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SOLID ROCKET BOOSTER THRUST VECTOR CONTROL SUBSYSTEM DESCRIPTION

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Structures and Propulsion Laboratory

September 1983

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16. ABSTRACT

This document identifies major Solid Rocket Booster-Thrust Vector Control (SRB-TVC) subsystem components and subcomponents used in the Space Transportation System (STS). Simplified schematics, detailed schematics, figures, photographs, and data are included to acquaint the reader with the operation, performance, and physical layout as well as the materials and instrumentation used.

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ABBREVIATIONS AND ACRONYMS

APU	Auxiliary Power Unit
DEG	Degree
DPF	Dynamic Pressure Feedback
ET	External Tank
F	Fahrenheit (degrees)
FSM	Fuel Supply Module
FT	Feet
G	Gravity
GAL	Gallons
GG	Gas Generator
GN_2	Gaseous Nitrogen
GPM	Gallons Per Minute
GSE	Ground Support Equipment
HP	High Pressure
HP	Horsepower
IEA	Integrated Electronics Assembly
IN	Inch
LH	Left Hand
LP	Low Pressure
MA	Milliampere
MPU	Magnetic Pickup Unit
MSFC	Marshall Space Flight Center
MTL	Material
NASA	National Aeronautics and Space Administration

N_2H_4	Hydrazine
PCV	Pulse Control Valve
PSI	Pounds Per Square Inch
PSIA	Pounds Per Square Inch Absolute
PSIG	Pounds Per Square Inch Gauge
REV	Revolution
RH	Right Hand
RPM	Revolutions Per Minute
SEC	Second
SOV	Shut Off Valve
SRB	Solid Rocket Booster
SRM	Solid Rocket Motor
TVC	Thrust Vector Control
W	Watt

TECHNICAL MEMORANDUM

SOLID ROCKET BOOSTER THRUST VECTOR CONTROL SUBSYSTEM DESCRIPTION

1. INTRODUCTION

1.1 Purpose

This document provides a physical and functional description of the Space Shuttle Solid Rocket Booster Thrust Vector Control (SRB-TVC) subsystem. This document covers the SRB-TVC major components, subcomponents, and the Solid Rocket Motor (SRM) electro-hydraulic servoactuators.

To maintain the descriptive intent of this document, dimensions, tolerances, and other numerical values have been omitted except where their inclusion adds understanding and clarity. Component specification numbers are noted to provide reference sources for individuals requiring more detailed information.

2. DESCRIPTION

2.1 SRB TVC Subsystem

The TVC subsystem in conjunction with the SRM provides pitch, roll, and yaw movements as desired by the Orbiter Guidance Navigation and Command system. The TVC subsystem and actuators (Figs. 1 and 2) located in the aft skirt, consists of two separate fluid power modules that supply hydraulic power to the SRB gimbal actuators to effect mechanical positioning of the nozzle in response to

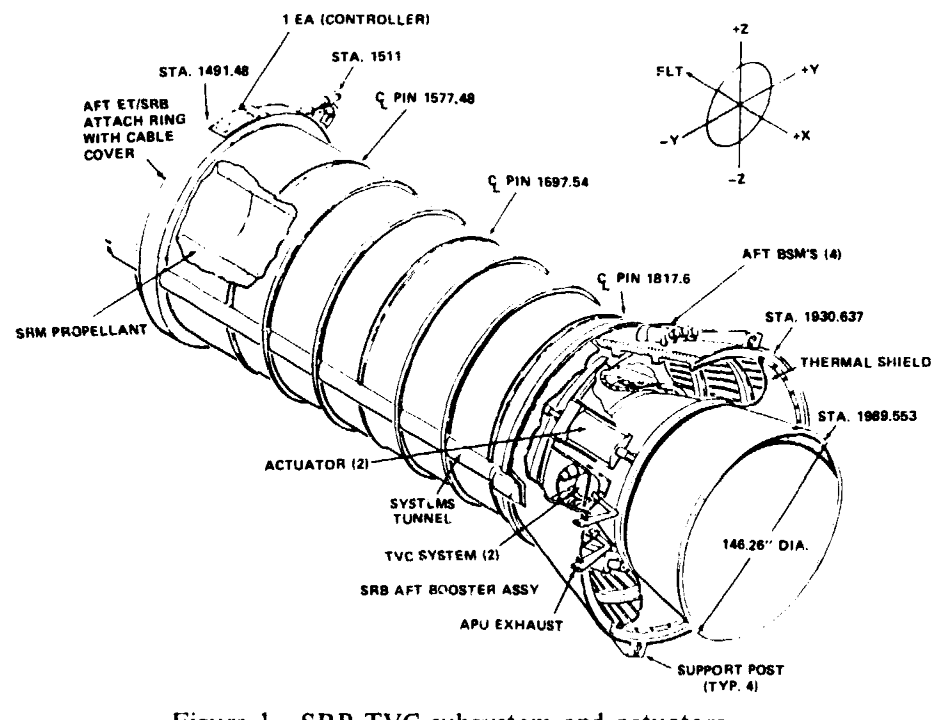


Figure 1. SRB TVC subsystem and actuators.

steering commands. One module controls the nozzle position in the tilt plane; the other module controls the nozzle position in the rock plane. If a single module fails, the surviving module increases its hydraulic power output and controls the nozzle position in both the rock and tile planes at a slightly degraded nozzle gimbal velocity. The actuators are designed to retain the nozzle in the null position throughout the separation sequence until water entry after SRB/External Tank (ET) separation.

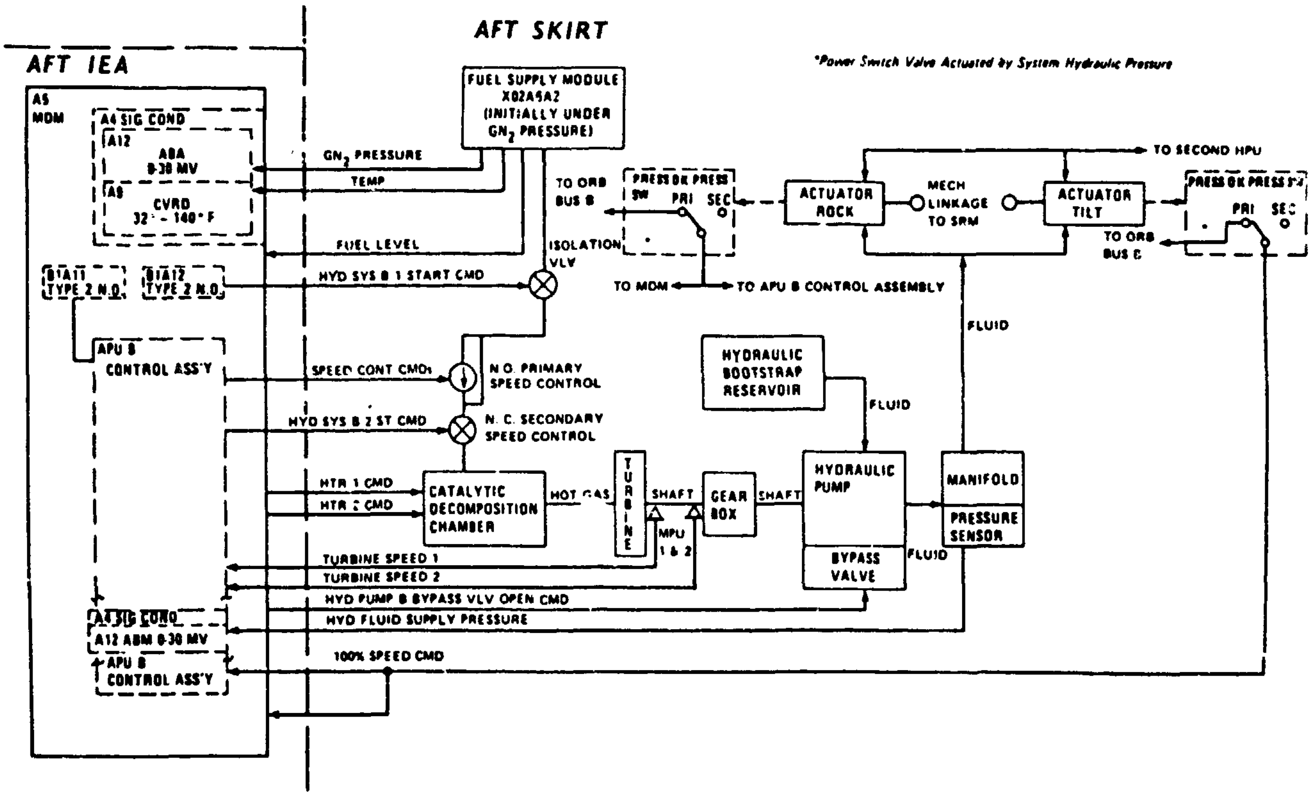
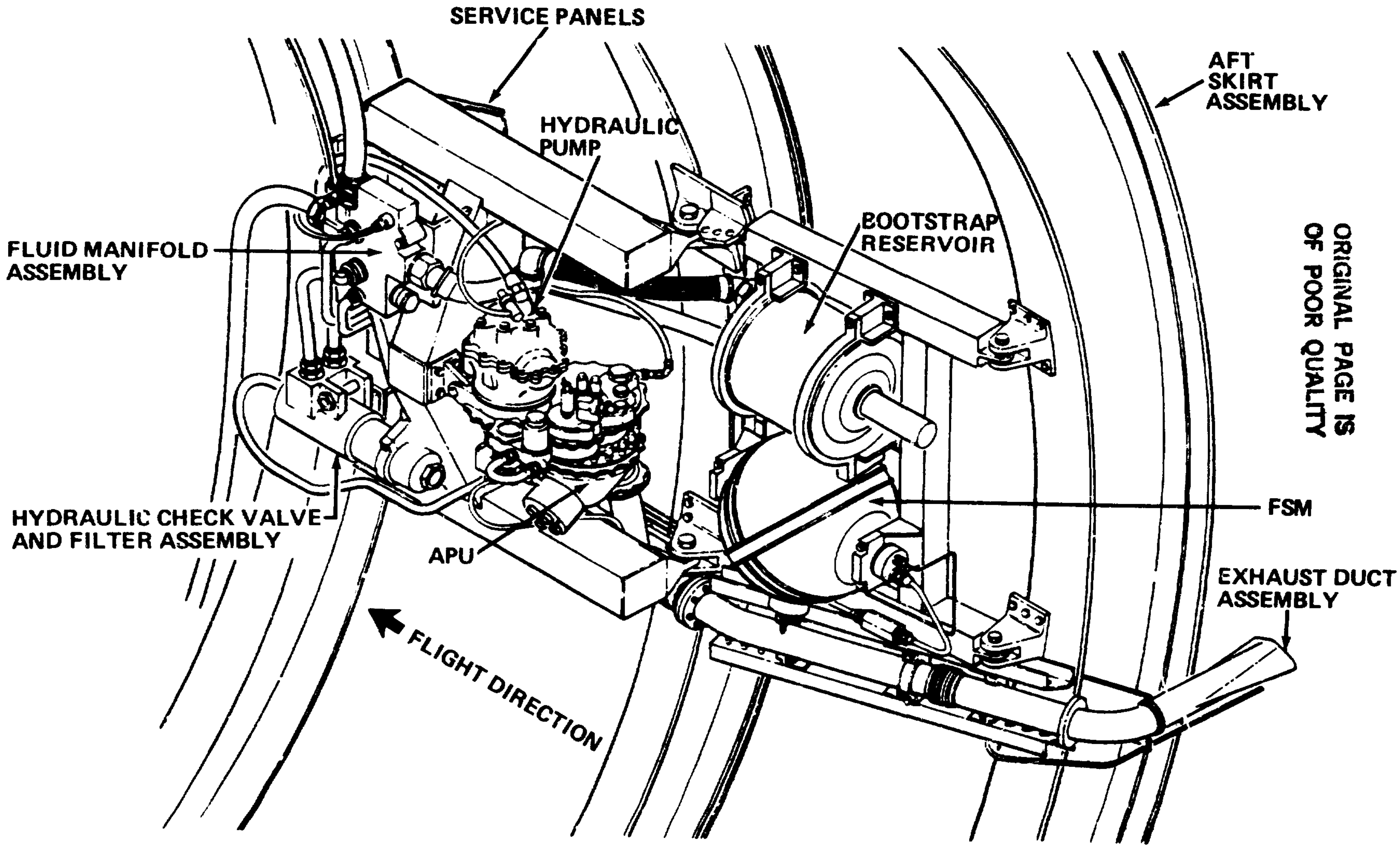


Figure 2. SRB-TVC schematic diagram.

2.2 Components

Each fluid power module consists of an upper panel, lower panel, and overboard exhaust as shown in Figure 3. The components mounted to the upper panel are:

- Auxiliary Power Unit (APU)
- Gearbox (mounted to APU)
- Hydraulic Pump (mounted to gearbox)
- Fluid Manifold Assembly
- Hydraulic Fluid Check Valve and Filter Assembly
- Fuel Isolation Valve
- Service Panels
- Instrumentation and Wiring
- Interconnecting tubing



NOTE: FUEL ISOLATION VALVE, SERVOACTUATOR, WIRING, AND INSTRUMENTATION NOT SHOWN.

Figure 3. SRB TVC panel locations.

Mounted adjacent to the upper panel on the skirt is the hydraulic fluid accumulator and an APU lube oil accumulator.

The components mounted to the lower panel are:

- Hydraulic Bootstrap Reservoir
- N_2H_4 Fuel Supply Module (FSM)
- Instrumentation and Wiring
- Interconnecting Tubing

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The overboard exhaust components are:

- Upper Duct Assembly
- Lower Duct Assembly
- Brackets

In addition to the above, two electro-hydraulic servoactuators, mechanically linked to the nozzle and hydraulically connected to the fluid power modules, and two APU controllers located in the Aft IEA comprise the total subsystem. Figures 1, 2, and 3 depict these locations. General system requirements are as follows:

TORQUE (FT. LBS.)................4.2×10^6
MOMENT ARM (IN.).................64
GIMBAL ANGLE (DEG)..............± 5.0
ACTUATOR AREA (IN^2)............32.32
SLEW RATE (DEG/SEC)..............5.0
ACTUATOR STROKE (IN)............± 6.40

- ACTUATORS CAPABLE OF SIMULTANEOUSLY DEFLECTING THE SRB NOZZLE ± 5° IN EACH ACTUATOR PLANE.
- SIMULTANEOUSLY GIMBAL BOTH ACTUATORS 5°/SEC AT RATED LOAD (100% APU SPEED).
- AT 110% APU SPEED SIMULTANEOUSLY GIMBAL BOTH ACTUATORS 3°/SEC AT RATED LOAD OR ONE ACTUATOR AT 5°/SEC AT RATED LOAD.

FULL FLOW SYSTEM PRESSURE (PSIA).......................3050 ± 50
NO FLOW SYSTEM PRESSURE (PSIA).........................3200 ± 50
RETURN PRESSURE (PSIA).................................60 TO 65
REDUNDANCY...FAIL SAFE
100% SPEED (NORMAL) FLOWRATE (GPM)....................55
110% SPEED (BACKUP) FLOWRATE (GPM)....................70
HYDRAULIC HP (PUMP OUTPUT) AT 100% SPEED...........98
HYDRAULIC HP (PUMP OUTPUT) AT 110% SPEED...........124
HYDRAULIC OIL..MIL-H-83282A

FLUID VOLUME (GAL)......................................15
COMPONENT QUAL TEMPERATURE RANGE (°F)...............20° TO 250°
SYSTEM MAXIMUM OPERATING
(CLOSED LOOP) TEMPERATURE INCREASE (°F)............25°

<u>OPERATIONAL TIME</u>

PRELAUNCH (SEC)..25
POWERED FLIGHT (SEC)....................................125
CONTINGENCY (SEPARATION) (SEC).........................10
TOTAL (SEC)................160
MISSIONS (REUSE)...20

3. COMPONENT DESCRIPTION

3.1 APU (13A10010)

The APU provides mechanical shaft power to the hydraulic pump. A pictorial and cutaway view of the APU is seen in Figures 4 and 5 (respectively). Figure 6 depicts the hardware scheme. The flow diagram for the APU is shown in Figure A-1.

The APU is a hydrazine-powered decomposition turbine engine of the single wheel reentry design (paragraph 3.1.5). The principle parts of the APU are as follows:

- Fuel Pump
- Gas Generator (GG)
- Fuel Pulse Control Valve (PCV)
- Fuel Shutoff Valve (SOV)
- Turbine Assembly
- Gearbox
- Lubrication System
- Controller

A description of the subcomponents is presented in the following paragraphs. The reader is referred to paragraph 3.1.9 for a general summary of APU operation.

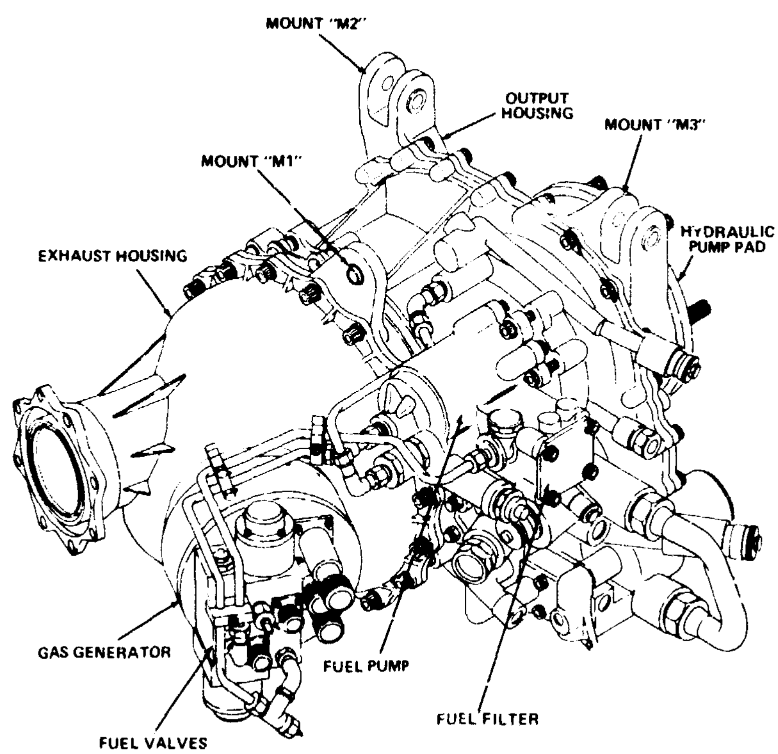

Figure 4. Auxiliary Power Unit.

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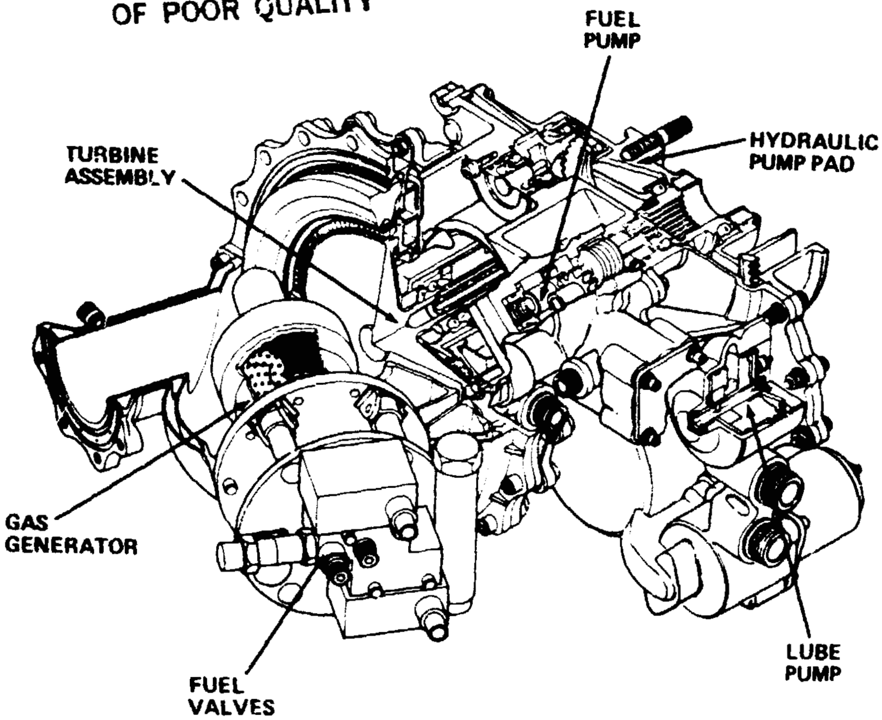


Figure 5. APU, cutaway view.

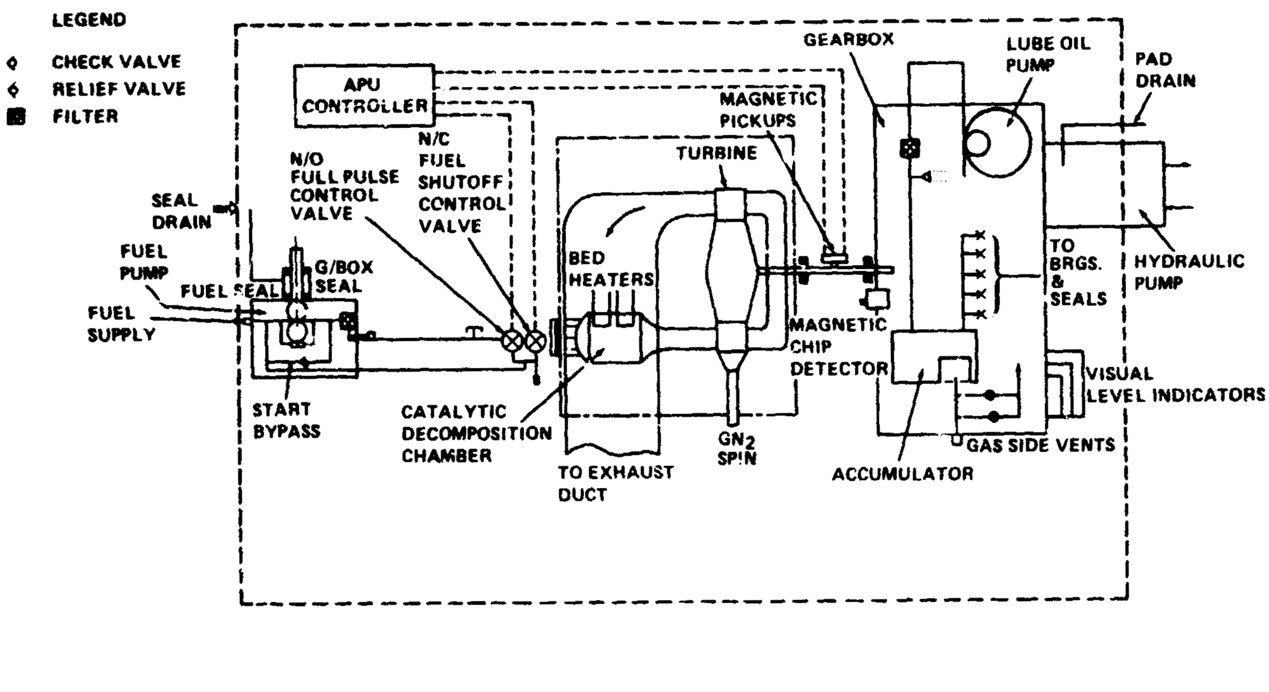


Figure 6. APU hardware schematic.

3.1.1 Fuel Pump

As shown in Figures 4 and 5, the fuel pump is an integral portion of the APU. The fuel pump, driven at 5.28 percent turbine rotor speed, is of the positive displacement external gear design with an overpressure relief valve, a start bypass check valve, and a 25-micron replaceable discharge filter element. Fuel is supplied at a temperature of 45°F to 150°F. Fuel is supplied at a nominal pressure of 400 psia at APU start, down to 200 psia (minimum) at shutdown. Supply pressure to the gas generator is 1270 psia. Refer to paragraph 3.1.9 for a general summary. Figure A-1 is a fuel flow diagram.

3.1.2 Gas Generator

The gas generator (Fig. 7) thermally decomposes the liquid hydrazine into gas which is fed to the nozzle plenum, expanded through the turbine nozzles, and directed against the turbine wheel. The gas generator is comprised of five major parts: the housing, the inner bed, the outer bed, and injector. In addition, the gas generator has two 60 W bed heaters (one active and one redundant) to insure the minimum bed temperature at 190°F in nonoperational periods of time.

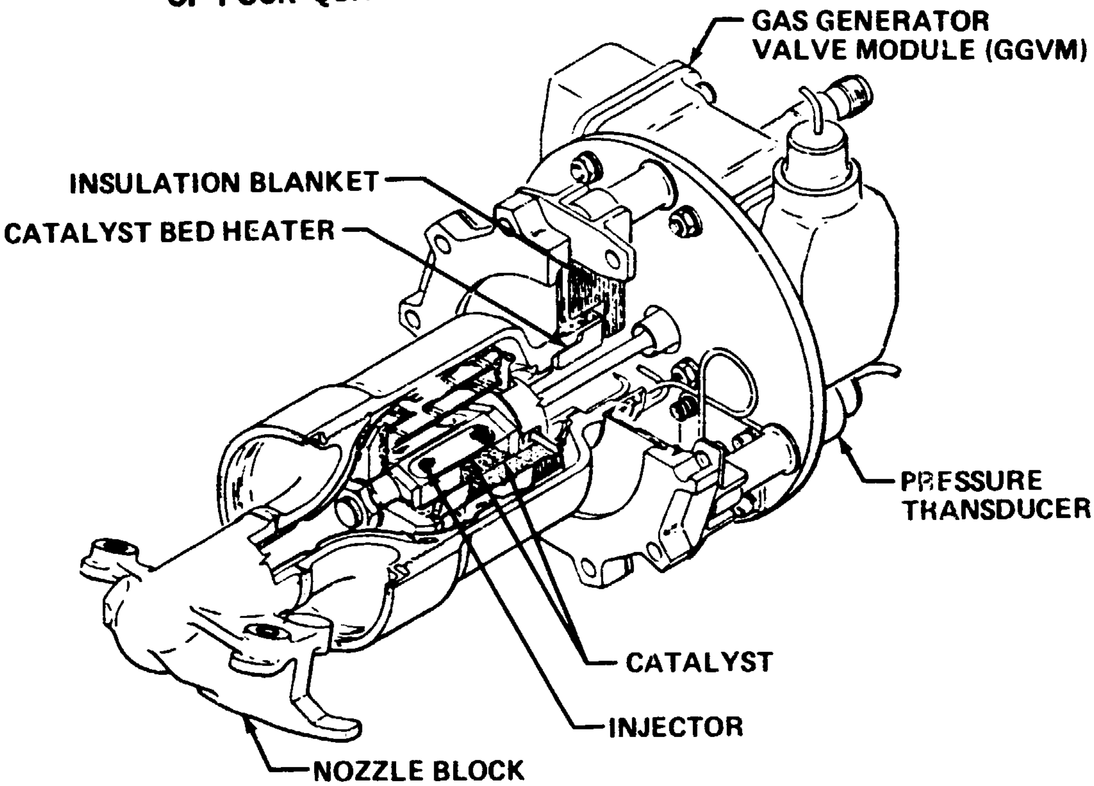
3.1.3 Fuel Pulse Control Valve (PCV)

The fuel pulse control valve is a direct acting, 3 port, 2 position, poppet type solenoid valve. The PCV provides pulse or "bang-bang" control of fuel flow from the fuel pump to the gas generator in response to signals from the controller. These control signals are the result of a magnetic pickup unit (MPU), located on the turbine shaft which senses rotor speed. In the normal (open) position, the PCV permits fuel flow from the fuel pump to the gas generator and shuts off the bypass fuel flow to the pump inlet. In the closed position, flow to the gas generator is stopped and the bypass circuit is opened routing fuel back to the fuel pump inlet.

The PCV and SOV (paragraph 3.1.4) are manifolded in series to the same housing. Both the PCV and SOV have position indication switches to positively indicate the normal poppet position.

3.1.4 Fuel Shutoff Valve (SOV)

The fuel shutoff valve is a direct acting, three port, two position, poppet type solenoid valve. In the primary mode, the SOV shuts off fuel flow to the gas generator until the APU is ready for operation. In its secondary mode, the SOV controls the flow of fuel from the fuel pump to the gas generator in response to signals from the controller. The SOV secondary mode is series redundant to the PCV and cycles only if the PCV does not control fuel flow properly. In the normal (closed) position, the SOV shuts off fuel flow to the gas generator and bypasses it back to the fuel pump inlet. In the through flow (open) position, the SOV permits fuel flow to the gas generator and closes the fuel flow bypass circuit. SOV operation in the primary mode, requires one cycle from the closed position to the open position at the beginning of APU operation and one cycle from the open position to the closed position at the termination of APU operation. In the secondary mode of operation, the SOV operates in a pulse or "bang-bang" fashion as described for the PCV (3.1.3).



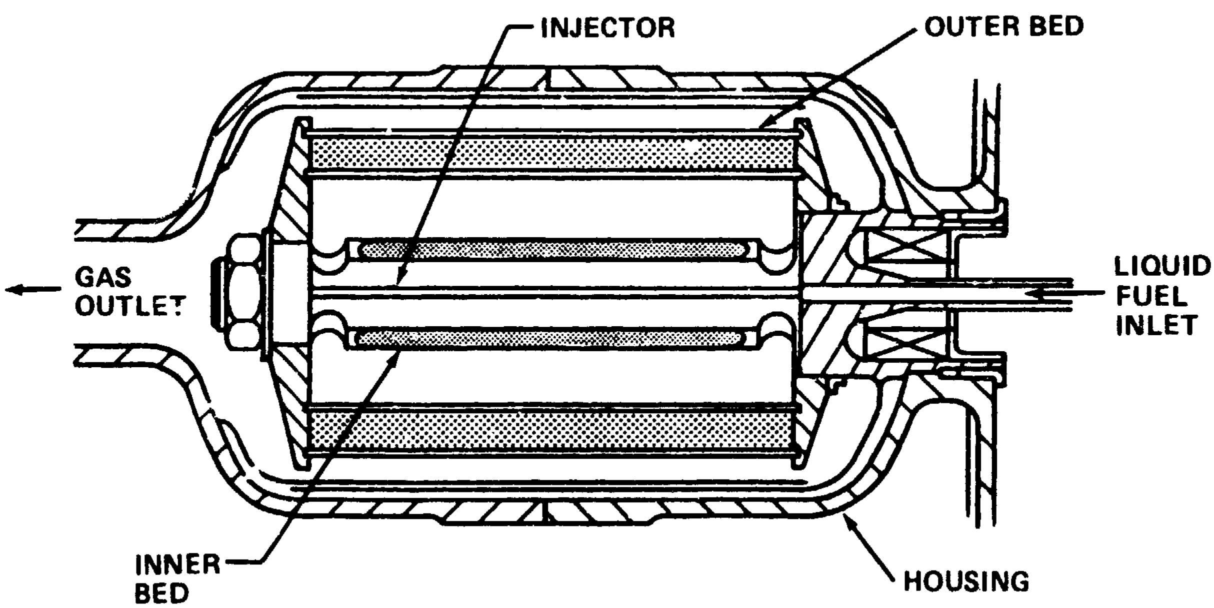


Figure 7. Gas Generator.

3.1.5 Turbine Assembly

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The turbine is of the one stage, single wheel, axial flow impulse, reentry type design. The assembly (Fig. 8) operates at partial admission, is pressure compounded, and speed controlled by pulse modulation fuel flow. The turbine assembly has a gaseous nitrogen spin capability to checkout the APU without hot firing. The following is a list of turbine assembly characteristics:

Rotational Speed (RPM) 72,000
Shaft Horsepower (HP) 135 (100%)
Pitch Diameter (in.) . . . . 5.500 (Hot)
Tip Speed (ft/sec) 1821
Radial Clearance (in.) . . . . 0.010 (Hot)
Number of Blades 123
Bearings (Type) . . . . Ball, Class ABEC 7, M50 MTL
Rotor Material . . . . Rene' 41
Housing Material . . . . Stellite 31
Shaft Material . . . . Rene' 41

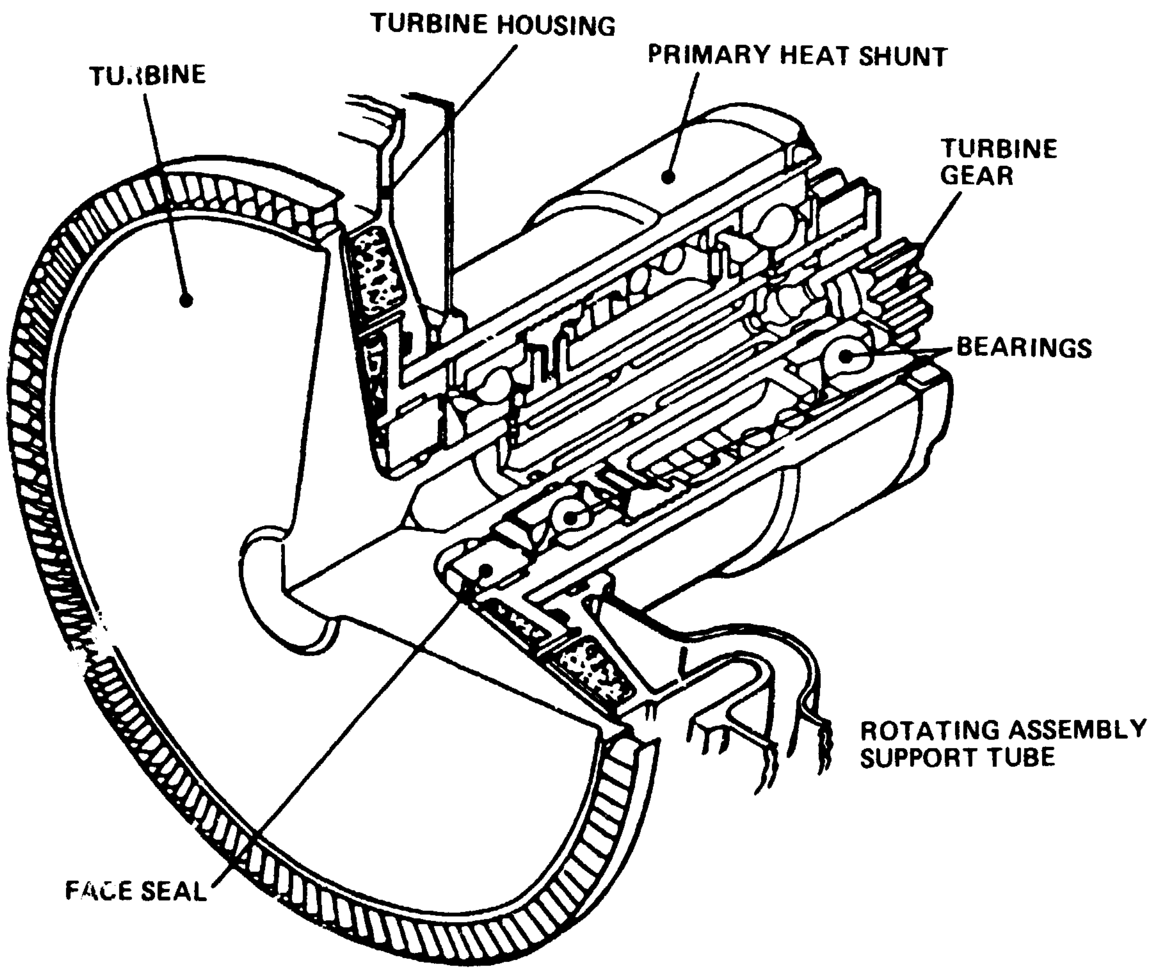

Figure 8. Turbine Assembly.

3.1.6 Gearbox

The gearbox subassembly is depicted in Figure 4. The APU gearbox is of the single jack shaft, two stage reduction design. The gearbox provides a speed reduction of 18.93 from the APU output pad to the hydraulic pump. The gearbox lubrication system is described in the following paragraph.

3.1.7 Lubrication System

The lubricati n system used for the SRB APU gearbox is an all attitude system. The system incorporates a centrifugally fed scavenging circuit, a supply circuit, an accumulator, a replaceable filter, a magnetic chip detector, and an internal gear gerotor type lubrication supply pump. During operation, the lubrication is directed radially outward from the rotating assemblies and ducted to the scavenge pump, hence, the all attitude capability. The accumulator controls gearbox oil level insuring no windage losses. Upon shutdown, the accumulator spring forces all of the accumulated oil into the gearbox. Figure 9 displays lubrication supply and scavenge circuits. Figure A-1 displays the fluid flow schematic.

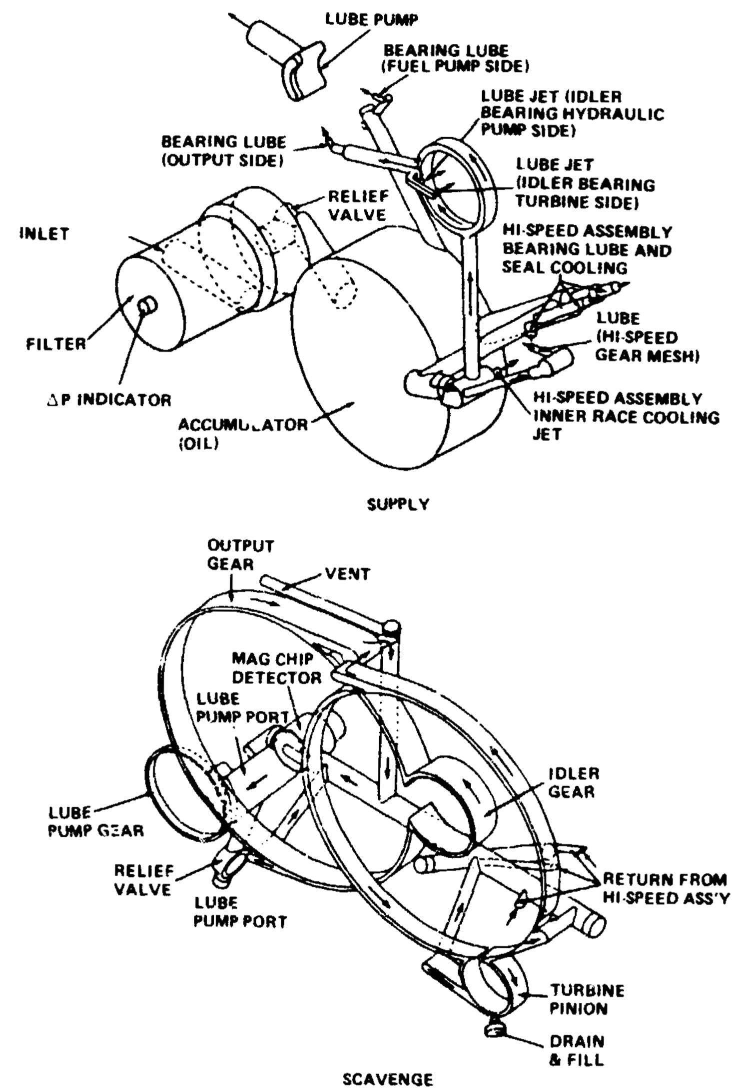

Figure 9. Lubrication system.

The SRB APU lubrication system employs an equalization device to protect it from seawater intrusion during immersion in the ocean. The device consists of an externally mounted, oil filled bladder type accumulator, connected to the gearbox through a flex hose and snap open type pressurization valve. Upon entering the water, the accumulator bladder is compressed by the water pressure which forces oil against the pressurization valve poppet causing it to snap open. This permits oil from the accumulator to flow into the APU gearbox and equalize the internal and external pressures on the gearbox.

3.1.8 Controller

The controller, located in the aft IEA (Fig. 1), provides the APU with turbine speed control logic. Speed is controlled by signaling the APU's PCV or SOV opened and closed in response to pulses from MPUs located on the turbine shaft. The APU control speeds are 100 percent speed (72,000 rpm), 110 percent speed (79,200 rpm), or 112 percent speed (80,649 rpm). The speed tolerance is ±8 percent of the 100 percent value (±5,760 rpm) for all control speeds. As long as the externally generated 100 percent (normal) signal is inputed to the controller, the APU fuel supply is controlled by the PCV. Without the externally generated 100 percent signal, the APU is controlled with the PCV at the 110 percent (backup) speed. Should the APU speed exceed control limits at either the 100 percent or the 110 percent speeds using the PCV, the controller automatically controls the APU at the 112 percent (secondary) control speed using the SOV. The 100 percent and 110 percent speed control are accomplished through a common circuit and common components. The 112 percent speed control is accomplished through a circuit totally separate from and completely redundant to both the 100 percent and the 110 percent speed controls. Figure 10 shows the general control scheme.

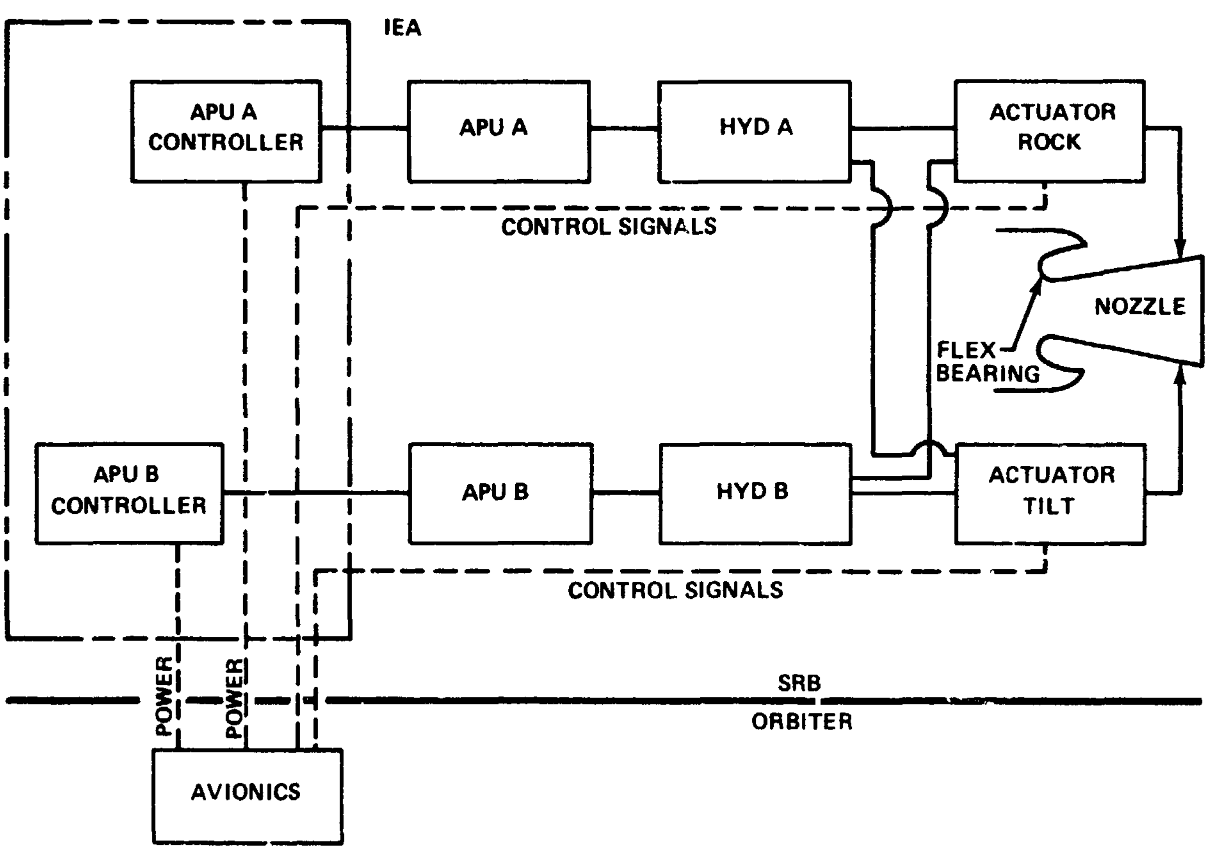

Figure 10. General control schematic.

3.1.9 APU Summary Data

APU summary data is given in the following:

SYSTEM

RATED OUTPUT POWER (100%)	135 HP
POWER OUTPUT (110% DESIGN)	148 HP
POWER OUTPUT (112% DESIGN)	151 HP
DRIVEN ACCESSORY	ABEX HYDRAULIC PUMP
OUTPUT PAD SPEED	3803 RPM
FUEL	HYDRAZINE
SPEED TOLERANCE	± 8%
OPERATIONAL TIME (TOTAL)	160 SEC
PRELAUNCH	25 SEC
POWERED FLIGHT	125 SEC
CONTINGENCY (SEPARATION)	10 SEC
WEIGHT (APU PLUS GEARBOX)	73 LBS
SYSTEM SUPPLIER	SUNDSTRAND

COMPONENTS

TURBINE ASSEMBLY

TYPE	AXIAL FLOW IMPULSE
ROTATIONAL SPEED (100%)	72,000 RPM
SHAFT HORSEPOWER (100%)	135 HP
ROTOR PITCH DIAMETER	5.500 IN
TIP SPEED	1821 FT/SEC
NUMBER OF BLADES	123
RADIAL CLEARANCE (HOT)	0.010 IN
BEARINGS (TYPE)	BALL, CLASS ABEC 7, M50 MTL.
ROTOR MATERIAL	RENE' 41
SHAFT MATERIAL	RENE' 41
HOUSING MATERIAL	STELLITE 31
MANUFACTURER	SUNDSTRAND

FUEL PUMP

TYPE	POSITIVE DISPLACEMENT EXTERNAL GEAR
SPEED	3803 RPM
DISPLACEMENT	.1085 IN^3/REV
DESIGN FLOW	.217 LBM/SEC
DRIVE	GEARBOX DIRECT AT 18.93 : 1 REDUCTION FROM TURBINE SPEED
FUEL TEMPERATURE	45°F TO 150°F
INLET PRESSURE (NOMINAL)	400 PSIG TO 200 PSIG
OUTLET PRESSURE	1725 PSIA
FILTER (AT DISCHARGE)	25 MICRON
MANUFACTURER	SUNDSTRAND

GAS GENERATOR

TYPE	CATALYTIC
CATALYST	SHELL X-405
OPERATING PRESSURE	1403 PSI
OPERATING TEMPERATURE	1700°F
MANUFACTURER	ROCKET RESEARCH CORP.

CONTROLLER

COMPONENTS	CONVENTIONAL (EEE PARTS)
TYPE CONTROL	VARIABLE FREQUENCY, PULSE MODE FUEL CONTROL

FUEL VALVES (PCV AND SGV)

TYPE	SOLENOID VALVE 2 POSITION, POPPET
MANUFACTURER	MAROTTA

GEARBOX

TYPE	SINGLE JACK SHAFT, TWO STAGE REDUCTION
SPEED RATIO	18.93 : 1
LUBRICATION SYSTEM	CLOSE CONFORMING, GEAR SCAVENGING
LUBRICATION PUMP	INTERNAL GEAR
NOMINAL OPERATING PRESSURE	20 PSIA
MANUFACTURER	SUNDSTRAND

3.2 Hydraulic Pump (13A10038)

The hydraulic pump (Fig. 11) is a variable delivery, APU driven, single-stage variable displacement cam actuated unit with pressure compensated control to regulate the volume of fluid delivered to the actuator while maintaining a predetermined pressure. The reader is referred to the Appendix (Fig. A-1) for a fluid flow diagram.

The heart of the pump is a revolving barrel assembly that contains nine pistons. As the assembly rotates, an inclined cam plate causes the pistons to reciprocate. The angle of the inclined cam plate is varied by moving a trunnioned hanger on which it is mounted, thereby changing the displacement of the pump. The hanger, in turn, is controlled by the pressure compensator.

The pressure compensator (Figs. 12 and E-1) regulates the volume of fluid delivered in accordance with the hydraulic demand, thereby maintaining a predetermined pressure. To do this, system pressure is directed to a spring loaded spool valve assembly. In the overpressure mode, system pressure exceeds the spring load and the spool is moved to admit fluid into a stroking cylinder. The stroking piston, in turn, moves the trunnioned hanger and changes the cam angle such that the volume delivered decreases. In the underpressure mode, the spool is moved to vent the hydraulic fluid in the stroking cylinder to the case. The stroking piston then retracts and a spring load on the hanger moves the cam plate angle and thus increases the volume pumped. Pressure compensator operation is depicted in Figure 12. In addition to the pressure compensation feature, a bypass solenoid valve is used to vent hydraulic pressure (i.e., pump load) during APU startup. This feature allows the APU to operate at the proper output speed level before full pump demand is placed on the system. Hydraulic pump characteristics are as follows:

Type: Variable delivery, single stage variable displacement

Control: Pre-set pressure compensated cam actuated, volume regulated

Weight (dry)	34.0 lb
Rated Outlet Pressure	3200 + 50 psig
Rated Inlet Pressure	55 to 75 psig
Flow (at rated load, 3050 psig)	55.0 gpm
Flow (maximum load, 3050 psig)	66.3 gpm
Rated speed (P)	3803 rpm
Hydraulic Fluid	MIL-H-83282A
Fluid Volume	1.5 gal
Manufacturer	Abex
Model No.	AP27V-10

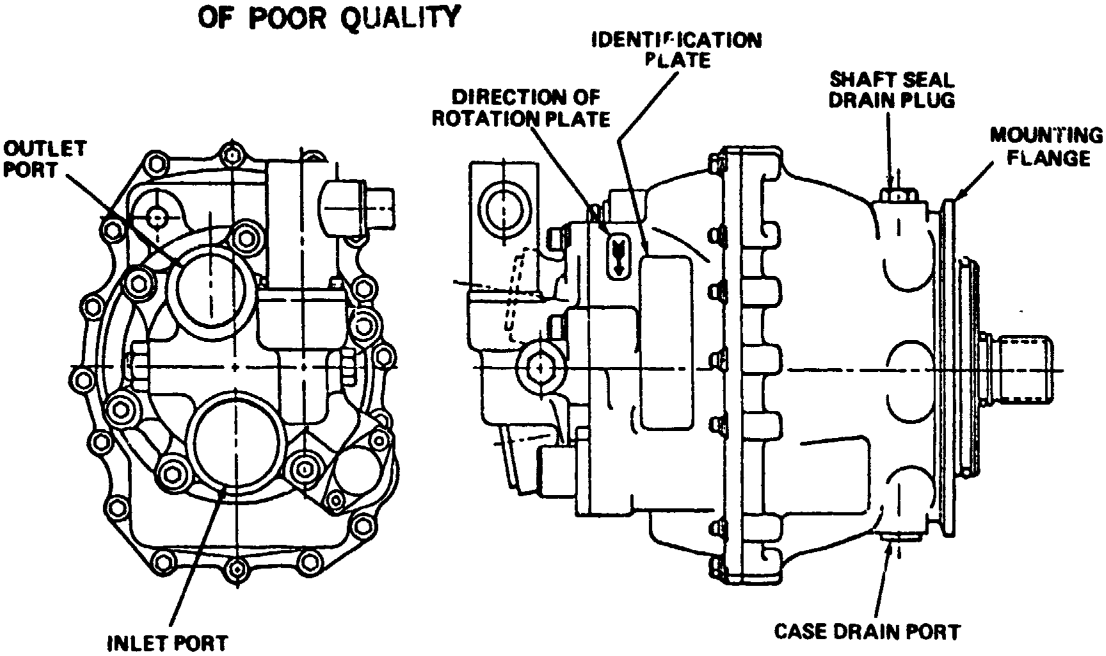

Figure 11. Hydraulic pump.

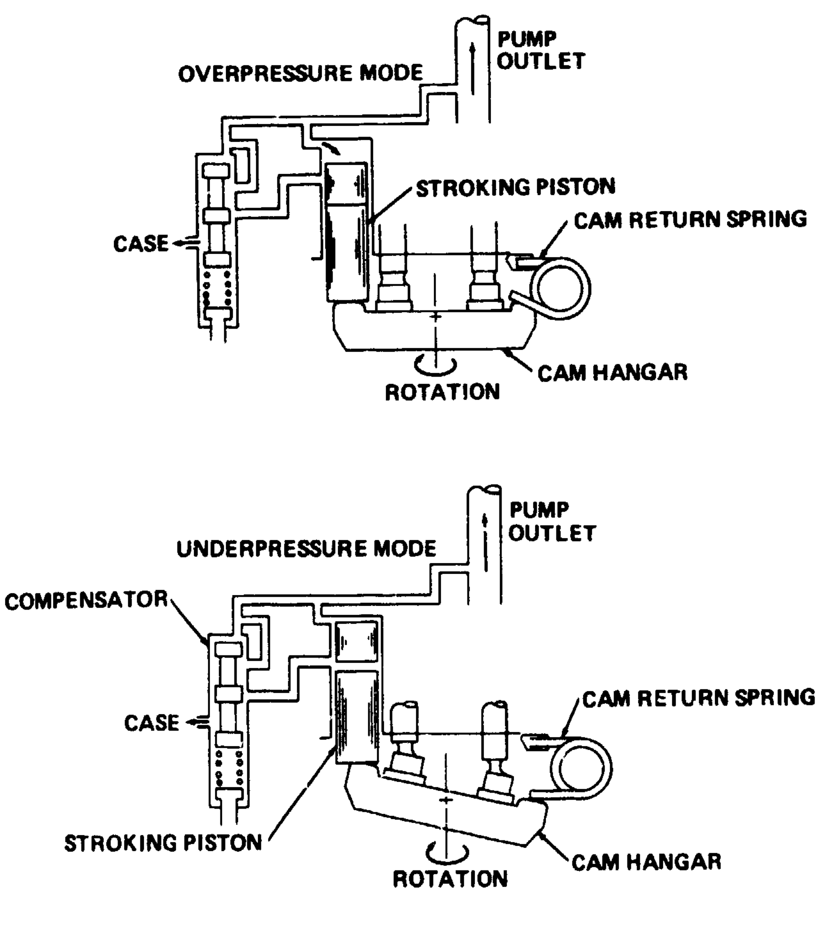

Figure 12. Hydraulic pump pressure compensator.

3.3 Fluid Manifild Assembly (13A10037)

The fluid manifold assembly collects and distributes hydraulic fluid to the TVC subsystem. The fluid manifold assembly permits filling and bleeding of the system and the initial pressurization of the hydraulic bootstrap reservoir. Fluid flow for the manifold is shown in Figure A-1. The fluid manifold assembly consists of:

- High Pressure (HP) Chamber
- Low Pressure (LP) Chamber
- HP Relief Valve
- Case Drain Filter
- LP Relief Valve

Figures 13 and 14 define the general configuration and schematic operation of the fluid manifold assembly. During ground operation and checkout, HP (3000 to 3250 psig) hydraulic fluid is supplied from the ground support equipment (GSE) to the HP chamber. This chamber routes HP fluid to the HP port of the hydraulic bootstrap reservoir, to the HP high point bleed bulkhead fitting on the service panel, and to the electro-hydraulic servoactuator.

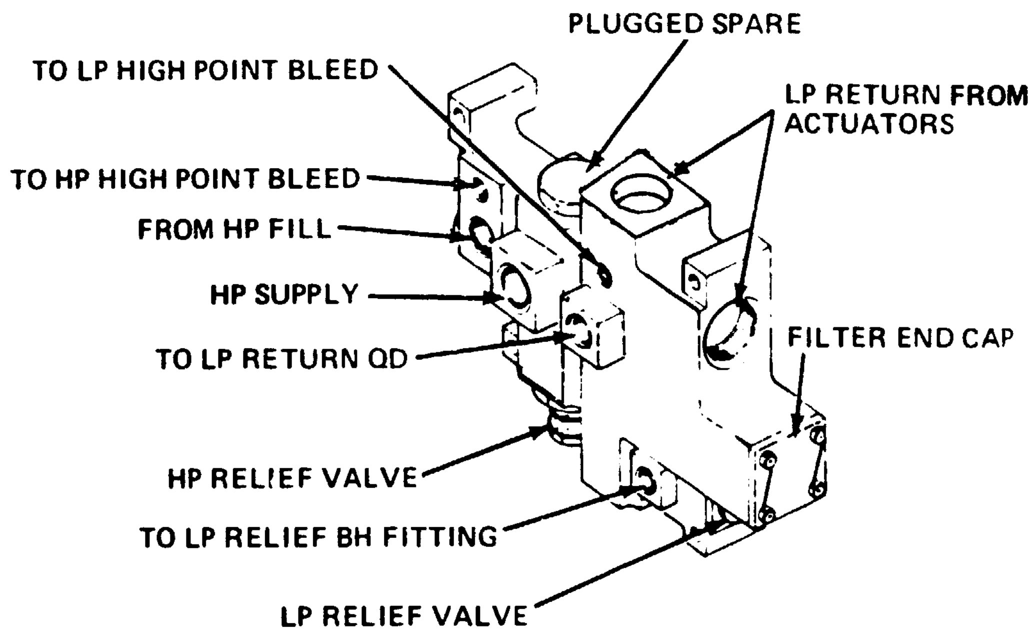

Figure 13. Fluid manifold assembly.

Overpressurization (3650 psig or greater) in the HP chamber is mechanically relieved by the HP relief valve that will open and permit fluid to flow into the LP chamber. During flight operations, HP fluid is bled from the hydraulic fluid check valve and filter assembly to the fluid manifold assembly HP chamber and is used to pressurize the hydraulic bootstrap reservoir.

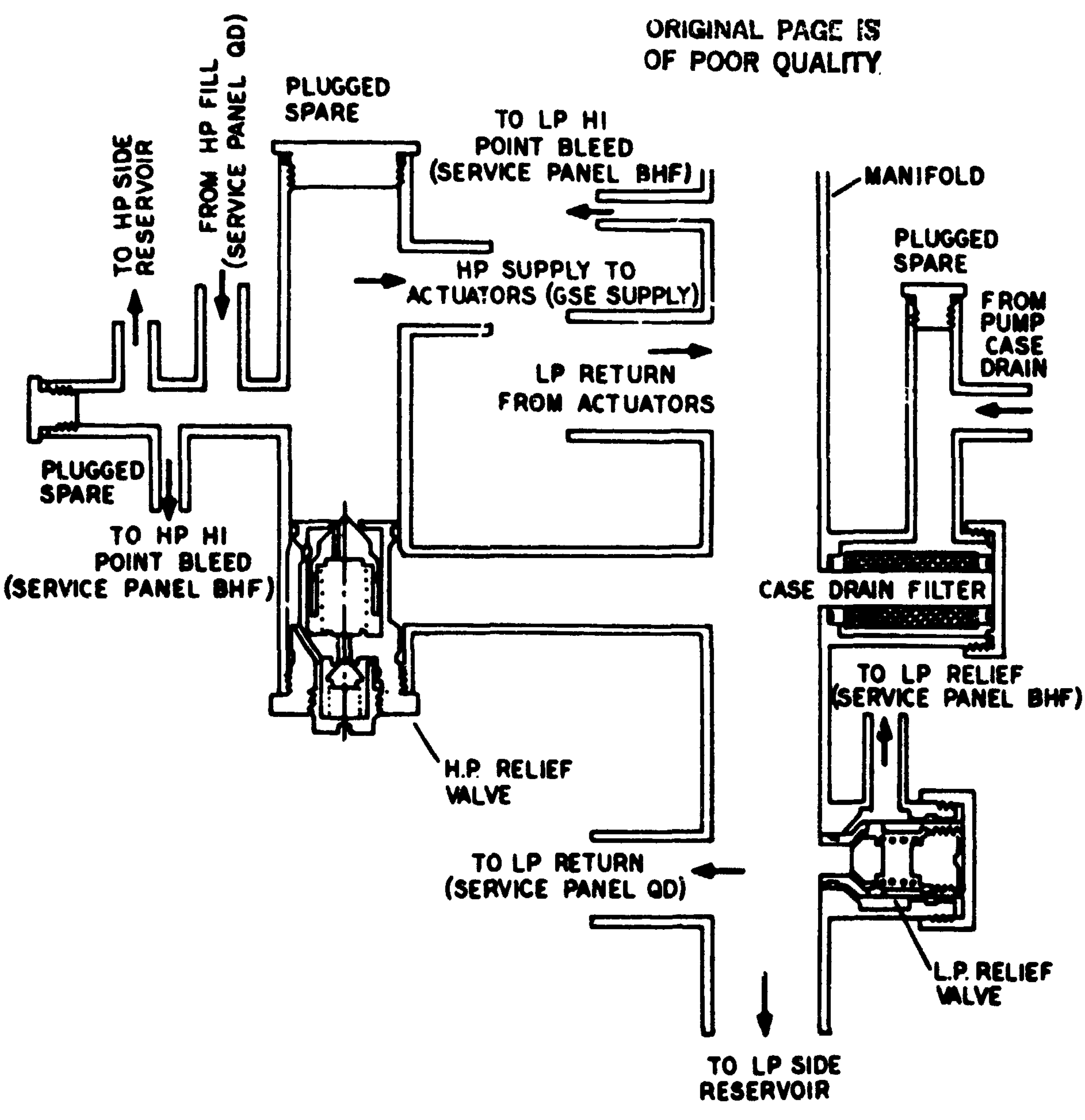

Figure 14. Fluid manifold assembly schematic.

LP (55 to 80 psig) hydraulic fluid is returned from the electro-hydraulic servoactuator to the fluid manifold assembly LP chamber in all TVC subsystem operating modes. This chamber distributes the fluid to the LP side of the hydraulic bootstrap reservoir for resupply to the hydraulic pump during in-flight operation. Fluid from the LP chamber is also distributed to the LP high point bleed bulkhead fitting during bleed and fill servicing, and to the LP return quick-disconnect (13A10050) on the service panel during ground operations. Fluid from the hydraulic pump case drain is recirculated into the hydraulic bootstrap reservoir supply through the LP chamber case drain filter. Overpressurization (80 psig or greater) of the LP chamber is mechanically relieved through the LP relief valve to the LP relief bulkhead fitting on the service panel during preflight checkout (the LP relief bulkhead fitting is capped during flight.)

3.4 Hydraulic Fluid Check Valve and Filter Assembly (13A10042)

The hydraulic fluid check valve and filter assembly shown in Figure 15 is installed in the HP hydraulic line between the hydraulic pump and the electro-hydraulic servoactuator. The hydraulic fluid check valve and filter assembly blocks backflow to the hydraulic pump during system bleed and fill servicing and permits uninterrupted flow from the pump during system operation. Fluid flow for the hydraulic check valve and filter assembly is shown in Figure A-1. Nonsoluble pollutants larger than 5.0 micron that are present in the hydraulic fluid are trapped and retained within the filter. The filter will also retain a high percentage by weight of nonsoluble pollutants of 5.0 micron and smaller. A differential pressure indicator across the filter element provides a measure of contaminant entrapment and filter condition.

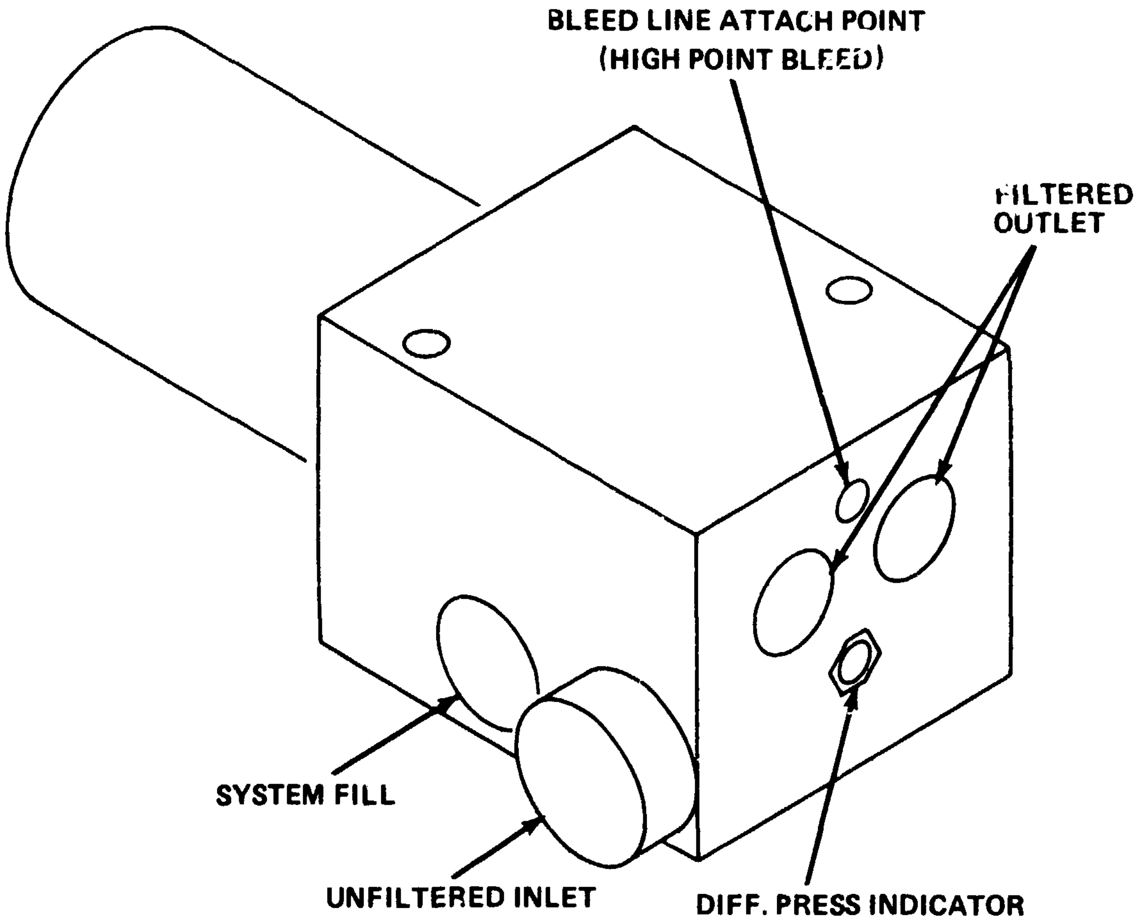

Figure 15. Hydraulic fluid check valve and filter assembly.

3.5 Fuel Isolation Valve (13A10041)

The normally closed fuel isolation valve shown in Figure 16 ensures positive isolation of the fuel in the FSM from the APU during nonoperational periods. The fuel isolation valve remains closed during system ground operation and checkout, is electrically energized to the open position at system startup initiation, and returns to the normally closed position upon SRB separation from the Orbiter vehicle.

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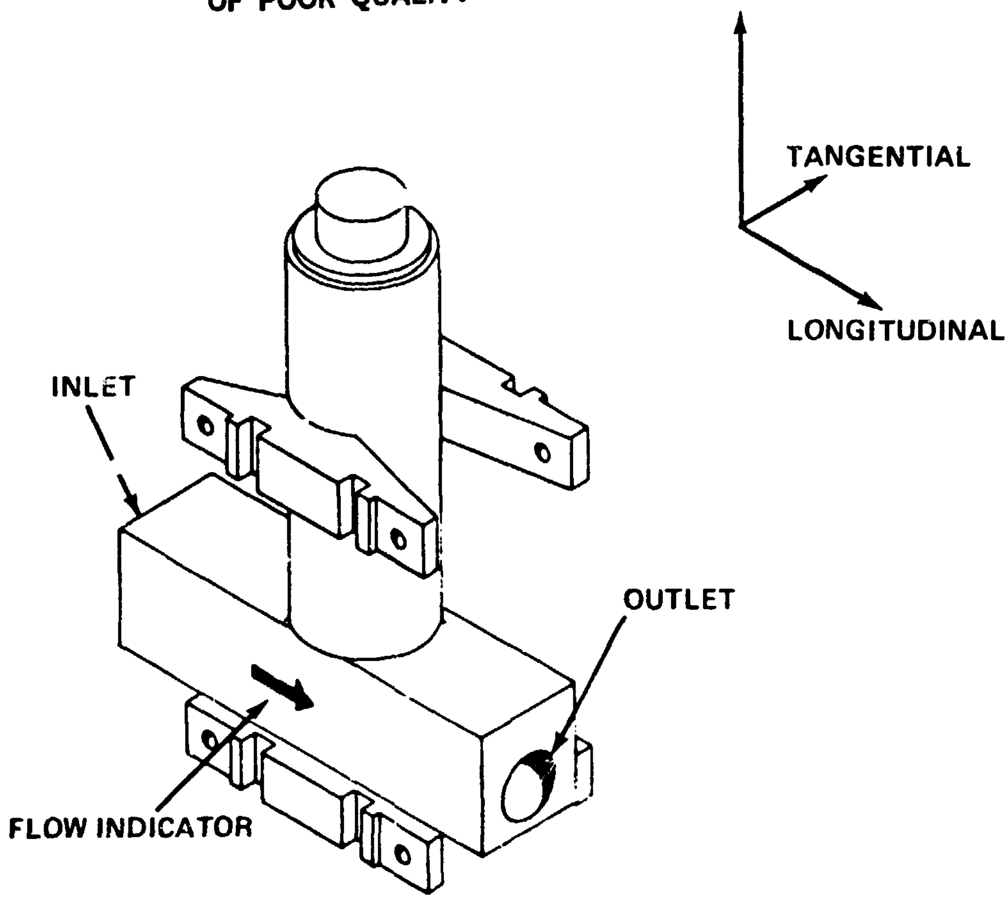

Figure 16. Fuel isolation valve.

3.6 Subsystem Service Panels

Three service panels (Fig. 17) for each fluid power module facilitate TVC subsystem ground servicing, checkout, and testing. These panels are accessible through cutouts in the aft skirt skin. Figure 18 shows the general configuration of TVC service panels.

Quick-disconnects (13A10050), manual valves (13A10C52), and bulkhead fittings, as appropriate, are installed on the service panels for performing the following TVC subsystem operations: (Refer to Figure A-1 for fluid flow diagrams.)

- N_2H_4 Fill and Drain
- GN_2 Pressurization and Purge
- APU Ground Checkout with GN_2
- Hydraulic Fluid Fill, Bleed, and Drain
- Hydraulics Ground Checkout with GSE

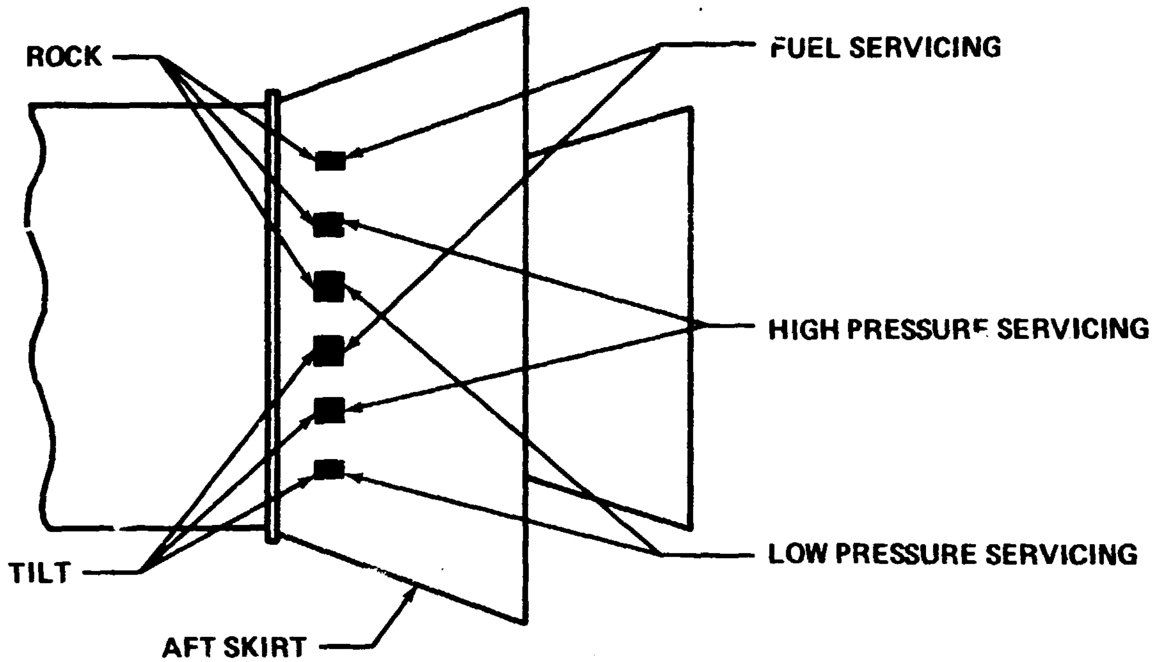

Figure 17. Service panels – location.

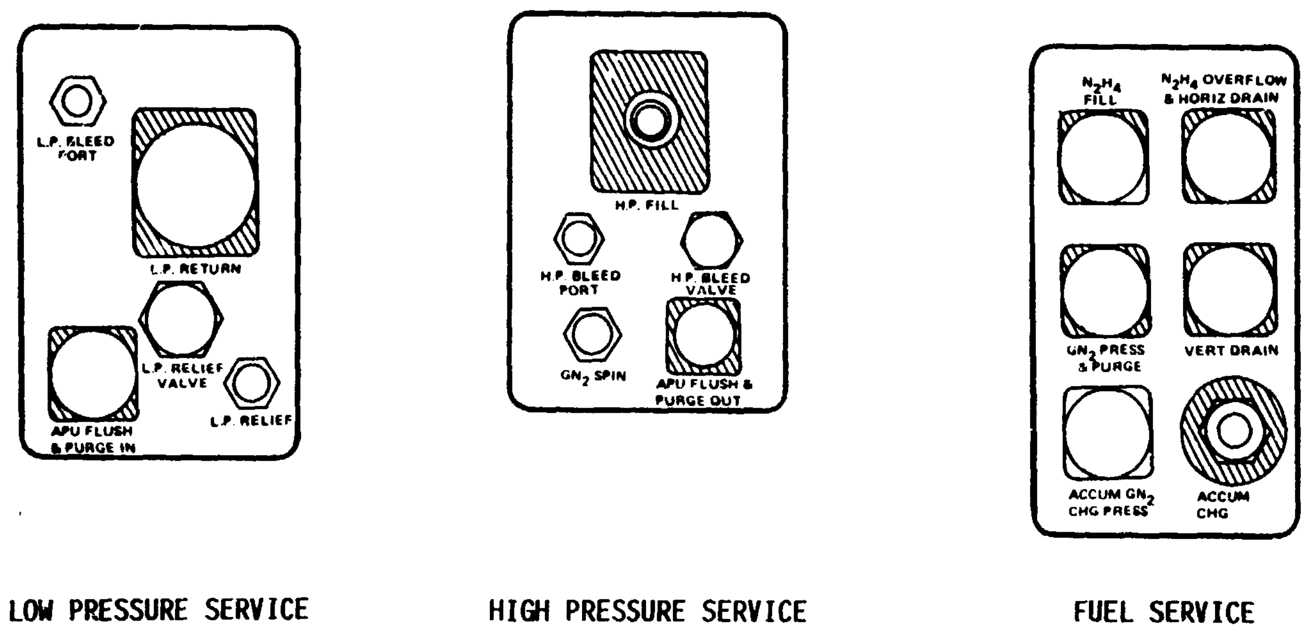

Figure 18. Service panels – configuration.

- LP Relief Valve Venting
- Post-Operation Servicing
- Accumulator Charging

3.7 Hydraulic Fluid Accumulator (13A10141)

The hydraulic accumulator assembly (Fig. 19) consists of a hydraulic accumulator, relief valve, pressure gauge, and fill valve. The purpose of the accumulator is to provide reserve hydraulic power at times when the hydraulic pump cannot meet system demand (load spikes) and to provide damping when transients are encountered. The accumulator vessel contains a gaseous nitrogen charge, a hydraulic fluid chamber, and a floating piston that separates the fluid and gas chambers. A relief valve is located in the vent port so that a positive pressure exists in the vent cavity during the flight. The fill valve permits the remote charging of GN_2 from a boss located on the SRB TVC service panel (Figs. 17 and 18). Likewise, the assembly is outfitted with a pressure gauge for remote sensing of GN_2 precharge pressure. This gauge also mounts into a SRB TVC service panel boss. The fluid and gas schematic for the accumulator is depicted in Figures 2 and A-1. Incorporated on STS-7 is an accumulator bleed/orifice arrangement. This feature allows a rapid decay of accumulator pressure should the system become depressurized (failure). As a result of the rapid pressure decay, the switching valve will have positive engagement and the good system will take over in the 110 percent mode much more assuredly. General specifications follow:

Dry Weight (lb)..............................12.0
Volume (in.^{3})
    GN_2 ....98.1 ± 1
    Hydraulic Fluid..........................49.0 ± 1
Pressures (psig)
    Operating 3250
    Proof....................................6500
    Burst....................................13,000
Temperature (°F)............................ +20 to +250
Supplier.....................................Parker Hannifan

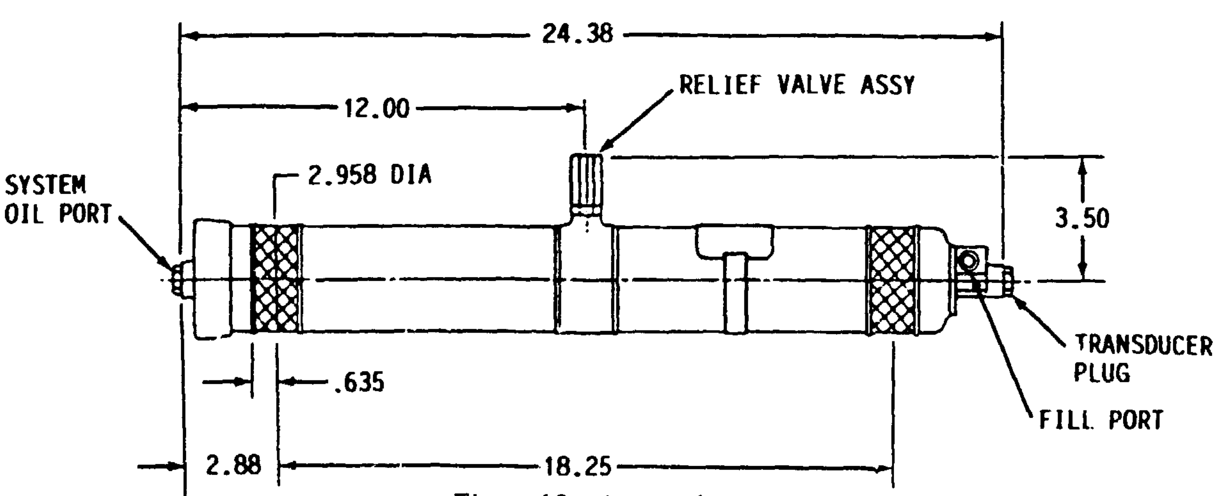

Figure 19. Accumulator.

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3.8 Hydraulic Bootstrap Reservoir (13A10036)

The hydraulic bootstrap reservoir shown in Figure 20 stores a maximum of 3.16 gal of the total 5.3 gal of hydraulic fluid contained within the fluid power module. Fluid flow for the reservoir is shown in Figure A-1. During system operation, the hydraulic bootstrap reservoir supplies pressurized hydraulic fluid at 60 ± 5 psig to the inlet port of the hydraulic pump. The pressure source within the hydraulic bootstrap reservoir is a system pressure-actuated, differential area piston that compensates for fluid volumetric changes created by temperature and/or system operating condition variations. The hydraulic bootstrap reservoir provides a minimum of 25 psig starting pressure at the pump inlet port.

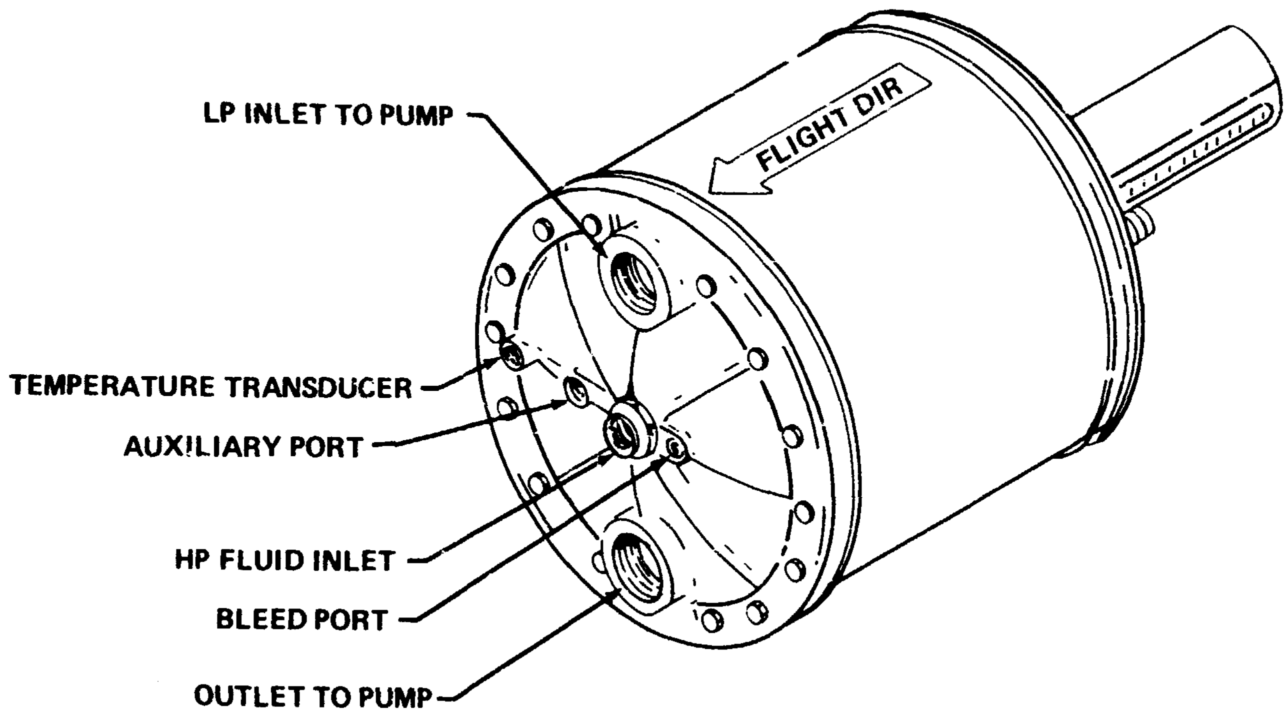

Figure 20. Hydraulic bootstrap reservoir.

As shown on the hydraulic bootstrap reservoir schematic (Fig. 21), fluid is delivered from the hydraulic bootstrap reservoir to the hydraulic pump inlet. Pressurized fluid from the hydraulic pump enters the hydraulic check valve and filter assembly, which routes HP hydraulic fluid to the hydraulic bootstrap reservoir pressurizing chamber via the fluid manifold assembly (to maintain flow and pressure at the hydraulic pump inlet) and to the electro-hydraulic servoactuator. LP hydraulic fluid discharged from the electro-hydraulic servoactuator is returned via the fluid manifold assembly to the hydraulic bootstrap reservoir storage (LP) chamber. The air chamber behind the differential area piston is vented to the atmosphere to eliminate a positive or negative back pressure . action against the piston. The vent also prohibits the entrance of salt water into the air chamber following post-flight splashdown, since it is plugged for flight.

NOTE

DURING NORMAL SYSTEM OPERATION ACTUATORS #1 & #2 ARE POWERED SIMULTANEOUSLY BY THEIR OWN INDEPENDENT HYDRAULIC SYSTEMS. THE #2 SYSTEM IS IDENTICAL TO THE ONE SHOWN & POWERS #2 ACTUATOR.

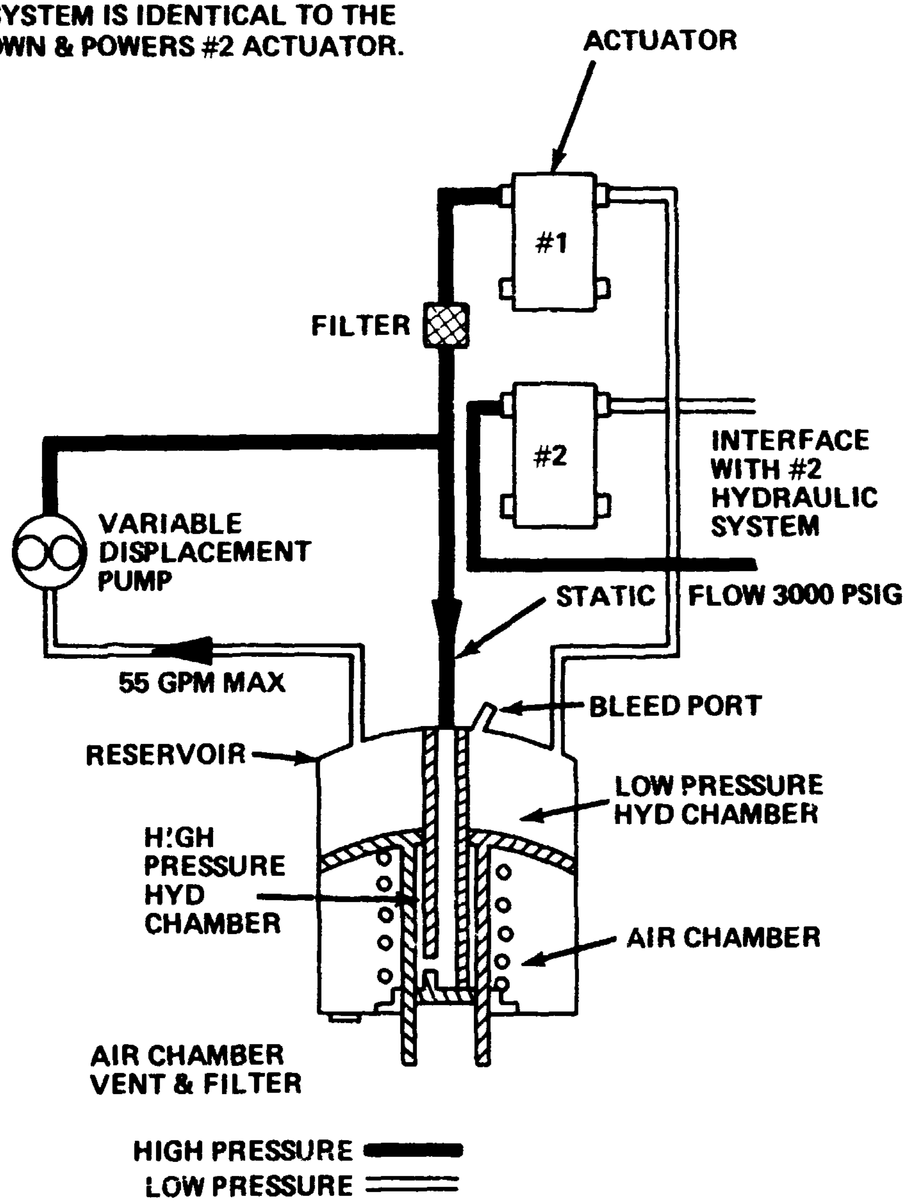

Figure 21. Hydraulic system schematic.

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3.9 N_2H_4 Fuel Supply Module (13A10009)

The FSM shown in Figure 22 is a spherical pressure vessel that stores approximately 15 lb of liquid N_2H_4 fuel for the APU. Approximately 1.1 lb of GN_2 at 400 psi is used to deliver the N_2H_4 to the APU fuel pump inlet. Fluid flow for the FSM is shown in Figure A-1. The FSM contains appropriate sumps, N_2H_4 feed and drain lines, GN_2 pressurization and purge lines, a 25 micron absolute fuel filter, pressure and temperature sensors, and fluid motion control devices to inhibit flow-induced liquid motion phenomena.

The FSM supplies pressurized N_2H_4 to the APU fuel pump at an initial working pressure of 400 psi at APU startup. The pressure decreases to approximately 310 psi, a minimum during 166 sec of operation.

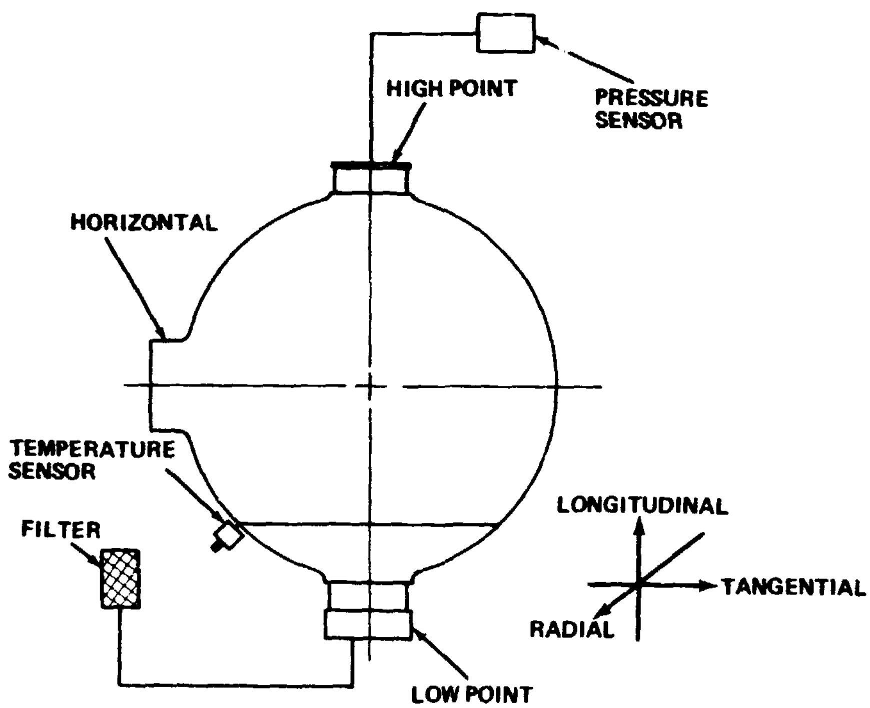
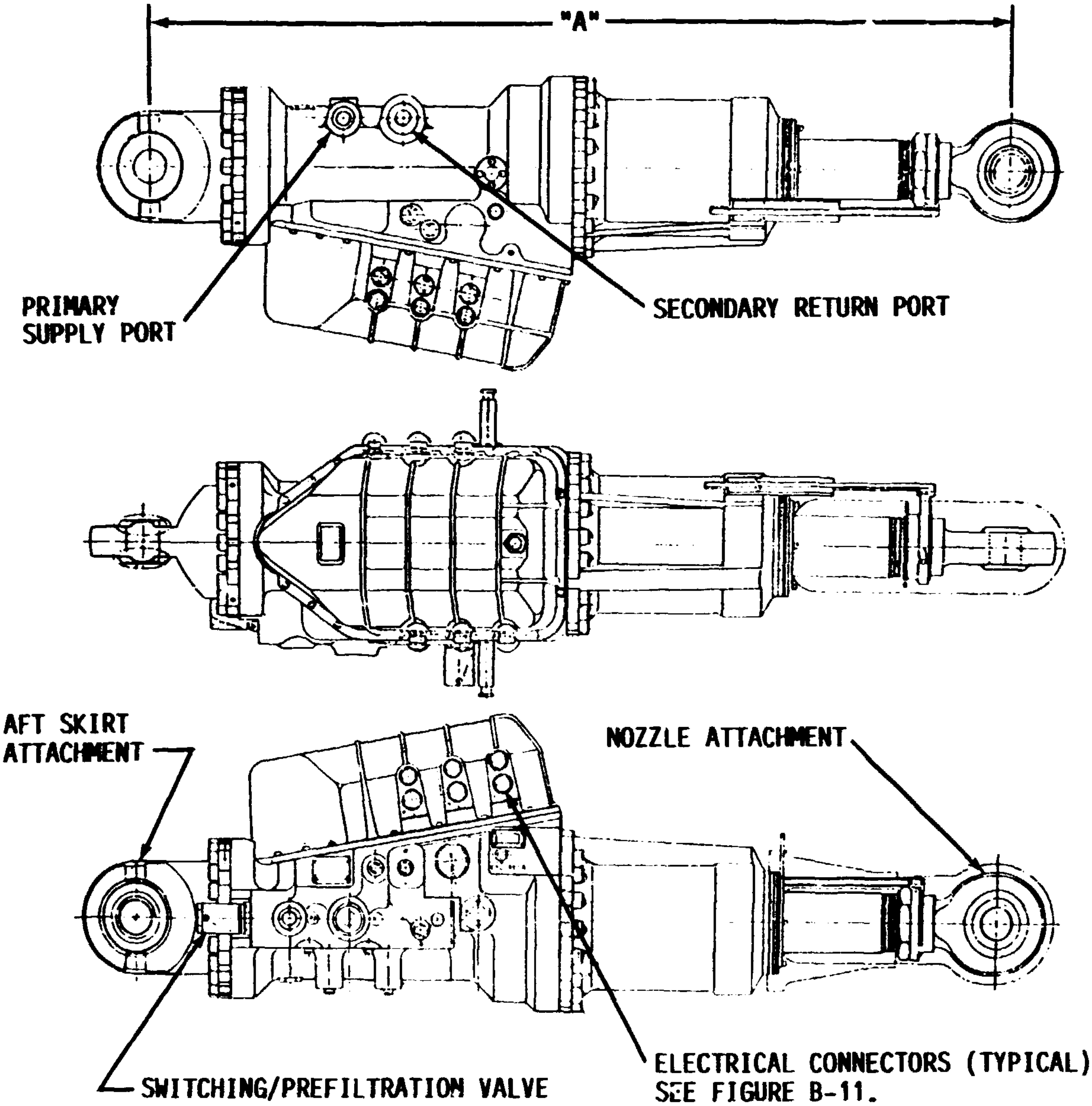


Figure 22. Fuel supply module.

3.10 Electro-hydraulic Servoactuator (16A03000)

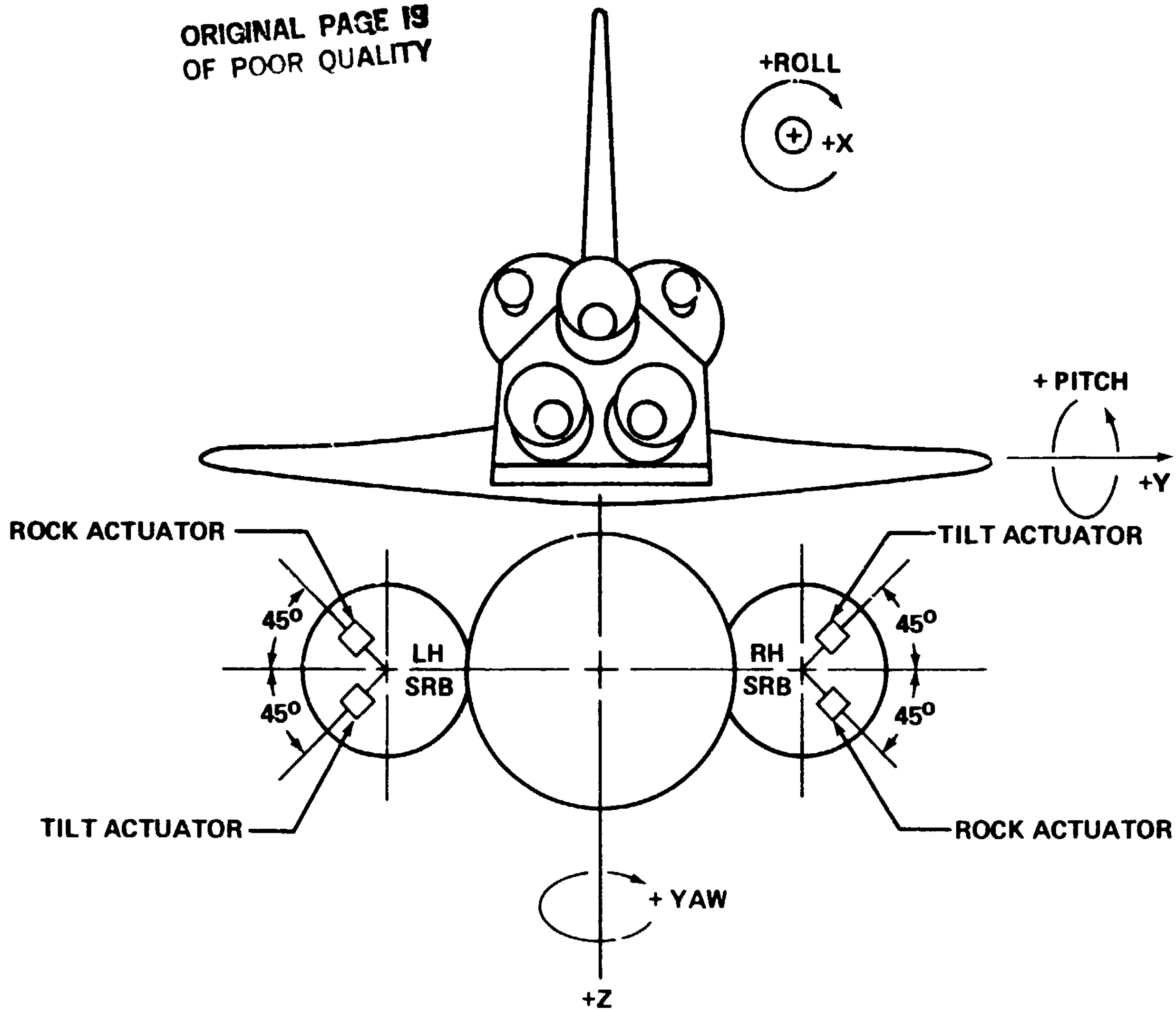
The electro-hydraulic servoactuator (Fig. 23) converts TVC subsystem hydraulic fluid power into a linear motion for positioning the SRM nozzle in response to the Orbiter Guidance Navigation and Command system. The actuator is oriented 45 deg outboard to the vehicle pitch and yaw axes and the individual rock and tilt commands to the actuator on the Left-Hand (LH) and Right-Hand (RH) SRBs are provided with the polarity as shown in Figure 24. Each SRB actuator is hydraulically linked to each TVC fluid power module for operating redundancy, i.e., if one module fails, then the surviving module increases its hydraulic power output and controls the nozzle in both the rock and tilt planes at a slightly degraded performance level.



DIMENSION "A":

NULL LENGTH	53.00 INCHES
EXTENDED LENGTH	59.40 INCHES
RETRACTED LENGTH	46.60 INCHES

Figure 23. Electro-hydraulic servoactuator.



SHUTTLE VEHICLE MANEUVER	LH SOLID ROCKET BOOSTER		RH SOLID ROCKET BOOSTER	
	ROCK ACTUATOR	TILT ACTUATOR	ROCK ACTUATOR	TILT ACTUATOR
+ PITCH	–	+	+	–
– PITCH	+	–	–	+
+ YAW	+	+	–	–
– YAW	–	–	–	–
+ ROLL	+	–	+	–
– ROLL	–	+	–	+

+ INDICATES ACTUATOR EXTENSION
– INDICATES ACTUATOR RETRACTION

Figure 24. SRB TVC actuator polarity.

The SRB TVC servoactuator is a four channel fail operate/fail operate device that will operate normally after one or two channel failures. The unit is designed to function after input failures from the drive electronics or failures within the servoactuator. Failures are detected by monitoring the output pressures of each of four servovalves. If the differential pressure across any servovalve exceeds a predetermined value, the offending channel is isolated from the system.

The hydraulic fluid enters the servoactuator through ports located on the main actuator body. The fluid flows through the large pressure selector valve, through metering slots in the power valve, and through the hydraulic lock valve to the actuator piston. The rate of flow, which is controlled by the metering slots in the power valve, determines the piston velocity.

All servoloops within the unit including the main position feedback, are closed mechanically. Loss of all electrical power ot the unit causes the piston to move to or remain in a centered position.

The principle elements in the servoactuator are as follows:

- Switching/Prefiltration Valve
- Servo Valves
- Dynamic Feedback Module
- Position Feedback Mechanism
- Main Power Element
- Hydraulic Lock Valve
- Transient Load Relief Valve
- Piston Position and Load Pressure Transducer

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Performance characteristics for the SRB actuator are as follows:

SYSTEM PRESSURE	3000 TO 3250 PSI
PROOF PRESSURE	4875 PSI
BURST PRESSURE	8125 PSI
INTERNAL LEAKAGE	3.0 GPM
INTERSYSTEM LEAKAGE	0.034 GPM
PISTON STROKE	
EXTEND	6.4 ± 0.03 INCHES
RETRACT	6.4 ± 0.03 INCHES
RATED SIGNAL	± 50 MILLIAMPERES
SERVOVALVE COIL RESISTANCE	125 OHMS
ELECTRICAL - MECHANICAL NULL	0.128 INCHES
NULL LENGTH	53.00 INCHES
EXTENDED LENGTH	59.40 INCHES
RETRACTED LENGTH	46.60 INCHES
NULL SHIFT	
SUPPLY PRESSURE	0.5 MILLIAMPERES
RETURN PRESSURE	0.5 MILLIAMPERES
TEMPERATURE	1.0 MILLIAMPERES
VIBRATION	1.0 MILLIAMPERES
ACOUSTICS	1.25 MILLIAMPERES
ACCELERATION	1.25 MILLIAMPERES
HYSTERESIS	1.15 MILLIAMPERES
THRESHOLD	.5 MILLIAMPERES
POSITION GAIN	0.128 INCHES/MA
NULL BIAS	0.055 INCHES
DRY WEIGHT	348.41 LBS
PRESSURE GAIN	5000 PSI/MA
RATED LOAD	63,358 POUNDS
RATE AT RATED LOAD	5.95 - 8.33 INCHES/SEC
OPERATING FLUID	MIL-H-83282
FILTER	10 MICRON
TEMPERATURE RANGE	
OPERATING	+20 TO +150°F
STORAGE	+20 TO +275°F
WATER PRESSURE	71 PSI
WATER ENTRY PRESSURE	155 PSI
SERVOVALVE PRESSURE GAIN	500 ± 125 PSI/MA

3.10.1 Switching/Prefiltration Valve

The main pressure switching valve is a pressure actuated spool type valve which is normally positioned to connect the primary hydraulic system to the servoactuator while blocking the secondary system. If the primary supply pressure drops below a specified level, the spool automatically switches to block the primary supply and connect the secondary source to the servoactuator. Switching from the primary to secondary system is designed to occur between 1900 and 2200 psi. The spool position is monitored by a pressure switch which senses pressure at the spool end. The pressure in the chamber is controlled by the spool position and is at system pressure with the spool in the primary position and at zero with the spool in the secondary position. The switching valve also serves as a prefiltration valve. Depressing and rotating an external handle allows the spool to be moved to a position which blocks all fluid from passing the switching valve and interconnects each system's supply and return lines. Refer to Appendix C for schematics.

3.10.2 Servovalves

The servovalves (Fig. 25) are two stage mechanical feedback type units. The first stage consists of a 2 in.-lb torque motor and a conventional four leg orifice bridge. The orifice bridge is made up of two fixed orifices and a movable flapper positioned between two nozzles. The second stage of the servovalve is a closed center spool and bushing or sleeve. Servovalve output pressure is fed back to a portion of the spool end area to reduce the servovalve pressure gain. This reduced pressure gain feature minimizes the force flight between valves as they drive the power valve spool. The first stage orifices are protected by a filter built into each servovalve in addition to the main filter. Mechanical feedback of the spool position is accomplished through a wire spring element which rides in a groove in the spool and exerts a torque on the valve torque motor. The feedback torque is proportional to spool position.

The output pressure of each servovalve is sensed by a differential pressure transducer. The transducer is basically a spring centered piston. The position of the piston is proportional to the output pressure of the servovalve. An L.V.D.T. coil is mounted concentric to the piston. The L.V.D.T. probe is driven by the piston. The voltage output of the transducer is therefore proportional to servovalve differential pressure. If the output pressure exceeds a given level, that channel is isolated from the system. This is accomplished through solenoid operated bypass valves.

Energizing the solenoid results in the application of system pressure to the end of a spring load spool. The pressure drives the spool to a position which blocks the servovalve output pressure from one side to the servovalve and connects the other side to both sections of the power valve which are normally driven by that servovalve. This eliminates the control of the servovalve on the power valve and eliminates any force fight which could develop by simply blocking the servovalve output. Each channel has its own solenoid operated isolation valve.

The outputs of the four servovalves are force summed on the large power spool. This is the component that meters the flow to the main piston and controls piston velocity. The power spool position is mechanically fed back to the torque motors of the servovalves through feedback wires or springs which track the spool position. Refer to Appendix C for schematics and component locations.

3.10.3 Dynamic Feedback Module

The servoactuator contains four dynamic pressure feedback modules. Each module, acting with a servovalve, provides frequency sensitive load damping. The system remains stiff against a static load, but dissipates energy created by the resonating load. Refer to Appendix C for the schematic.

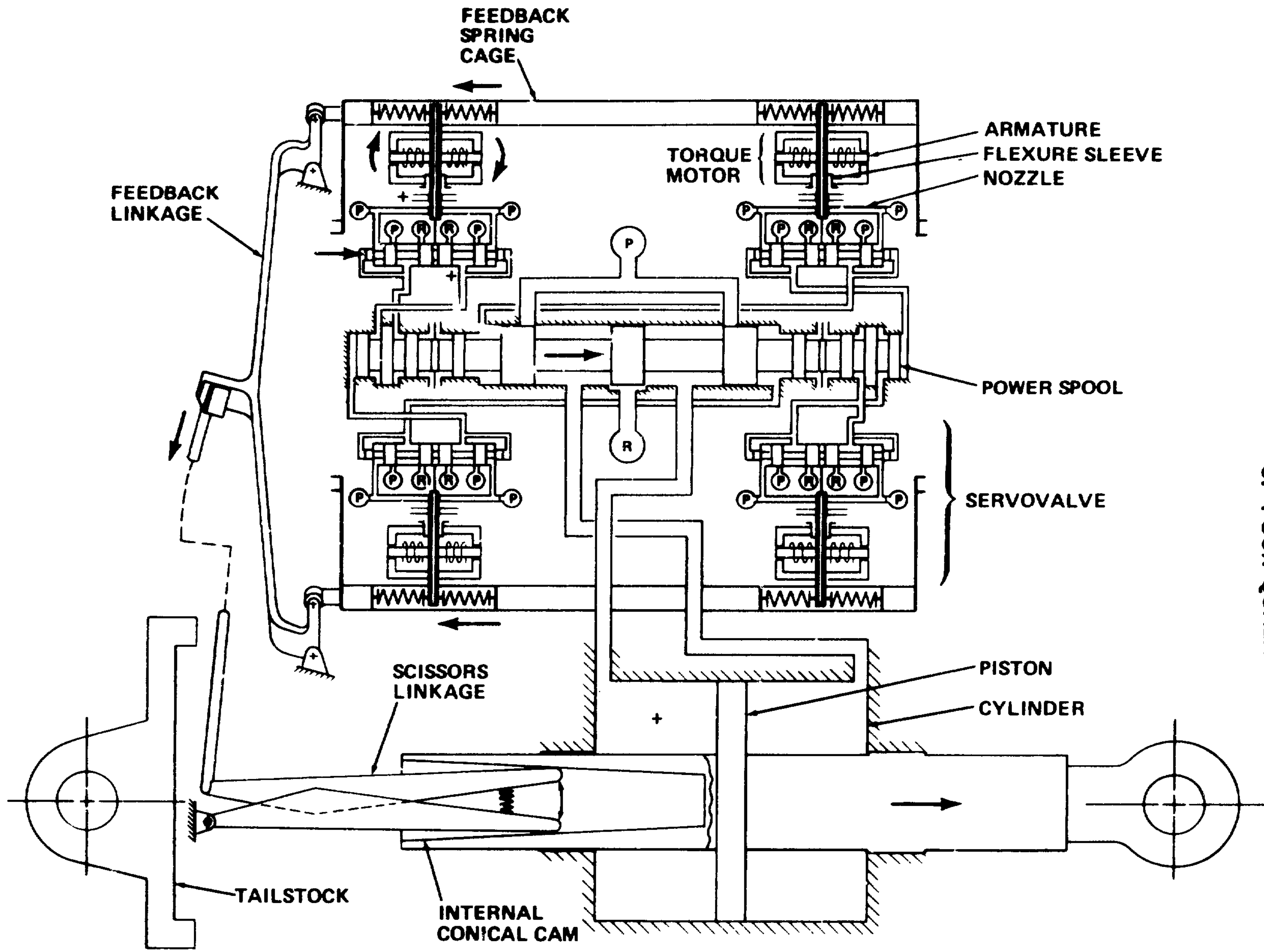

Figure 25. SRB TVC quadruplex servoactuator schematic – position servoloop.

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3.10.4 Position Feedback Mechanism and Main Power Element

The main power element is the large piston located on the servoactuator centerline. The piston rod is guided by two bearings, one in the actuator body, the other in the cylinder. The piston position is sensed by a scissors-like element which opens and closes as a function of piston position. The ends of the scissors assembly ride in an internal conical cam which is located within the piston rod. The output of the scissors drives two spring loaded cages. The cage motion results in a force input back to the servovalves torque motors through springs which are located within the cage assemblies. The result is a piston position proportional to servovalve input. Figure 22 (previous) displays the mechanical feedback element's operation.

3.10.5 Hydraulic Lock Valve

A hydraulic lock valve is located in the actuator body. The lock valve is a pressure actuated spool valve. With system pressure on, fluid passes through the lock valve with very little restriction. With pressure off the spool position blocks the fluid at the piston from the rest of the unit. Therefore, with the hydraulic fluid off, the piston is locked in a fixed position.

3.10.6 Transient Load Relief Valve

A large transient load relief valve is located within the piston assembly. It is a two stage device designed to protect the engine, structure, and servoactuator from damage during water impact. High pressure on either side of the piston head causes the relief valve to open and allows fluid to be bypassed from one side of the piston head to the other (Fig. C-2).

3.10.7 Piston Position and Load Pressure Transducer

The actuator contains a piston position transducer and a load pressure transducer. The piston position is sensed by an instrumented cantilevered beam. The movable end of the beam contacts the scissors assembly. Piston motion is transmitted through the scissors feedback assembly to the transducer. See Figures C-1 and C-2 for schematics.

4. SUBSYSTEM INTERFACES

4.1 Mechanical

The mechanical interfaces between the TVC subsystem and the SRB aft skirt assembly consists of:

- The TVC upper and lower panels and exhaust duct to the aft skirt structure.
- The electro-hydraulic servoactuator to the aft skirt structure and to the SRB nozzle.
- The TVC service panels to the access ports in the aft skirt structure.

4.2 Electrical

The TVC subsystem interfaces to the SRB power distribution system and to the SRB avionics for:

- Electrical actuation of APU primary and secondary fuel control valves, fuel isolation valves, and hydraulic pump decompression valves.
- Electrical bias current for subsystem temperature and pressure sensors.
- Electrical steering commands from the orbiter reaction control subsystem.
- Readout and recording of TVC subsystem instrumentation (temperature and pressure) outputs.

4.3 Ground Support Equipment

The TVC subsystem interfaces through the TVC service panels with launch facility GSE to:

- Fill and drain the FSM (N_2H_4)
- Pressurize the filled FSM (GN_2)
- Fill, bleed, drain, and check out the subsystem hydraulics loop (MIL-H-83282 oil)
- Flush the FSM (TBD)
- Dry the FSM (TBD)
- Turbine spin (GN_2)
- Pressurize the accumulator (GN_2)

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APPENDIX A

SRB TVC COMPONENT FLOW DIAGRAMS AND INSTRUMENT LIST

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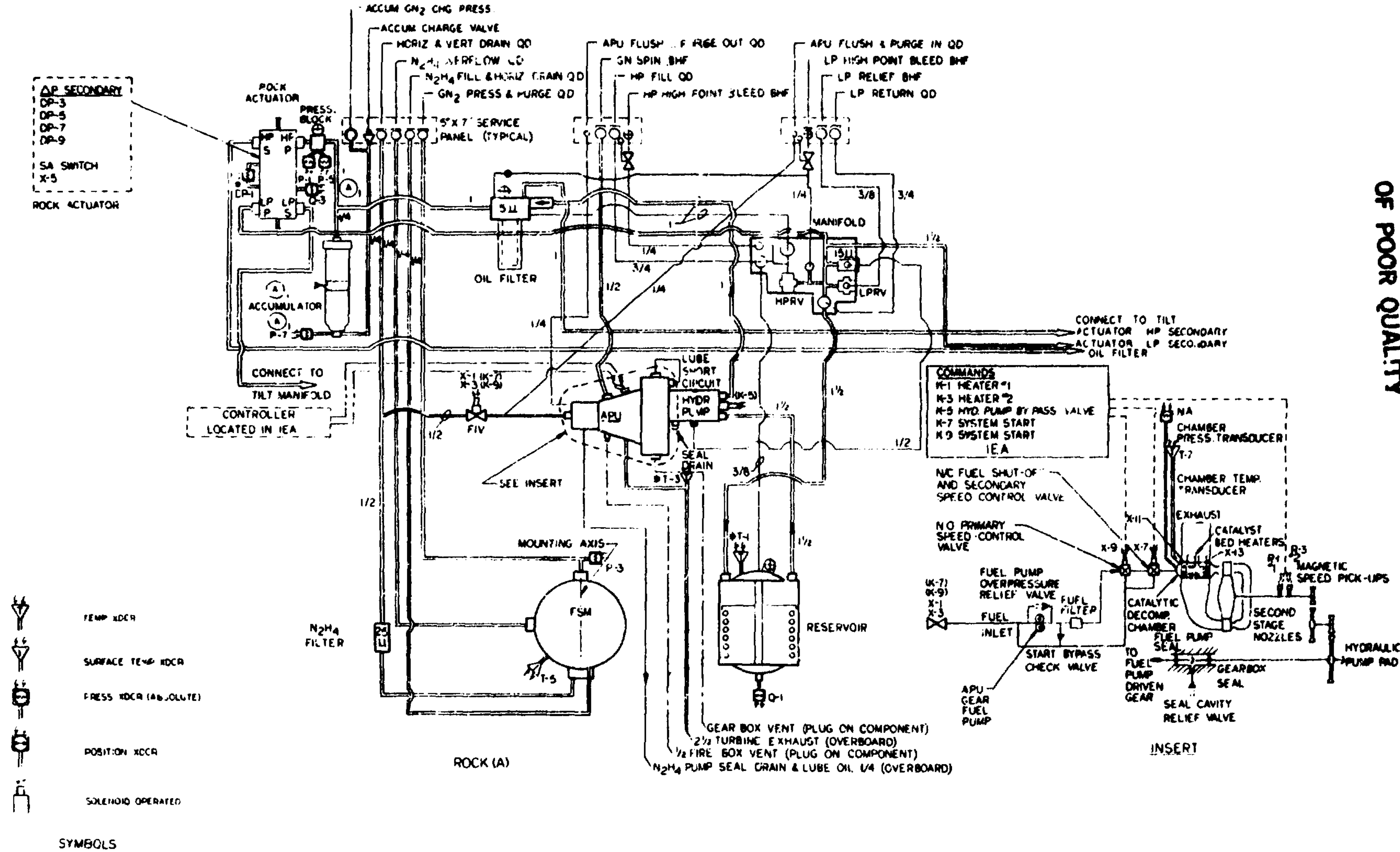

Figure A-1. SRB TVC flow diagram – rock.

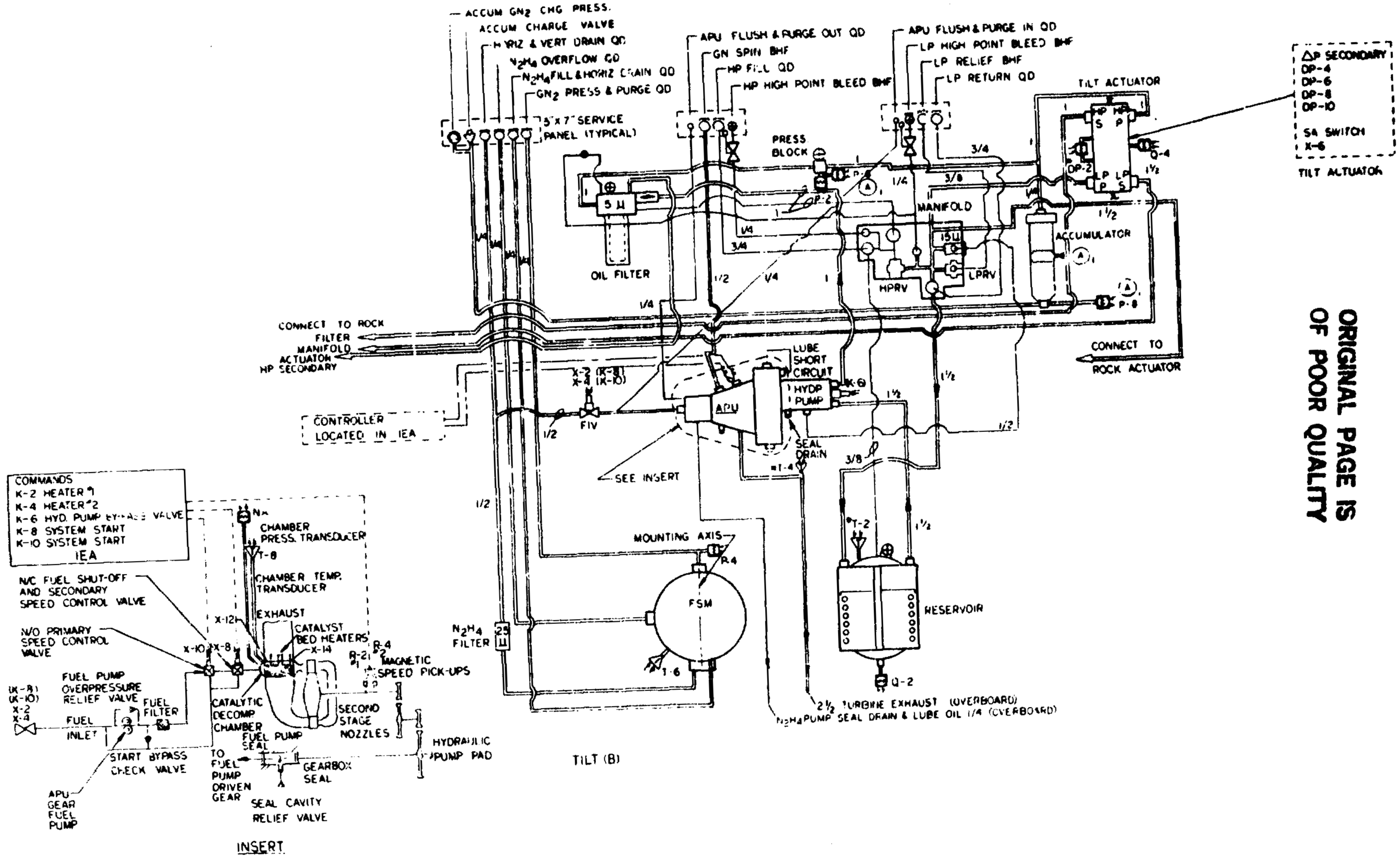

Figure A-2. SRB TVC flow diagram – tilt.

IDENT NO.	A (ROCK) B (TILT)	MEAS. NUMBER (LEFT)	MEAS. NUMBER (RIGHT)	MEASUREMENT	RANGE	REF DESIG (LEFT)	REF DESIG (RIGHT)
DP-3	A (1)	B58P1311A	B58P2311A	Δ PRESS, SECONDARY [illegible]	±3200PSID	—	—
DP-5	(2)	B58P1312A	B58P2312A	Δ PRESS, SECONDARY ROCK	±3200PSID	—	—
DP-7	(3)	B58P1313A	B58P2313A	Δ PRESS, SECONDARY ROCK	±3200PSID	—	—
DP-9	(4)	B58P1314A	B58P2314A	Δ PRESS, SECONDARY ROCK	±3200PSID	—	—
DP-4	B (1)	B58P1315A	B58P2315A	Δ PRESS, SECONDARY TILT	±3200PSID	—	—
DP-6	(2)	B58P1316A	B58P2316A	Δ PRESS, SECONDARY TILT	±3200PSID	—	—
DP-8	(3)	B58P1317A	B58P2317A	Δ PRESS, SECONDARY TILT	±3200PSID	—	—
DP-10	(4)	B58P1318A	B58P2318A	Δ PRESS, SECONDARY TILT	±3200PSID	—	—
K-1	A (1)	B46K3022X	B46K4022X	APU G. G. HEATER "ON"			
K-3	(2)	B46K3023X	B46K4023X	APU G. G. HEATER "ON"			
K-2	B (1)	B46K3024X	B46K4024X	APU G. G. HEATER "ON"			
K-4	(2)	B46K3025X	B46K4025X	APU G. G. HEATER "ON"			
K-5	A	B58K3020X	B58K4020X	HYD PUMP BYPASS VALVE			
K-6	B	B58K3021X	B58K4021X	HYD PUMP BYPASS VALVE "OPEN"			
K-7	A (1)	B58K3016X	B58K4016X	SYSTEM START			
K-9	(2)	B58K3017X	B58K4017X	SYSTEM START			
K-8	B (1)	B58K3018X	B58K4018X	SYSTEM START			
K-10	(2)	B58K3019X	B58K4019X	SYSTEM START			
P-1	A (1)	B58P1303C	B58P2303C	PRESSURE, HYDRAULIC FLUID SUPPLY	0-3500PSIA	102A4A3	202A4A3
P-2	B (2)	B58P1304C	B58P2304C	PRESSURE, HYDRAULIC FLUID SUPPLY	0-3500PSIA	102A6A3	202A6A3
P-3	A	B46P1305C	B46P2305C	PRESSURE, N_2H_4 BOTTLE OUTLET	0 - 600PSIA	102A4A2	202A4A2
P-4	B	B46P1306C	B46P2306C	PRESSURE, N_2H_4 BOTTLE OUTLET	0 - 600PSIA	102A6A2	202A6A2
Q-1	A	B58Q1350C	B58Q2350C	LEVEL, HYDRAULIC FLUID RESERVOIR	0 - 100 %	102A4A4	202A4A4
Q-2	B	B58Q1351C	B58Q2351C	LEVEL, HYDRAULIC FLUID RESERVOIR	0 - 100 %	102A6A3	202A6A3
Q-3	A	B58H1150C	B58H2150C	POSITION, TVC ACTUATOR	±6.4"	102A1	202A1
Q-4	B	B58H1151C	B58H2151C	POSITION, TVC ACTUATOR	±6.4"	102A1	202A1
R-1	A (1)	B46R1406C	B46R2406C	RATE, APU TURBINE SPEED	0 - 120KRPM	102A3A2	202A3A2
R-3	(2)	B46R1408C	B46R2408C	RATE, APU TURBINE SPEED	0 - 120KRPM	102A3A2	202A3A2
R-2	B (1)	B46R1407C	B46R2407C	RATE, APU TURBINE SPEED	0 - 120KRPM	102A5A2	202A5A2
R-4	(2)	B46R1409C	B46R2409C	RATE, APU TURBINE SPEED	0 - 120KRPM	102A5A2	202A5A2
T-5	A	B46T1501C	B46T2501C	TEMP, GAS N_2H_4 GN_2 BOTTLE	32-140°F	102A4A2	202A4A2
T-6	B	B46T1502C	B46T2502C	TEMP, GAS N_2H_4 GN_2 BOTTLE	32-140°F	102A5A2	202A6A2
T-7	A	B46T1503C	B46T2503C	TEMP, G. G. BED	0 - 250°F	102A3A2	202A3A2
T-8	B	B46T1504C	B46T2504C	TEMP, G. G. BED	0 - 250°F	102A5A2	202A5A2
X-1	A	B46X1851X	B46X2851X	EVENT, APU ISOLATION VAL. OP.	0 - 28VDC	—	—
X-2	B	B46X1852X	B46X2852X	EVENT, APU ISOLATION VAL. OP.	0 - 28VDC	—	—
X-3	A	B46X1853X	B46X2853X	EVENT, APU ISOLATION VAL. CL.	0 - 28VDC	—	—
X-4	B	B46X1854X	B46X2854X	EVENT, APU ISOLATION VAL. CL.	0 - 28VDC	—	—
X-5	A	B58X1860X	B58X2860X	EVENT, S.A. PRI PRESS. OK	0 - 28VDC	—	—
X-6	B	B58X1859X	B58X2859X	EVENT, S.A. PRI PRESS. OK	0 - 28VDC	—	—
X-7	A	B46X1861X	B46X2861X	EVENT APU SEC. SP. CON. VAL. CL	0 - 28VDC	--	—
X-8	B	B46X1863X	B46X2863X	EVENT APU SEC. SP. CON. VAL. CL	0 - 28VDC	—	—
X-9	A	B46X1862X	B46X2862X	EVENT APU PRI. SP. CON. VAL. OP	0 - 28VDC	—	—
X-10	B	B46X1864X	B46X2864X	EVENT APU PRI. SP. CON. VAL. OP	0 - 28VDC	—	—
X-11	A (1)	B46X1908X	B46X2908X	EVENT APU G. G. HEATER ON	0 - 28VDC	—	—
X-12	B (1)	B46X1910X	B46X2910X	EVENT APU G. G. HEATER ON	0 - 28VDC	—	—
X-13	A (2)	B46X1909X	B46X2909X	EVENT APU G. G. HEATER ON	0 - 28VDC	—	—
X-14	B (2)	B46X1911X	B46X2911X	EVENT APU G. G. HEATER ON	0 - 28VDC	—	—
P-5*	A	B58P7386A	B58P8386A	PRESS. HYDRAULIC FLUID SUPPLY	0-3500PSIA	102A540	202A566
P-6*	B	B58P7387A	B58P8387A	PRESS. HYDRAULIC FLUID SUPPLY	0-3500PSIA	102A541	202A567
P-7*	A	B58P7388A	B58P8388A	PRESS. ACCUMULATOR	0-3500PSIA	102A538	202A564
P-8*	B	B58P7389A	B58P8389A	PRESS ACCUMULATOR	0-3500PSIA	102A539	202A565
DP-1*	A	B58P7300A	B58P8300A	PRESS., DIFF, SERVO ACTUATOR	±5000 PSID	102A2	202A2
DP-2*	B	B58P7301A	B58P8301A	PRESS., DIFF, SERVO ACTUATOR	±5000 PSID	102A1	202A1
T-1*	A	B58T7507A	B58T8507A	TEMP, HYDRAULIC FLUID	0 - 250°F	102A509	202A525
T-2*	B	B58T7508A	B58T8508A	TEMP, HYDRAULIC FLUID	0 - 250°F	102A510	202A525
T-3*	A	B46T7534A	B46T8534A	TEMP, APU TURBINE EXHAUST	0 - 1500	102A515	202A529
T-4*	B	B46T7535A	B46T8535A	TEMP APU TURBINE EXHAUST	0 - 1500	102A516	202A530

* DEVELOPMENT MEASUREMENTS

Figure A-3. SRB TVC Instrument List.

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APPENDIX B

SRB ELECTRICAL DIAGRAMS

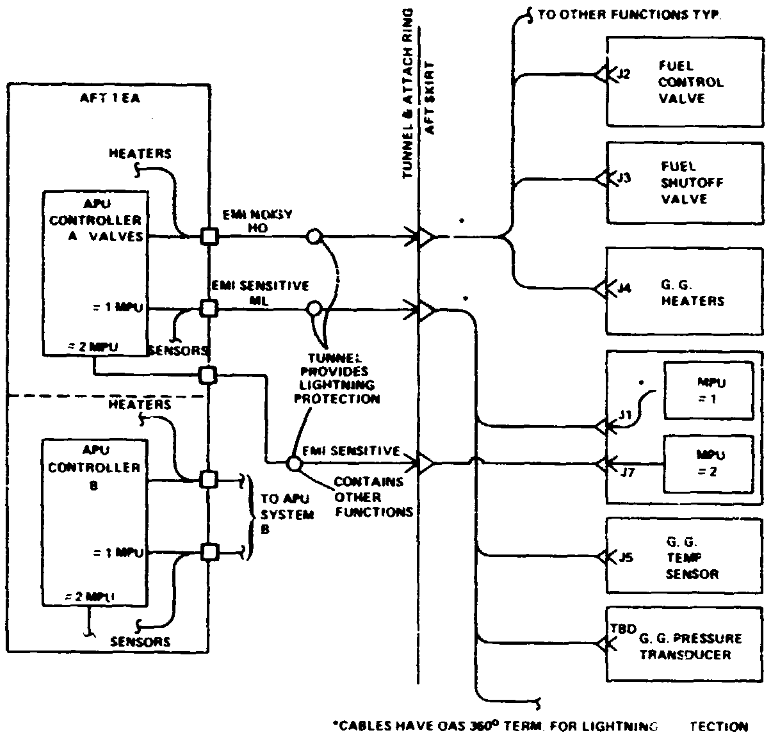

Figure B-1. SRB APU integrated electrical and instrumentation schematic (cabling).

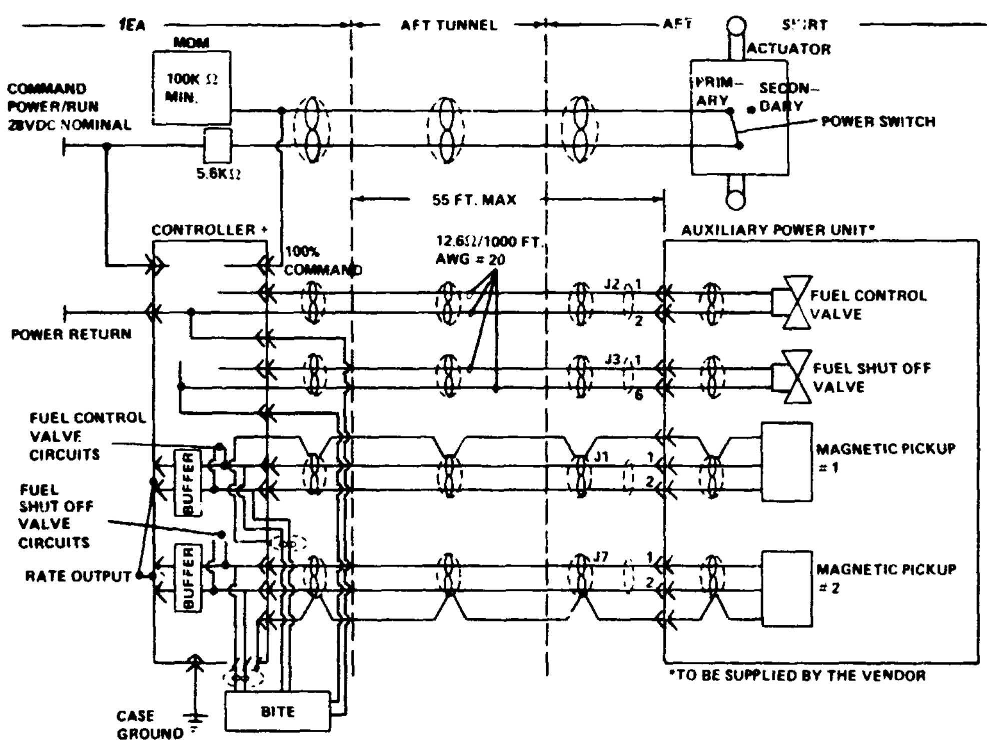

Figure B-2. SRB APU integrated electrical and instrumentation schematic.

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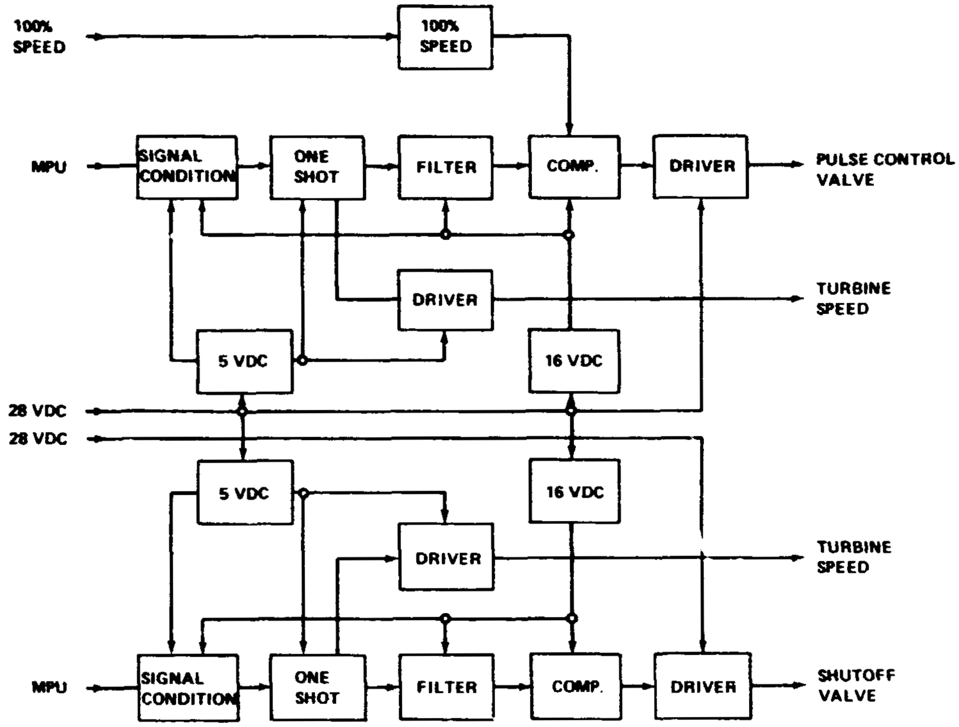

Figure B-3. SRB APU controller block diagram.

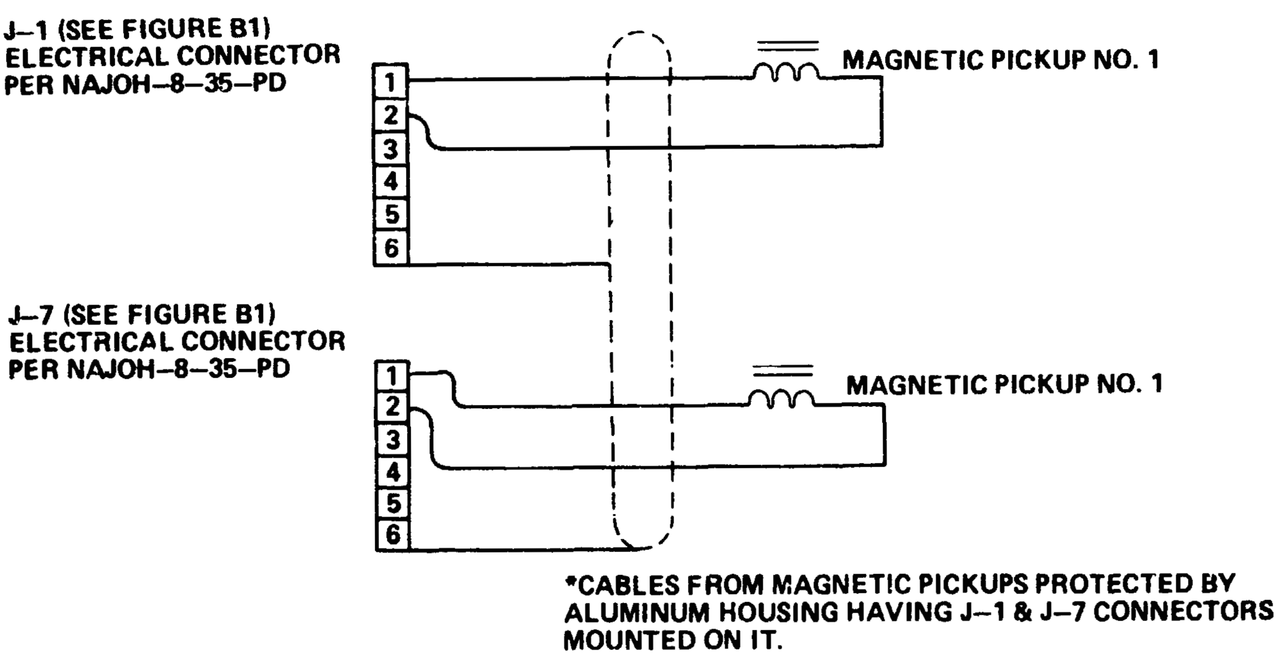

Figure B-4. Pin function diagram – MPU.

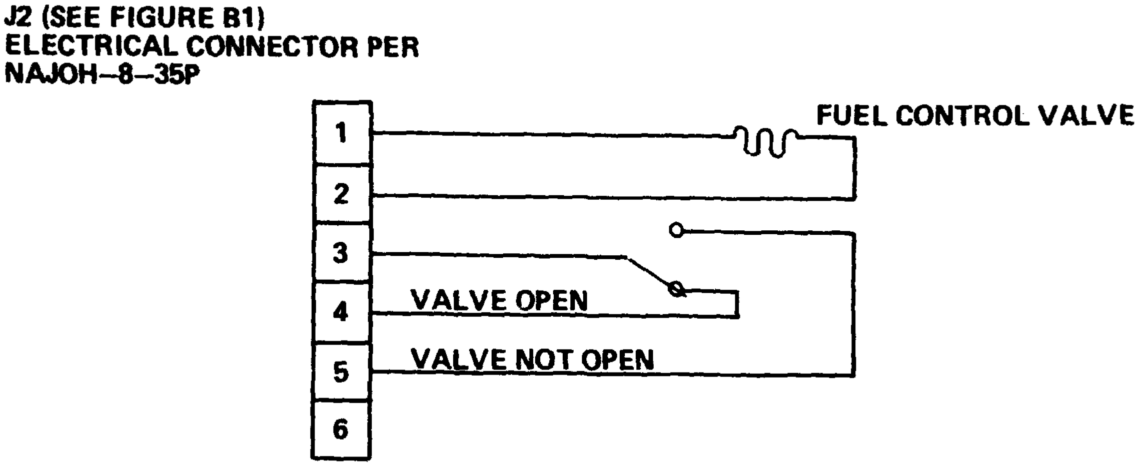

Figure B-5. Pin function diagram – fuel control valve.

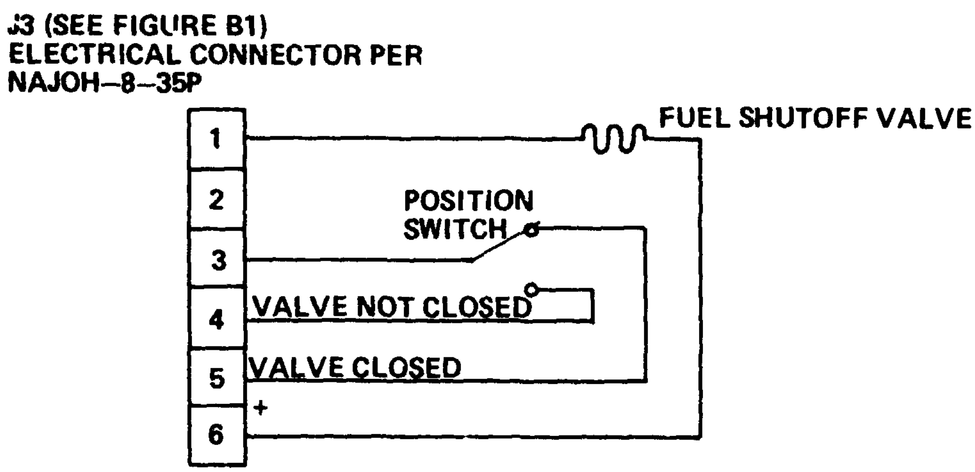

Figure B-6. Pin function diagram – SOV.

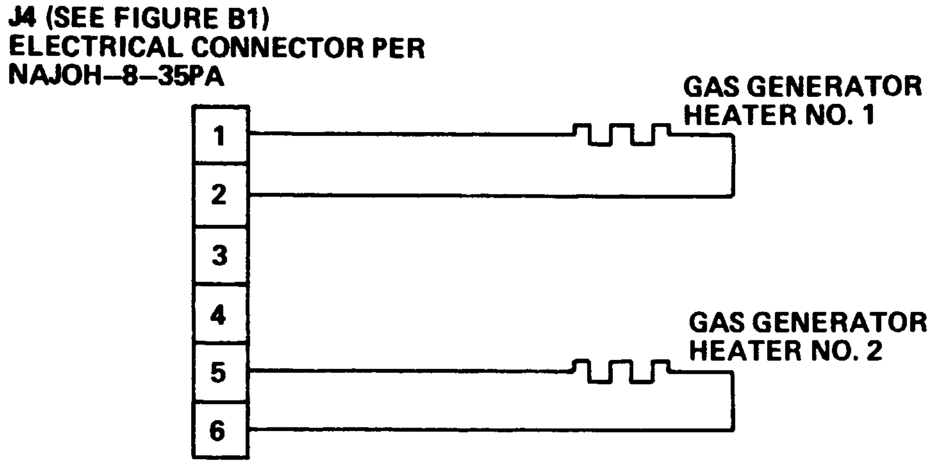

Figure B-7. Pin function diagram – GG heaters.

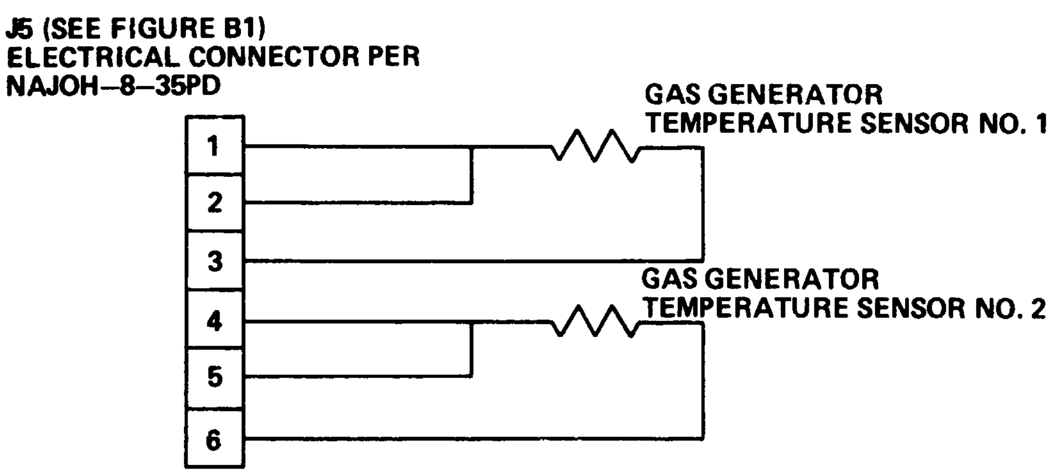

Figure B-8. Pin function diagram – GG temperature sensors.

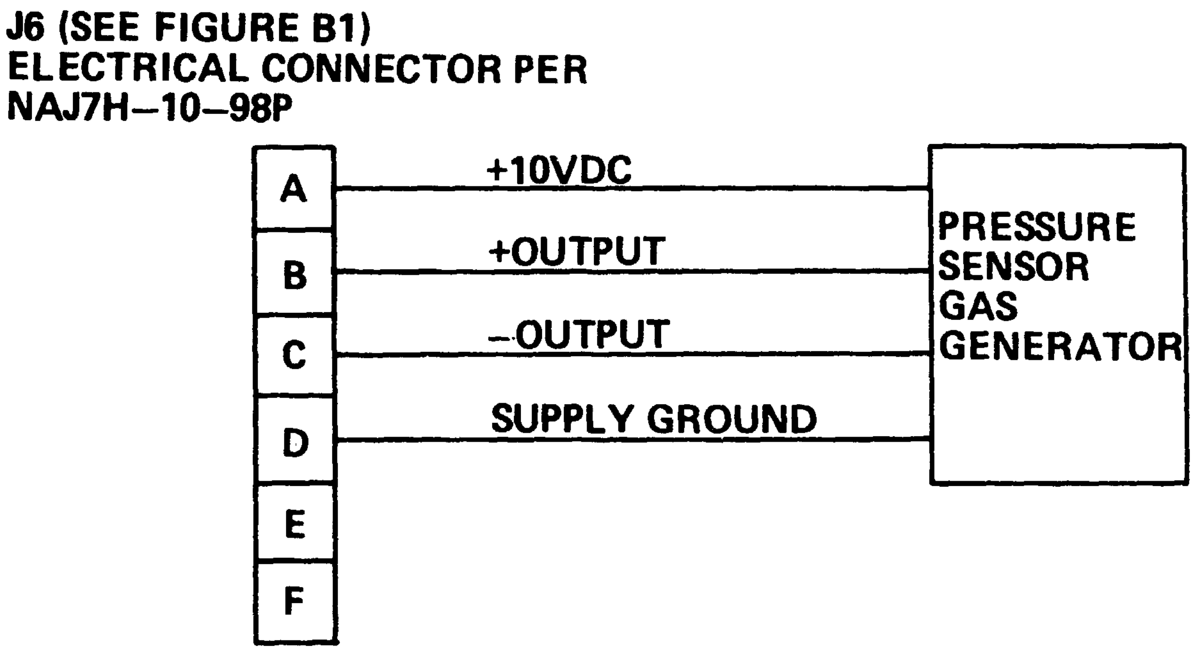

Figure B-9. Pin function diagram – GG pressure sensors.

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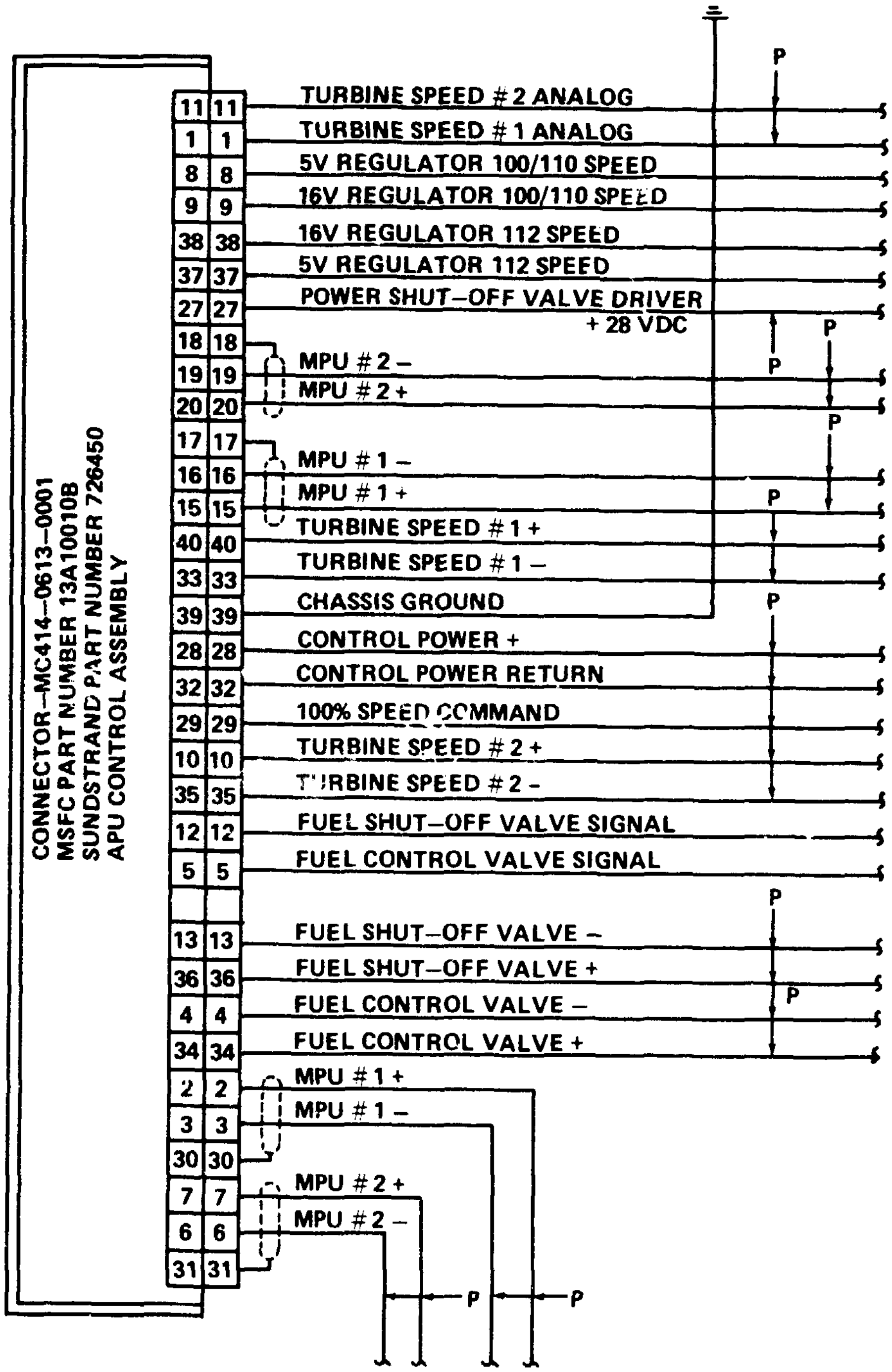
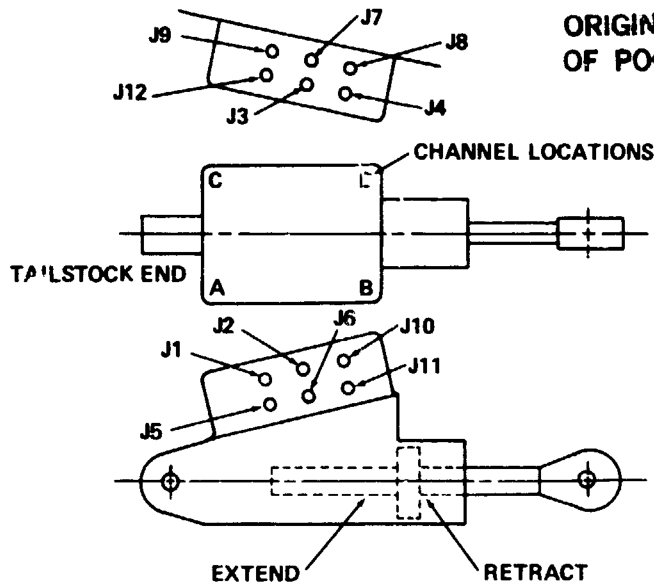
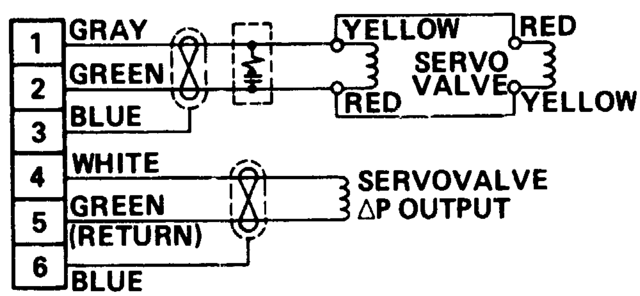


Figure B-10. Pin function diagram – APU interface control board.



NOTE: SEE FIGURES B–12 THROUGH B–17 FOR CONNECTOR PIN FUNCTIONS.

Figure B-11. Servoactuator connector locations and channel designations.



NOTE: TYPICAL J–1 THROUGH J–4 (SERVO–VALVES A THROUGH D).

Figure B-12. Servovalve pin functions.

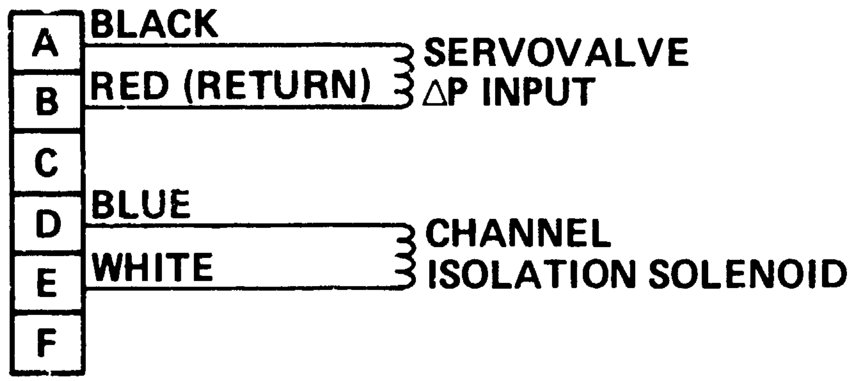


Figure B-13. Servovalve pin functions.

NOTE: TYPICAL J–5 THROUGH J–8 (SERVO–VALVES A THROUGH D).

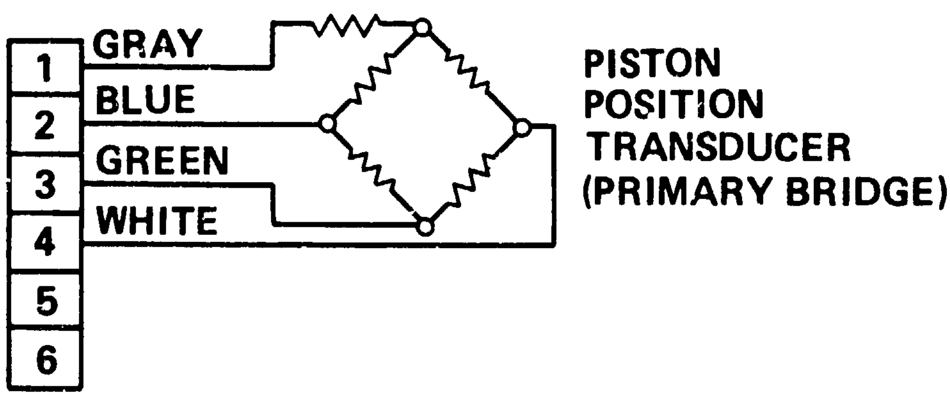


Figure B-14. Servoactuator connector J-9.

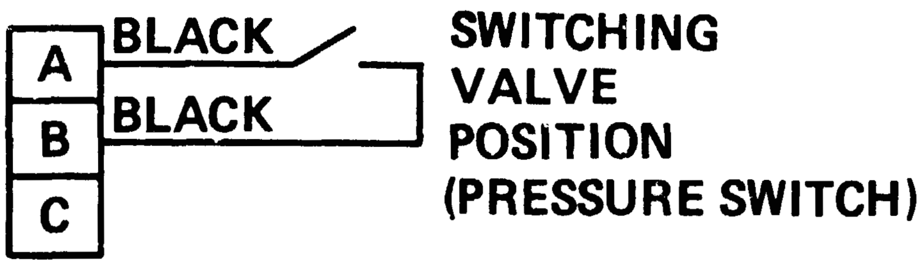


Figure B-15. Servoactuator connector J-10.

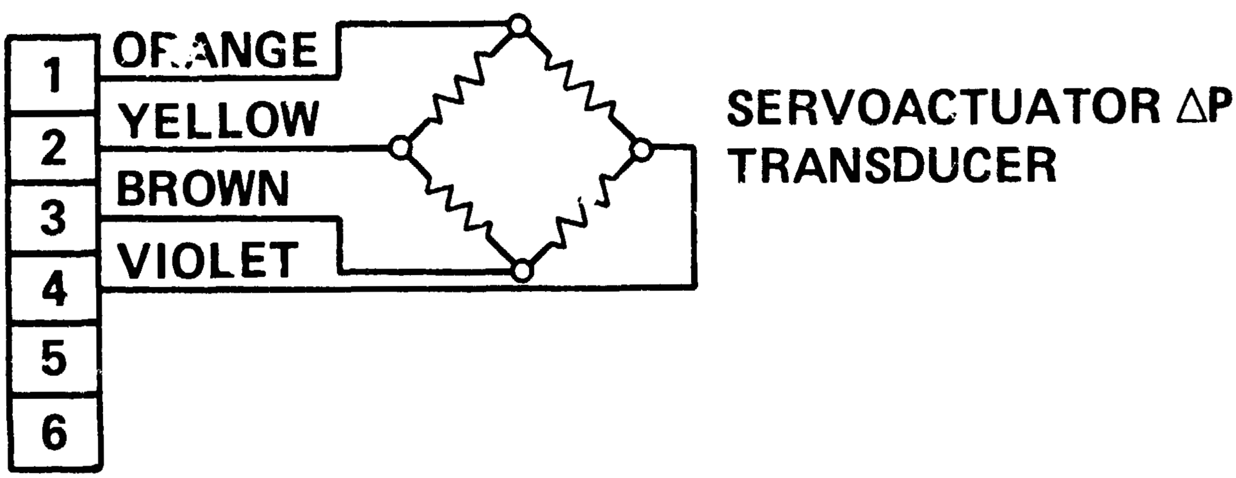


Figure B-16. Servoactuator connector J-11.

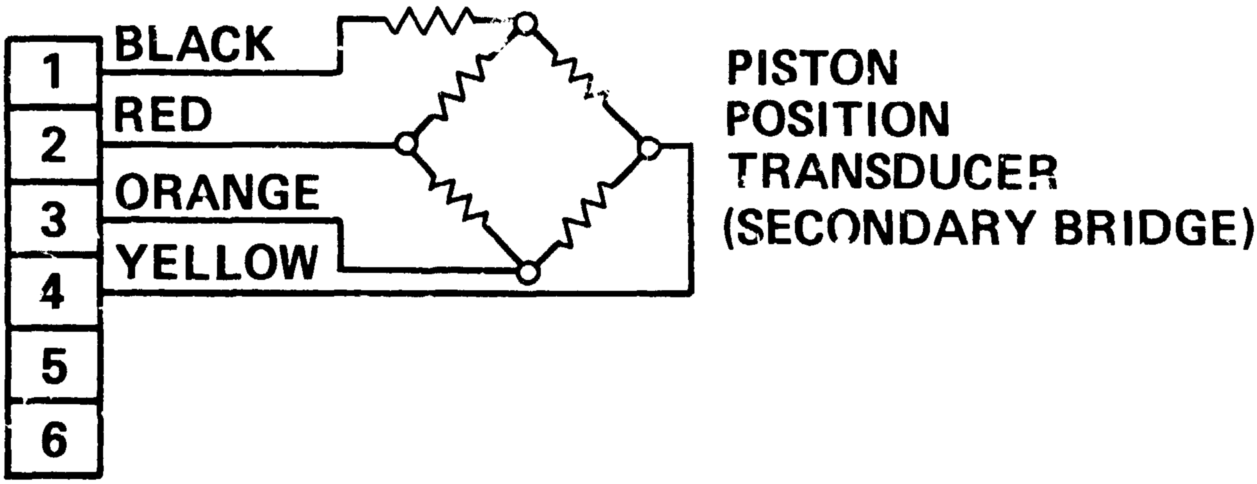


Figure B-17. Servoactuator connector J-12.

APPENDIX C

SERVOACTUATOR DIAGRAMS

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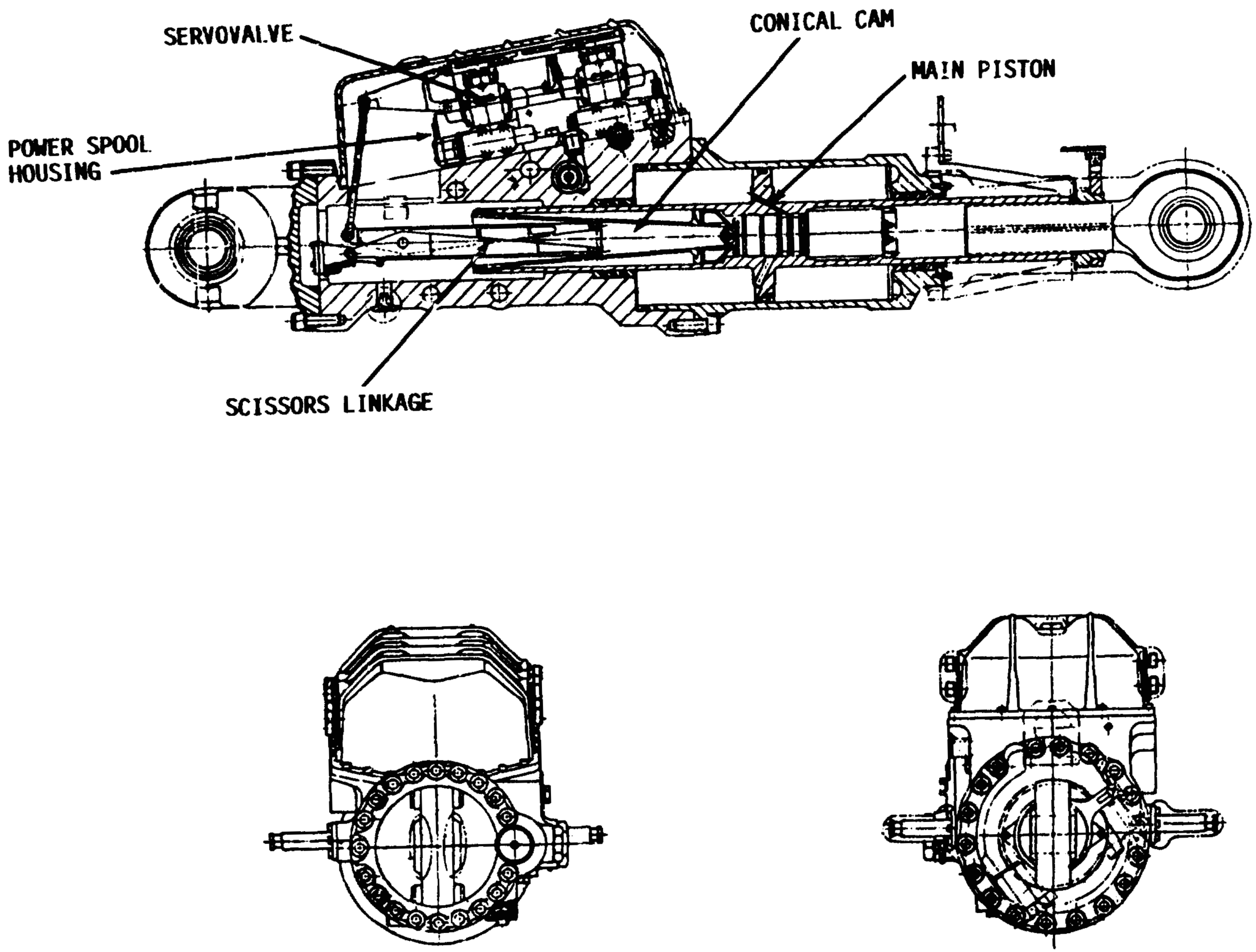

Figure C-1. Servoactuator – cutaway view.

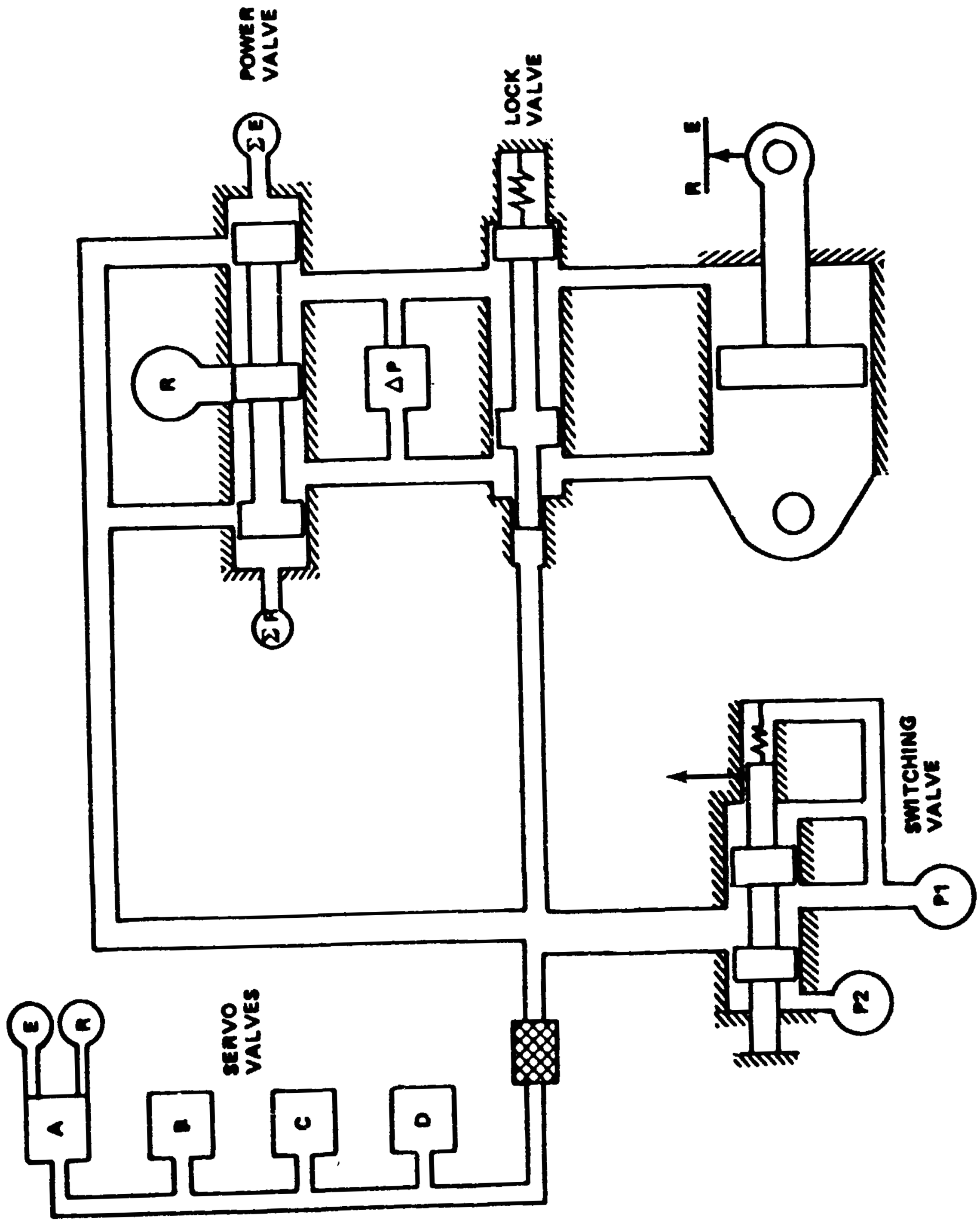

Figure C-2. Servoactuator – schematic diagram.

APPENDIX D

SRB APU EXPLODED PARTS VIEWS

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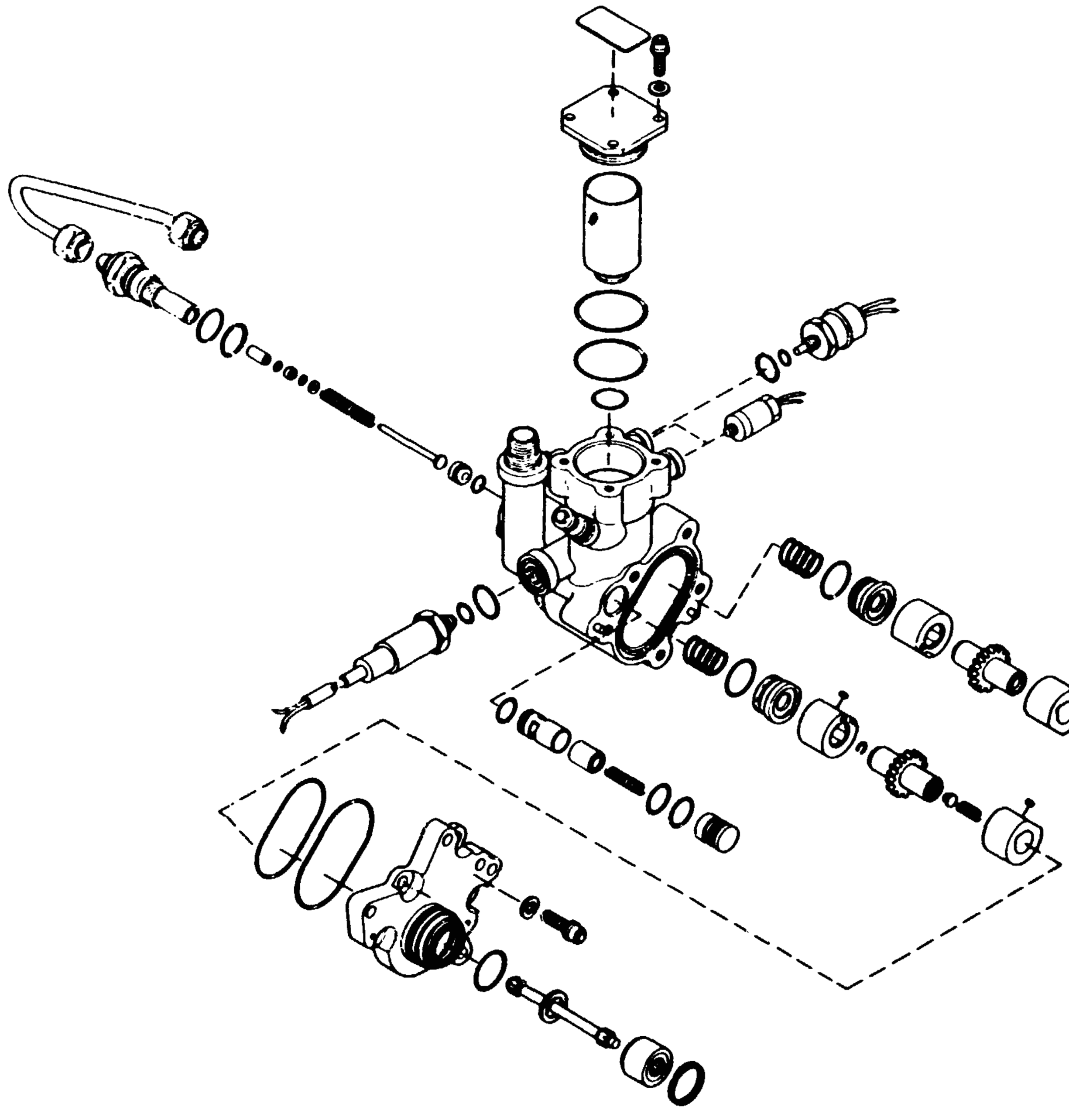

Figure D-1. SRB APU fuel pump – exploded parts.

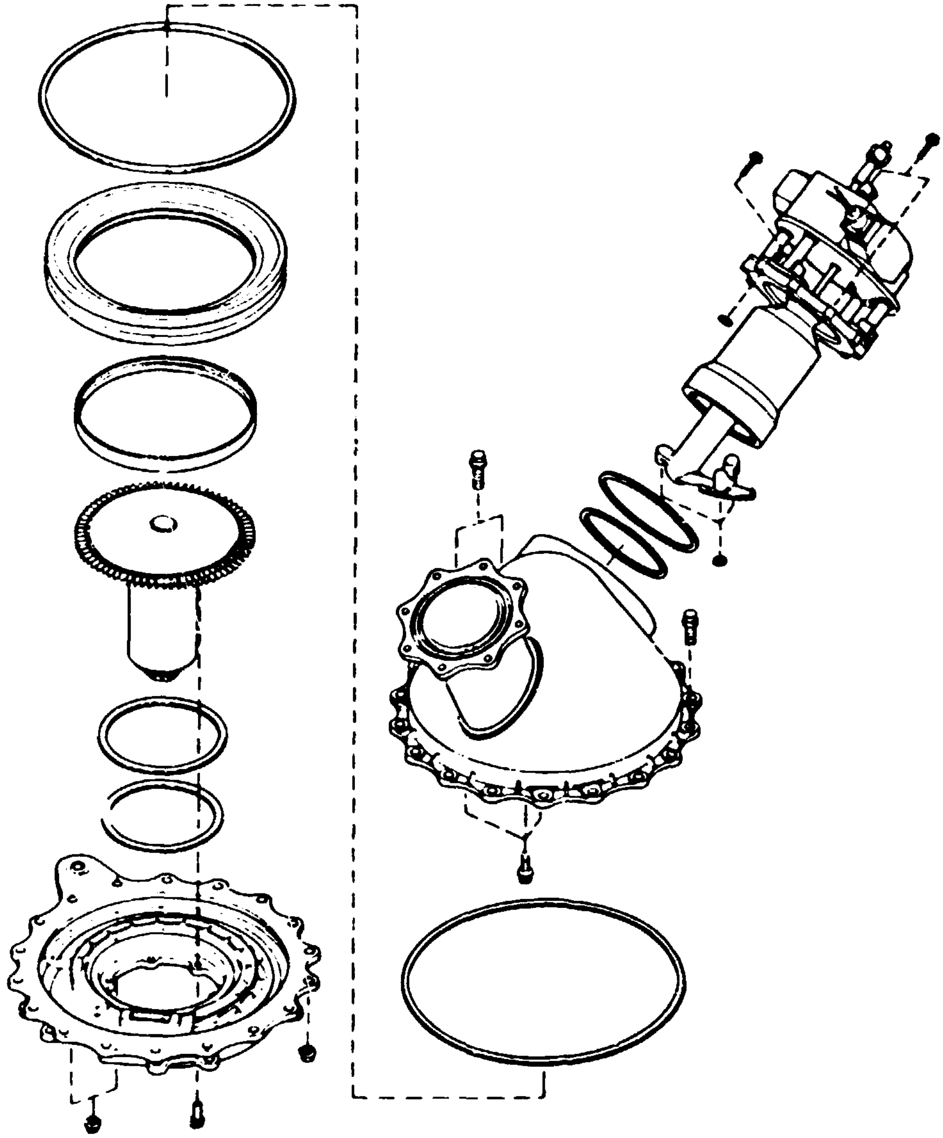

Figure D-2. SRB APU turbine and GG assembly – exploded parts.

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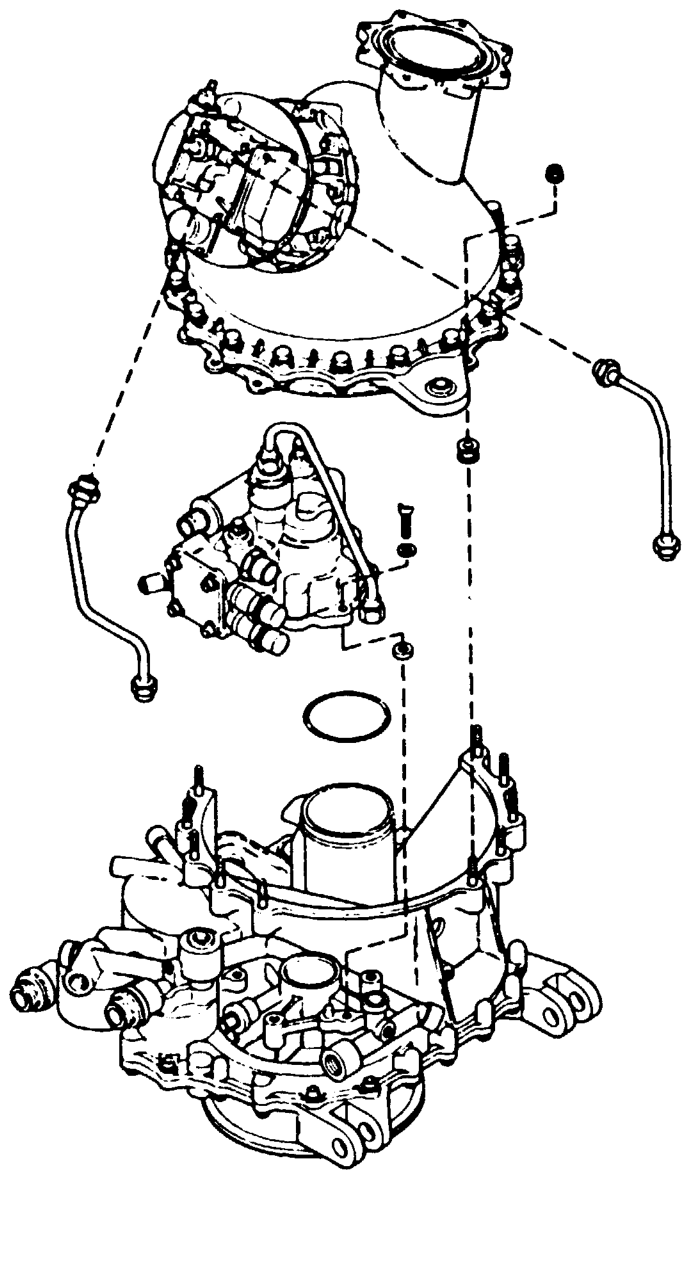

Figure D-3. SRB APU exhaust dome and fuel pump – exploded parts.

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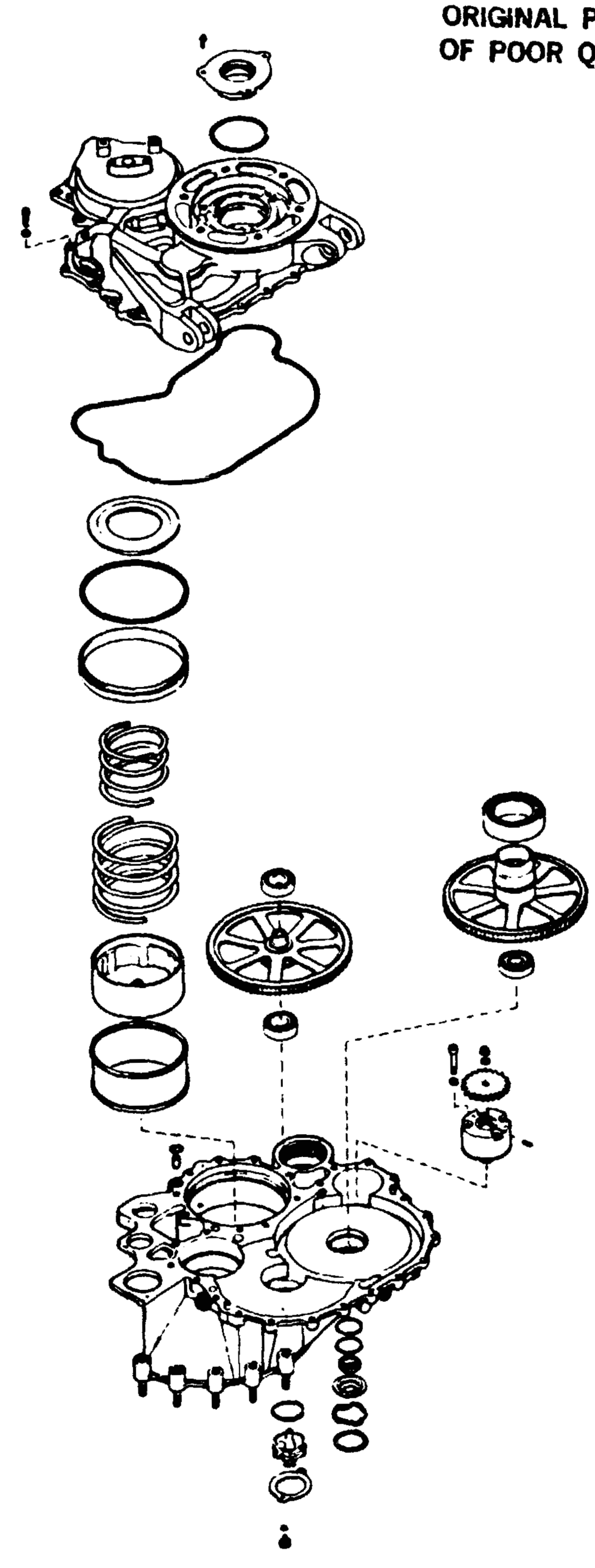

Figure D-4. SRB APU gearbox – exploded parts.

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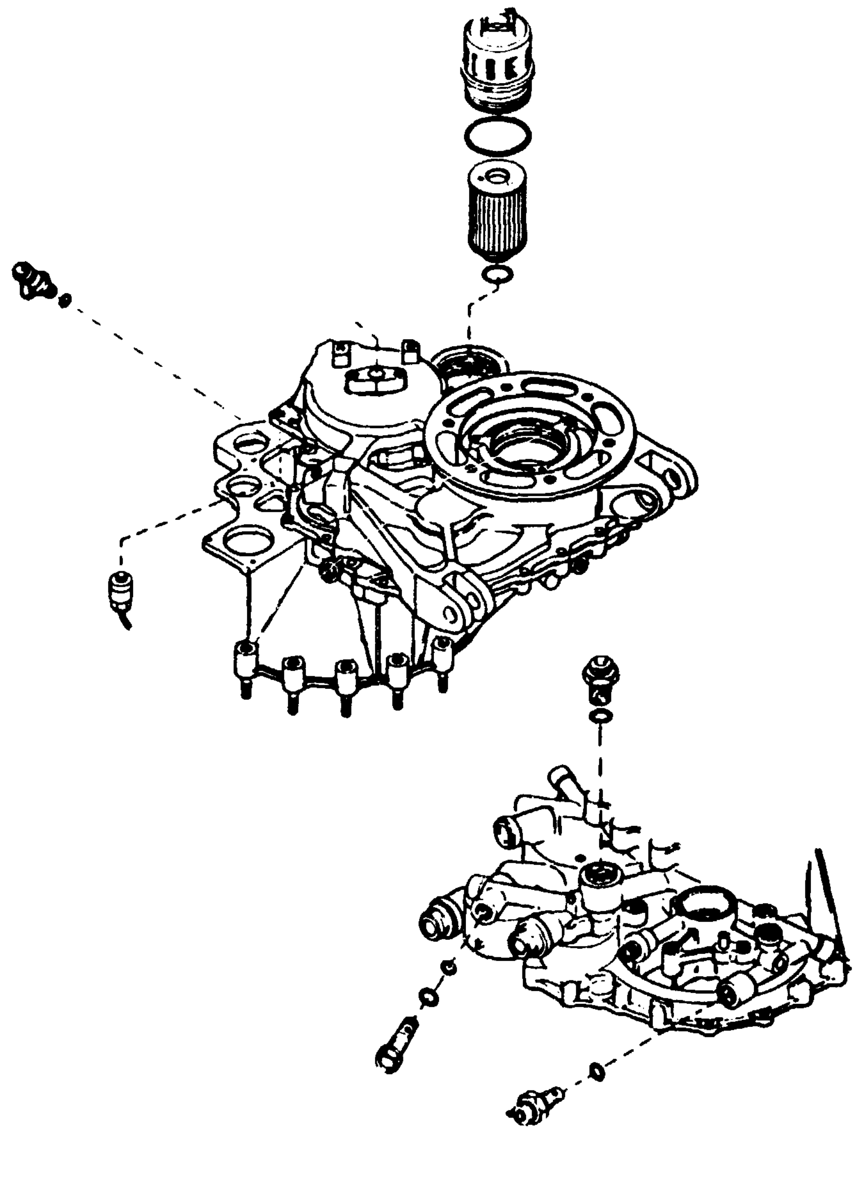

Figure D-5. SRB APU gearbox – exploded parts.

APPENDIX E

HYDRAULIC PUMP PRESSURE COMPENSATOR

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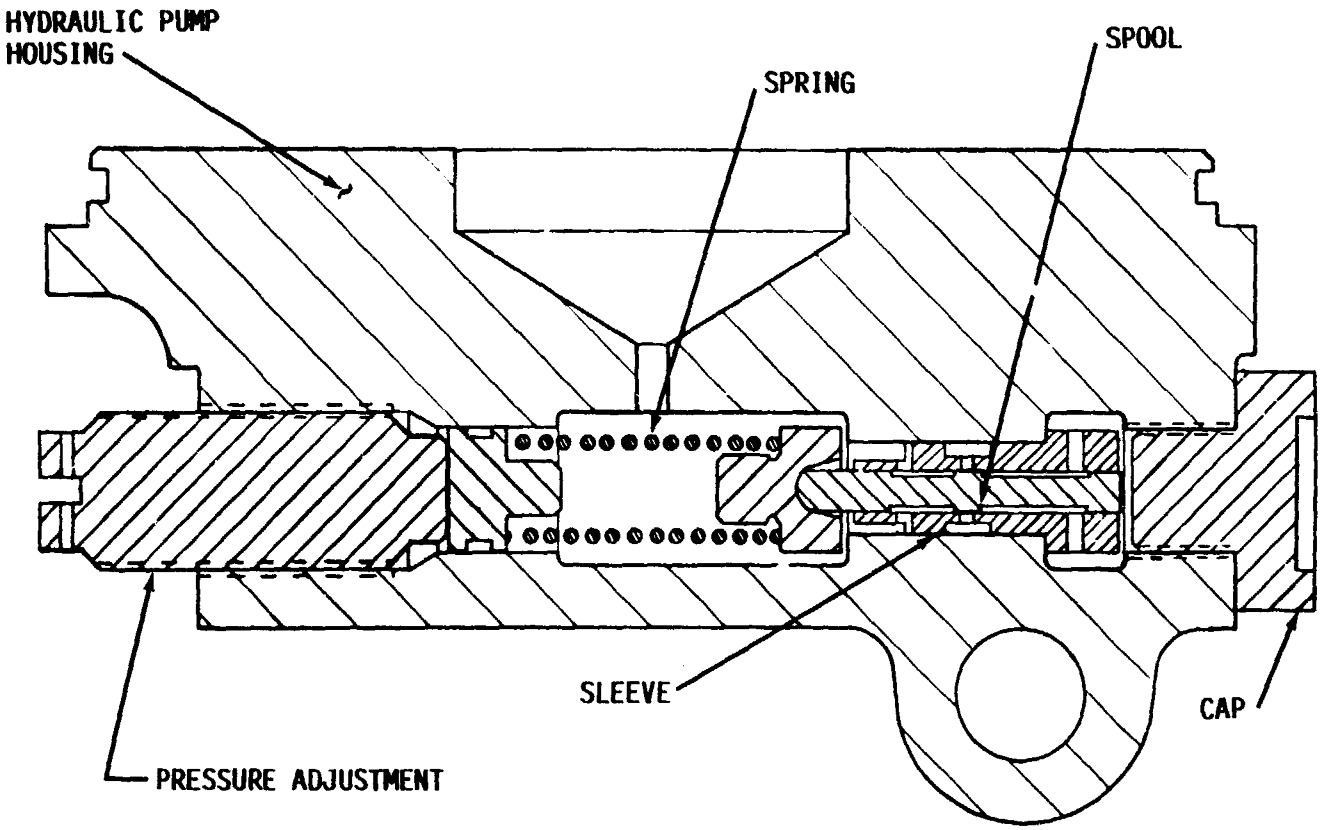

Figure E-1. Hydraulic pump pressure compensator.

APPENDIX F

APU LUBE OIL ACCUMULATOR

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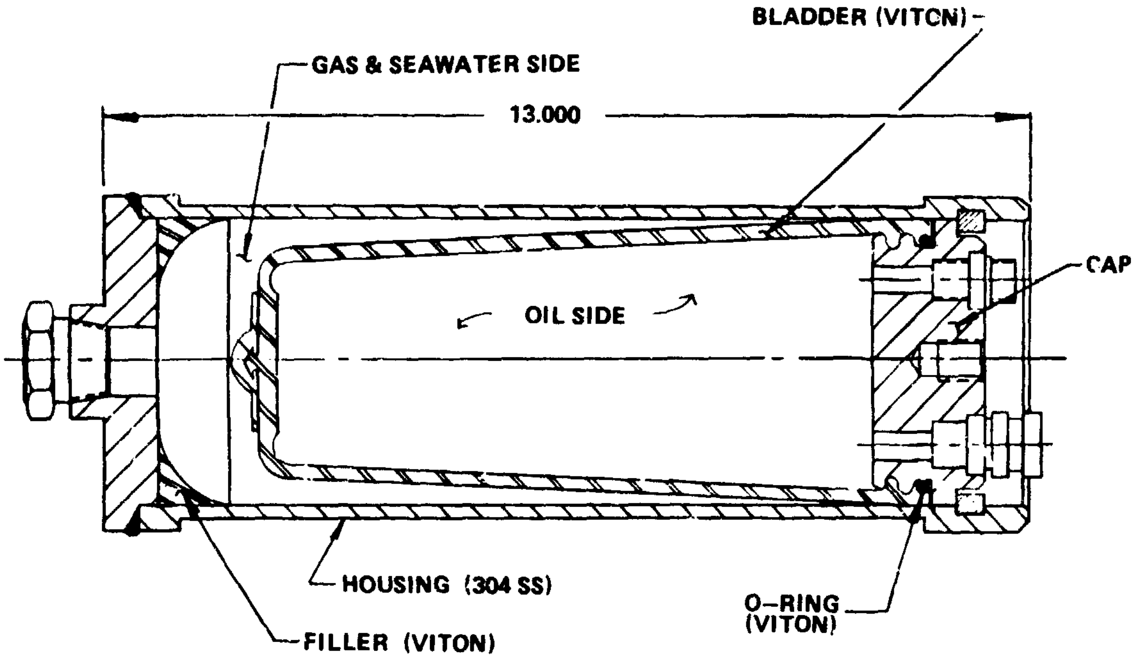

Figure F-1. APU lube oil accumulator.

APPENDIX G

CROSS REFERENCE TO UNITED SPACE BOOSTER, INC. (USBI) PART NUMBERS

ITEM	USBI PART NUMBER
APU	10201-0049
Hydraulic Pump	10201-0051
Fluid Manifold Assy	10201-0066
Check Valve and Filter Assy	10201-0047
Accumulator	10207-0002
Bootstrap Reservoir	10203-0008
FSM	10203-0015
Actuator	10208-0002

APPENDIX H

TVC PHOTOGRAPHS

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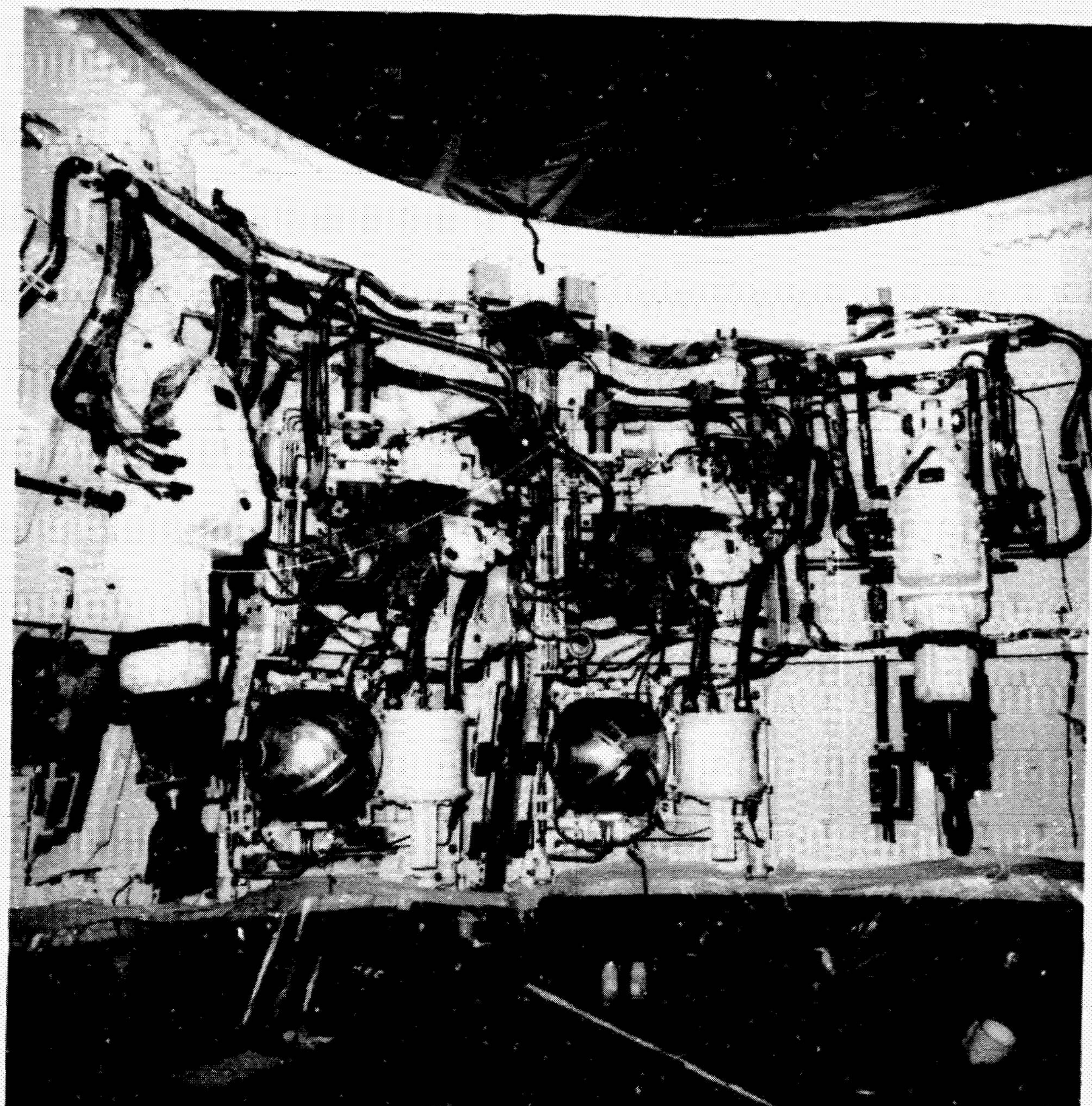

Figure H-1. SRB-TVC subsystem assembled in aft akirt prior to stacking (STS-3 photograph).

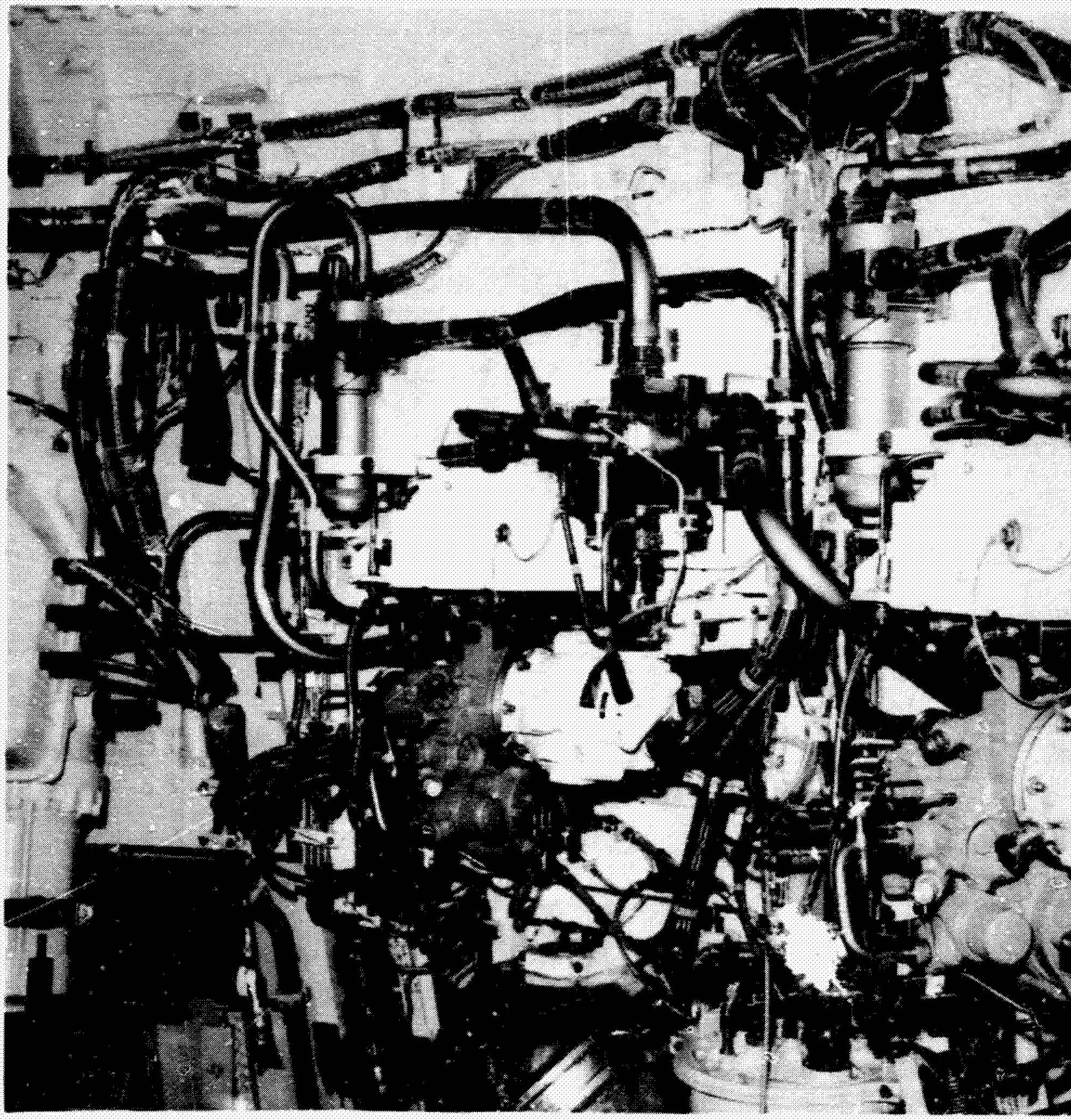

Figure H-2. SRB-TVC assembly showing APU, hydraulic pump, check valve and filter assembly, and fluid manifold assembly (STS-3 photograph).

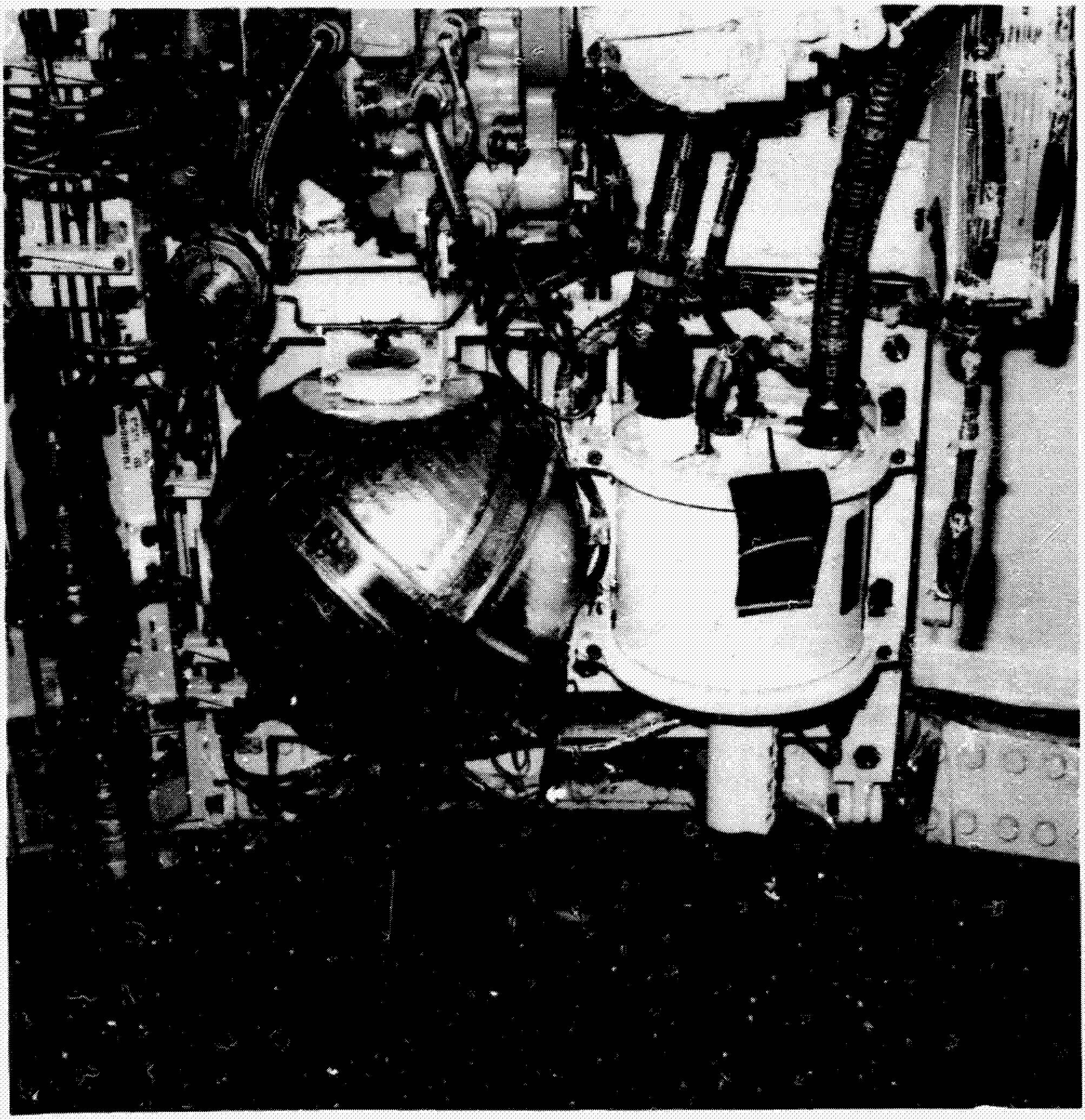

Figure H-3. SRB-TVC assembly showing FSM, hydraulic bootstrap reservoir, and overboard exhaust duct (STS-3 photograph).

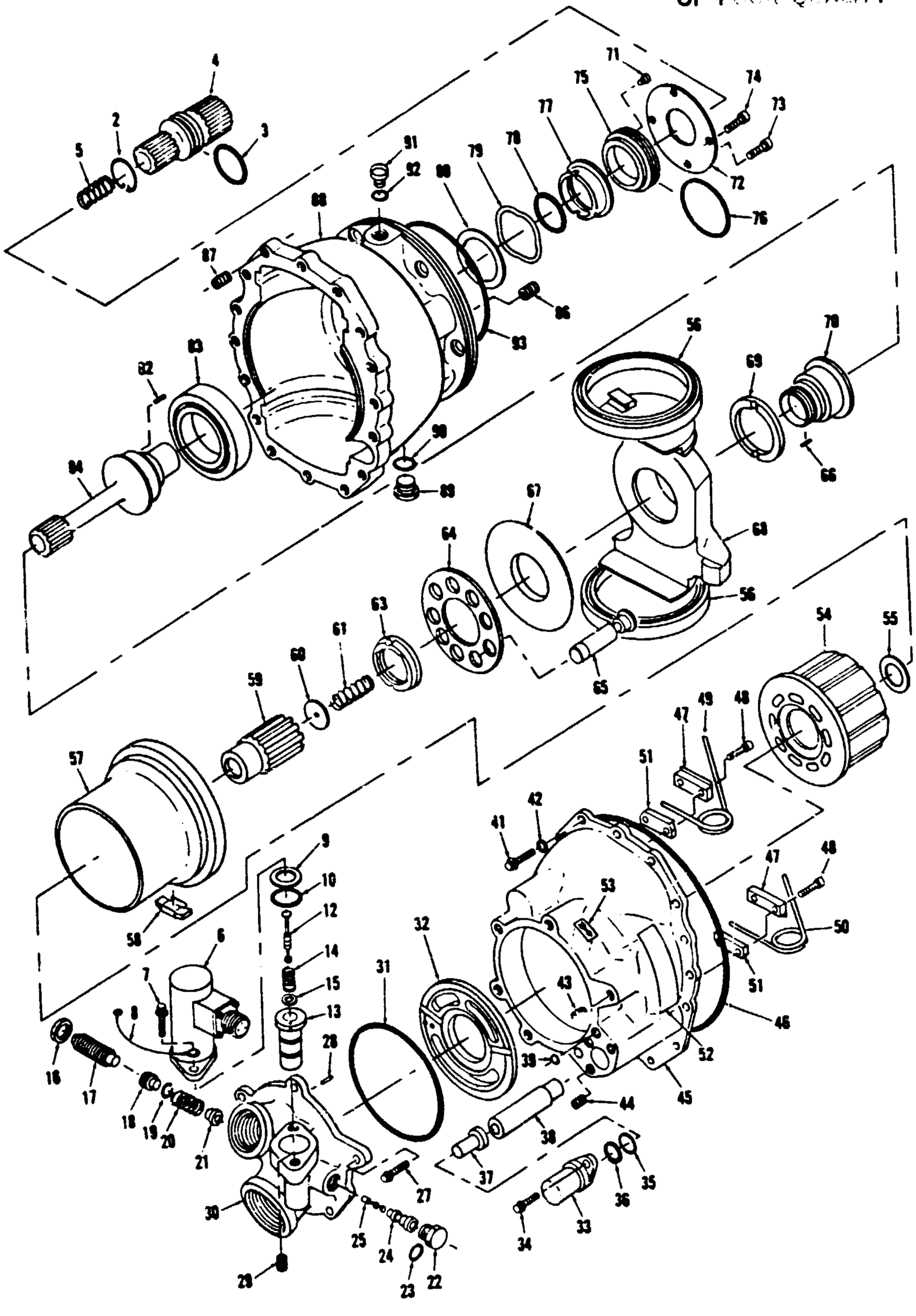

Figure I-1. Hydraulic Pump, Model AP27V-10 (Exploded View)