC. The ΔP fault detection energizes a signal to the isolation valve when the counter is saturated. This isolates the EH valve pertaining to the driver. However, if the bypass monitor channel fails on, there is no possible way of removing the faulty bypass command through an item entry or through the override monitor since the MDM is failed.

Figure 3-6 gives an example of a faulty bypass command.



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Figure 3-6. Bypass monitor short

Figure 3-7 gives a representation of a Data Processing System (DPS) command path failure. Table 3-2 gives a scenario for several ATVC types of faults.



Failure	Indication	Consequences
DPS Command path failure	<ul style="list-style-type: none"> Large secondary ΔP readings for downlink telemetry Driver output Δ from good channels 	<ul style="list-style-type: none"> Loss of control over 10 ATVC drivers (6 MPS, 4 SRB) One of four servo valves on each MPS and SRB actuator will most likely be Isolated

usa006502_016.cnv

Figure 3-7. DPS command path failure

Table 3-2. ATVC faults

Fault	Possible cause
<ul style="list-style-type: none"> Large SEC ΔP readings for downlink telemetry, (constant) Inability to isolate EH valve No C&W display indications 	<ul style="list-style-type: none"> ATVC channel and isolation valve driver power failure ΔP fault detection failure Isolation valve driver failure
<ul style="list-style-type: none"> Large SEC ΔP readings for downlink telemetry, (momentarily) C&W display indications are energized 	<ul style="list-style-type: none"> ATVC channel power failure: Isolation valve driver power still functioning (Note: C&W displays will be for MPS and SRB FCS channels) 1 to 10 EH valves for a given FCS channel have been isolated Electrohydraulic valve driver failure Redundant channel equalization failure
<ul style="list-style-type: none"> Inability to reset isolated value or loss of ability to keep EH valve in override condition 	<ul style="list-style-type: none"> Override monitor failure FCS channel monitor switch failure Faulty bypass command

QUESTIONS

1. What does ATVC stand for?
2. How is feedback to the EH valve driver provided?
3. How are override commands used to prevent port bypass?
4. What will happen when an FSC CH SW is put to OVERRIDE when a port has already popped on its respective channel?
5. When an ATVC power switch is in the off position, all the servovalves controlled by the affected channel are sent to
 - (a) A null position, which corresponds to a zero voltage
 - (b) The last commanded position
 - (c) Full rotation clockwise
 - (d) Full rotation counterclockwise
6. What is the value of the secondary ΔP that will turn on the isolation valve driver energizing the isolation valve for that port on the actuator?
7. What are the two primary functions of the ATVC?
8. What is the condition called when the isolation valve equalizes pressure on both sides of the hydraulic supply to the EH valve allowing it to float and offer no resistance to changes in the actuator position?
9. What are four aspects of port bypass?
10. If an MDM were to fail and the channels wired to the bypass monitor failed, what could occur?
11. List four general characteristics of the ATVC.

4.0 SSME ATVC ELECTROHYDRAULIC SERVOACTUATOR

4.1 OBJECTIVES

At the end of this section, the student should be able to

- Recognize the subsystems that make up an MPS ATVC servoactuator
- Understand how the subsystems function together as an MPS ATVC servoactuator

4.2 PURPOSE

The purpose of the MPS hydraulic ATVC actuator is to change the thrust direction of each SSME as needed during the flight sequence of the orbiter.

4.3 GENERAL CHARACTERISTICS

- There are two ATVC actuators for each SSME, one for pitch movement and one for yaw movement.
- Each actuator receives four command voltages, one from each ATVC channel.
- Each actuator employs two of the three orbiter hydraulic systems (one primary and one secondary).

Table 4-1 gives some of the SSME ATVC design specifications. Figure 4-1 shows the exterior view of a typical main engine EH servoactuator.

Table 4-1. Actuator physical characteristics

	Center engine pitch	Left and right engine pitch	Yaw
Actuators/vehicles	1	2	3
Piston area (in ²)	24.8	20.0	20.0
Rated load (lb)	48,200	38,900	38,900
Total stroke (in.)	10.8	10.8	8.8
Rates velocity (in/sec)	5.7	5.7	5.7
Approx. peak flow (GPM)	50	45	45
Actuator weight (lb)	263	245	240

Note: That the center engine pitch actuator has a larger rated load and piston area. This is to compensate for aeroloads on the center engine.

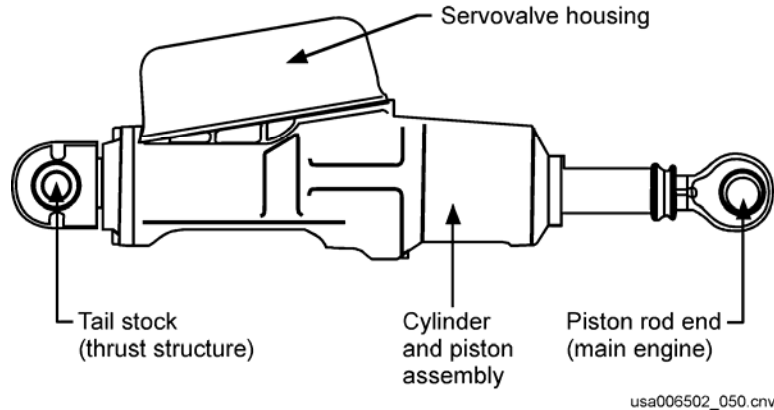


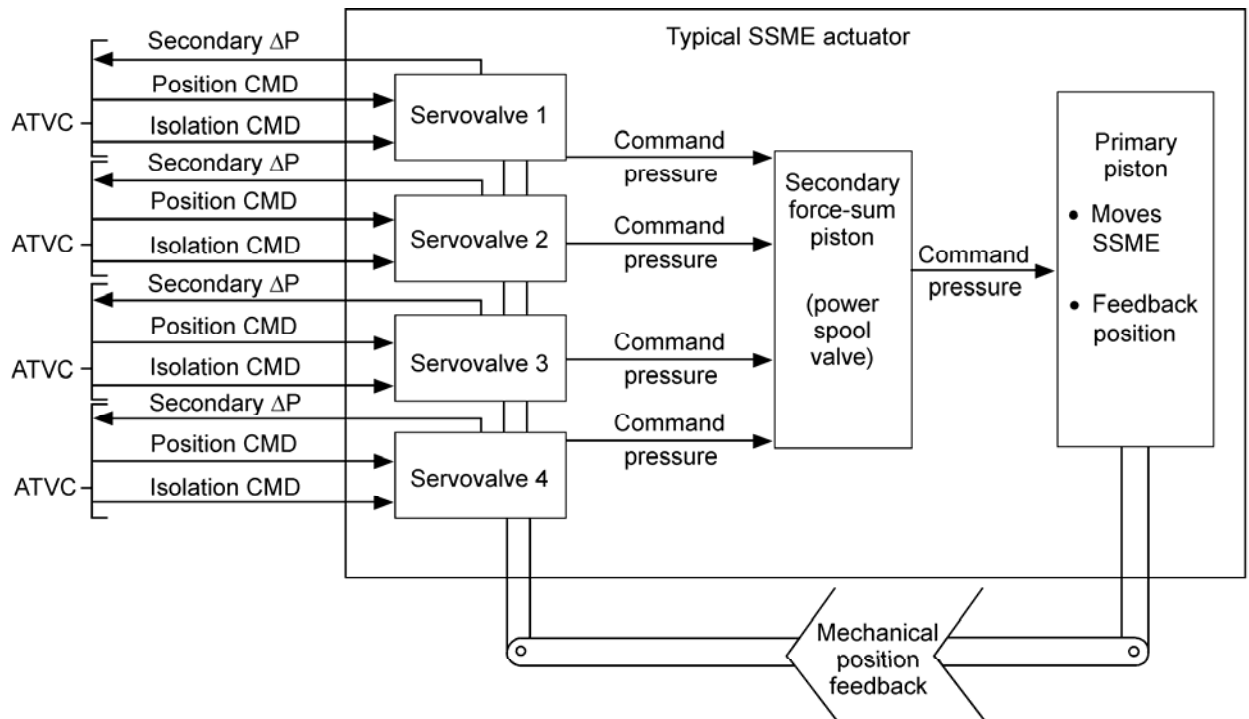
Figure 4-1. Main engine electrohydraulic servoactuator (exterior)

4.4 TYPICAL SSME ACTUATOR (SERVOACTUATOR SUBSYSTEMS)

Each SSME actuator is composed of four servovalves, one second-stage power spool valve, one primary piston, and a switching valve (Figure 4-2). The switching valve is not shown in Figure 4-2. The sum of the four second-stage servovalves on the power spool valve allows primary hydraulic pressure to move the primary piston. When the primary piston moves in response to the commanded hydraulic pressure displacement, the SSME is gimballed. Elaborating upon the cause and effect, the story goes as follows: The MPS ATVC CMD SOP generates a quadruple redundant actuator position command that is received by the four servovalves. Each of the four servovalves receives the position command and displaces its respective flapper. The sum of the four forces from the four servovalves displaces the power spool valve, generating a primary hydraulic pressure command to displace the primary piston. The displacement of the primary piston that gimbals the SSMEs closes the loop with a mechanical feedback loop. The mechanical feedback, when summed with the servovalve commands, causes the power spool valve to return to null position when the actuator is at the commanded position. The displacement of the flappers in the four servovalves generates four secondary delta pressures that are monitored by transducers and sent as telemetry to the MCC. These secondary delta pressures are also used by the redundant channel equalization network.

The switching valve (not shown in Figure 4-2) provides source hydraulic pressure from a selected hydraulic system. The secondary hydraulic pressure data for each servovalve is sent to the servovalve's corresponding ATVC for processing. If the hydraulic pressure exceeds a 2200 psid limit for more than 120 msec, an isolation command is issued to remove that servovalve from operation.

In summary, an SSME actuator contains four servovalves that each generate a command hydraulic pressure in response to position commands from the ATVC. The command hydraulic pressures are summed together at the power spool valve. These hydraulic pressures drive the power spool valve in order to generate primary command hydraulic pressure to drive the primary piston. The primary piston extends or retracts, gimbaling an SSME.



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Figure 4-2. Typical SSME actuator

4.5 TYPICAL ACTUATOR ASSEMBLY

Figure 4-3 shows the SSME actuator subsystems located in the servovalve housing and main body housing. The servovalve housing contains the four EH servovalves (only three are shown) as well as the ΔP sensors, power spool, and the spring cage linkage to the mechanical feedback assembly. The main cylinder housing contains the main actuator piston and mechanical position feedback linkage. The purpose of the mechanical feedback assembly is to mechanically transmit the position of the main actuator and piston assembly to each EH servovalve. The subsystem consists of a position feedback scissor mechanism, which is fastened to a series of linkages, which contain spring cage assemblies that are linked to the four EH servovalves. The scissor mechanism is designed to pivot in response to linear motion of the actuator ram assembly, where the scissor assembly makes contact in a cone at the aft end of the ram. The other end of the ram (not shown) is fastened to the powerhead of an SSME. When the scissor mechanism pivots, it causes the other linkages to shuttle about, mechanically transmitting the position of the main ram to the four EH valves pertaining to the hydraulic actuator. These systems are discussed in the following pages.

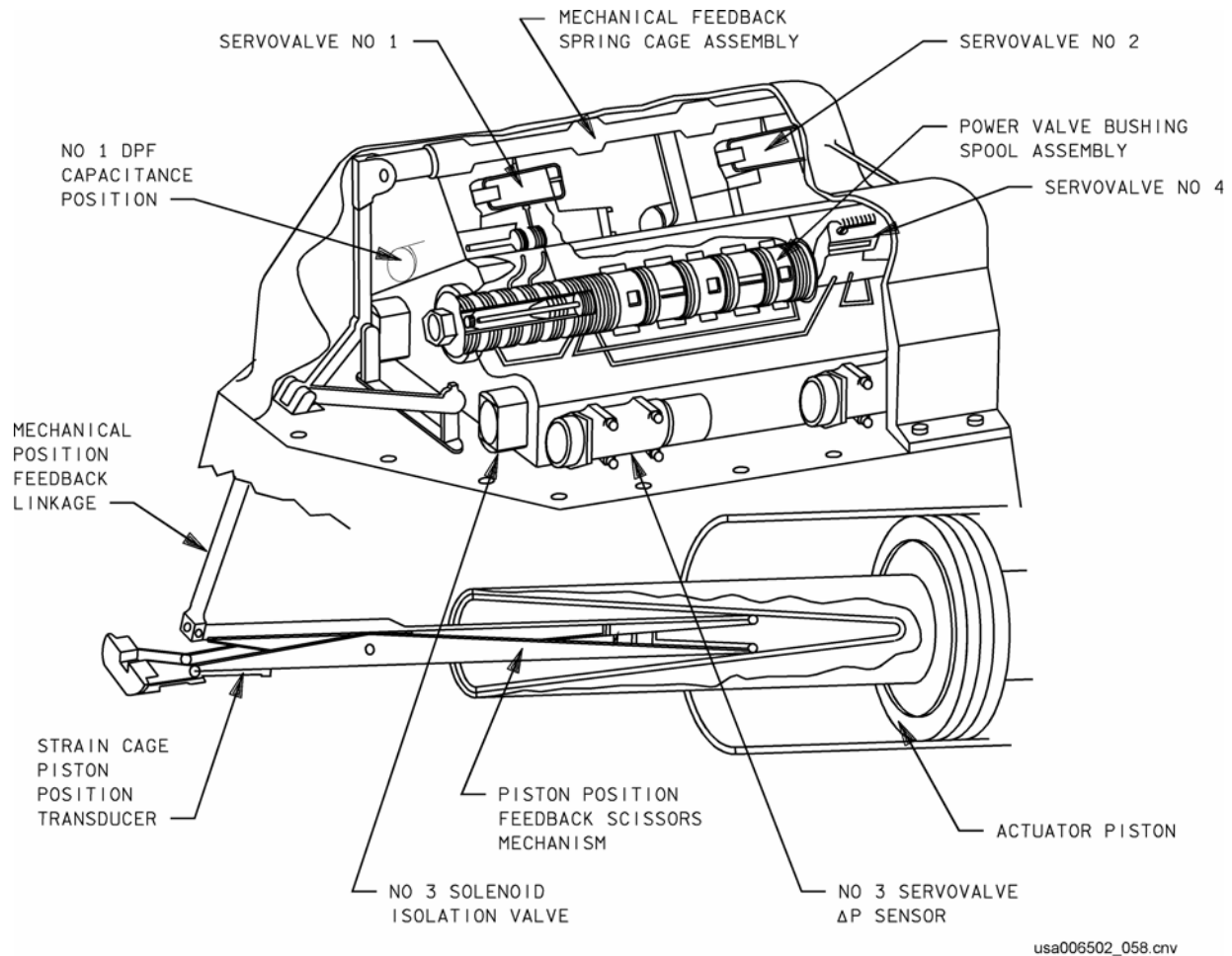


Figure 4-3. Typical actuator assembly

4.6 ELECTROHYDRAULIC ACTUATOR SCHEMATIC

Figure 4-4 shows all the gimbal actuator subsystems and how they hydraulically interface with each other. For clarity only, two of the four EH valve assemblies are shown. In order to explain each actuator subsystem effectively, the following pages cover each of the subsystems listed separately below:

- The switching valve
- The Electrohydraulic servovalve assemblies
- The power valve assembly
- The primary ΔP feedback assembly (Delta Pressure Feedback (DPF))
- The lock valve assembly

- The bypass valve assemblies and secondary ΔP feedback assemblies
- The cylinder and piston ram assembly

4.7 SWITCHING VALVE

Each SSME hydraulic actuator has a switching valve. Unlike the aerosurface switching valves, the SSME switching valve has only a primary spool. Two orbiter hydraulic systems are fastened to the primary spool. The Primary system (P) and the Standby system (S_1) are connected to the spool (Figure 4-5). The output of the spool is fastened to the SSME actuator. The position of this spool is sent to downlink telemetry through a Linear Variable Differential Transformer (LVDT). Normal system operating pressure is 3000 psia; the spool will shift position in the valve cylinder when the pressure of the primary system is less than 1200 to 1500 psia. For example, if the primary pressure were to fall below the controlling pressure (1200 to 1500 psia), the spool would be shuttled downward, removing the primary pressure from operation and allowing the standby hydraulic system to takeover. The output line from the valve would show a slight drop in pressure but not enough to affect operation of the SSME actuator. Note that each hydraulic system has a return system to the orbiter hydraulics. The switching valve assembly is also used to receive hydraulic fluid returning from the SSME actuator and then direct it to the hydraulic system in control at the time of operation.



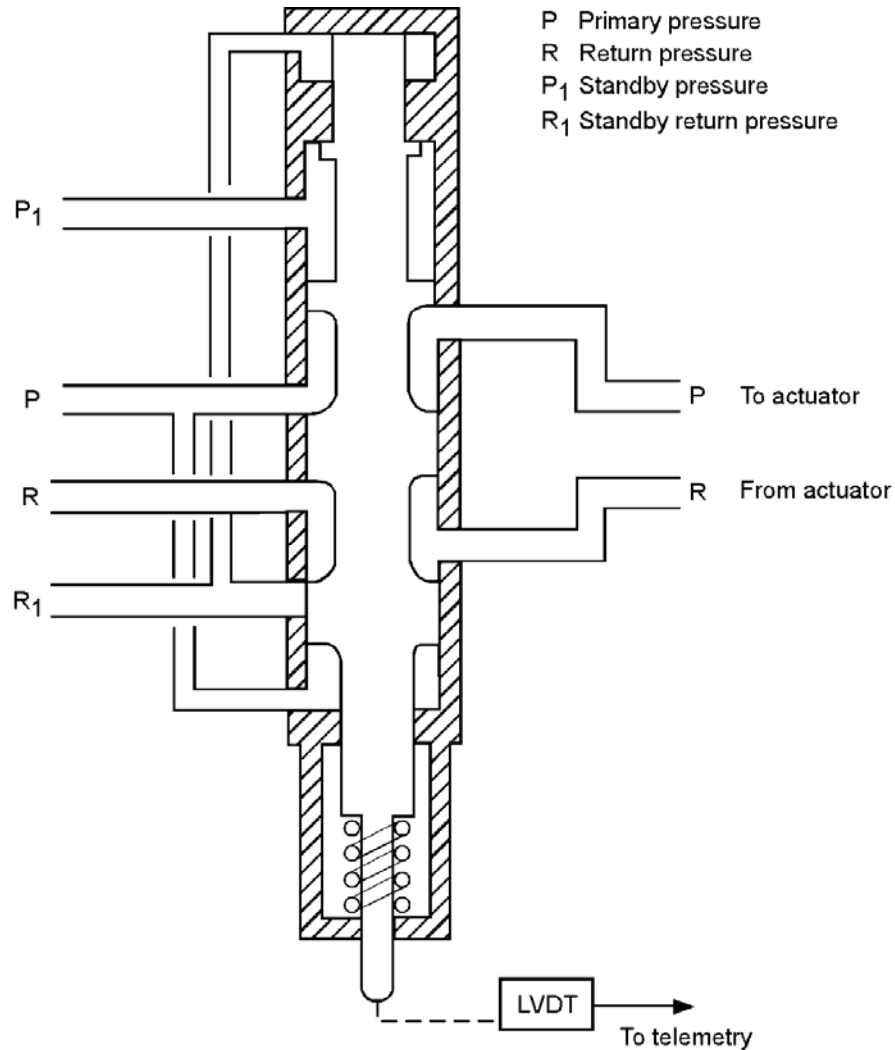


Figure 4-5. Switching valve

4.7.1 SSME Switching Valve Summary

- Two orbiter hydraulic systems are connected to one switching valve (primary spool).
- The primary system and standby system are connected to the switching valve.
- The switching valve's output connects to an SSME actuator.
- The switching valve position is sent to downlink telemetry.
- The switching valve position spool will shift position when the pressure of the controlling system is less than 1200 to 1500 psia.
- Normal system operating pressure is 3000 psia.

Note: The switching valve system was originally designed to accommodate three hydraulic source inputs. A hydraulic leak in one main engine actuator could deplete all three hydraulic sources by switching through the primary, standby 1, and standby 2 hydraulic systems. To ensure that this could not happen, the existing hardware was modified for only two hydraulic source inputs.

4.8 ELECTROHYDRAULIC SERVOVALVE ASSEMBLY

The EH servovalve assembly consists of a torque motor, a second stage hydraulic valve assembly, a mechanical position feedback spring cage assembly, and a dynamic pressure feedback assembly. The purpose of the EH servovalve assembly is to generate secondary hydraulic pressure, which positions the power spool valve allowing the primary hydraulic pressure to flow to the primary piston and cause the SSMEs to gimbal. Each of these subsystems is described separately in the following pages.

4.8.1 Hydraulic Source Pressure

Each servovalve assembly receives hydraulic source pressure at 3000 psi and generates a secondary pressure that works via force summing on a power spool valve. The hydraulic Pressure (P) is shown entering the left-hand side of the page, (Figure 4-6), and is supplied to the next servovalve until all four servovalves are satisfied.

When the sum of the four secondary ΔP s is enough to move the power spool valve, the primary hydraulic source pressure is directed to the primary valve. The secondary ΔP is generated by rotation of the flapper and the flow of hydraulic fluid through the orifices, **B**, **1**, and **3**. The hydraulic flow is completed via a return line back to the orbiter hydraulic supply from the flapper.

4.8.2 Torque Motor

The purpose of the torque motor is to transform the command voltage generated by the ATVC to a secondary ΔP . The sum of this secondary ΔP with the other three is used to gimbal the SSMEs.

The torque motor consists of dual magnets and a flapper assembly. When the command voltage generates a torque, it causes the flapper to rotate in a clockwise or counterclockwise direction. In Figure 4-6 the torque motor has received a positive command voltage causing the flapper to rotate clockwise about its pivot. A pressure buildup will result in the left-hand 1 and 2 sections causing a force on the second stage valve that wants to move it to the right.

4.8.3 Second Stage Hydraulic Valve Assembly

The sum of the four second stage hydraulic servovalve assemblies causes displacement of the power spool valve. When the power spool valve is displaced, it supplies primary hydraulic fluid to the primary piston, which gimbals the SSMEs.

With our clockwise rotation of the flapper we saw that the second stage valve wants to be displaced to the right above.

4.8.4 Spring Cage Assembly

Each hydraulic actuator has a mechanical position feedback assembly, which is linked to each of the four torque motor flappers. The linkage between the flapper and the position feedback assembly consists of a piston (which is pinned to the linkage) and two springs. This linkage is known as the spring cage assembly, and there is one for each servovalve (Figure 4-6).

The purpose of the spring cage assembly is to allow the flapper to rotate initially in response to its command voltage input and then mechanically move the flapper back to its neutral (central) position, mechanically equalizing the command voltage input as the actuator main ram reaches its commanded position.

The mechanical position feedback system (including the spring cage assembly) is known as a negative feedback system because of its ability to counter the servovalves action in response to the actuator ram position. For example, the ATVC driver controlling the servovalve in Figure 4-6 issues a positive command voltage to the servovalve. Initially, the flapper would torque clockwise in response to the voltage input and block the left-hand orifices **1** and **3** (as shown by the arrow in the figure). This would cause a differential buildup in the hydraulic canals, causing a hydraulic pressure rise in the left canal and a hydraulic pressure drop in the right canal. The pressure changes would be transmitted to the hydraulic valve reservoirs through the passages at point **2**, causing the second stage valve to shuttle to the right. This allows hydraulic pressure to flow into the valve chamber at **A** on the right, out of the valve chamber at **C** on the right, and on down to the power spool valve. On the left side of the valve inlet **C**, hydraulic fluid is allowed to return into the left valve chamber and out passage **D** to the orbiter hydraulic supply.

The four hydraulic pressures that result from the four servovalves are channeled to the power spool valve and are known as the secondary hydraulic pressures. The sum of these four secondary hydraulic pressures drives the power spool valve, which allows hydraulic fluid to flow to the primary piston, when the power spool valve is displaced. The primary piston moves the main ram.

As the main ram moves into the position commanded by the ATVC driver, the mechanical position feedback mechanism is acted upon relative to the amount of position change. How this affects the servovalve is that the mechanical position feedback linkage (containing the spring cage assembly) shuttles to the left a proportional distance to that of

the main ram movement. This causes the feedback linkage to pull the flapper back to a neutral position as the main ram reaches the commanded position. In doing so, the differential pressure created by the flapper on the hydraulic canals is momentarily reversed and then bled off through the bleed orifices **1**. This momentary hydraulic pressure change aids in shuttling the hydraulic valve spool to a neutral position.

It was stated earlier that the mechanical position feedback mechanism moves to a neutral position as the main ram achieves its commanded position. In addition, each of the servovalves has two other feedback systems consisting of two feedback wires on each servovalve assembly. One feedback wire is linked between the flapper and the second stage valve, and the other is linked between the flapper and the power spool valve. As the hydraulic spool is shuttled due to hydraulic differential pressure, the feedback wire linked between the spool and the flapper pulls the flapper back slightly to reduce the differential pressure as the spool reaches its limit in movement. The feedback wire linked from the flapper to the power spool is used as a mechanical feedback link to the flapper.

4.8.5 Dynamic Pressure Feedback Assembly

Each SSME generates 232 natural frequencies through its range of thrust levels. These frequencies vary from 5.24 Hz to 959.99 Hz. Every natural frequency generated is damped out to an extent by the SSME servactuators. As the frequency vibration is transmitted to the actuator main ram, it causes the ram to extend and retract slightly in response to the transmitted frequency. This causes the hydraulic fluid within the primary cylinder to have pressure fluctuations relative to the cycled vibration to the main ram. The dynamic pressure feedback assembly receives these hydraulic pressure cycles and uses them to act upon its corresponding servovalve in order to apply a damping force at the servovalve assembly to damp the engine resonance.

The assembly consists of a cylinder, two springs, and a spool. The cylinder has three reservoirs; the left and right reservoirs are somewhat larger than the center reservoir. See the DPF casing in Figure 4-6. The spool extends through the center reservoir with a piston mounted in the center reservoir, which is held in a central position by the spring at either end of the spool. The two springs are mounted in the left and right reservoirs. The reservoirs are linked to the main cylinder. When a left and right cycled load is generated, a hydraulic pressure imbalance is generated between the left and right reservoirs. This causes the spool to shift either to the left or right. In doing so, the piston in the center reservoir will be shuttled back and forth, creating hydraulic pressure rises and pressure drops on either side of the piston.

These pressure changes are transmitted through two orifices **3** (one on either side of the torque motor assembly leading to the flapper). When the dynamic pressure feedback spool is shuttled, it causes hydraulic fluid to flow out of one canal against one side of the flapper and hydraulic fluid to flow into the other canal, removing hydraulic fluid resistance from the other side of the flapper. This results in the servovalve system generating opposing forces, which are hydraulically linked down to the power valve, which, in turn, transmits it down to the main ram assembly. This damps out any natural frequency vibrations being transmitted to the servactuators from the SSMEs.

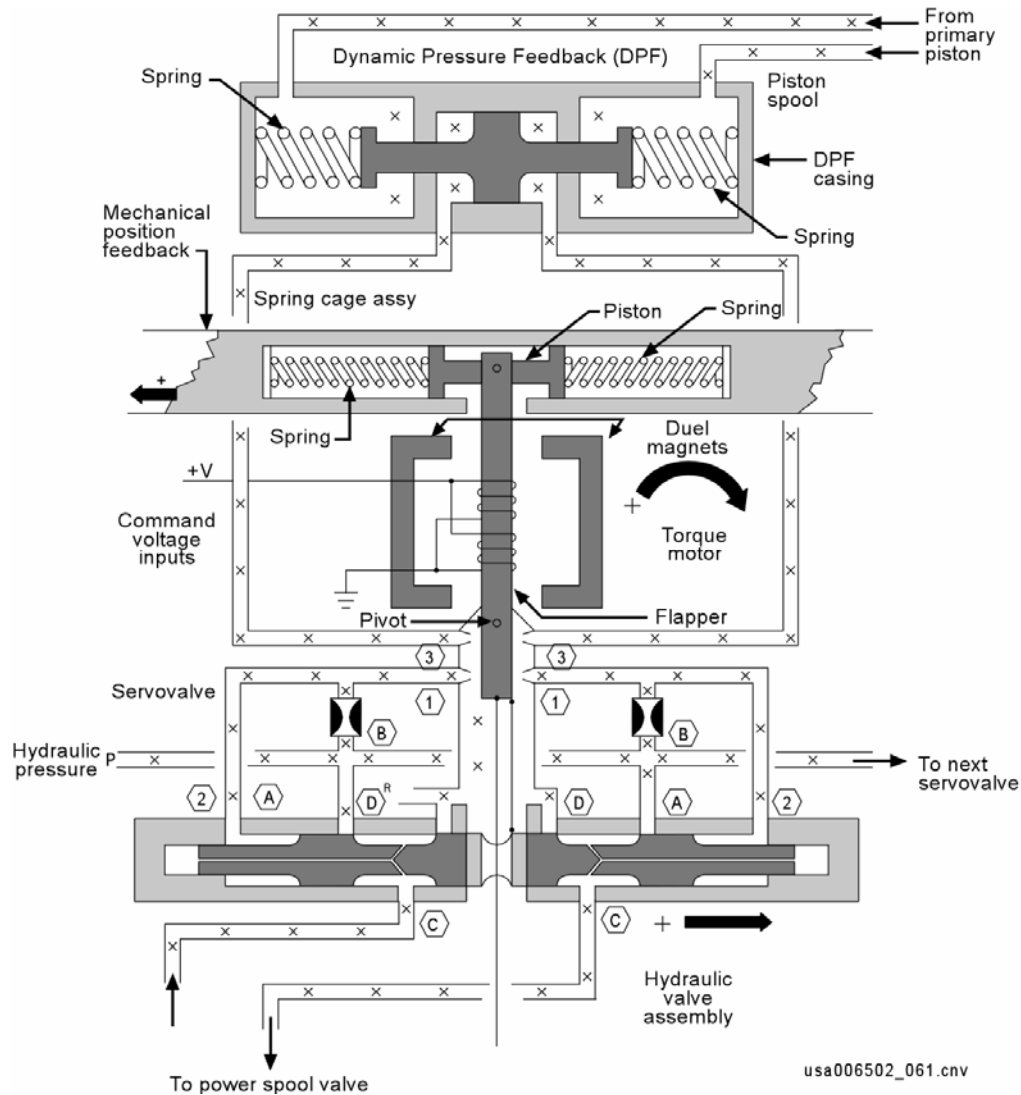
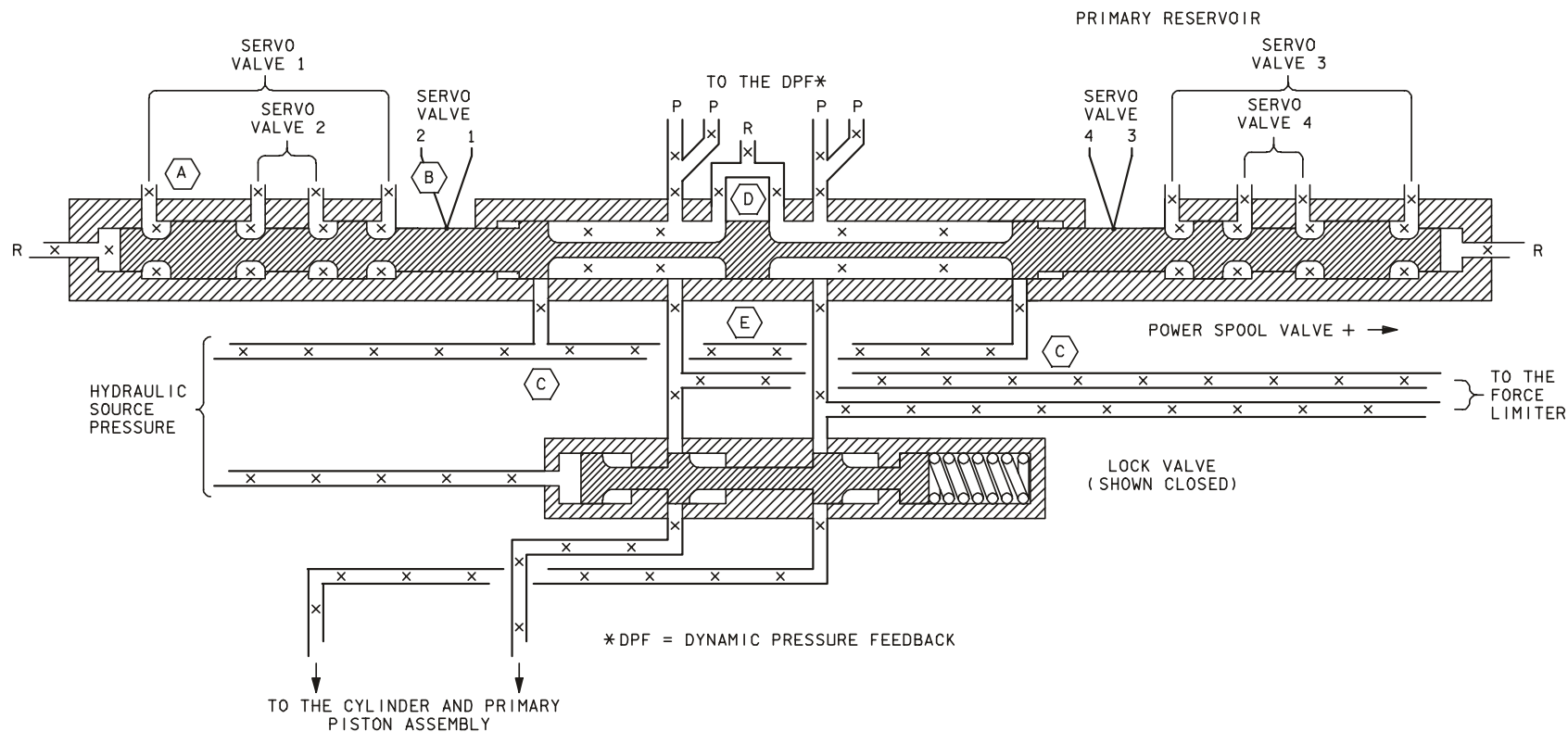


Figure 4-6. Electrohydraulic servovalve assembly

4.9 POWER SPOOL VALVE ASSEMBLY

The function of the power spool valve is to provide primary hydraulic pressure to the primary piston, which moves the SSME. When the power spool valve is displaced, the ram moves the SSME at a proportional rate. Figure 4-7 shows the power spool valve with all four servovalve outputs and the primary hydraulic pressure flow paths.



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Figure 4-7. Power spool valve assembly

The power spool valve assembly consists of a cylinder that contains a linear power spool, which is shuttled to the left or right when a SSME is required to be deflected. The power spool has a central piston whose motion is driven by the summation of the forces exerted by the four servovalves. Servovalves 1 and 2 have their fluid outputs on the left side of the power spool central piston and servovalves 3 and 4 have their fluid outputs on the right. A displacement of the power spool valve allows the primary hydraulic fluid to enter the central chamber by way of one of the inlets at points **C**. One of the return lines at **D** is blocked by the power spool valve piston in such a way that the primary hydraulic fluid flows into the primary piston assembly causing the SSME to move. When the primary piston moves, it causes the pressure to build in the return portion of the power spool valve chamber wanting to return the power spool valve to null. This action with the hydraulic actuator feedback causes the power spool valve to return to null when the SSME reaches its commanded position.

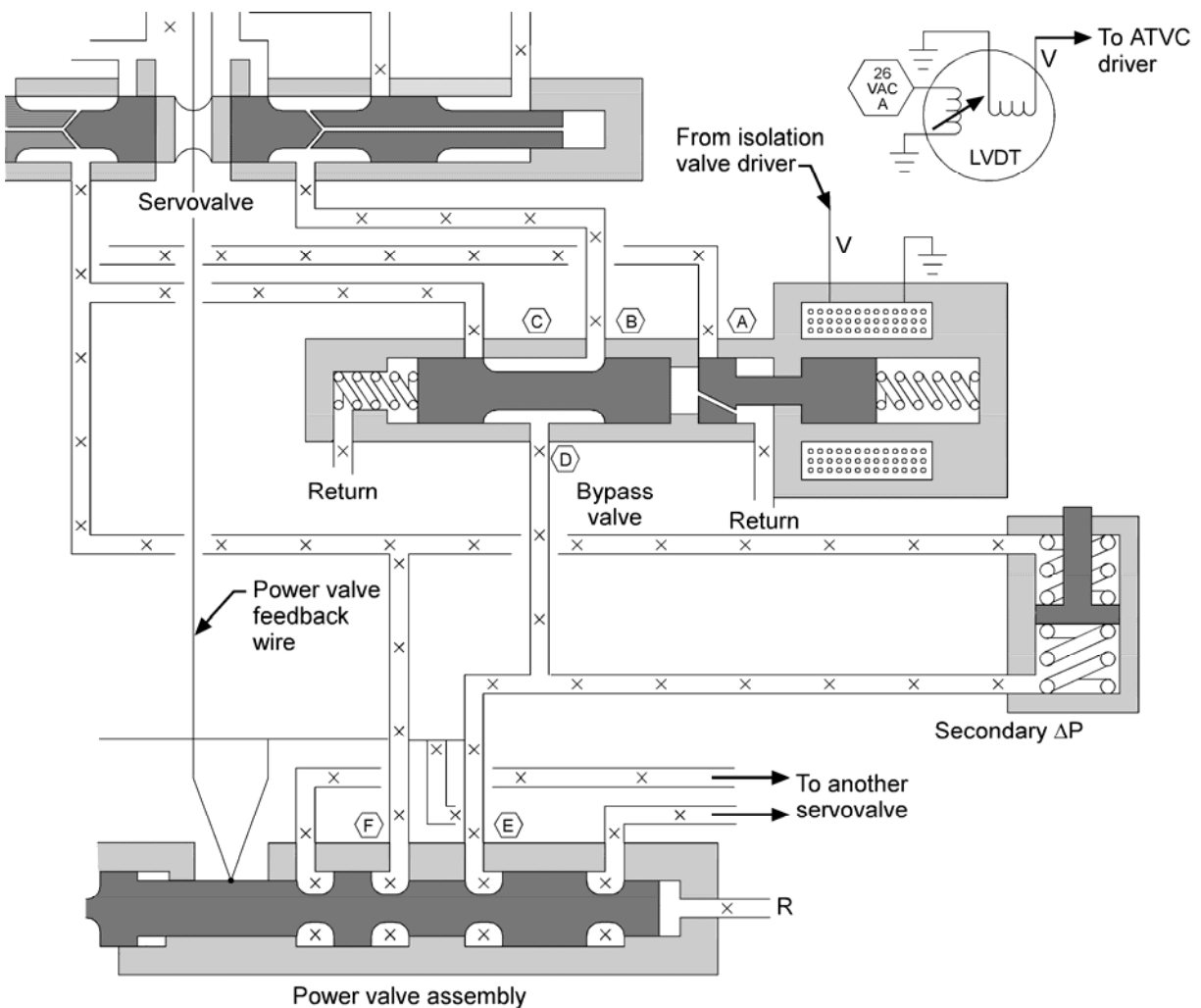
An example of how the system functions is as follows: As we saw in Figure 4-6, when the four servovalves receive equal positive voltage commands, the four servovalves want to move to the right. The sum of these four servovalves would exert a force on the power spool valve that would cause it to move to the right. In Figure 4-7 you can see that when the power spool valve moves to the right, the return line on the right at **D** is blocked by the central piston of the power spool valve and the orifice at the right hand **C** is opened. The primary hydraulic fluid enters the right passage at **E** and flows through the lock valve (provided the primary pressure is greater than the lock valve spring force) to the primary piston, which gimbals the SSME. There are also four feedback wires (one per servovalve) connected to the power spool at either end of the primary reservoir. These are used to aid in equalizing the amount of secondary hydraulic pressure being generated by the four servovalves, in order to correct for the hardware differences between the servovalves. It was mentioned that the primary hydraulic fluid flow is sent to the cylinder and piston assembly via the lock valve assembly. Note that the lock valve is shown in the closed position. The valve consists of a cylinder, a spool, and a spring, which is connected to the hydraulic feedlines between the power valve and cylinder piston assembly. The function of the lock valve is to hydraulically isolate the cylinder and piston assembly from the primary hydraulic source to prevent further movement of the actuator piston. The lock valve is activated through an orbiter supply pressure failure, which supplies the actuator its primary hydraulic pressure. When hydraulic pressure is sent to the actuator, source pressure is sent to the lock valve, shuttling the lock valve spool to the right against the spring and opening the flow path between the power valve and the cylinder and piston assembly. If there is a hydraulic failure, the lock valve spool shuttles left (due to spring pressure) to the closed position, preventing any further movement of the main piston ram in the cylinder. This locks the main ram in the last position before the hydraulic pressure failure.

4.10 BYPASS VALVE ASSEMBLY/SECONDARY ΔP FEEDBACK ASSEMBLY

The function of the second stage servovalve is to generate four secondary ΔP s to be algebraically summed on the power spool valve. The displacement of the power spool valve allows primary hydraulic fluid to flow into the primary piston and ram assembly to

gimbal the SSMEs. Redundancy management requires the capability to bypass one or more of the secondary delta pressures when they are determined to be bad.

The device that bypasses the secondary ΔP s is the bypass valve assembly. Figure 4-8 is a schematic of the bypass valve assembly. The bypass valve hydraulically shunts the secondary ΔP eliminating the pressure differential and canceling the bypassed secondary pressure driving force on the power spool valve. The secondary assembly transforms the hydraulic pressure to a voltage for monitoring purposes. The secondary ΔP assembly consists of the same components, which make up the primary ΔP feedback assembly (Figure 4-7). The secondary delta pressure transducer sends its sensed voltage signals to the ATVC driver. The ATVC driver uses the secondary ΔP signals in its equalization network. If the secondary ΔP exceeds a limit of ± 2200 psi for 120 milliseconds, the ATVC driver issues an isolation command from the isolation valve driver to the bypass valve (also called the isolation valve).



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Figure 4-8. Bypass valve

The bypass valve is a solenoid valve, which contains a solenoid, two springs, two pistons, and a cylinder. A diagram of the bypass valve is given in Figure 4-8. When the isolation command is issued to the solenoid, piston 1 shuttles to the right against the spring on the right. This allows hydraulic source pressure to flow into inlet **A** and raise the hydraulic pressure so that piston 2 is shuttled to the left, inhibits any further hydraulic flow from the servovalve right feed/return line to inlet **B**. The left feed/return line fluid flow from the servovalve is allowed to flow into inlet **C**, through the bypass reservoir, and out passage **D**. This allows the left return/feed line to equalize hydraulic pressure in either power valve reservoir connected to the servovalve. The secondary ΔP piston will stay neutral, showing a zero secondary ΔP value due to the equal fluid pressure on either side of the piston. When the bypass valve is activated, hydraulic pressure in both feed/return lines is equalized. For example, say the bypass valve in Figure 4-8 is activated. Passage **B** is cutoff to outlet **D**, and inlet **C** is opened to outlet **D**. Now, say a power spool shifts to the right. In doing so, hydraulic fluid would flow out of the power spool reservoir at point **E**, up through the bypass valve and out passage **C** and through the fluid lines to the power spool reservoir at point **F**. If the power spool were to shuttle left, the reverse flow would occur. In either case, no hydraulic resistance is generated at the power valve by the isolated servovalve.

When the isolation command is removed, piston 1 is shuttled to the left by way of the right-hand spring. In doing so, the hydraulic pressure holding piston 2 is removed, allowing piston 2 to shuttle to the right due to spring pressure on the left. This opens passage **B** and closes off passage **C**, which reinstates the servovalve in operation.

4.11 CYLINDER AND PISTON/RAM ASSEMBLY

The function of the cylinder and piston/ram assembly (Figure 4-9) is to produce linear movement (expansion or retraction) of the piston/ram end of the piston assembly. This portion of the actuator is fastened to the SSME (see Figure 4-10). The assembly consists of a main cylinder, a piston/ram, and a cam (within the aft portion of the piston/ram).

Hydraulic fluid flows in and out of the cylinder reservoirs on either side of the piston, causing the ram to move with linear motion (extension or retraction). The main cylinder reservoirs receive hydraulic pressure or return hydraulic fluid to the orbiter hydraulic supply through the feed/return lines leading to the power valve via the lock valve assembly. When hydraulic fluid pressure is applied to the reservoir on the backside of the piston (reservoir on the left), the piston/ram assembly moves to the right.

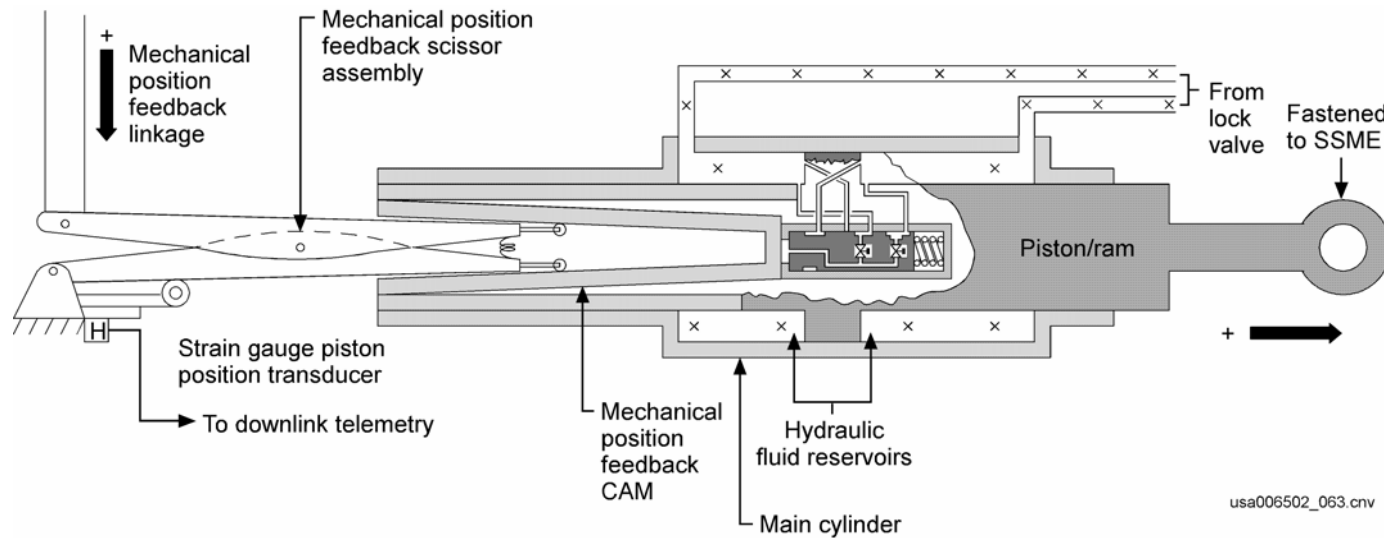


Figure 4-9. Cylinder and piston/ram assembly

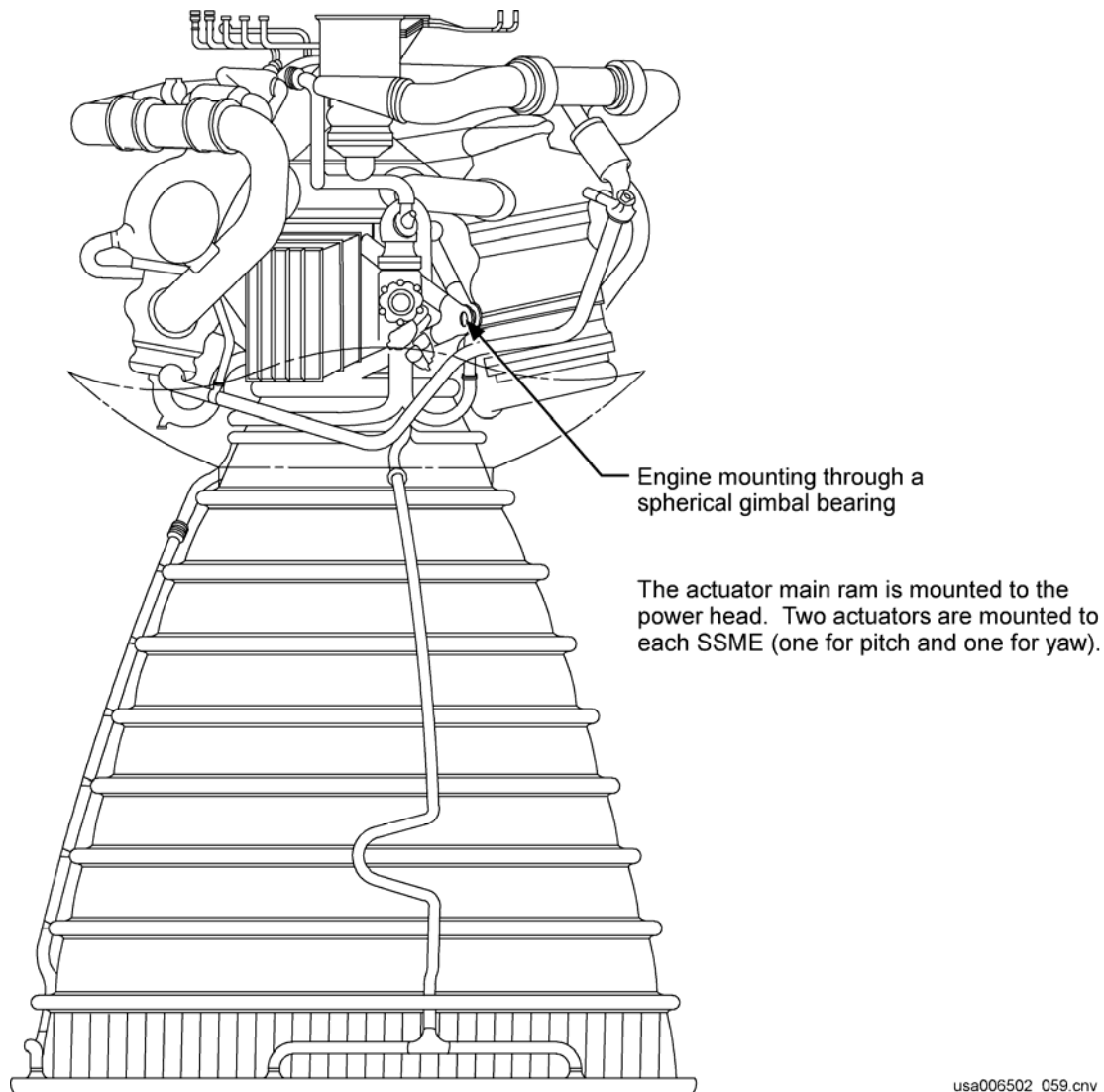


Figure 4-10. Space shuttle main engine

This results in the hydraulic fluid in the front reservoir (reservoir on the right) being forced back to the orbiter hydraulic supply via the feed/return line.

At the left end of the piston/ram assembly is the mechanical position feedback scissor assembly. The scissor assembly is fixed to the actuator main body (not shown) at the left end and is housed by the cone-shaped cam assembly at the right end. The scissor assembly is stationary, not having any linear motion, while the cam moves as part of the ram assembly. As the ram moves to the left (retraction), the cam causes the scissor assembly to contract on the right and expand on the left, pushing the mechanical position feedback linkage upward. This linkage leads to a series of linkages, which are connected to the flapper. The full linkage assembly was shown in Section 4.7. If the ram moves to the right (extension), the scissor assembly within the cam expands, causing the other end of the scissor to close together, pulling down on the mechanical position feedback linkage. This motion is linked to the linkages connected to the

servovalves, where the feedback linkages transmit the position changes of the main ram to the servovalves so as to remove the secondary fluid pressure to the power valve. This in turn removes the primary fluid pressure to the piston/ram assembly as it reaches the commanded position.

As a note of interest, when the hydraulic system has been powered down (MPS/TVC ISOL valves closed) for a long period, such as from launch day to entry day, the hydraulic fluid in the cylinder shrinks due to low temperatures. It shrinks enough to cause the SSME to move up to 3° when the orbiter enters the atmosphere. This movement is unacceptable: so to prevent this from occurring, the crew does the SSME HYD REPRESS procedure (Entry Checklist, Post-Burn) to allow hydraulic fluid to fill the void caused by the shrinkage. This is accomplished by opening the MPS/TVC ISOL valve for about 10 seconds.

This concludes the main text of the workbook, please review the appendices for supplemental information.

If this workbook has been completed as part of a formal training syllabus, the reader is reminded to complete and submit the evaluation form at the end of this document.

QUESTIONS

1. What are the components of an SSME actuator?
2. What is the purpose of the mechanical feedback assembly?
3. What is the normal operating pressure of an SSME actuator? Also, at what pressure will the switching valve spools shift position?
4. What are the parts of an EH servovalve?
5. What is the function of the EH servovalve assembly?
6. What is the purpose of the MPS hydraulic actuator?
7. Why is it that the center engine pitch actuator has a larger rated load and piston area?
8. Does each electrohydraulic actuator have its own bypass valve and secondary ΔP feedback assembly?
9. What are the two functions of the bypass valve?
10. Where is each SSME actuator fastened?
11. Draw in the lines to match up the correct combinations.

Servovalves	(a) Extends or retracts to gimbal an SSME
Power spool valve	(b) Provides primary hydraulic fluid to drive the SSME piston/ram. It is driven by secondary hydraulic pressure and is found within the secondary force sum piston
Primary piston	(c) Generates a command hydraulic pressure in response to position commands from the ATVC

APPENDIX A
ACRONYMS AND ABBREVIATIONS

ACTR	Actuator
ASA	Aerosurface Amplifier
ASC	Ascent
ATVC	Ascent Thrust Vector Control
BFS	Backup Flight System
C&W	Caution and Warning
CH	Channel
CMD	Command
CRT	Cathode Ray Tube
ΔP	Delta Pressure
DAP	Digital Autopilot
DBIA	Data B Isolation Amplifier
DFI	Development Flight Instrumentation
DPF	Dynamic Pressure Feedback
DPS	Data Processing System
DSC	Dedicated Signal Conditioner
EH	Electrohydraulic
ENG	Engine
ET	External Tank
FA	Flight Aft
FBK	Feedback
FCS	Flight Control System
FF	Flight Forward
G&N	Guidance and Navigation
GN&C	Guidance, Navigation, and Control
GNC	
GPC	General Purpose Computer
HYD	Hydraulic
Hz	Hertz
ISOL	Isolate
LVDT	Linear Variable Differential Transformer
MCC	Mission Control Center
MDM	Multiplexer/Demultiplexer
ME	Main Engine

MEC	Main Engine Controller
MM	Major Mode
MN	Main
MPS	Main Propulsion System
MSEC	Millisecond
MSK	Manual Select Keyboard
OPS	Operational Sequence
ops	Operations
OVRD	Override
P	Pressure
PASS	Primary Avionics Software System
PCA	Power Control Assembly
PRI	Primary
RHC	Rotational Hand Controller
RM	Redundancy Management
RPC	Remote Power Controller
S/C	Signal Conditioner
sec	Second
SEP	Separation
SEQ	Sequence
SOP	Subsystem Operating Program
SRB	Solid Rocket Booster
SSME	Space Shuttle Main Engine
STS	Space Transportation System
SW	Switch
TAL	Transoceanic Abort Landing
TVC	Thrust Vector Control
VLV	Valve

APPENDIX B ANSWERS

SECTION 1 ANSWERS

1. The purpose of ATVC is to provide attitude control and trajectory shaping by gimbaling of the SSMEs and SRBs by steering of the thrust vector (Section 1.2).
2. There are four electrohydraulic servovalves for each servoactuator. The electrohydraulic servovalves receive voltage commands from their respective ATVC MPS driver. For example, ATVC number 1 issues commands to the number 1 electrohydraulic valves on all the MPS actuators (Section 1.4.5).
3. When any engine is in the null position, the other engines cannot have an engine-to-engine collision with that engine (Section 1.4.6).
4. The crew can make inputs to the MPS ATVC system by using the Rotational Hand Controller, issuing override commands via the FCS switch or turning off the ATVC power (Section 1.4.2).
5. The FCS channel monitor switches are on panel C3 and the ATVC power switches are on panel 017 (Section 1.4.7.1).
6. The function of the hydraulic switching valve is to provide a single source pressure to the actuator. It does this by bypassing the primary supply for standby 1 source pressure to the actuator. The switching valve controls only two of the three orbiter hydraulic source pressures per actuator (Section 1.4.3.2).
7. Each servoactuator receives four identical command voltages from the four different ATVC drivers (Section 1.4.5).
8. The major subsystems composing the ATVC are the MPS ATVC CMD SOP, the ATVC black box, and the hydraulic servoactuator (Section 1.4.1).
9. The MPS ATVC command flow starts at the GPC and is terminated at the SSME actuator (Section 1.4.1).
10. Each main engine has a pitch and yaw gimbal capability supplied by the two gimbal actuators. Naturally the pitch and yaw actuators for each main engine may be algebraically summed to provide roll control to the vehicle (Section 1.4.3.1).
11. Each of the six SSME ATVC servoactuators is designed to produce linear motion so as to gimbal an SSME in either a pitch or a yaw axis (Section 1.4.5).

SECTION 2 ANSWERS

1. MPS ATVC CMD SOP stands for the Main Propulsion System Ascent Thrust Vector Control Command Subsystem Operating Program (Section 2.1).
2. The MPS ATVC SOP is the device that transforms DAP commands to MPS actuator extend and retract commands (Section 2.2).
3. The pitch and yaw displacement for each main engine are about their installed null position (Section 2.4).
4. The purpose of the MPS ATVC CMD SOP is
 - d. To distribute MPS pitch and yaw actuator position commands, received from the DAP, and MPS actuator override requests, issued by the crew (Section 2.2).

SECTION 3 ANSWERS

1. ATVC stands for Ascent Thrust Vector Control (Section 3.0).
2. Feedback to the EH valve driver is provided by the redundant channel equalization logic and mechanical feedback (Section 3.4).
3. Override commands are used to prevent port bypass by overriding the ΔP fault detection logic (Section 3.6).
4. If a port is already popped (isolated), the FCS CH SW in override will reactivate the popped port by inhibiting the ΔP fault logic from energizing the isolation valve driver. This removes the bypass capability since the isolation valve driver will lose power (Section 3.5).
5. When an ATVC power switch is in the off position, all the servovalves controlled by the affected channel are sent to
 - (a) A null position, which corresponds to a zero voltage (Section 3.7.4).
6. A secondary ΔP value greater than ± 2200 psid for 120 msec or longer will turn on the isolation valve driver (Section 3.5).
7. The primary functions of the ATVC are to provide command signals to the actuator and to provide fault detection of the hydraulic actuators (Section 3.2).
8. This position is called a port bypass (Section 3.5).
9. Four aspects of port bypass are
 - (a) A class 2 alarm tone
 - (b) System FCS CH (1,2,3,4) CRT message
 - (c) Down arrow under FCS channel (due to the MPS) on GN&C System Summary 1 CRT display
 - (d) Backup C&W light (Section 3.5)
10. When the channels wired to the bypass monitor fail, the bypass monitor is activated and the ports are bypassed on the affected channel (Section 3).
11. Four general characteristics of the ATVC are
 - (a) There are four ATVC channels per actuator
 - (b) Each channel string contains 10 ATVC drivers: 6 MPS and 4 SRB
 - (c) Each ATVC controls one port on one gimbal actuator.
 - (d) Each ATVC channel also feeds its corresponding servovalve on all 10 gimbal actuators. (ATVC 1 feeds servovalve number 1 on all 10 actuators.) (Section 3.3)

SECTION 4 ANSWERS

1. Each SSME actuator is comprised of four servovalves, one second-stage power spool valve, one primary actuator, and a switching valve (Section 4.4).
2. The purpose of the mechanical feedback assembly is to mechanically transmit to each EH servovalve the position of the main actuator and piston assembly, which provides the negative feedback to close the servoloop (Section 4.5).
3. Each SSME actuator has a switching valve assembly consisting of two valves mounted back to back. The normal system operating pressure is 3000 psia, and the spools shift positions in the valve cylinders when the pressure of the controlling system is less than 1200 to 1500 psia (Section 4.7).
4. An EH servovalve is made up of a torque motor, a second stage hydraulic valve assembly, a mechanical position feedback spring cage assembly, and a dynamic pressure feedback assembly (Section 4.8).
5. The EH servovalve generates a secondary delta hydraulic pressure which positions the power spool valve which in turn controls the SSME gimbaling (Section 4.8.1).
6. The purpose of the MPS hydraulic actuator is to change each thrust direction of the SSME as needed during the flight sequence of the orbiter (Section 4.2).
7. The center engine pitch actuator has a larger rated load and piston area to compensate for greater aero loads on the center engine (Section 4.3).
8. Yes, each EH actuator has its own bypass valve and secondary ΔP feedback assembly (Section 4.10).
9. The function of the bypass valve is twofold. First, it hydraulically shunts a secondary ΔP greater than ± 2200 psid (bypasses the port), and second, it relieves any further hydraulic resistance to the other servovalves in conjunction with the isolated servovalve (Section 4.10).
10. Each SSME actuator is fastened to the orbiter thrust structure and the powerhead of an SSME (Section 4.3).
11. Draw in the lines to match up the correct combinations.

Servovalves	(c) Generates a command hydraulic pressure in response to position commands from the ATVC
Power spool valve	(b) Provides primary hydraulic fluid to drive the SSME piston/ram. It is driven by secondary hydraulic pressure and is found within the secondary force sum piston
Primary piston	(a) Extends or retracts to gimbal an SSME

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SIZE OF AUDIENCE/CLASS:

1. How well did this lesson meet its purpose?

For each statement below, mark one box on the scale:

Strongly
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Strongly
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- a. *The lesson objectives are clearly stated.*
- b. *The lesson objectives are clearly defined.*
- c. *The lesson effectively teaches skills and information.*
- d. *The lesson meets its purpose and objectives.*

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2. How satisfying is the content of this lesson?

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- b. *The content is clear.*
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