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Space Program Operations Contract

APU/Hydraulic/Water Spray Boiler Systems Training Manual

APU/HYD/WSB 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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United Space Alliance

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Rev. A

APU/Hydraulic/Water Spray Boiler Systems Training Manual APU/HYD/WSB 21002

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APU/Hydraulic/Water Spray
Boiler Systems Training Manual
APU/HYD/WSB 21002

LIST OF EFFECTIVE PAGES

The status of all pages in this document is shown below:

Page No.	Change No.
Preface	Rev. A
i - v	Rev. A
1-1 – 1-2	Rev. A
2-1 – 2-36	Rev. A
3-1 – 3-31	Rev. A
4-1 – 4-17	Rev. A
5-1 – 5-6	Rev. A
6-1 – 6-4	Rev. A
A-1 – A-4	Rev. A
B-1 – B-4	Rev. A
C-1	Rev. A

PREFACE

The content of this document was provided by the Systems Training Group, Vehicle Systems Training Branch, Space Transportation Vehicle Division, Mission Operations Directorate (MOD), Lyndon B. Johnson Space Center (JSC), National Aeronautics and Space Administration (NASA). Technical documentation support was provided by Bastion Technologies, Inc. Any questions concerning this training manual or any recommendations should be directed to the training manual book manager, Russell Newland III, DS45 at 281-244-7576.

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A Training Materials Evaluation is included at the end of this document. Inputs on this sheet will be used to evaluate the lesson material. You do not need to sign the sheet.

CONTENTS

Section **Page**

Appendix

TABLES

FIGURES

Figure **Page**

1.0 INTRODUCTION

The orbiter has three independent Auxiliary Power Unit/Hydraulic/Water Spray Boiler (APU/HYD/WSB) systems (Figure 1-1).

The hydraulic systems are similar to those found on large aircraft. These systems are used to move the orbiter aerosurfaces, throttle and steer the orbiter main engines, deploy the landing gear, provide nosewheel steering, apply the brakes, and retract the external tank umbilical plates after External Tank Separation (ET SEP).

Power for the hydraulic systems is provided by three identical APUs. The APUs convert the chemical energy of liquid hydrazine into mechanical shaft power to drive the hydraulic main pumps. A fuel pump delivers hydrazine to the Gas Generator (GG) bed, where a catalyst decomposes it into a hot gas. This gas drives the turbine wheel, which provides the rotational shaft power to the hydraulic main pump.

Cooling for the hydraulic fluid and lubricating oil is provided by a WSB on each system.

During a typical flight, the APUs are started 5 minutes before lift-off and operate through the Orbital Maneuvering System-1 (OMS-1) burn when hydraulic power is no longer required.

The APUs are basically inactive on orbit. One APU is run briefly the day before deorbit to support the Flight Control Surface (FCS) checkout.

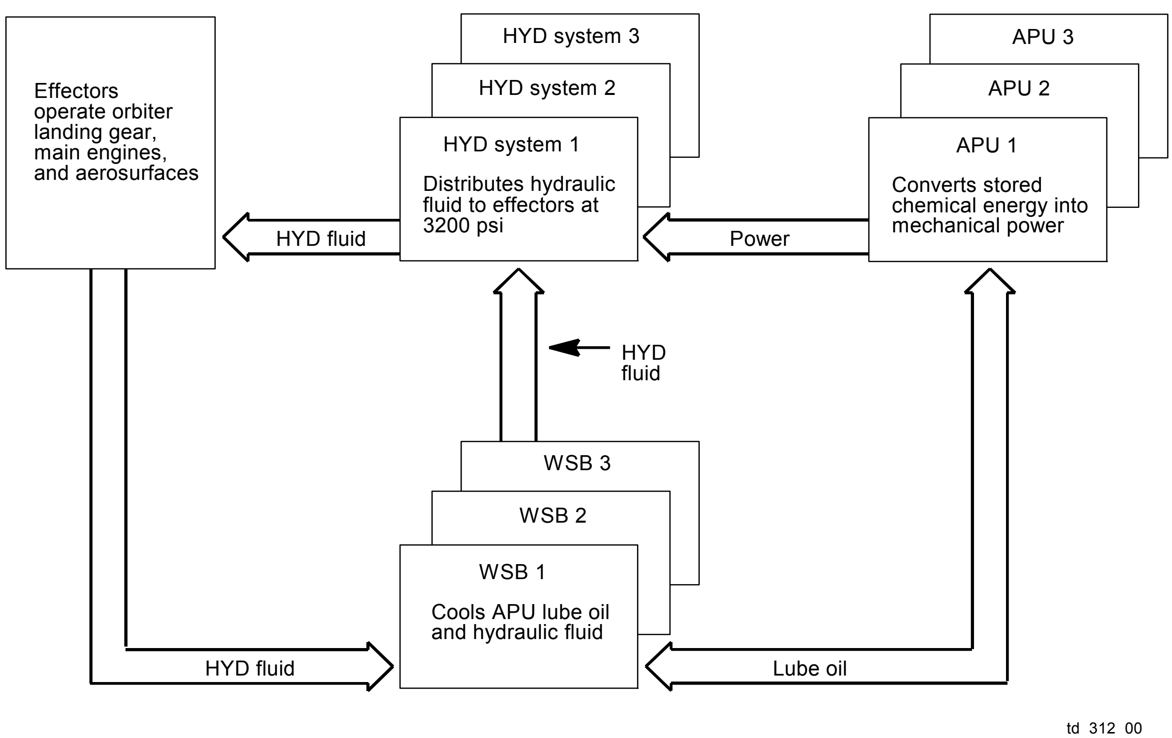

Figure 1-1. Three independent APU/HYD/WBS systems

The APUs are restarted for the deorbit burn and entry. They are shut down shortly after landing.

Figure 1-2 shows the locations of the APU and hydraulic system components in the orbiter.

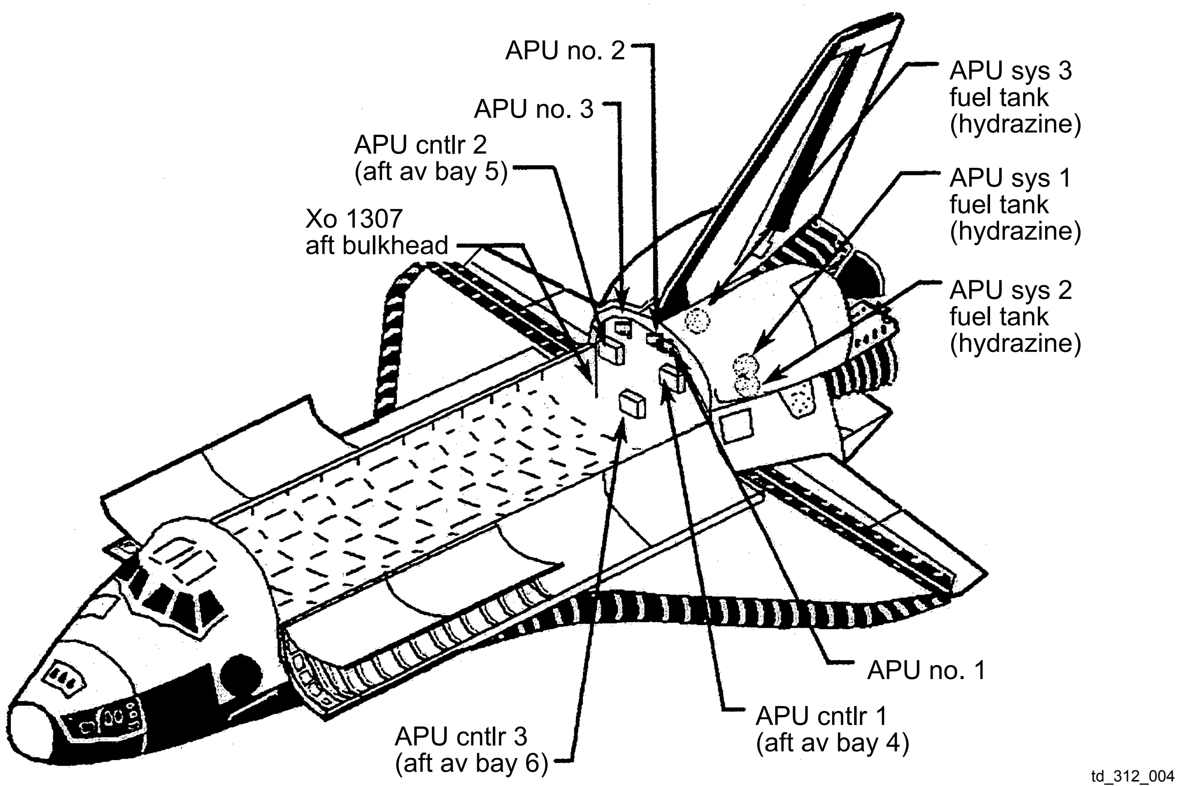

Figure 1-2. APU locations

2.0 AUXILIARY POWER UNIT

2.1 OBJECTIVES

Upon completing this section, you should be able to

- State where the APUs are located in the orbiter
- Recognize the function of the APUs
- Match the APU components to their functions

2.2 OVERVIEW

The orbiter APU system consists of three independent, yet functionally identical, APUs (Figure 2-1). They are auxiliary only in the sense that they generate power separately from the orbiter fuel cells.

The APUs are located aft of the orbiter 1307 bulkhead beneath the OMS pods.

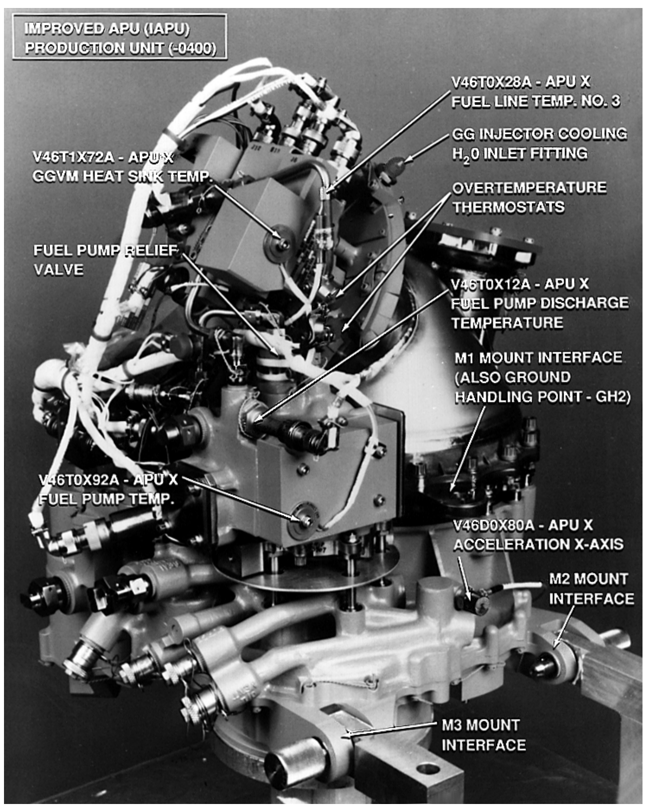

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Figure 2-1. APU

The APUs are essential for providing hydraulic power to gimbal and throttle the main engines during ascent; moving the aerosurfaces during ascent and entry; retracting the ET plates after ET SEP; deploying the landing gear for touchdown; and providing braking and steering during rollout.

Each APU converts the chemical energy of liquid hydrazine into mechanical shaft power to drive its hydraulic main pump through a reduction gearbox (Figure 2-2). In addition to powering the hydraulic pump, the APU shaft power is used to drive both the fuel and lubricating oil pumps through the same gearbox.

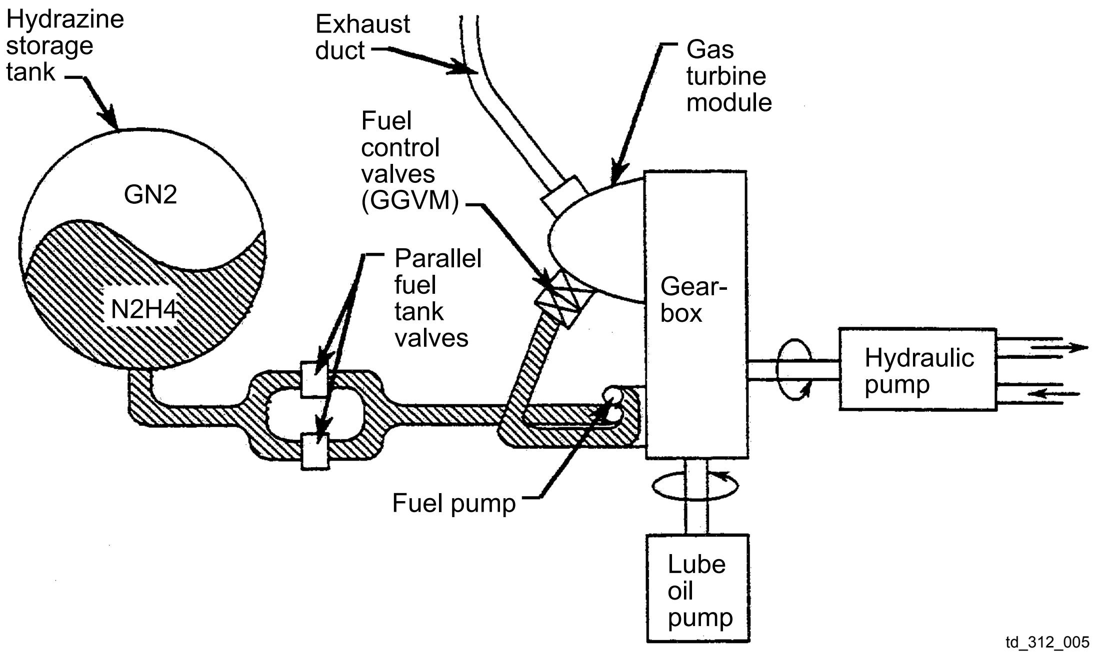

Figure 2-2. APU system layout

2.3 SYSTEM DESCRIPTION

In this section, we will discuss the following major components of the APU system:

- Fuel tank
- Fuel tank valves
- Fuel pump
- Fuel control valves
- GG and turbine
- Lubricating oil system
- Digital controller
- Injector cooling system
- Heaters

Throughout this section, the APU will be referred to singularly. Keep in mind that there are three identical, but independent, APUs on the orbiter. All three APUs are functionally (operationally) alike.

Figure 2-3 shows a schematic of the APU system. We will reference this schematic throughout this workbook when discussing the various system components.

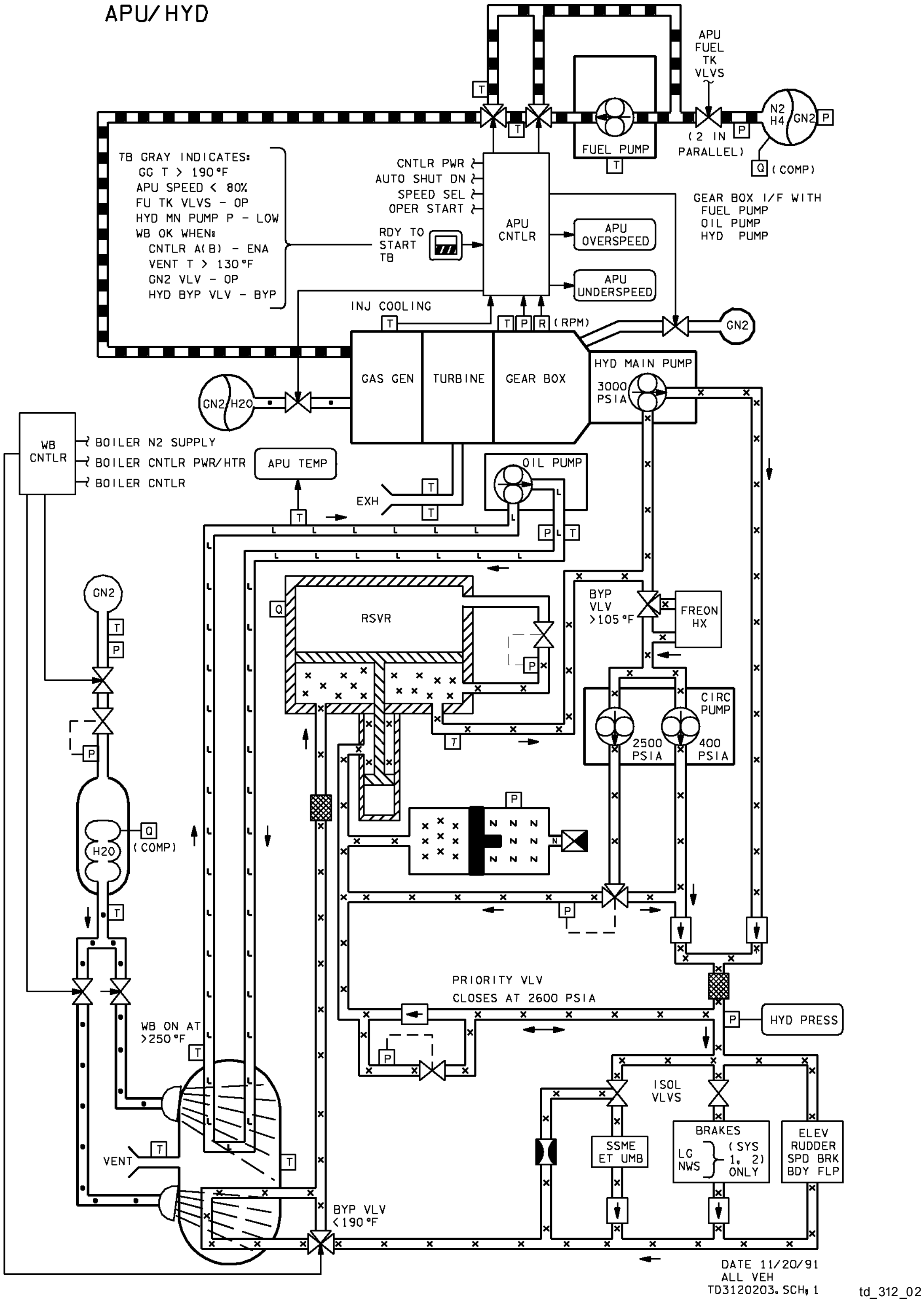

Figure 2-3. APU/HYD/WBS schematics

2.3.1 Fuel Tank

Liquid anhydrous hydrazine (N_2H_4) is used to fuel the APU. It is different from the monomethyl hydrazine used in the orbiter Reaction Control System (RCS).

The hydrazine is stored in a tank capable of holding about 350 lb of fuel. Gaseous nitrogen (GN_2) is used to pressurize the fuel in the fuel tank. It is isolated from the hydrazine by a rubber diaphragm dividing the tank. The nitrogen provides sufficient pressure to force the fuel to the APU for startup prior to APU fuel pump operation (Figure 2-4). The fuel quantity is determined by use of a Pressure/Volume/Temperature (PVT) computation performed by the onboard computers.

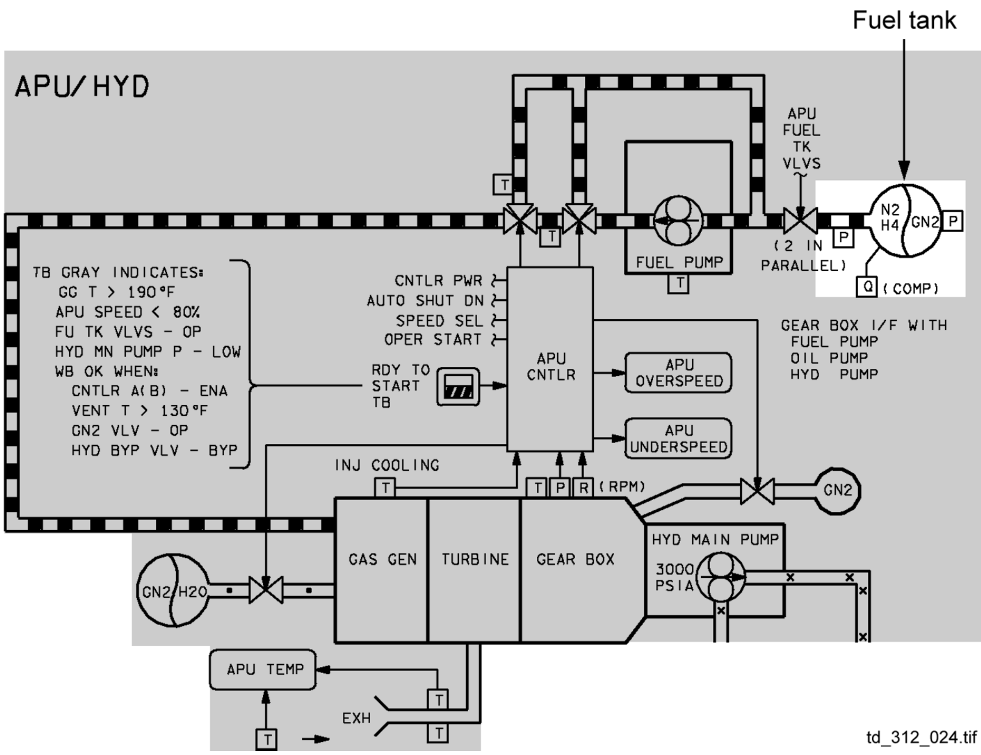

Figure 2-4. APU fuel tank

A typical prelaunch APU fuel load is 325 lb. This allows more than enough fuel to support the nominal APU operating time and any defined launch abort mode, such as the Abort Once Around (AOA) in which the APU runs continuously for about 110 minutes. Under normal hydraulic load, an APU uses about 3 lb/min of fuel.

2.3.2 Fuel Tank Valves

Two fuel tank valves isolate the fuel tank from the APU (Figure 2-5). They are aligned in parallel for redundancy. Both of these solenoid-operated valves are opened simultaneously by the crew during the APU PRESTART procedure. Upon opening the valves, hydrazine is forced into the fuel pump by internal fuel tank pressure.

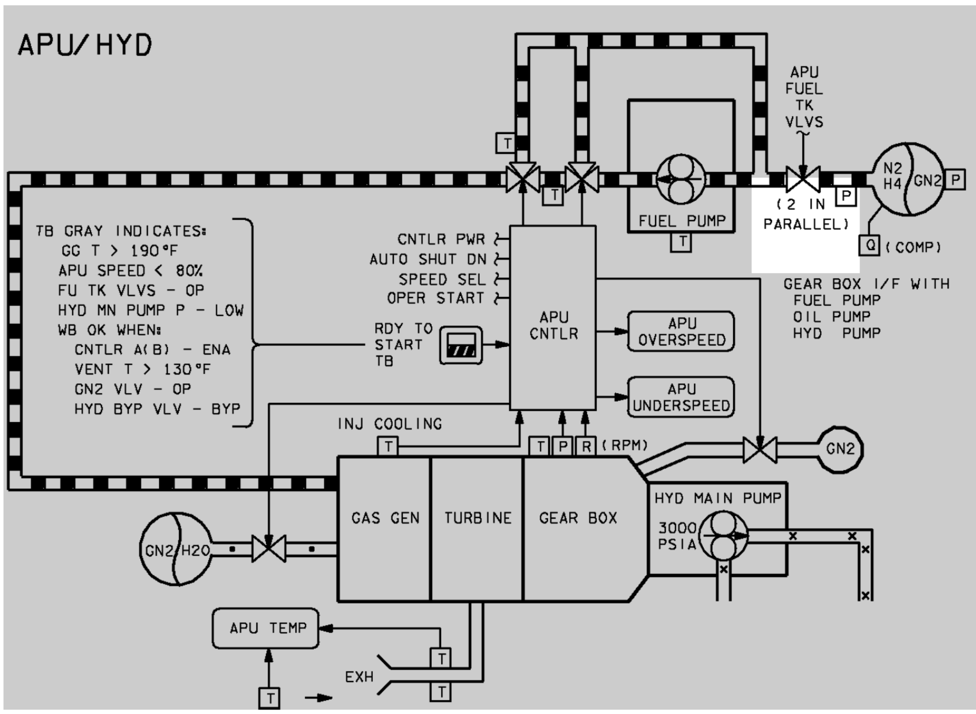

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Figure 2-5. Fuel tank valves

Should a fuel tank valve fail to the open position, which is the powered state, two circuit breakers, one for fuel tank valve A and one for fuel tank valve B, can be pulled on panel R2 to remove electrical power from the solenoid so that the valves do not eventually overheat. Should the fuel tank valves ever lose power, they default to the closed position. The APU can operate normally with just one fuel tank valve.

2.3.3 Fuel Pump

The fuel pump (Figure 2-6) is a fixed-displacement pump that delivers hydrazine at a rate of 14 lb/min to the GG bed, where it is decomposed into a gas. It is driven by the APU turbine; therefore, it is not turning during the startup because the turbine is not spinning. Instead, the fuel bypasses the fuel pump by way of a startup bypass line (not shown), allowing hydrazine into the GG. When the fuel contacts the catalyst (Shell 405), it decomposes from a liquid to a hot, expanding gas. As the gas expands, it drives the turbine wheel, which in turn drives the fuel pump through a reduction gearbox.

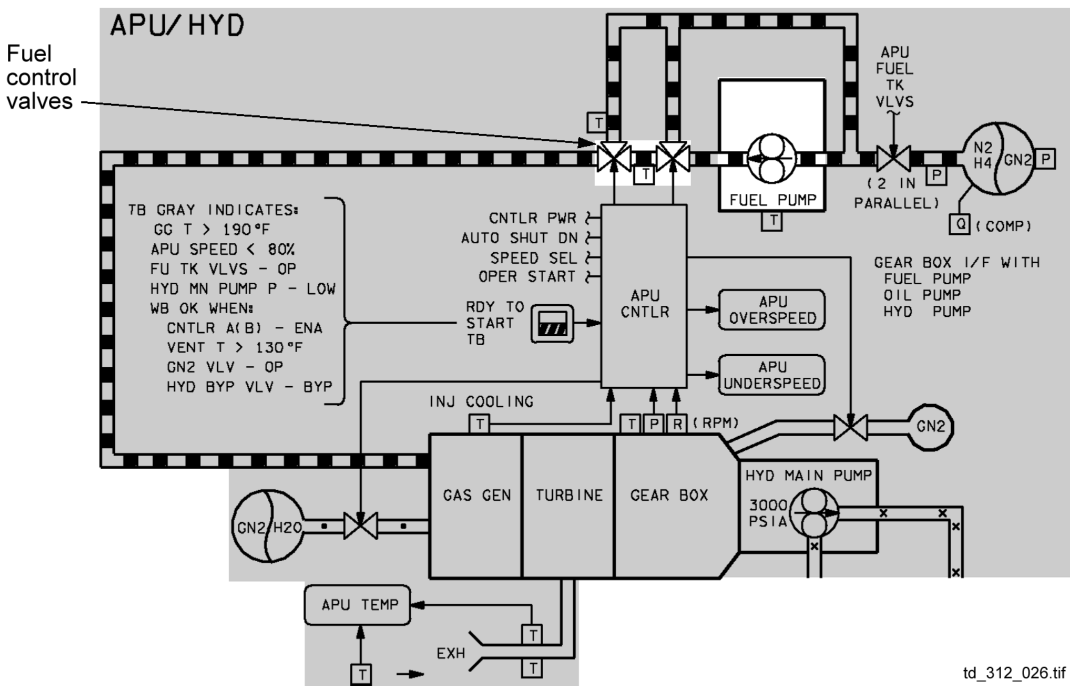

Figure 2-6. APU fuel pump

The fuel pump is mated onto the gearbox partly inside a cavity designed to help contain leakage of fuel or lubricating oil through the pump seals. If fuel and oil mix, a wax-like substance forms and can clog the filter and oil pump. However, two cavities exist between the gearbox and fuel pump for the power shaft to separate the fuel from the oil. One cavity collects leaking fuel and the other cavity collects leaking oil from the pump seals. Additional fuel leakage is collected in a 500-cc catch bottle from the fuel cavity. If the catch bottle fills, it relieves overboard through a drain port.

2.3.4 Fuel Control Valves

The APU operating speed is maintained by the primary and secondary fuel control valves, which are installed downstream of the fuel pump. The primary valve is sometimes referred to as the control valve. The secondary valve is sometimes referred to as the shutoff valve. This workbook will refer to these valves as the primary and secondary valves.

The hardware package, which contains these valves, is called the Gas Generator Valve Module (GGVM). These solenoid-operated pulser valves are controlled by four identical speed control channels within the APU digital controller. Three magnetic pickup units on the APU provide rpm inputs that the controller converts to turbine speed outputs before sending them to the speed control channels. The speed control channel logic uses the data to command the fuel control valves for operating the APU in either normal or high speeds. These two-speed selections for the turbine wheel are 103 percent (74,000 rpm) for normal speed and 113 percent (81,000 rpm) for high speed. The speeds are greater than 100 percent because actual performance is better than the original design specifications. When the APU is operating in normal speed, the primary control valve is controlling to a turbine speed of 103 percent, and the secondary control valve is controlling to 113 percent. The primary valve is pulsing open and closed to maintain 103 percent, while the secondary valve is staying full open in an attempt to let enough fuel through to increase the speed to 113 percent. These valves work independently. If the APU is taken to high speed, the secondary valve pulses to maintain 113 percent while the primary valve stays full open in an attempt to control to a new speed at 115 percent. As a result of the high-speed selection, the overall control speed becomes 113 percent.

If power is removed from these valves, they go to different positions. The unpowered state of the primary control valve is open, whereas the unpowered state of the secondary control valve is closed. Figure 2-7 shows the speed control channels.

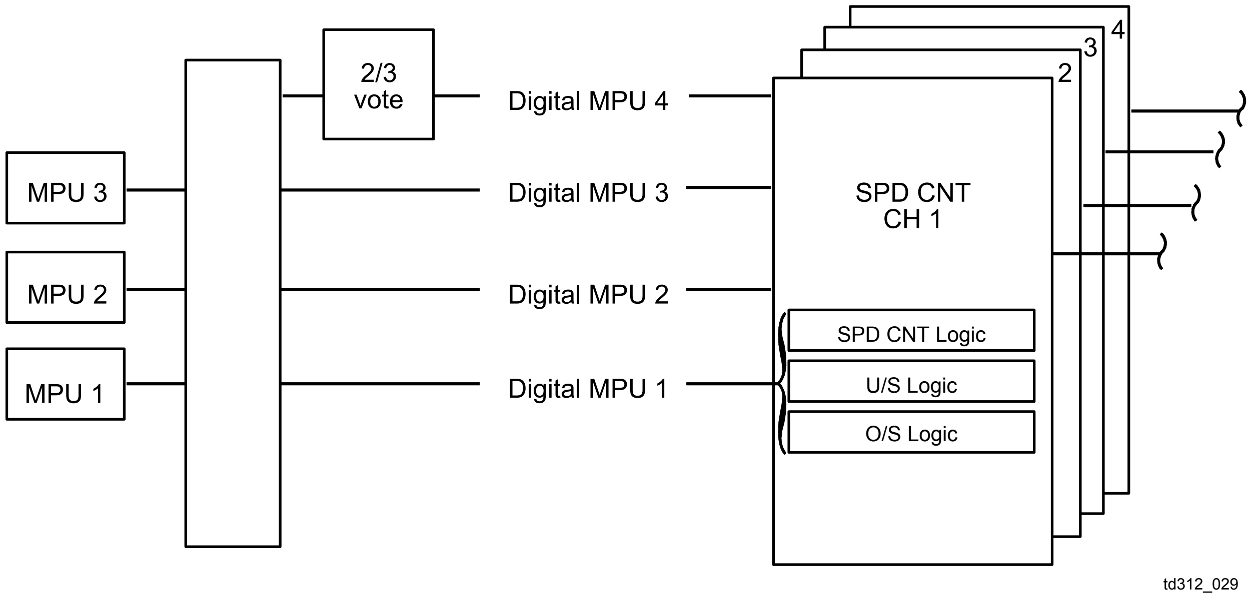

Figure 2-7. Speed control channels

An APU running in high speed is not a normal operating mode. High speed is used in two cases:

- If an APU fails, the remaining APUs will have their speed switches taken to high speed. This higher speed gives more power on demand should one of the associated hydraulic main pumps (to be discussed later) require it for a quick response.
- A valve or controller failure on an APU can cause it to shift itself to a higher operating speed. In this case, the APU will be taken to high speed. This changes the roles of the primary and secondary control valves, as discussed above, and changes the caution and warning limits to the higher range to avoid nuisance alarms. Because of the likelihood that a failure of the primary control valve caused the unintended speed shift (for example, the primary control valve failed open to its unpowered state), it cannot be assumed that the primary valve is still able to control to its new range of 115 percent. With only a single valve in control, the APU is only one failure away from an uncontained overspeed (the turbine comes apart in an explosion) and will be shut down if the other two APUs are still good.

2.3.5 Gas Generator and Turbine

The GG consists of an injector and a bed of Shell 405 catalyst in a pressure chamber that is mounted inside the APU exhaust chamber. This allows the APU exhaust gas to cool the GG. Fuel from the fuel control valves enters the injector tube and is distributed across the catalyst bed. When the fuel comes in contact with the catalyst, it undergoes an exothermic reaction, which decomposes it into a hot gas. The gas expands rapidly and makes two passes through the turbine wheel, passes over the outside of the GG chamber, and exits overboard via an exhaust duct. By expanding past the turbine wheel, the gas is cooled by several hundred degrees before it reaches the exhaust duct (Figure 2-8).

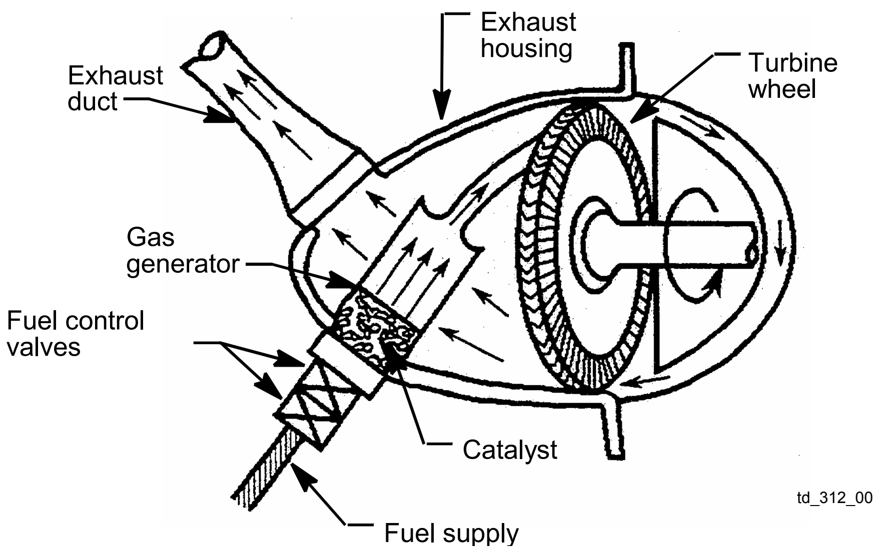

Figure 2-8. GG layout

The shaft power from the spinning turbine (Figure 2-9) is transferred to the hydraulic main pump associated with the APU via a speed reduction gearbox. It is also used to drive the APU fuel pump and lubricating oil pump. The lubricating oil system is necessary to lubricate the APU gearbox and the fuel pump.

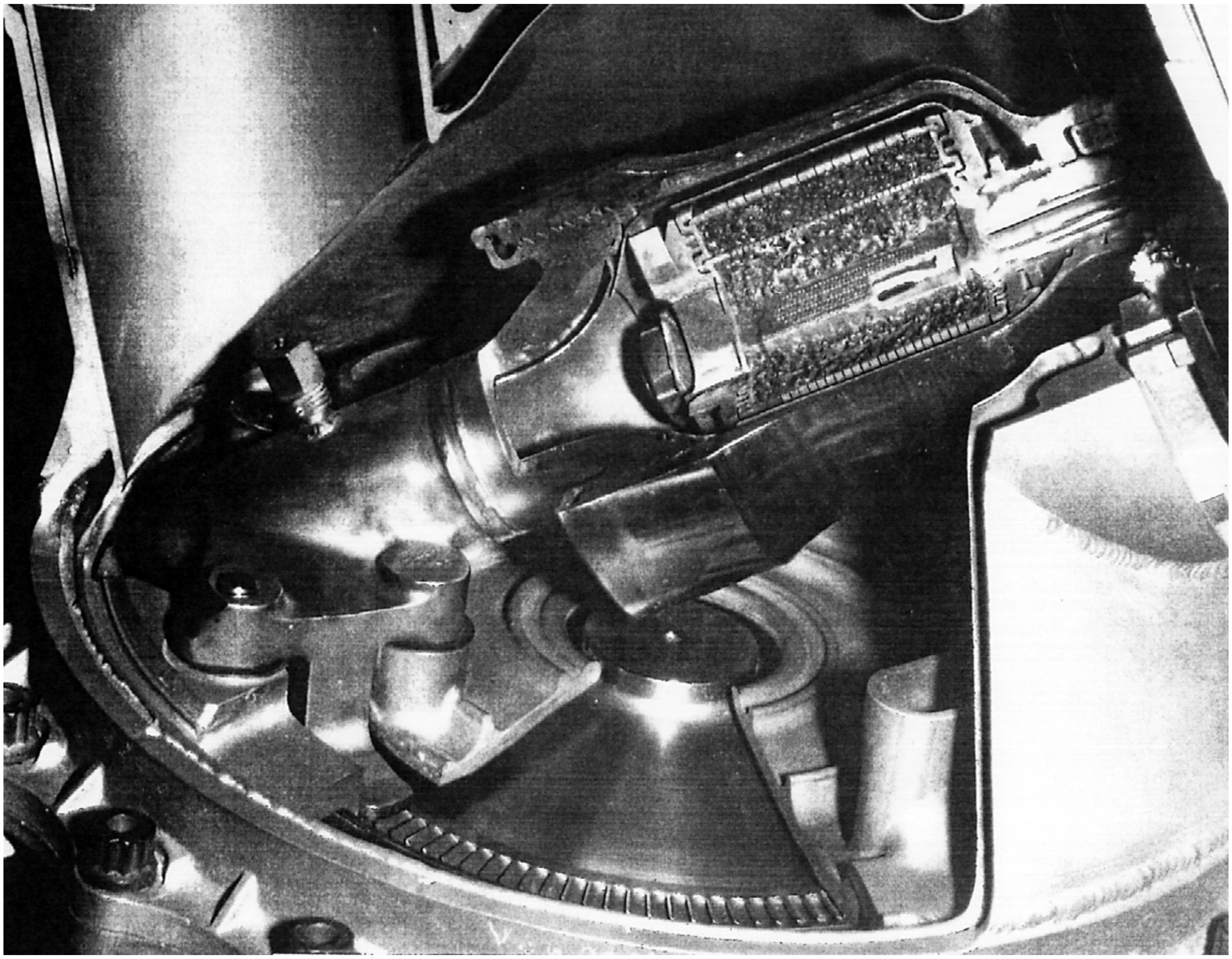

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Figure 2-9. GG and turbine

2.3.6 Lubricating Oil System

The lubricating oil system is a scavenger-type system with a fixed displacement pump. The oil picks up heat from the gearbox and fuel pump and flows from the lube oil pump to the WSB system for cooling (Figure 2-10). The return oil comes back to an oil reservoir located in the gearbox (not shown). This reservoir is used to accommodate thermal expansion and any leakage of the lubricating oil.

Nitrogen for pressurizing the lubricating oil in the gearbox (if necessary) is stored in a small bottle and is routed to the system through a shutoff valve (Figure 2-10). Two accumulators maintain pressure in the lubricating oil system.

When the APU is started, and the RUN command is present, the nitrogen bottle isolation valve will automatically be opened by the controller to pressurize the gearbox for APU startup if the gearbox pressure is less than 5.5 psia. There is enough GN_2 in the bottle to repressurize the gearbox two times. The RUN command must be present for the gearbox to be repressurized. It should be noted that it is not normal for the gearbox pressure to be less than 5.5 psia. It would require either a lube oil or GN_2 leak for this condition to occur. Sometimes a repress of the gearbox is seen upon APU start as GN_2 briefly leaks past the dynamic seals in the gearbox. However, this is not the norm. Usually during an APU start, this bottle is not used to repressurize the gearbox.

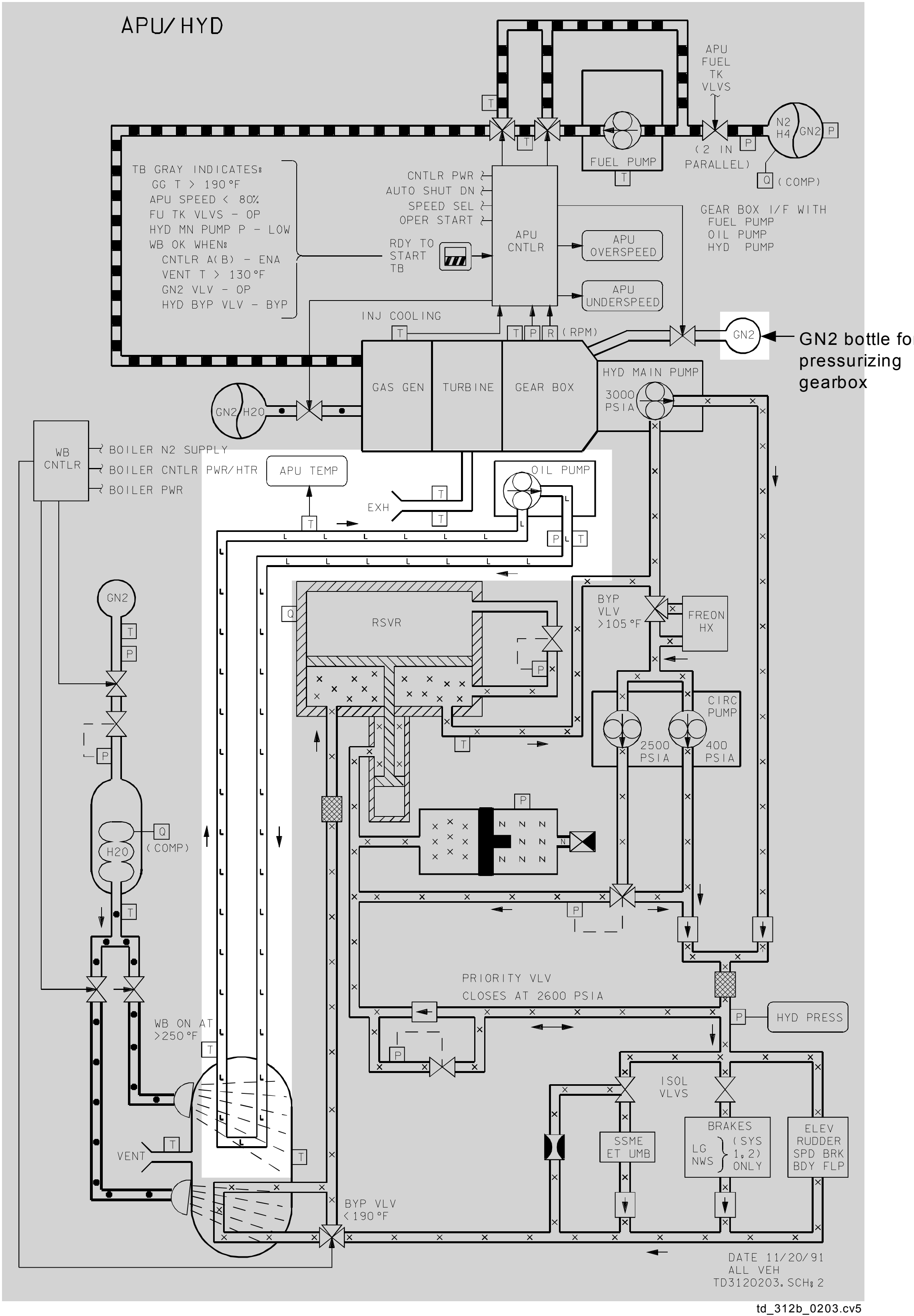

Figure 2-10. Lube oil system

2.3.7 Digital Controller

Each APU has its own digital controller that provides

- Speed control logic
- Logic for APU start and shutdown
- Malfunction detection
- Signal conditioning for APU transducers
- Logic for GG bed heater and gearbox repressurization operations

The main purpose of the controller is to operate the APU within a controlled speed range and to provide automatic shutdown protection for overspeed and underspeed situations. The digital controller first flew in 1993 and was designed to provide increased fault tolerance. With this new design, there is no single component failure that will cause an APU shutdown.

The APU speed control logic drives the primary and secondary control valves. As mentioned previously, these valves either open or pulse to control the APU in normal speed or high speed. There are four redundant Magnetic Pickup Units (MPUs)/speed control channels within the controller. There are three actual MPUs providing inputs to the controller; the fourth MPU is just a signal created by a two-thirds vote of the three MPU inputs. These inputs are routed to the controller's four speed control channels, which output fuel control valve commands and overspeed or underspeed indications based on the MPU values.

The logic in the controller also monitors the readiness of an APU to start. For the controller to indicate that the APU is ready to start, five conditions must be met:

- The GG bed temperature must be greater than 190° F.
- The APU turbine speed must be less than 80 percent.
- One of the APU fuel tank valves must be open.
- The hydraulic main pump must be in low pressure mode (to reduce startup torque on the pump).
- The WSB must be ready to operate.

If all these criteria are met, the crew will receive a gray READY TO START talkback on panel R2 (Figure 2-11) after performing the APU PRESTART procedure. It should be noted that this ready-to-start indication is only a status of the APU. The APU controller will still issue a start command when the crew moves the switch to the START/RUN position, even though the ready-to-start indication is absent.

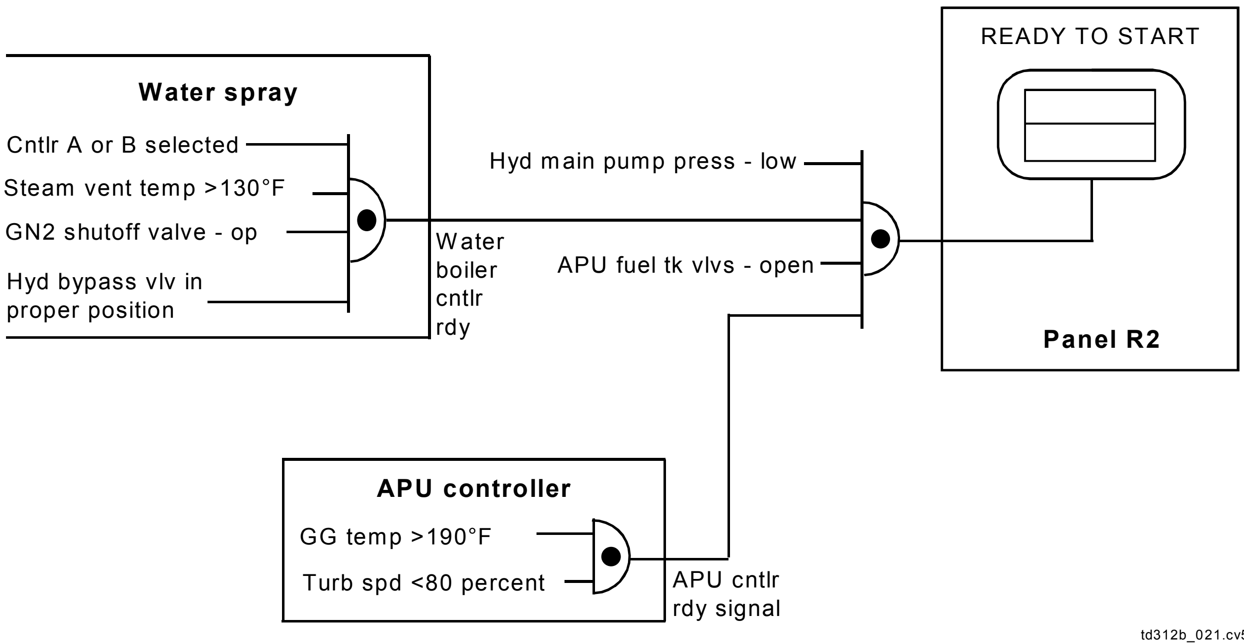

Figure 2-11. APU ready-to-start talkback logic

The startup logic includes a timer that delays the APU automatic underspeed shutdown logic (discussed later) for 10.5 seconds after the run command is issued. This allows the APU to reach normal speed before the shutdown logic begins checking for a speed of less than 80 percent (underspeed condition). The logic **will** shut the APU down for an overspeed (speed greater than 129 percent) if any single MPU detects it during this time, however.

The APU start command will automatically repressurize the gearbox, if needed, and turn off the APU GG/fuel pump heaters before going to run. The run command also removes power from the hydraulic circulation pumps to inhibit them from running while the hydraulic main pump is running. You will learn more about circulation pumps in Section 3.

The malfunction detection features of the APU controller consist of the automatic shutdown for an overspeed or underspeed condition. An overspeed is considered to be a turbine speed greater than 129 percent, and an underspeed is a turbine speed that is less than 80 percent. The APU shutdown command generated by the automatic shutdown logic removes the APU run command and power from the fuel control valves, causing the secondary fuel control valve and the fuel tank valves to close. An APU OVERSPEED or APU UNDERSPEED light will be illuminated on the panel F7 Caution and Warning (C&W) matrix (Figure 2-12), and a primary C&W tone will be generated. For this automatic shutdown logic to be active, the APU AUTO SHUTDOWN switch on the control panel must be in ENABLE. The crew can inhibit the automatic shutdown logic by moving the APU AUTO SHUTDOWN switch to INHIBIT. If this is done, the APU will not shut down automatically when its speed is too high or too low, but the C&W light and tone will still be generated.

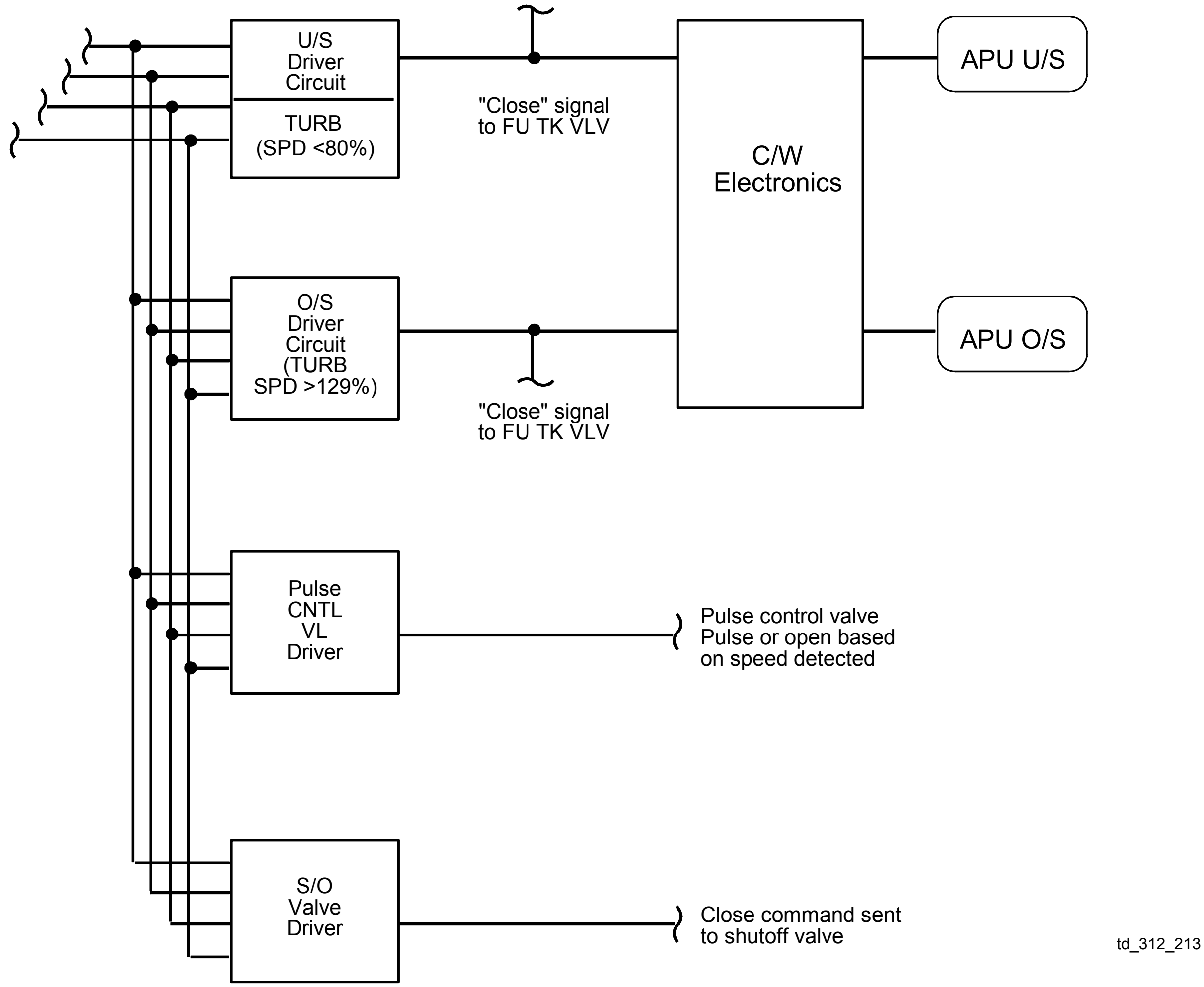

Figure 2-12. APU overspeed/underspeed detection

The controller also provides signal conditioning for the APU GG bed temperature and gearbox nitrogen (N_2) pressure transducers. It takes an analog signal input from these transducers and amplifies it for output to an orbiter Multiplexer/Demultiplexer (MDM) for conversion to a digital signal.

In addition, the controller provides logic for commanding the APU GG bed heaters on or off and for automatic gearbox repressurization. The controller logic will automatically turn APU GG heaters off or on based on high/low temperature limits. These commands are active only when the APU GAS GEN/FUEL PUMP heaters are in A or B AUTO and the APU is not running. The heaters are not required during APU operation and are commanded off at APU start and inhibited by controller logic. Should an APU gearbox need repressurization, controller logic commands the APU GN_2 repress valve open to repressurize the gearbox when the run command is present.

2.3.8 Injector Cooling System

The injector cooling system (Figure 2-13) circulates water around the fuel injector tube, which decreases its temperature in preparation for restarting an APU that has recently been shut down and has not had sufficient time to cool. A minimum of 3-1/2 minutes of continuous cooling is required before restarting an APU with a hot GG bed. This ensures that there is no premature hydrazine detonation due to heat soakback in the fuel line branch passages leading into the GG. It should be noted that restarting an APU that has recently been shut down is not normally done. It is usually due to the failure of another APU that consideration is given to restarting an APU with a hot GG bed.

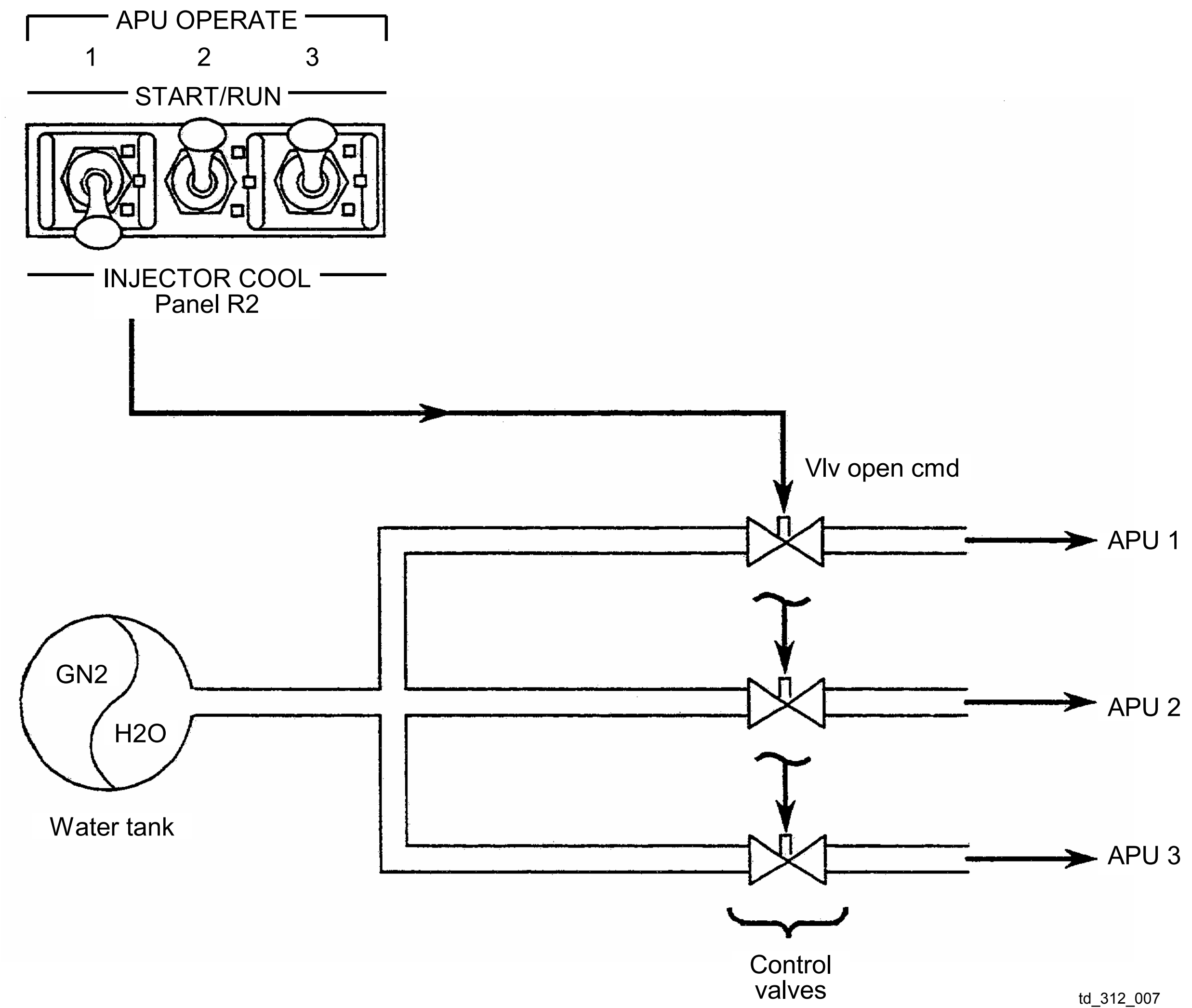

Figure 2-13. APU injector cooling

The injector cooling system consists of one water tank and three control valves, one for each APU. The system is activated by placing the APU OPERATE switch on panel R2 in the INJECTOR COOL position. This provides a constant injector water spray to the APU.

The injector water tank is pressurized by gaseous nitrogen. The tank is loaded with approximately 9 lbs of water prior to launch. This is sufficient for six total cool down cycles or approximately 20 minutes of cooling.

2.3.9 Heaters

While the vehicle is on orbit, the APU fuel, lube oil, GGVM, and injector cool water lines must not become too cold or too hot because the lines could freeze, rupture, or detonate (in the case of fuel becoming too hot). To prevent this, these lines are provided with thermostatically controlled heaters that are activated by switches on panel A12.

Every heater location has two independent heaters, A and B, for redundancy. Only one set of heaters is used at a time.

The APU GG has two sets of heaters, A and B, to maintain a temperature range high enough to ensure an efficient catalytic reaction at APU startup. The GG heaters also activate the A or B heaters for the APU fuel pump. These heaters are automatically deactivated when the APU is started.

2.4 APU CONTROLS AND DISPLAYS

2.4.1 Panels

The panels that the crew uses to interface with the APU system are as follows. For descriptions of the switches on these panels and their functions, see Table 2-2.

- R2
- A12
- F7

2.4.1.1 Panel R2

Panel R2 (Figure 2-14) is located in the forward flight deck just to the right of the Pilot's (PLT) seat. It lies parallel to the seat so the PLT can simply reach down and move the switches.

The switches on this panel are used primarily for APU activation and shutdown. Most of the switches that the pilot will need to reach for any off-nominal situation during ascent or entry are located on this panel.

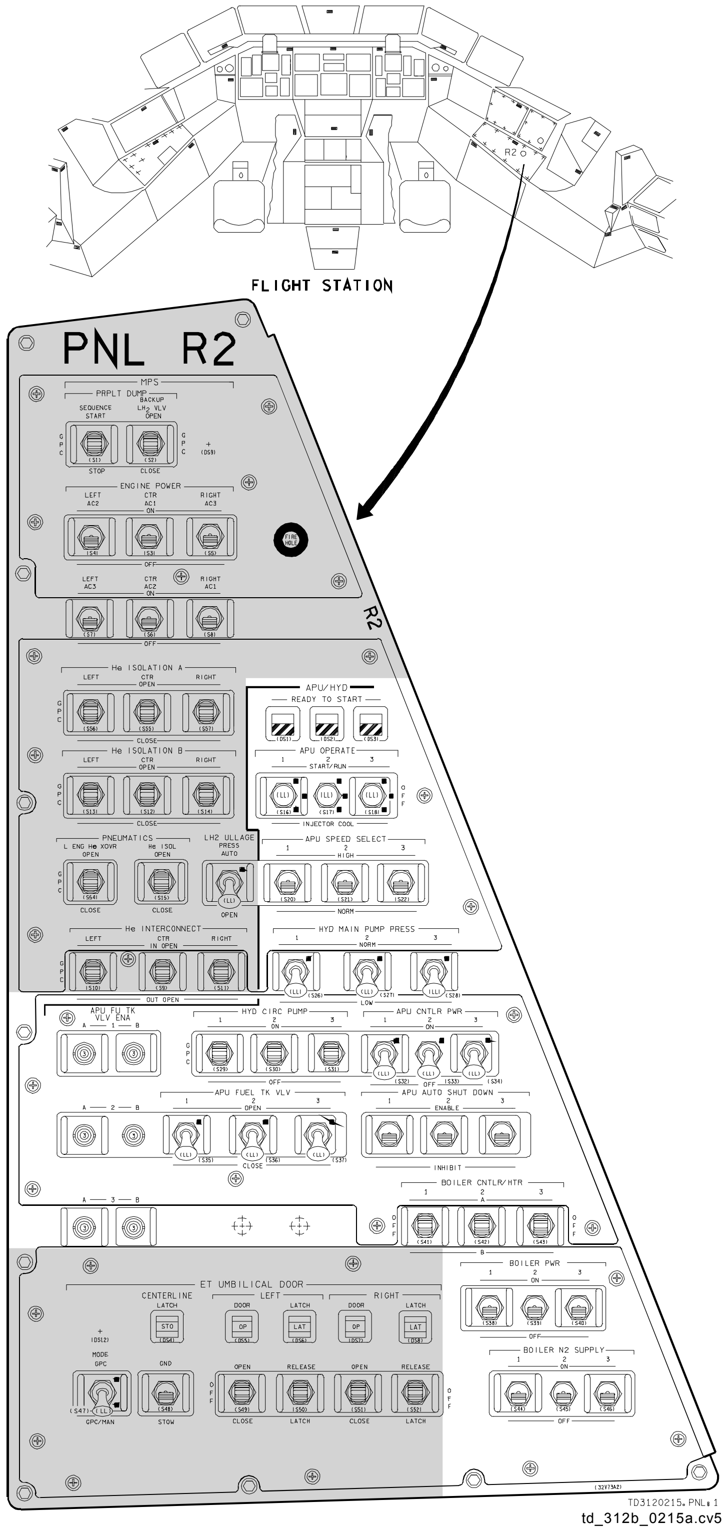

Figure 2-14. Panel R2 and its location

2.4.1.2 Panel A12

Panel A12 (Figure 2-15) is located in the aft flight deck near the floor.

The switches on this panel control the heaters for APU system components.

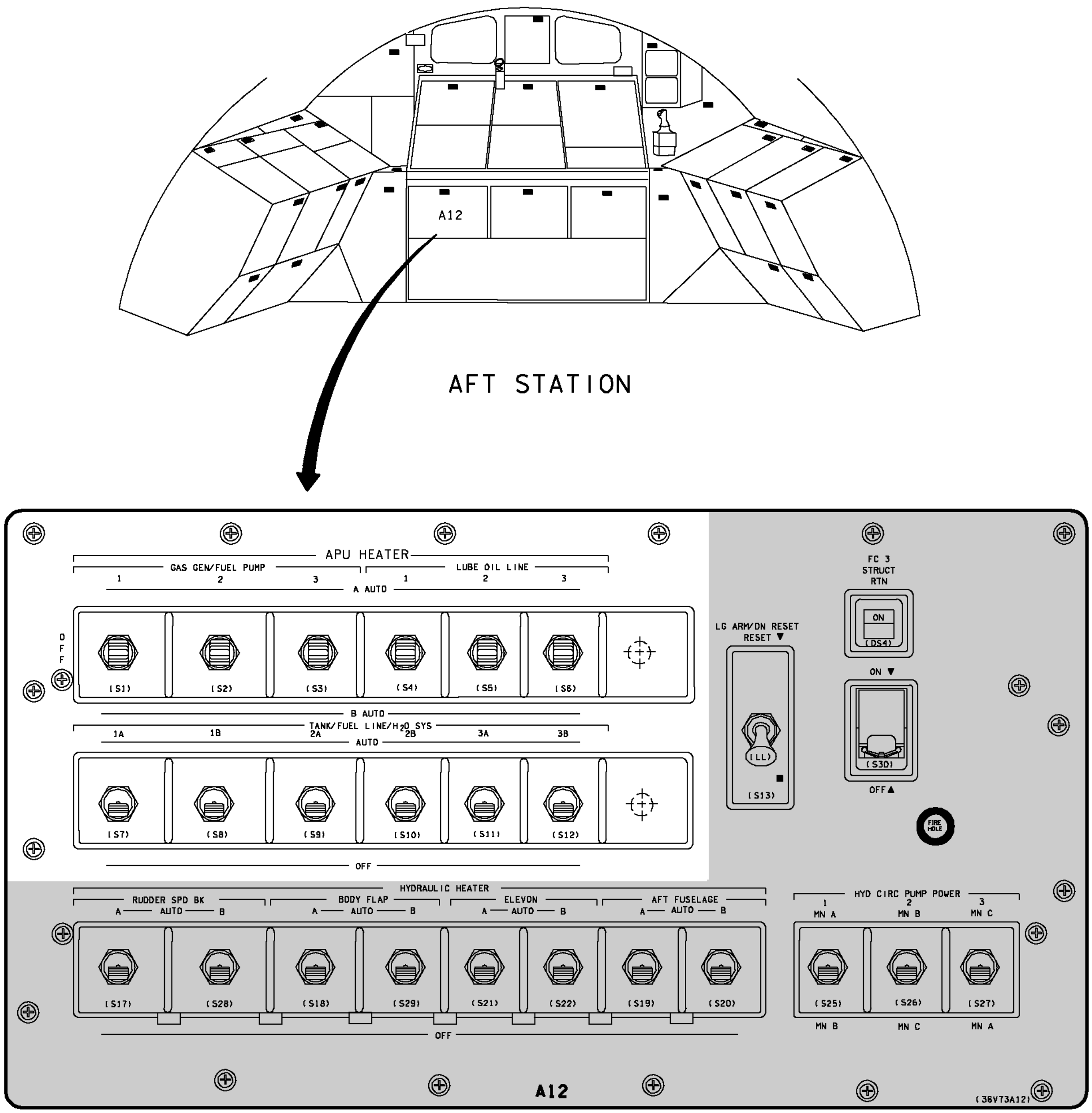

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Figure 2-15. Panel A12 and its location

2.4.1.3 Panel F7

Panel F7 (Figure 2-16) is located in the center of the forward flight deck panels in front of the CDR and PLT seats.

The C&W matrix is located on this panel. The matrix consists of 40 indicator lights that illuminate when set limits are violated. The indicator lights on this matrix associated with the APU system are

- APU TEMP
- APU OVERSPEED
- APU UNDERSPEED

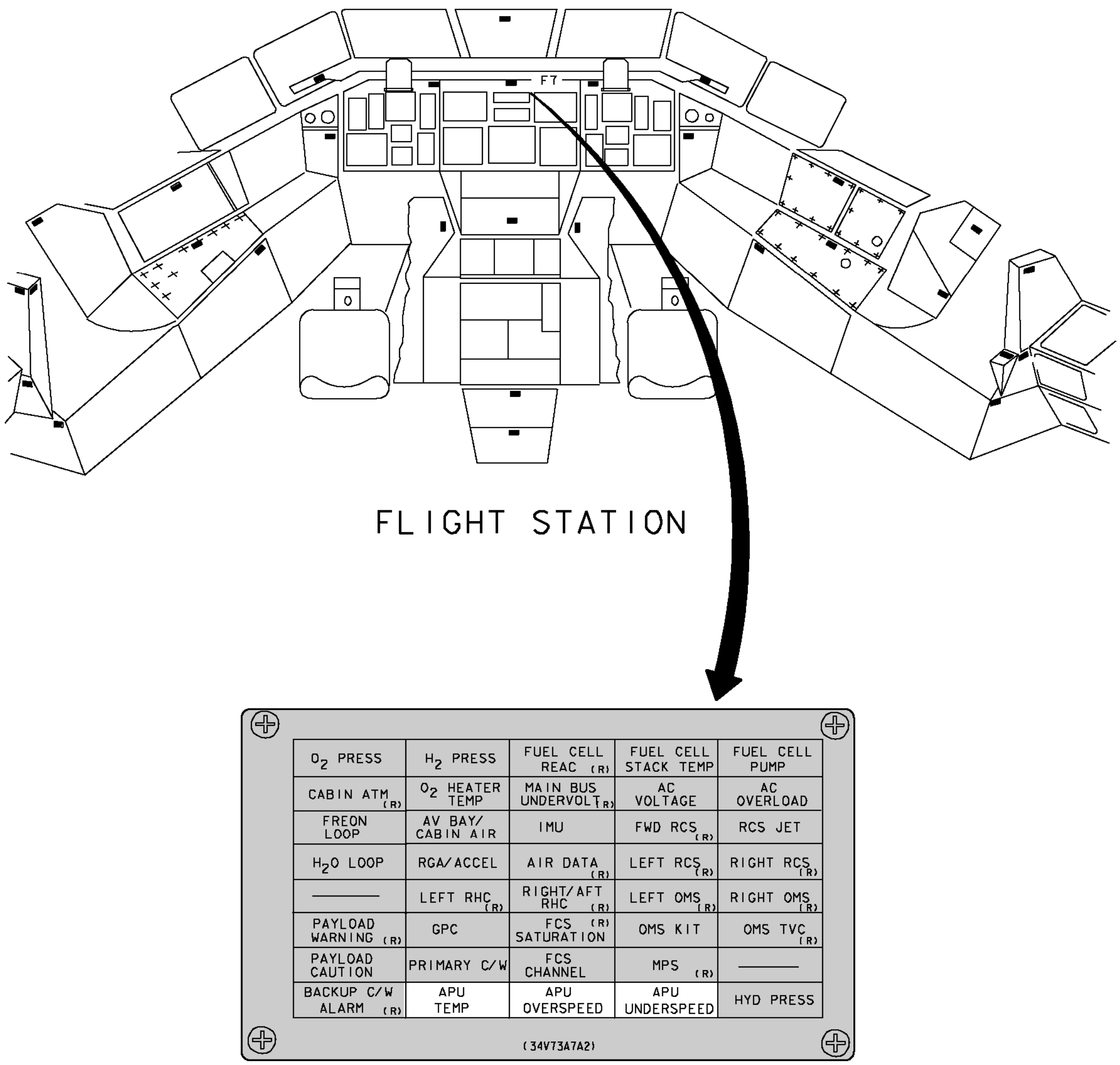

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Figure 2-16. Panel F7 C&W matrix

These lights illuminate and generate a master alarm tone if the limits specified below (Table 2-1) have been violated.

Table 2-1. Panel F7 APU C&W limits

Parameter name	Low limit	High limit	Panel F7 indicator light
APU turbine overspeed	–	129 percent	APU OVERSPEED
APU turbine underspeed	80 percent	–	APU UNDERSPEED
APU lubricating oil return temperature	–	290° F	APU TEMP

2.4.2 Displays

2.4.2.1 Subsystem Display

The subsystem display that the crew uses to monitor the APU system is the HYD/APU subsystem status display (Figure 2-17).

The APU meters give readings of the following:

- APU fuel quantity
- APU fuel pressure
- APU water quantity
- APU oil temperature

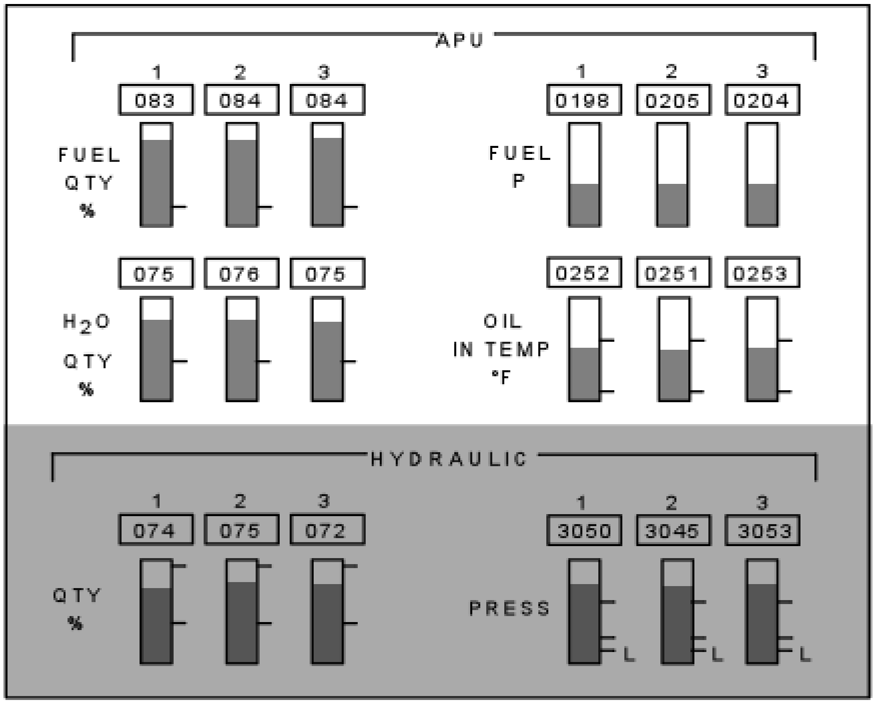


Figure 2-17. HYD/APU Subsystem Status Display meters

Table 2-2 details the various switches on each panel and describes their functions.

Table 2-2. APU controls and displays

Panel	Type	Nomenclature	Position	Function	Remarks
A12	3-pos sw	GAS GEN/FUEL PUMP	A AUTO or B AUTO	GG bed heater enabled to preheat catalyst to 190° F prior to APU start	Controlled to 360°-425° F
			OFF	Fuel pump heater enabled	Controlled to 73.5 -100° F
A12	2-pos sw	LUBE OIL LINE	AUTO A or OFF AUTO B or OFF	Lubricating oil line heaters enabled	Controlled to 55°-65° F
A12	3-pos sw	TANK/FUEL LINE/ H_2O SYS	A AUTO or B AUTO	APU tank, fuel line, and H_2O line heaters enabled	Controlled to 55°-65° F
			OFF	No power directed to enable heaters	
R2	Talkback	APU/HYD READY TO START	bp	Prior to start, the barberpole indicates that start conditions have not been met	
			gray	Indicates that all prestart conditions have been met • HYD main press – low • H_2O boiler controller ready: – Controller A or B enabled – Steam vent temperature >130° F – GN_2 shutoff valve open – HYD fluid bypass valve in proper position • At least one APU fuel isol valve - OPEN • APU controller ready – GG temp >190° F – turb speed <80 percent	

Table 2-2. APU controls and displays (continued)

Panel	Type	Nomenclature	Position	Function	Remarks
R2	3-pos lever lock sw	APU OPERATE	START/ RUN	Generates a signal that • Resets prestart conditions, overspeed and underspeed flip-flops • Generates two driver signals to turn GG/FU PMP heaters off • Activates a 10.5-sec timer inhibiting an underspeed shutdown during startup due to slow turbine spinup • Opens the secondary fuel control valve • Inhibits circulation pump power logic	
			INJECTOR COOL	• Bypasses controller start/run condition • Generates a continuous signal to provide water cooling to reduce the temperature of the fuel injector tubes before restarting a hot APU • Activates a 209-sec delay timer and injects water around the fuel injector tubes	
			OFF	No power to the APU startup logic in controller	
R2	2-pos sw	APU SPEED SELECT	NORM	Selects normal speed control range of 103 ± 8 percent (113 ± 8 percent backup)	
			HIGH	Selects high speed control range of 113 ± 8 percent (115 ± 8 percent backup)	
R2	2-pos sw	APU AUTO SHUTDOWN	ENABLE	Enables auto shutdown if overspeed (129 ± 1 percent) and underspeed (80 ± 3 percent) Enables auto shutdown if APU does not reach 80 percent of design speed in 10.5 sec	

Table 2-2. APU controls and displays (continued)

Panel	Type	Nomenclature	Position	Function	Remarks
			INHIBIT	Inhibits auto shutdown caused by slow turbine spinup during start (80 percent not reached by 10.5 sec)	
				Inhibits automatic overspeed and underspeed shutdown logic while operating	
R2	2-pos lever lock sw	APU CNTLR PWR	ON	Provides 28 V DC to redundant power supplies in APU controller	
			OFF	No power to controller	
R2	2-pos sw	HYD MAIN PRESS	LOW	HYD pump in low decreases startup torque until turbine spinup is complete (900 psig)	
			NORM	Allows normal HYD pump output (3000 psig)	
R2	2-pos sw	APU FUEL TK VLV	OPEN	Opens fuel tank valves between fuel tank and fuel pump	
			CLOSE	Closes fuel tank valves between fuel tank and fuel pump	
R2	cb	APU FU TK VLV ENA	A-1-B A-2-B A-3-B	Allows crewmember to deactivate the electrical power to the appropriate fuel tank valve solenoid	
F7	Display annunciator light	C&W LIGHT MATRIX	HRDW C&W	Displays hardware C&W for APU TEMP, APU overspeed, APU underspeed, and HYD PRESS	
			SOFT-WARE C&W	Displays software backup C&W for APU TEMP	
F7	Display	SM ALERT LIGHT	SOFT-WARE	Light indicates software SM ALERT	
		APU TEMP	ILLUMIN-ATED	Indicates lube oil return temp is ≥290° F, tripping HW C&W limit	

Table 2-2. APU controls and displays (concluded)

Panel	Type	Nomenclature	Position	Function	Remarks
		APU OVERSPEED	ILLUMIN-ATED	Indicates APU turbine speed is ≥129 percent, tripping HW C&W limit	
		APU UNDERSPEED	ILLUMIN-ATED	Indicates APU turbine speed is ≤80 percent, tripping HW C&W limit	
HYD/ APU	Subsystem Status Display Meter	APU FUEL QTY %	1 2 3	Indicates percent of fuel remaining in each of the three APU fuel tanks	Red: 0 < % < 20 Green: % >= 20
HYD/ APU	Subsystem Status Display Meter	APU H_2O QTY %	1 2 3	Indicates percent of water remaining in each of the three WSB water tanks	Red: 0 < % < 40 Green: % >= 40
HYD/ APU	Subsystem Status Display Meter	APU FUEL P	1 2 3	Displays tank inlet fuel pressure in psia	Green: psia
HYD/ APU	Subsystem Status Display Meter	APU OIL TEMP ^{o}F	1 2 3	Displays inlet lubricating oil temp into gearbox in degrees Fahrenheit	Red: 0 < ^{o}F < 45 Green: 45 <= ^{o}F <= 290 Red: ^{o}F > 290

2.4.3 DPS Displays

The onboard DPS displays that the crew uses to monitor the APU system are listed below. They have been divided into two categories: ascent/entry DPS displays and orbit DPS displays.

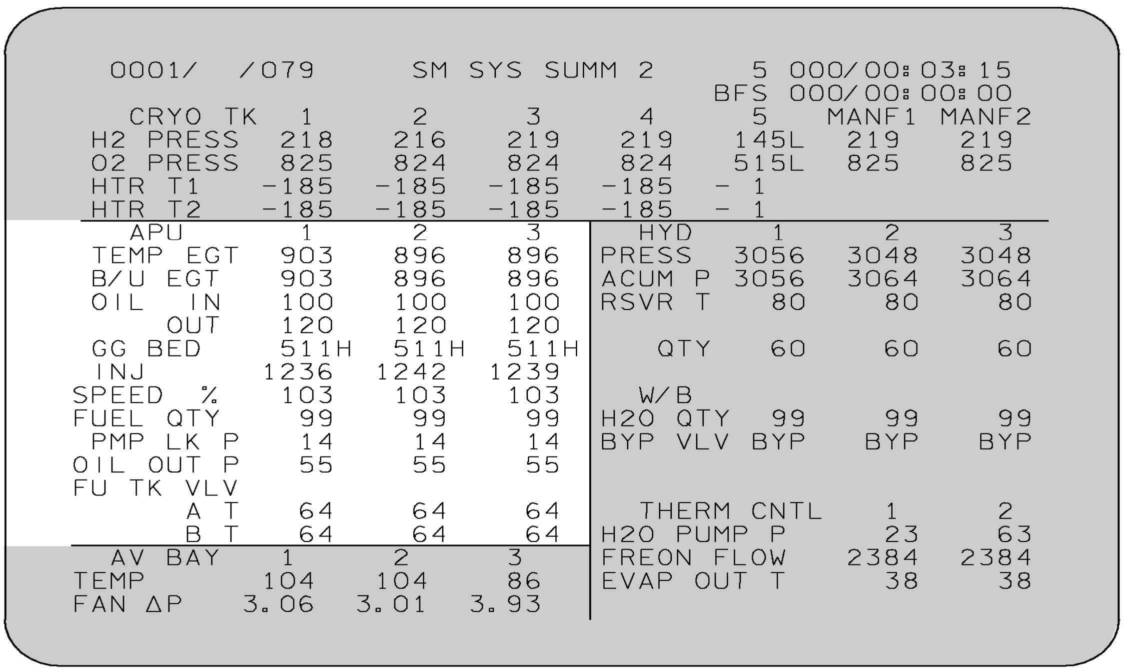
- Ascent/entry DPS displays
  - BFS SM SYS SUMM 2
  - BFS SM THERMAL
- Orbit DPS displays
  - SPEC 86
  - SPEC 88
  - PASS SM SYS SUMM 2

2.4.3.1 Ascent/Entry APU DPS Displays

The following three DPS displays for the APU system are available only during ascent and entry.

a. BFS SM SYS SUMM 2

The BFS SM SYS SUMM 2 display (Figure 2-18 and Table 2-3) allows the crew to monitor vital APU/HYD/WSB parameters. It monitors APU turbine speeds, various system pressures and temperatures, and various fluid quantities.



TD3120220.CRT;1
td_312_220.tif

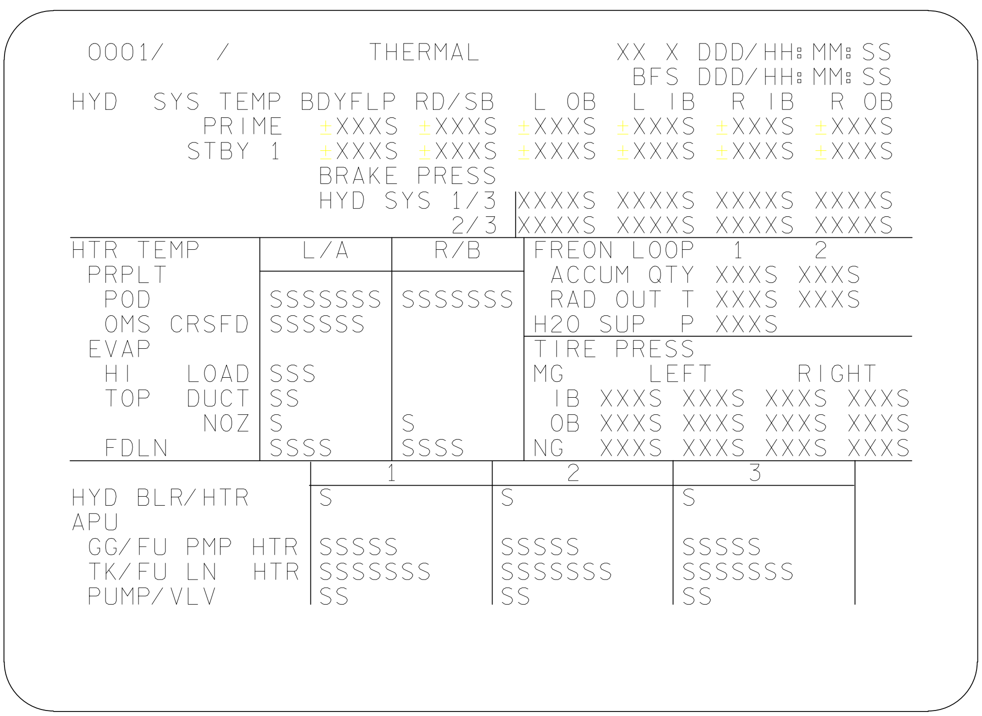
Figure 2-18. BFS SM SYS SUMM 2 display

Table 2-3. BFS SM SYS SUMM 2 APU parameters

DPS name			Units	Displayed range	Status indicators				
					M	H	L	↑	↓
APU:	TEMP	EGT	deg F	0 to 1500	M	H	L	↑	
	B/U	EGT	deg F	0 to 1500	M	H	L	↑	
	OIL	IN	deg F	0 to 500	M	H	L	↑	↓
		OUT	deg F	0 to 400	M	H	L	↑	↓
	GG BED		deg F	0 to 500	M	H	L		↓
	INJ		deg F	0 to 1500	M	H	L		↓
	SPEED %		percent	0 to 167	M	H	L	↑	↓
	FUEL QTY		percent	0 to 100	M	H	L		↓
	PMP LK P		psia	0 to 50	M	H	L	↑	
	OIL OUT P		psia	0 to 200	M	H	L	↑	↓
	FU TK VLV A, B T		deg F	0 to 250	M	H	L	↑	↓

b. BFS SM THERMAL

This display (Figure 2-19 and Table 2-4) is used to monitor APU and hydraulic system temperatures, tire pressure, brake pressure, and heater status.



TD3120219.CRT;2

Figure 2-19. BFS SM THERMAL display

Table 2-4. BFS THERMAL APU parameters

DPS name	Units	Displayed range	Status indicators				
			M	**H**	**L**	**↑**	**↓**
APU: GG/FU PMP HTR			M	H	L	↑	↓
TK/FU LN HTR			M	H	L	↑	↓
PUMP/VLV COOL			M	H	L	↑	

2.4.3.2 Orbit DPS Displays

The following three DPS displays for the APU system are available only on orbit.

a. SPEC 86

SPEC 86 (Figure 2-20 and Table 2-5) is also known as the APU/HYD display. It is divided into two parts, APU on the left and HYD/WSB on the right. It monitors many of the same parameters seen on the BFS SYS SUMM 2 display.

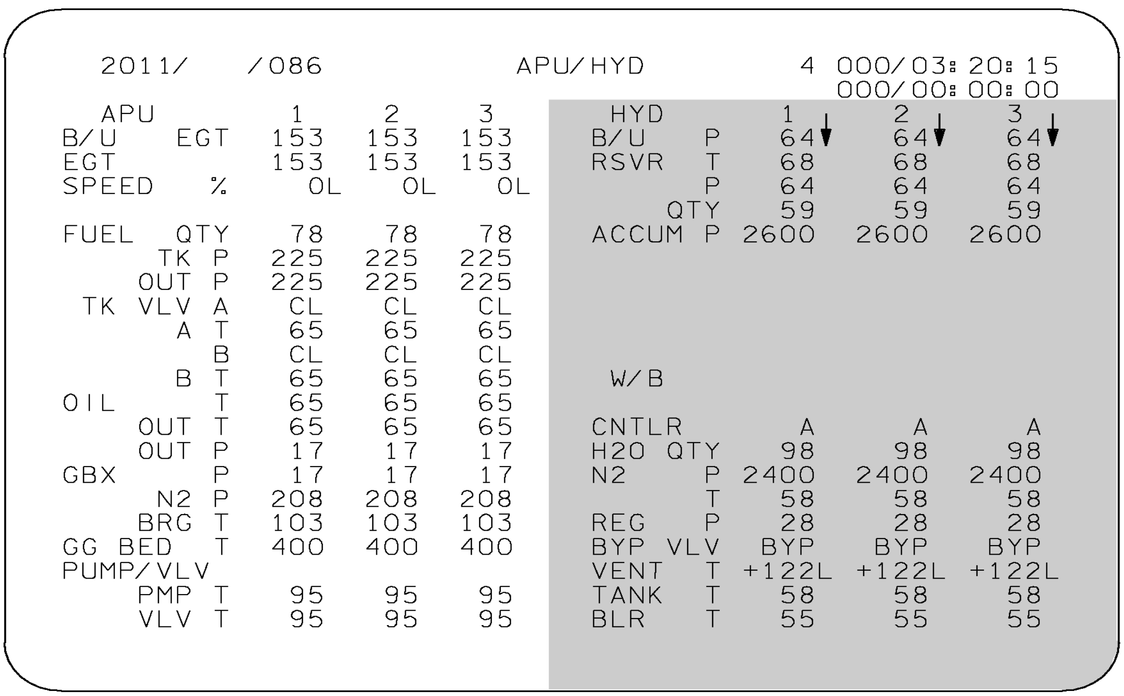


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Figure 2-20. SPEC 86 display

Table 2-5. SPEC 86 APU parameters

DPS name			Units	Displayed range	Status indicators				
					M	**H**	**L**	**↑**	**↓**
APU:	B/U EGT		deg F	0 to 1500	M	H	L	↑	↓
	EGT		deg F	0 to 1500	M	H	L	↑	↓
	SPEED %		percent	0 to 167	M	H	L	↑	↓
	FUEL	QTY	percent	0 to 100	M	H	L	↑	↓
		TK P	psia	0 to 500	M	H	L	↑	↓
		OUT P	psia	0 to 500	M	H	L	↑	↓
		TK VLV A,B T	deg F	0 to 250	M	H	L	↑	↓
		VLV A,B	text	‘OP’ or ‘CL’	M	H	L	↑	↓
	OIL T		deg F	0 to 500	M	H	L	↑	↓
		OUT T	deg F	0 to 400	M	H	L	↑	↓
		P	psia	0 to 200	M	H	L	↑	↓
	GBX P		psia	0 to 30	M	H	L	↑	↓
		N_2 P	psia	0 to 300	M	H	L	↑	↓
		BRG T	deg F	0 to 500	M	H	L	↑	↓
	GG BED T		deg F	0 to 500	M	H	L	↑	↓
	PUMP/VLV								
		PMP T	deg F	0 to 250	M	H	L	↑	
		VLV T	deg F	0 to 250	M	H	L	↑	

b. SPEC 88

SPEC 88 (Figure 2-21 and Table 2-6) is known as the APU/ENVIRON THERMAL display. The bottom right-hand side of the display shows APU component temperatures and the water cooling system temperatures.

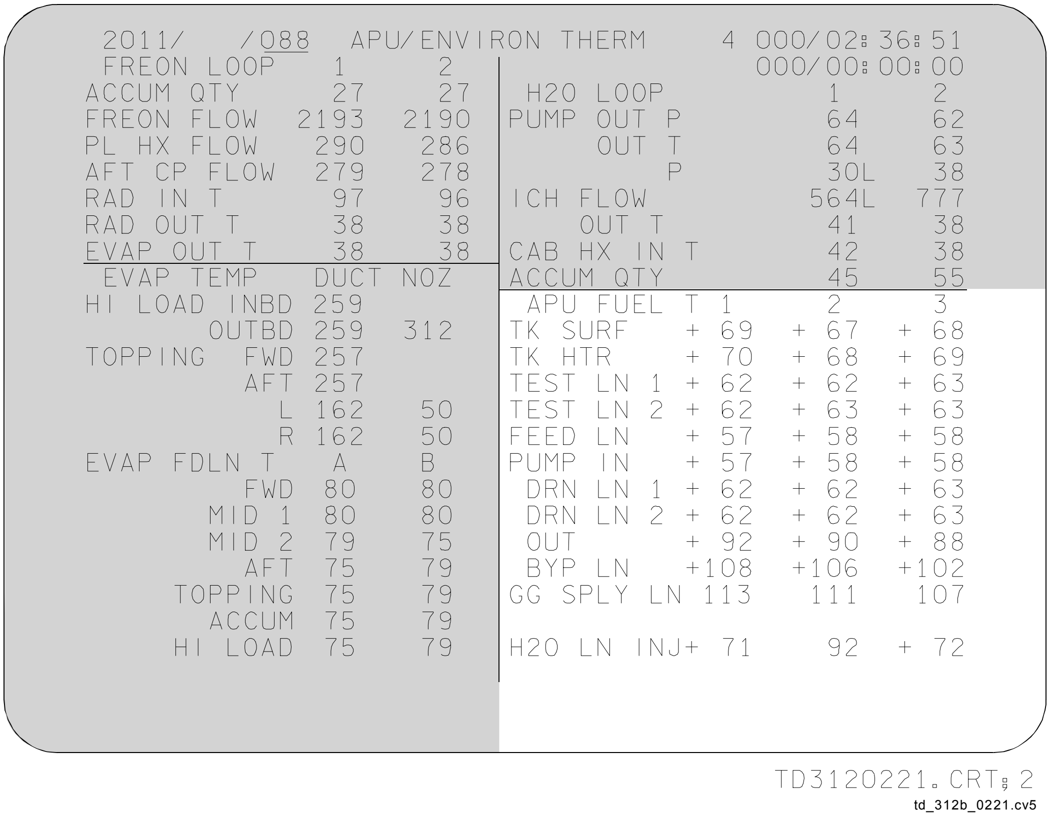


Figure 2-21. SPEC 88 display

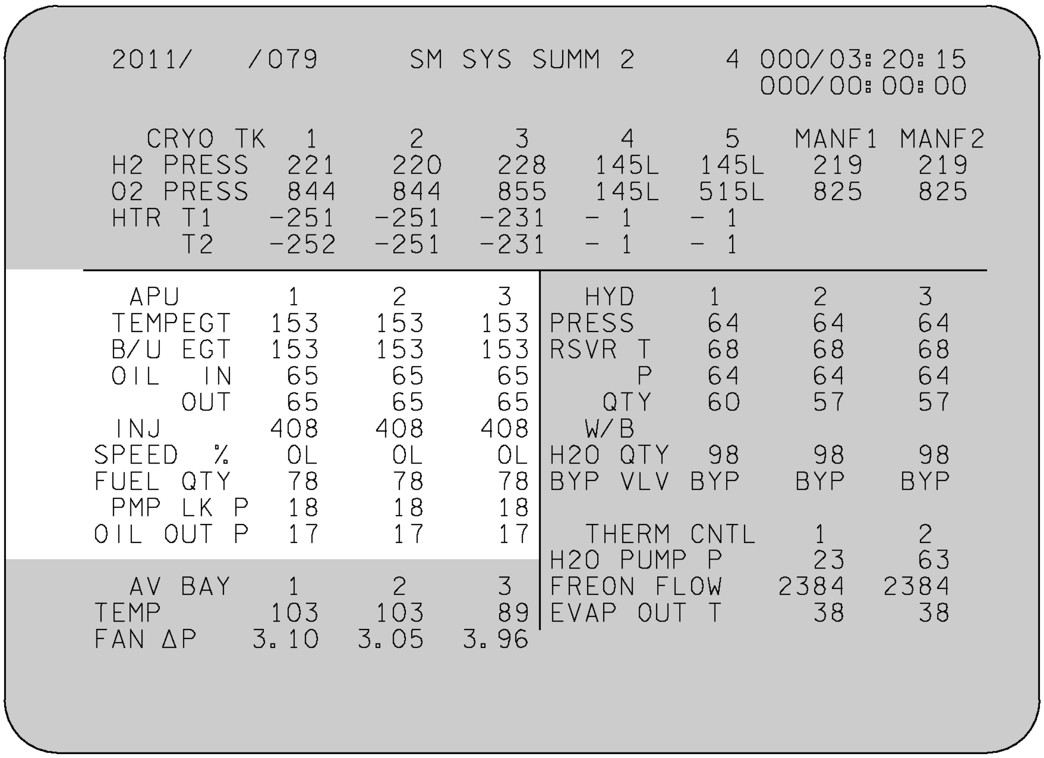
Table 2-6. SPEC 88 APU parameters

DPS name	Units	Displayed range	Status indicators				
			M	**H**	**L**	**↑**	**↓**
APU FUEL T: K SURF	deg F	0 to 160	M	H	L		↓
TK HTR	deg F	0 to 160	M	H	L	↑	↓
TEST LN 1,2	deg F	0 to 250	M	H	L	↑	↓
FEED LN	deg F	0 to 250	M	H	L	↑	↓
PUMP IN	deg F	0 to 250	M	H	L	↑	↓
DRN LN 1,2	deg F	0 to 250	M	H	L	↑	↓
OUT	deg F	0 to 250	M	H	L	↑	↓
BYP LN	deg F	0 to 400	M	H	L	↑	↓
GG SPLY LN	deg F	0 to 450	M	H	L	↑	
H_2O LN INJ	deg F	-75 to +300	M	H	L	↑	↓

c. PASS SM SYS SUMM 2

The primary avionics software system (PASS) SM SYS SUMM 2 display (Figure 2-22) contains APU/HYD/WSB parameters (Table 2-7).

It is similar to the BFS SM SYS SUMM 2 display except that it does not display the GG BED, INJ, FU TK VLV, and ACUM P parameters found on the BFS display.



TD3120228.CRT;2
td_312_228.tif

Figure 2-22. PASS SM SYS SUMM 2 display

Table 2-7. PASS SM SYS SUMM 2 APU parameters

DPS name	Units	Displayed range	Status indicators				
			M	H	L	↑	↓
APU: TEMP EGT	deg F	0 to 1500	M	H	L		
B/U EGT	deg F	0 to 1500	M	H	L	↑	
OIL IN	deg F	0 to 500	M	H	L	↑	
OUT	deg F	0 to 400	M	H	L	↑	↓
SPEED %	percent	0 to 167	M	H	L		
FUEL QTY	percent	0 to 100	M	H	L		↓
PMP LK P	psia	0 to 50	M	H	L		
OIL OUT P	psia	0 to 200	M	H	L	↑	↓

Questions

1. Where are the orbiter APUs located?
2. The function of an APU is to
   (a) Provide mechanical shaft power to turn the fuel pump
   (b) Provide mechanical shaft power to turn the lubricating oil pump
   (c) Provide mechanical shaft power to turn the hydraulic pump
   (d) All of the above
   (e) None of the above
3. Match each of the following APU components with its function or functions:

a. Fuel tank	________	1.	Prevents freezing of fluid lines
b. Fuel pump	________	2.	Provides logic for startup, shutdown, speed control
c. Fuel tank valves	________	3.	Delivers fuel to the gas generator
d. Fuel control valves	________	4.	Provides water cooling to the gas generator
e. Gas generator	________	5.	Valves that pulse or open to control APU speed
f. Lubricating oil	________	6.	Location where hydrazine is sprayed on the Shell 405 catalyst
g. Digital controller	________	7.	Stores liquid hydrazine fuel
h. Injector cooling	________	8.	Allows/prevents fuel flow to the fuel pump
i. Heaters	________	9.	Lessens friction between gears in the gearbox and the fuel pump

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3.0 HYDRAULIC SYSTEM

3.1 OBJECTIVES

Upon completing this section, you should be able to

- Locate the hydraulic system on the orbiter
- Recognize the function of the hydraulic system
- Match hydraulic system components to their function
- Define Priority Rate Limiting (PRL)

3.2 OVERVIEW

The hydraulic system (Figure 3-1) provides hydraulic power to throttle and gimbal the main engine, retract the ET umbilical plates at ET SEP, move the aerodynamic flight control surfaces, lower the landing gear, apply the brakes, and provide nosewheel steering.

As with the APUs, the hydraulic pumps are located in the aft compartment behind the orbiter aft 1307 bulkhead.

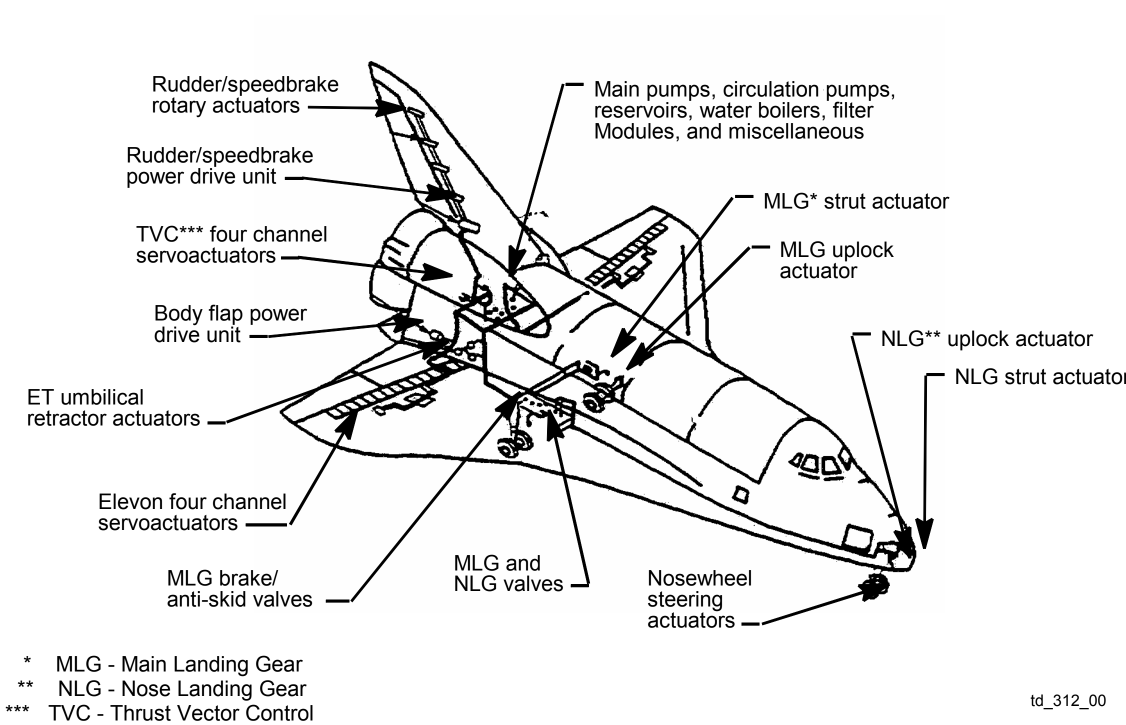

Figure 3-1. Hydraulic system location

3.3 SYSTEM DESCRIPTION

In this section, we will discuss the following hydraulic system components:

- Hydraulic main pump
- Reservoir and accumulator
- Circulation pump
- Hydraulic/Freon heat exchanger
- Heaters

The following discussion will deal with one hydraulic system. Remember that there are three separate systems that operate essentially the same way. Later in the section we will discuss hydraulic system redundancy and how it supports the orbiter systems requiring hydraulic power.

3.3.1 Main Pump

The main pump (Figure 3-2) provides 63 gal/min hydraulic fluid flow at 3000 psia pressure to the hydraulic system. It is a variable displacement pump, much like those found on high performance aircraft, and is driven by an orbiter APU.

The main pump can be electrically depressurized by placing the HYD MAIN PUMP PRESS switch on panel R2 in the LOW position, which reduces the pump outlet pressure to 900 psia. This action reduces main pump torque at APU startup.

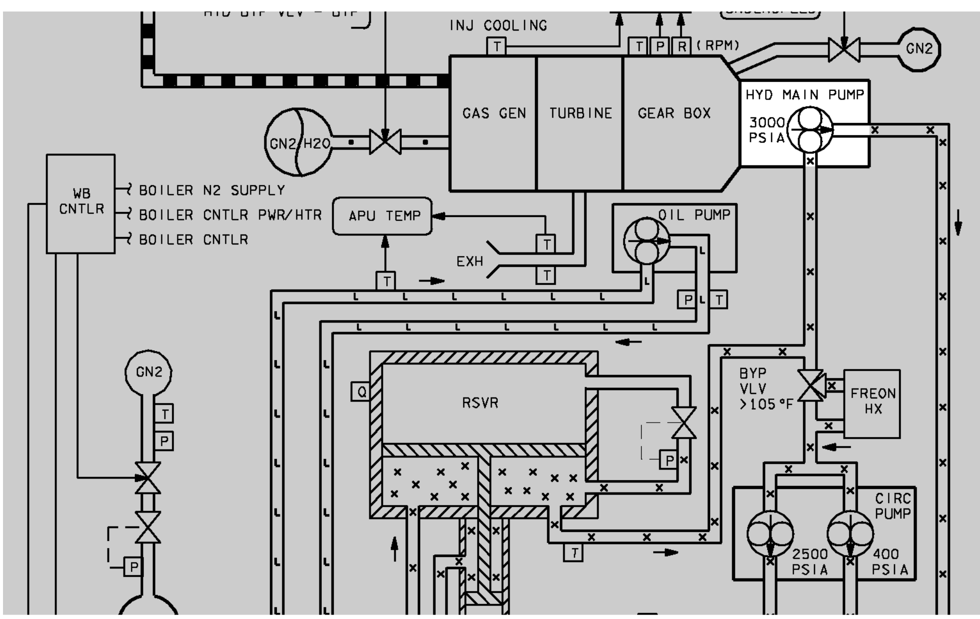

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Figure 3-2. Hydraulic main pump

3.3.2 Reservoir and Accumulator

The hydraulic reservoir ensures positive head pressure at the main pump and circulation pump inlets. The reservoir allows for the thermal expansion and contraction of the hydraulic fluid and for system demands. The reservoir also helps in sustaining hydraulic leaks if, for some reason, one develops.

The accumulator pressurizes the reservoir through a 40:1 differential area piston. On one side of the accumulator is GN_2, and on the other is hydraulic fluid. The accumulator dampens pressure surges in the hydraulic system caused by system demands.

When the hydraulic pump is running, the priority valve is open (Figure 3-3) and the accumulator pressure will be the same as the hydraulic pressure. Through the differential area piston, this corresponds to a reservoir pressure of about 65 psia. This pressure is required to ensure that the hydraulic pump will not cavitate due to lack of hydraulic fluid in the pump. When the APU is shut down and the hydraulic pressure bleeds down, the priority valve will close when the hydraulic pressure reaches 2600 psia, trapping 2600 psia of hydraulic fluid pressure in the accumulator. Since this pressure is translated to the fluid in the reservoir through a 40:1 differential area piston, this results in a reservoir pressure (and hence main pump inlet pressure) of approximately 65 psia.

On orbit when the hydraulic pump is not running (i.e., the APUs are not running), the accumulator provides a way to keep adequate pressure on the main pump inlet so that the system can be restarted in zero gravity. If pressure is absent, the pump could cavitate and that hydraulic system would be lost. The accumulator/reservoir package prevents this from happening.

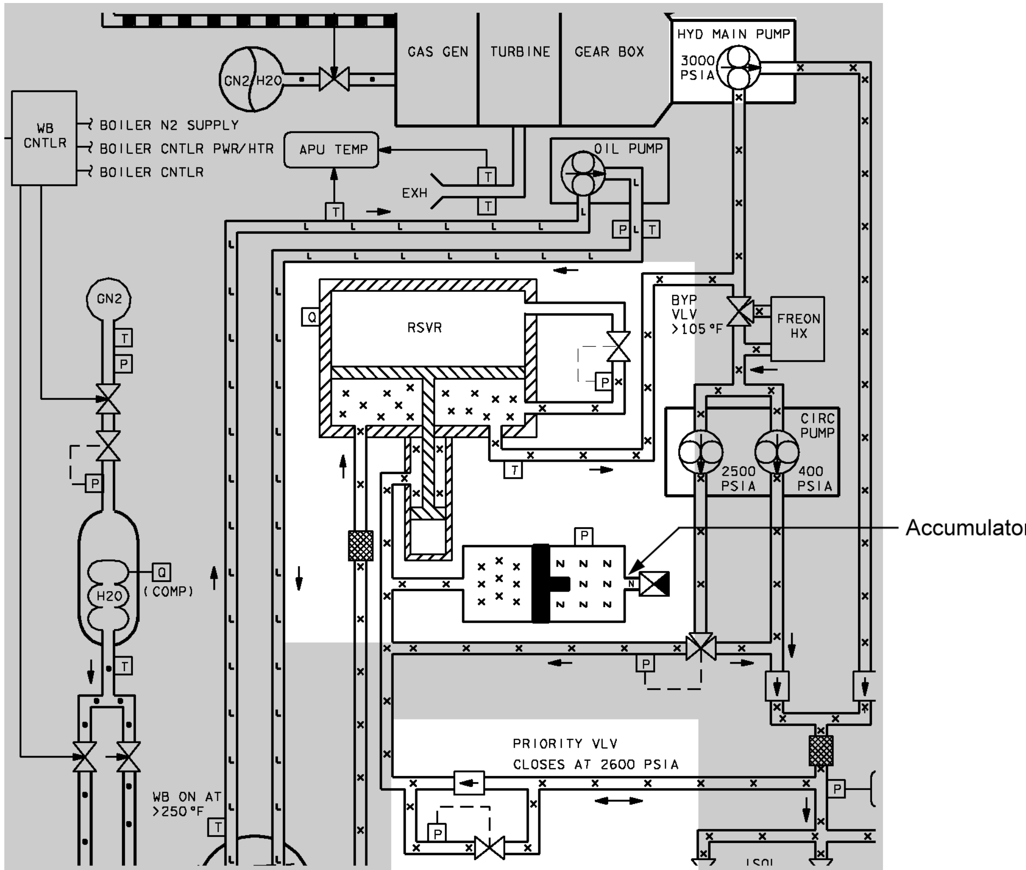

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Figure 3-3. Reservoir/accumulator package

3.3.3 Circulation Pump

In addition to the main pump, each hydraulic system contains a circulation pump (Figure 3-4). This pump is used on orbit when the hydraulic pumps are off to maintain accumulator pressure and for hydraulic thermal conditioning. These pumps are activated when either of two conditions exists: the hydraulic lines are cold and need to be thermally conditioned, or the hydraulic accumulator needs to be repressurized.

The circulation pump is actually two fixed-displacement pumps in parallel, driven by a single motor. One pump is a high pressure (2500 psia), low volume pump and is used to repressurize the accumulator. The other is a low pressure (200 psia), high volume pump used to circulate hydraulic fluid through the Freon/heat exchanger, where the hydraulic fluid will pick up heat from the Freon coolant loops to prevent the fluid from getting too cold.

While on orbit, the operation of the circulation pumps is controlled by the Systems Management (SM) General Purpose Computer (GPC) when the circ pump switch on panel R2 is in the GPC position. The SM GPC monitors the accumulator pressure and hydraulic line temperatures of each hydraulic system. It will automatically command the associated circulation pump on if either of the two conditions mentioned previously occurs (low accumulator pressure of <1960 or low hydraulic line temperatures).

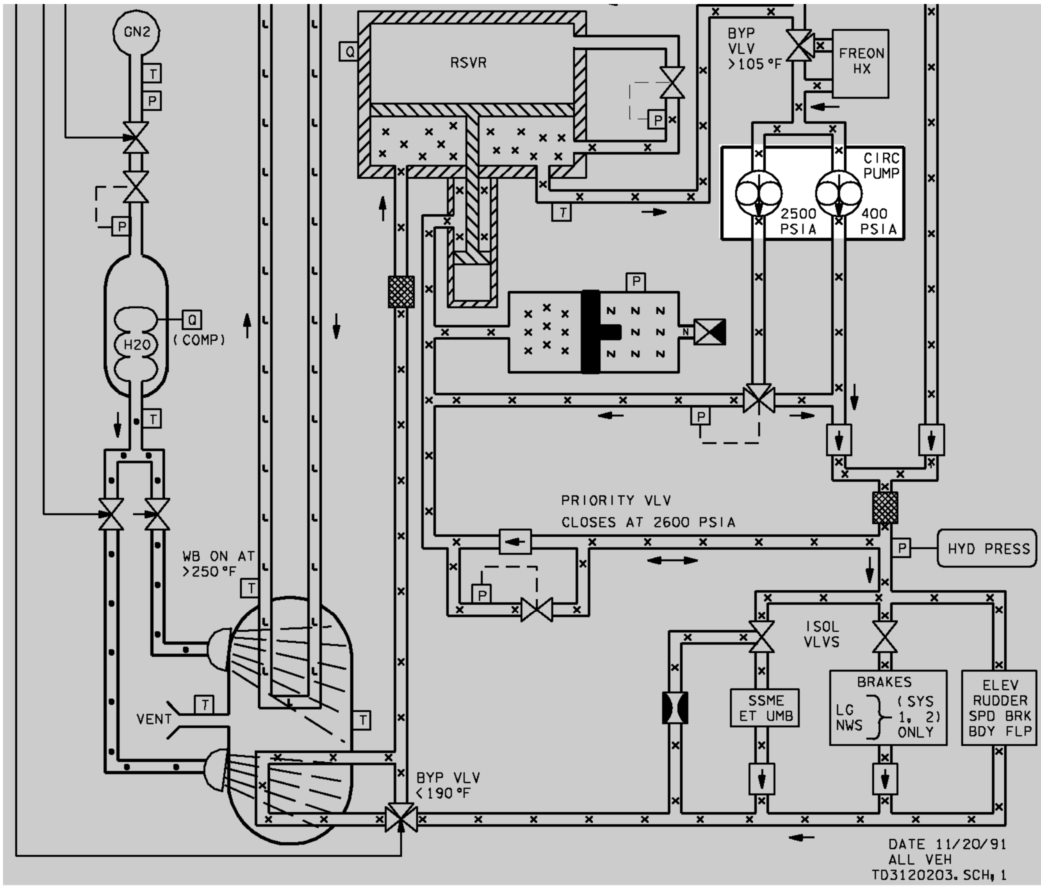

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Figure 3-4. Hydraulic circulation pumps

3.4 HYDRAULIC/FREON HEAT EXCHANGER

The hydraulic lines can be warmed by circulating hydraulic fluid through a heat exchanger (Figure 3-5) to pick up heat from the orbiter Freon coolant loops. The Freon coolant loops, part of the Environmental Control and Life Support System (ECLSS), remove heat from various parts of the orbiter. Some of this heat is transferred to the hydraulic fluid by the Freon loops.

A temperature-controlled bypass valve directs the hydraulic fluid through the heat exchanger if the temperature at the heat exchanger inlet is less than 105° F. The bypass valve directs the fluid around the heat exchanger if the temperature is greater than 115° F.

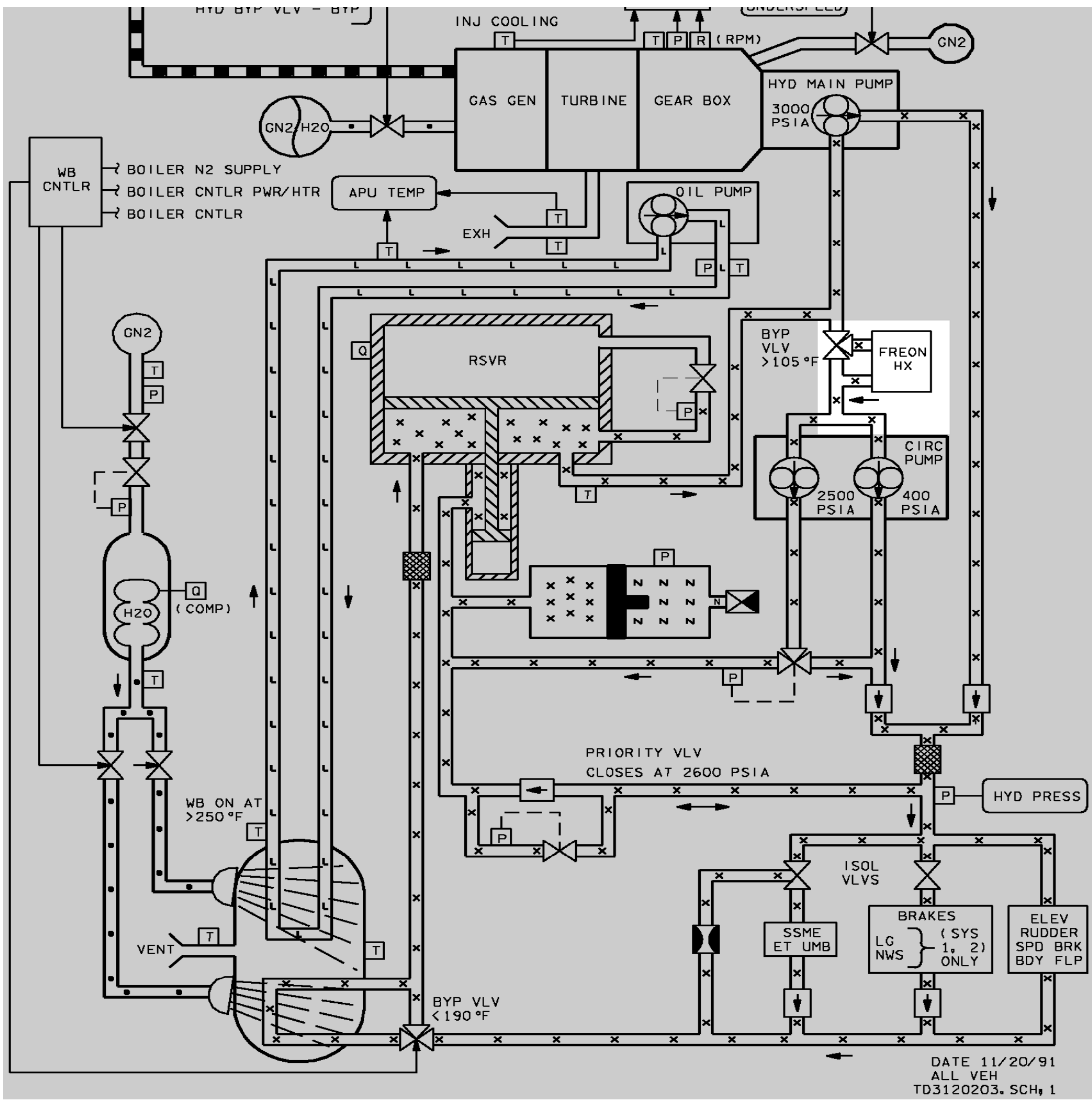

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Figure 3-5. Hydraulic/freon heat exchanger

3.4.1 Heaters

Hydraulic lines in the various orbiter aerosurfaces are also warmed by heaters. These heaters are automatically controlled by thermostats to maintain the hydraulic line temperatures within a specified range. Each heated area has redundant heaters, A and B, which are controlled by switches on panel A12 (Figure 3-6).

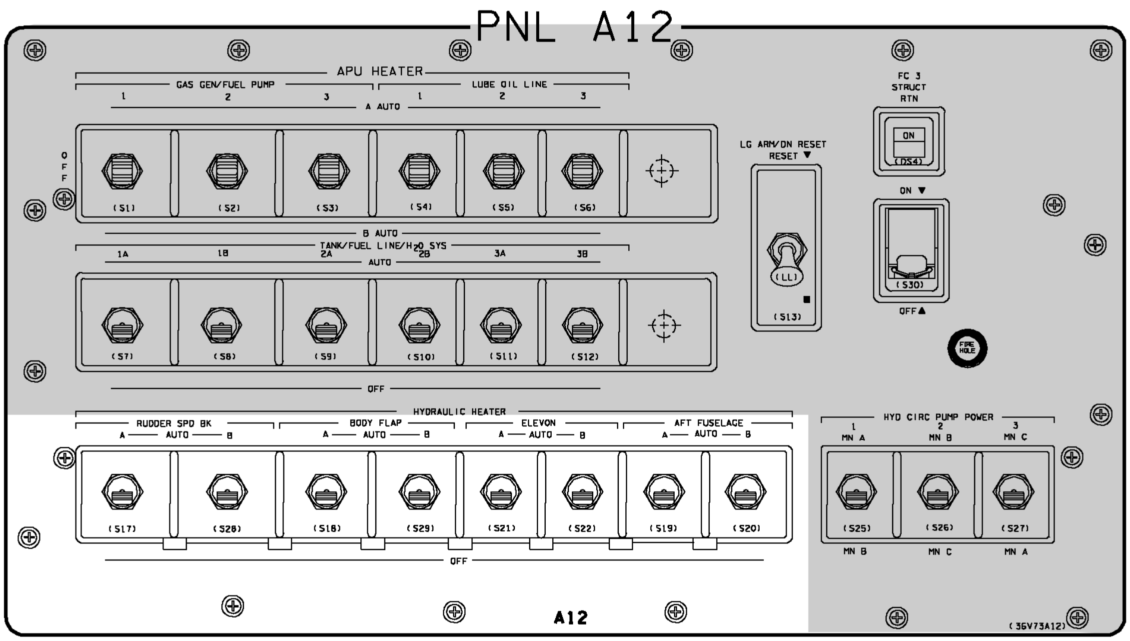

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Figure 3-6. Heater switches on panel A12

3.5 ORBITER COMPONENTS REQUIRING HYDRAULIC SYSTEM PRESSURE

Hydraulic pressure is used to operate various orbiter components. Some components can be supplied with hydraulic pressure from more than one hydraulic system. Others receive hydraulic pressure from just one hydraulic system. If that system is lost, the capability to hydraulically operate that component is lost. This section will discuss those orbiter systems requiring hydraulic pressure to operate and how they receive that pressure. The following components will be discussed:

- Main engine throttling valves
- Main engine thrust vector control
- Elevons
- Rudder/speedbrake
- Body flap
- ET umbilical plate retraction actuators
- Landing gear deploy mechanism
- Nosewheel steering
- Brakes

3.5.1 Main Engine Throttling Valves

Each of the hydraulic systems supports one of the three main engines for all five of the main engine valves. Hydraulic system 1 supports the center engine, hydraulic system 2 supports the left engine, and hydraulic system 3 supports the right engine (Table 3-1).

Table 3-1. Main engine valve hydraulic systems

Main engine throttling	Hydraulic system supplying pressure
Center	1
Left	2
Right	3

If the hydraulic pressure falls below approximately 1500 psig, a valve may shut off the inlet and outlet hydraulic lines to all five control valves. When this occurs, the engine is said to be in "hydraulic lockup," meaning it is frozen at its current throttle setting. Even if good hydraulic pressure is regained in that system, that main engine will not attempt to throttle again. The main engine shutdown is accomplished by a backup pneumatic system.

3.5.2 Main Engine Thrust Vector Control

Prelaunch, each main engine is gimballed to the proper position for launch by hydraulic actuators. Throughout ascent, these actuators gimbal the engines to various GPC-determined positions to maintain proper attitude control and trajectory. Each actuator can be fed by a primary or a secondary hydraulic system. A switching valve will move the actuator to its secondary hydraulic system if the primary system pressure falls below approximately 1500 psig. Therefore, it takes the loss of two hydraulic systems to lose gimballing capability on one main engine.

Table 3-2 correlates main engine Thrust Vector Control (TVC) actuators with hydraulic systems.

Table 3-2. Main engine TVC actuator hydraulic systems

Main engine	Hydraulic systems (primary, backup)
Center	Pitch 1, 3 Yaw 3, 1
Left	Pitch 2, 1 Yaw 1, 2
Right	Pitch 3, 2 Yaw 2, 3

3.5.3 Elevons

Each elevon can be driven by any of the orbiter hydraulic systems. For each elevon, one hydraulic system is designated as "primary," and the remaining two systems are designated "secondary 1" and "secondary 2."

Should the primary system fail, switching valves will switch the elevon to secondary 1, or, if that fails, to secondary 2. The switchover will occur if the hydraulic system pressure drops below approximately 50 percent of the next standby system.

3.5.4 Rudder/Speedbrake and Body Flap

The rudder/speedbrake is driven by three hydraulic motors, each of which is fed by a different orbiter hydraulic system. The outputs of the three motors are combined in a differential gearbox. Loss of one hydraulic system (i.e., one motor) means only a reduction in available power. Due to the nature of the gearbox, loss of two hydraulic systems (two motors) means that the output from the gearbox will be one-half the normal speed.

The body flap operates similarly to the rudder/speedbrake.

3.5.5 Orbiter/ET Umbilical Plates

The orbiter/ET umbilical plates retract into the orbiter after ET SEP to allow the ET umbilical doors to close. Each umbilical plate is driven by three actuators and each uses one of the three orbiter hydraulic systems. One good hydraulic system is sufficient to retract the two umbilical plates.

3.5.6 Brakes

Each main gear wheel (two wheels per strut) has eight brake pucks that provide braking to the orbiter during rollout. Each brake puck has a primary hydraulic system and a backup. The backup hydraulic system is always hydraulic system 3, and the primary system is either hydraulic system 1 or 2.

A switching valve will select the backup system if the primary system pressure drops below approximately 1000 psi. Loss of one primary hydraulic system and hydraulic system 3 backup means loss of half the normal braking capability.

3.5.7 Landing Gear

The landing gear system is unique in that only hydraulic system 1 can be used to deploy the landing gear (see Figure 3-7). If hydraulic system 1 fails, the landing gear will be unlocked by pyrotechnic devices. The gear will fall to its down and locked position by the force of its own weight. Hydraulic system 2 can deploy the nose landing gear if system 1 fails, but would require early opening of brake isolation valve 2.

3.5.8 Nosewheel Steering

Directional control of the orbiter during rollout is accomplished by steering the nosegear. Hydraulic system 1 or 2 can be used for nosewheel steering (Figure 3-7). If hydraulic system 1 fails, a switching valve will automatically switch control to system 2. If both systems fail, directional control can be maintained through differential braking and (to a lesser extent) rudder control.

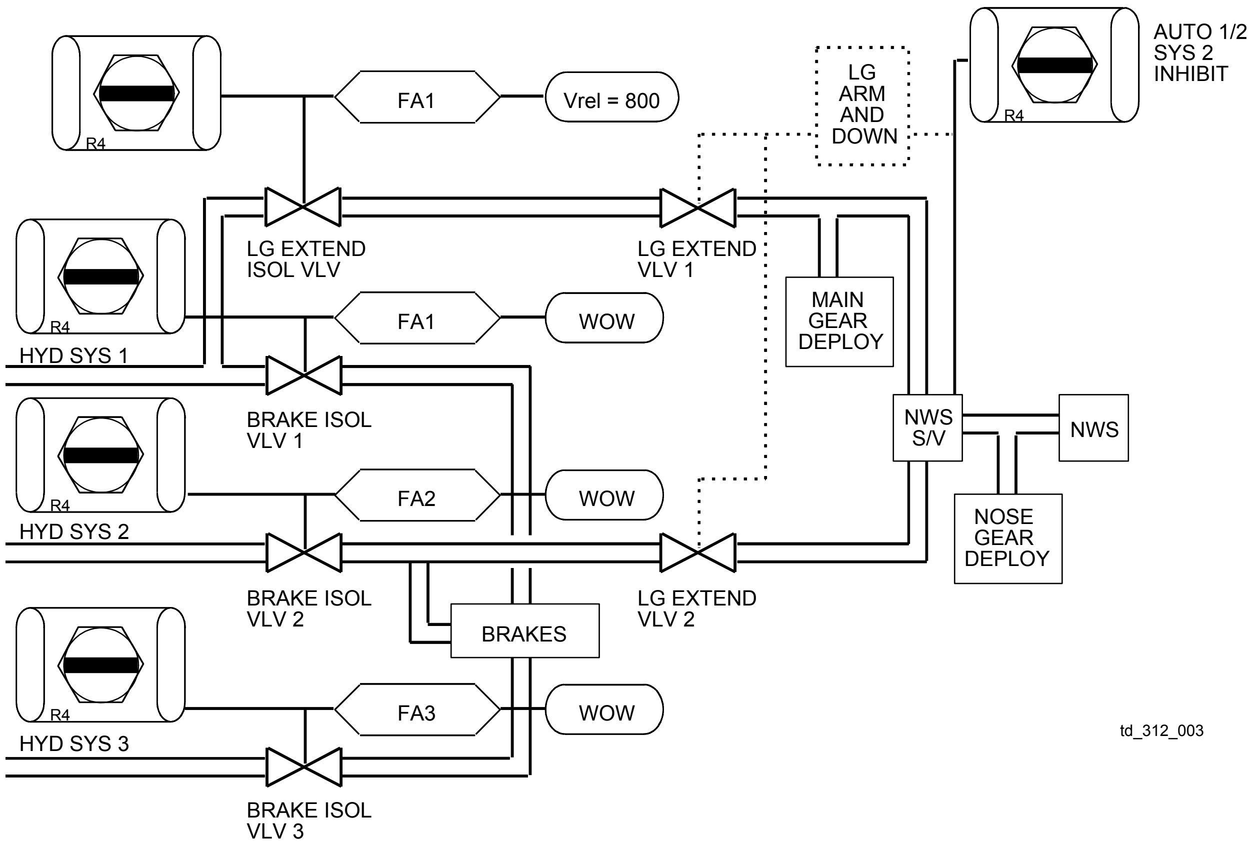

Figure 3-7. Landing gear/brake control

3.5.9 Priority Rate Limiting

PRL is a software scheme that matches the aerosurface movement rates to the number of available hydraulic systems; either one, two, or three. PRL performs this task by prioritizing aerosurfaces and limiting rates.

PRL resets aerosurface priorities as a function of the number of hydraulic systems available. This priority scheme gives the more critical aerosurfaces (elevons, rudder) high priority over the less critical aerosurfaces (speedbrake, body flap) (Table 3-3). PRL assigns the speedbrake and body flap the lowest priority.

Table 3-3. PRL aerosurface drive rate limits

Hydraulic system available	Elevator/aileron (deg/sec)	SPDBK closing/opening (deg/sec)	Rudder (deg/sec)
3	20	10.86/6.1	14
2	20	10.86/6.1	12
1	13.9	10.86/6.1	7

In addition to prioritizing aerosurfaces, PRL also limits the rates of certain aerosurfaces based on the number of hydraulic systems available. This prevents overdemanding the remaining hydraulic systems. Aerosurfaces are not significantly rate limited until two hydraulic systems are lost.

3.5.10 PRL Operation

The PRL software is a component of the Digital Autopilot (DAP), which resides in the Guidance, Navigation, and Control (GNC) computer. PRL is informed of an APU failure by the GNC Redundancy Management (RM) system.

RM will determine the status of a hydraulic system by monitoring the three hydraulic pressure sensors (A, B, and C) associated with each hydraulic system. The GNC RM selection filter will select an overall pressure value based on these three sensors and send that value to the hydraulic System Operating Program (SOP). If the selected value is below approximately 1740 psia, the hydraulic SOP will declare the hydraulic system failed and adjust the aerosurface rates and priorities accordingly.

The method by which RM selects a value to send to the hydraulic SOP depends on the number of available pressure transducers.

If all three sensors are valid, RM will select the middle value and send it to the SOP. This is called mid-value selecting.

Example	<u>HYD SENSOR DATA</u>		
	A = 3000		
	B = 3050	←	mid-value, 3050,
	C = 3085		sent to SOP

If only two sensors are valid, then RM will send the average of the two values to the SOP.

Example	<u>HYD SENSOR DATA</u>		
	A = 3100	←	average of A and B,
	B = 3050	←	3075, sent to SOP
	C = failed		

If only one sensor is valid, that remaining value will be sent unaltered to the SOP.

Example

HYD SENSOR DATA

A = 3100 ← remaining sensor value, 3100, sent to SOP
B = failed
C = failed

Two reasons for which RM will declare a sensor invalid are an FA MDM failure or a miscompare. RM will automatically declare a sensor invalid for an FA MDM failure. Table 3-4 below shows which FA MDMs are associated with the different hydraulic sensors.

Table 3-4. Hydraulic sensors and associated FA MDM

FA MDM	Hydraulic sensors
FA1	1A, 2B
FA2	2A, 1B, 3C
FA3	3A, 2C
FA4	1C, 3B

When an FA MDM fails, the RM selection filter will no longer listen to its associated sensor and will declare it invalid. This is called a “comm fault.” The RM selection filter sends the average of the remaining values to the SOP.

3.5.10.1 Miscompare

RM will also determine the status of each sensor by comparing its value to the other two sensors.

If one sensor differs from both of the other two by greater than 250 psia, RM will declare that sensor invalid and will begin averaging the remaining two for the SOP.

If a comm fault has occurred and the remaining two sensors differ by more than 250 psia, RM will declare a miscompare, which will result in a dilemma. Since RM no longer knows which transducer is valid, it can no longer send a value to the SOP. Therefore, the SOP uses the last valid reading it received from RM until the dilemma is resolved.

Example

HYD SENSOR DATA

A = commfaulted (FA down)
Differ by >250 psi — B = 3000
C = 0 (sensor failed)

3.5.11 PRL Dilemma and Crew Interface

A dilemma occurs when the RM selection filter can no longer select an overall pressure value due to a combination of comm faults and/or miscompares. When a dilemma occurs, the SOP continues to use the last valid data it had until the dilemma is resolved.

Many times a dilemma will not need to be resolved, since the last valid data that the hydraulic SOP saw is still reflecting the present status of the hydraulic system. However, if a dilemma needs to be resolved, there are two methods that can be used.

- Wait for the miscompare or comm fault to clear itself.
- Take manual control of PRL.

Taking manual control of PRL can be performed only by the crew during OPS 1 and OPS 3 via the PASS GNC SPEC 51 OVERRIDE display.

When a dilemma occurs, either of two symbols will be displayed in the status field located next to the number of the hydraulic system.

If the hydraulic system was good prior to the dilemma, a "?" will be displayed. If the hydraulic system was unavailable prior to the dilemma, a "↓" will appear.

In both cases a PRL fault message will be annunciated along with an SM alert tone.

For more information on PRL and an in-depth look at how it works, take the PRL 2157 Computer-Based Training (CBT) lesson. The lesson provides you with more background information on PRL, practice exercises, and PRL case studies.

3.6 HYDRAULIC SYSTEM CONTROLS AND DISPLAYS

3.6.1 Panels

The panels that the crew uses to interface with the hydraulic system are

- R2
- R4
- A12
- F7
- L4

3.6.1.1 Panel R2

Panel R2 (Figure 3-8) contains the HYD MAIN PUMP PRESS and HYD CIRC PUMP switches.

The hydraulic system switches on this panel are used to place the hydraulic main pump in normal or low pressure and for hydraulic circulation pump activation and deactivation.

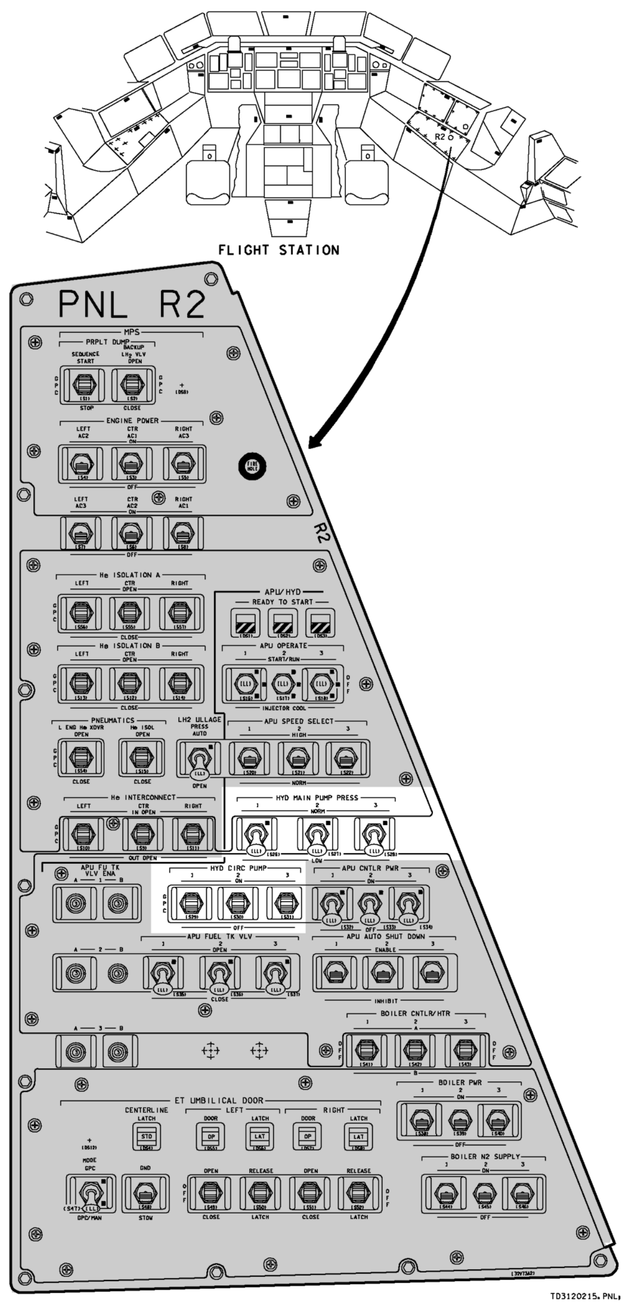

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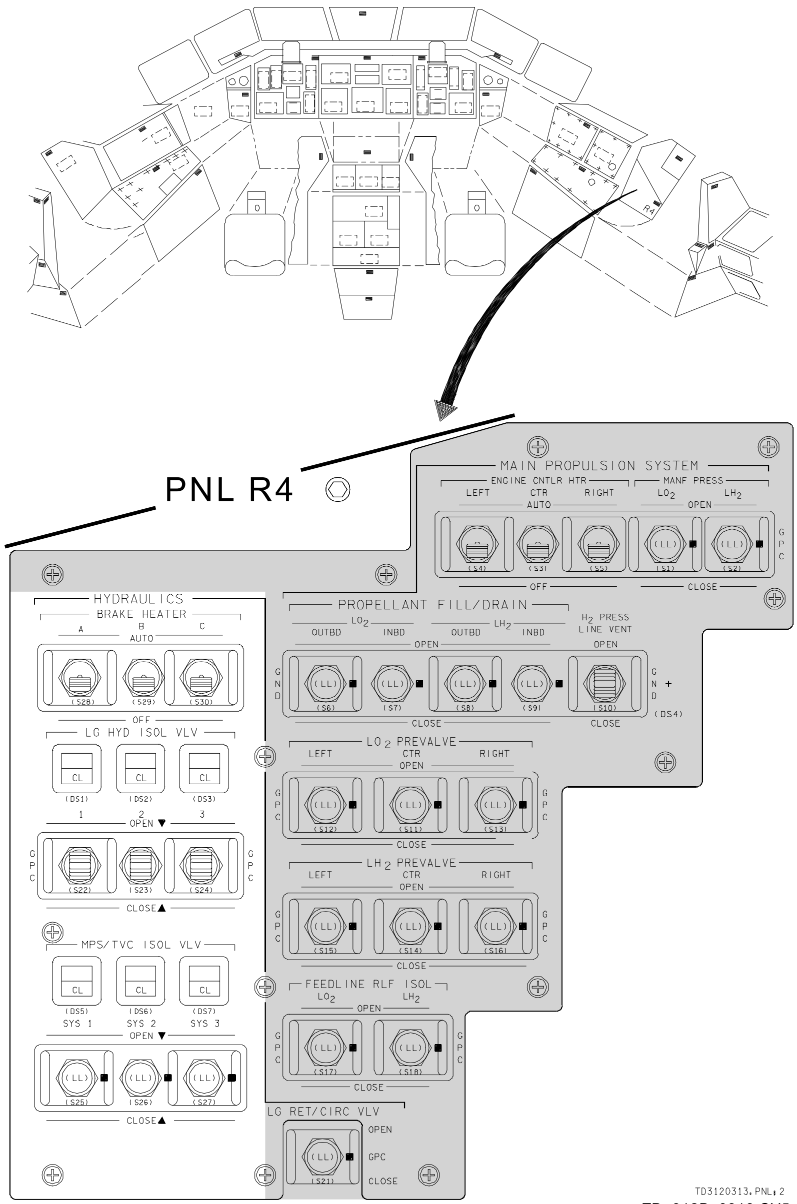
Figure 3-8. Panel R2 and its location

3.6.1.2 Panel R4

Panel R4 (Figure 3-9) contains the brake heater switches, Main Propulsion System (MPS)/TVC isolation valve switches, and the landing gear and brake isolation valve switches.

The hydraulic system switches on this panel are used to control the hydraulic flow to the landing gear, brakes, and MPS/TVC isolation valves and to control heaters to the brake lines.



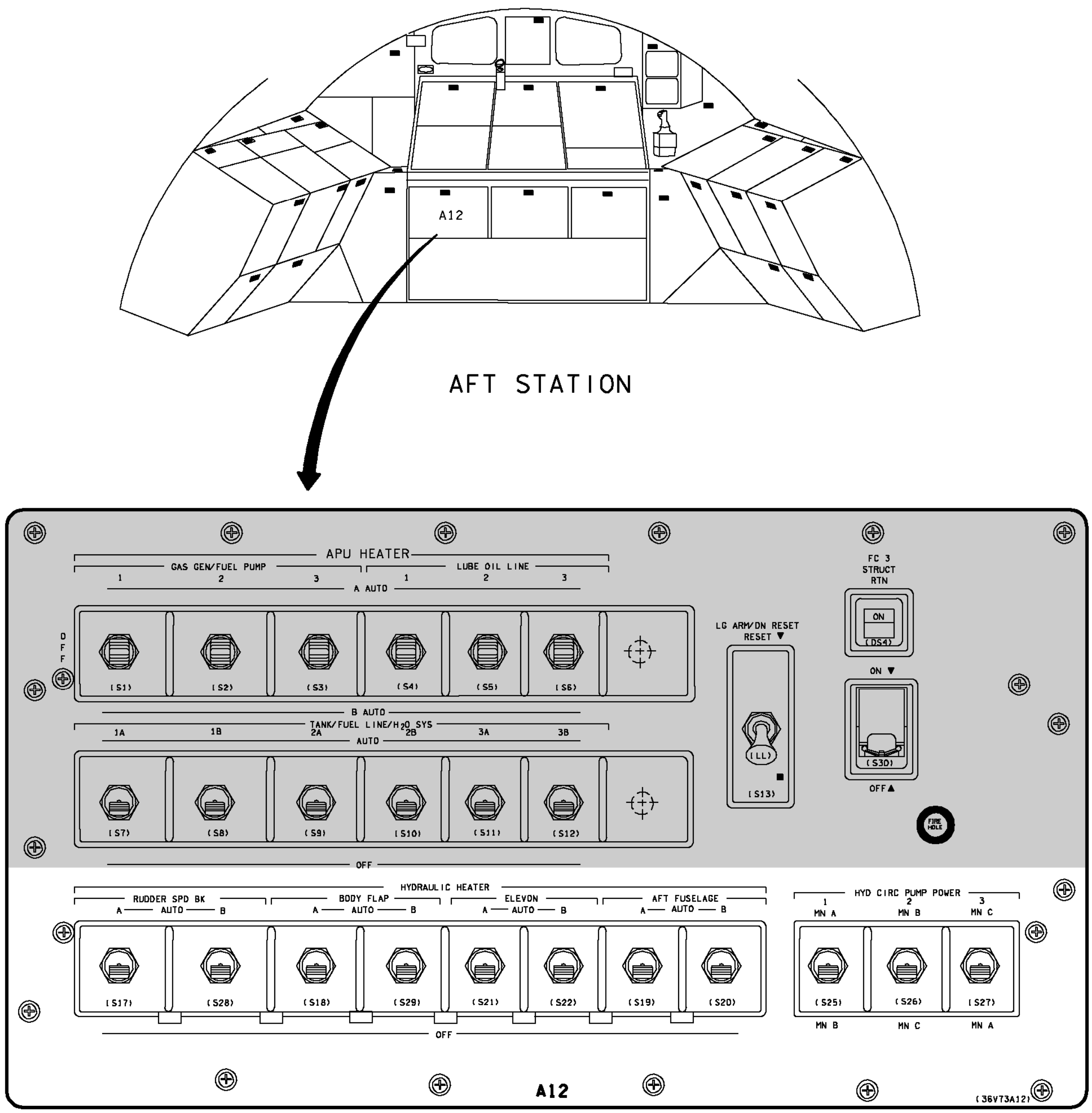
TD_312B_0313.CV5

Figure 3-9. Panel R4 and its location

3.6.1.3 Panel A12

Panel A12 (Figure 3-10) is located in the aft flight deck near the floor.

The hydraulic system switches on this panel control the heaters for the hydraulic lines going to the aerosurfaces. Panel A12 also includes the hydraulic circulation pump power source switches.



TD3120216.PNL; 1
td_312_310

Figure 3-10. Panel A12 and its location

3.6.1.4 Panel F7

The indicator light on the C&W matrix (Figure 3-11) associated with the hydraulic system is HYD PRESS.

The HYD PRESS light illuminates and generates a master alarm tone if the hydraulic main pump pressure falls below 2400 psia.

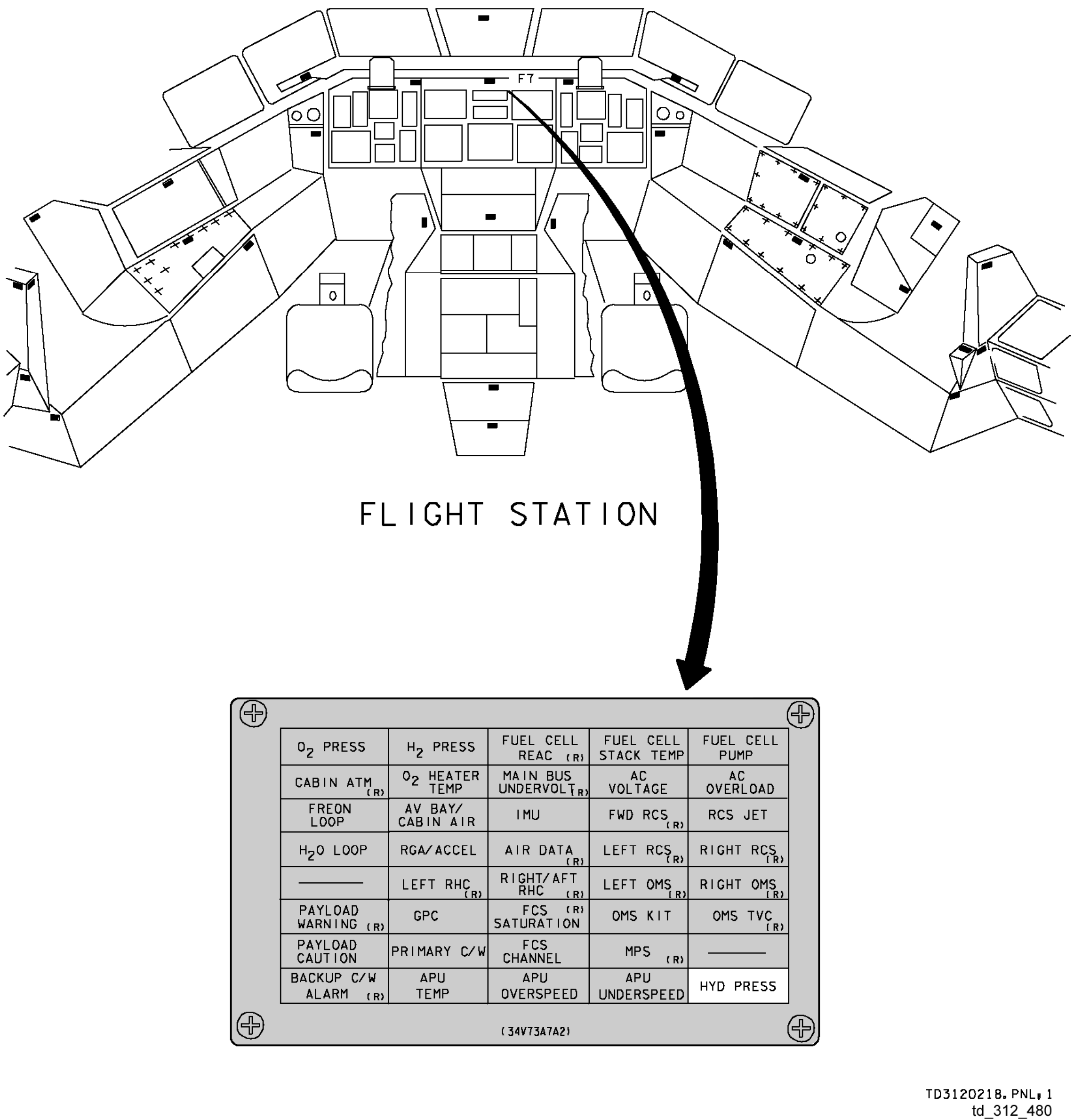


Figure 3-11. Panel F7 C&W matrix

3.6.1.5 Panel L4

Panel L4 (Figure 3-12) is located on the left side of the forward flight deck just behind the commander's seat.

The boiler hydraulic bypass and hydraulic quantity circuit breakers are located on this panel.

Table 3-5 describes the hydraulic controls and displays.

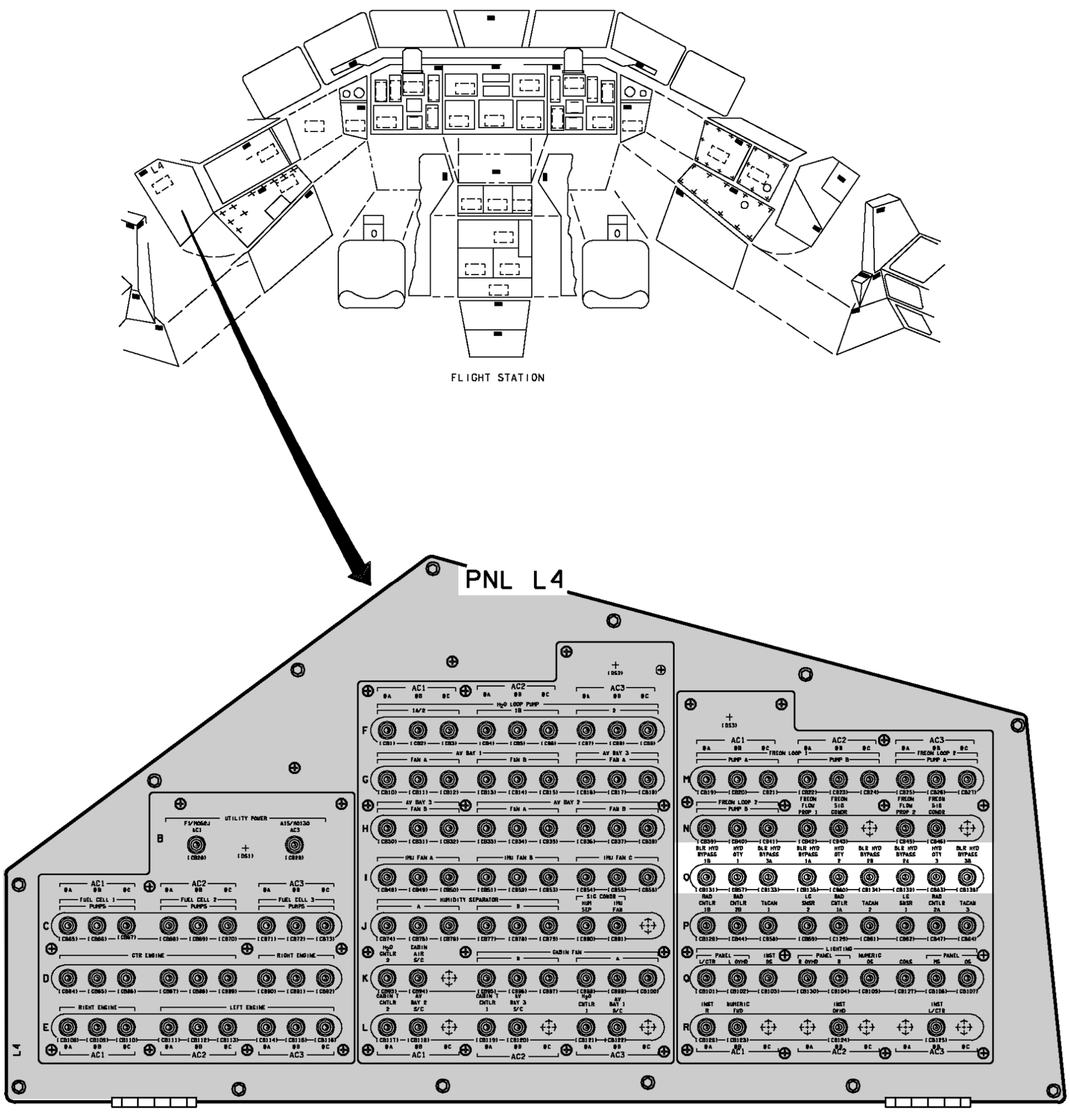


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Figure 3-12. Panel L4 and its location

3.6.2 Displays

3.6.2.1 Subsystem Display

The Subsystem display that the crew uses to monitor the hydraulic system is the HYD/APU Subsystem Status display (Figure 3-13).

The hydraulic meters give readings of

- Hydraulic pressure
- Hydraulic reservoir quantity

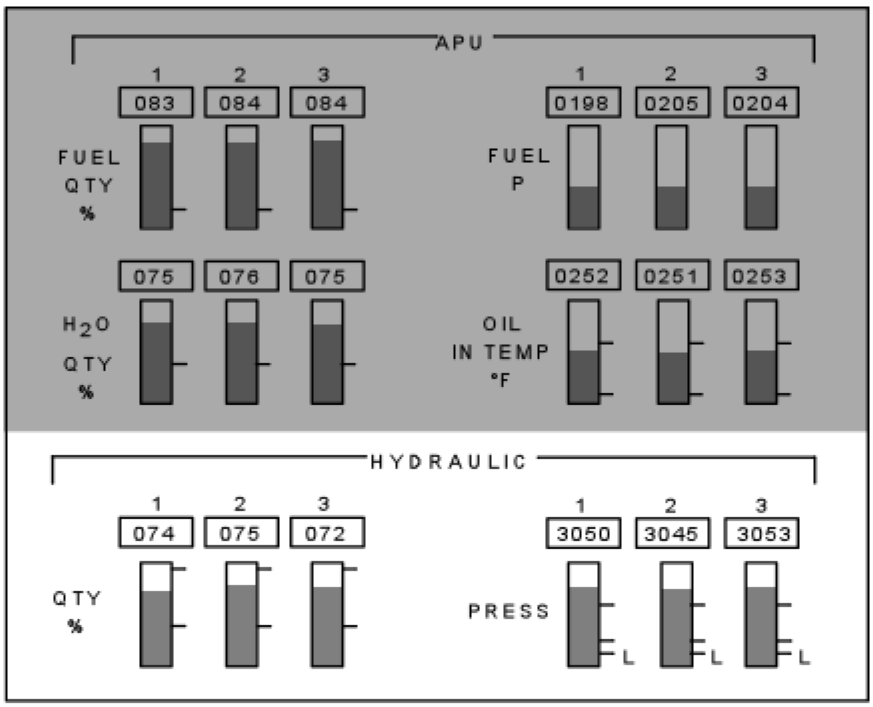


Figure 3-13. HYD/APU Subsystem Status Display meters

Table 3-5 details the various switches on each panel and describes their functions.

Table 3-5. Hydraulic controls and displays

Panel	Type	Nomenclature	Position	Function	Remarks
A12	sw	HYDRAULIC HEATER RUDDER/SPD BK	A-AUTO	Maintain actuator operating temperature (°F)	Open -10° to +5° Closed -25° to +5°
			B-AUTO		Open 150° to +10° Closed -10° to +5°
		HYDRAULIC HEATER BODY FLAP	A or B-AUTO	Maintain actuator operating temperature (°F)	-30° to +10°
		HYDRAULIC HEATER ELEVON	A-AUTO	Maintain actuator operating temperature (°F)	0° to +15°
			B-AUTO		-15° to +5°
		HYDRAULIC HEATER AFT FUSELAGE	A and B-AUTO	Maintain seal cavity drain temperature for body flap and rudder/speedbrake (°F)	-30° to +10°
L4	cb	HYDRAULIC QUANTITY	1,2 and 3	Protects hydraulic quantity transducer circuit	
L4	cb	BOILER HYD BYPASS	1A,1B,2A,2B, 3A,3B	Protects AC circuit to WSB controller and boiler bypass valve motors	
R2	sw	HYD MAIN PUMP PRESS	Low	Selects depress mode for main hydraulic pumps	500-1000 psig
R2			Norm	Selects normal operating pressure for main hydraulic pumps	2950 +150 -50 psig
R2	sw	HYD CIRC PUMPS	On	Activates circulation pump	2.9 gpm at 350 psig 0.1 gpm at 2500 psig
			Off	Deactivates circulation pump circuit	
		HYD CIRC PUMPS (cont'd)	GPC	Software control of circulation pumps to provide thermal conditioning of hydraulic system	350 psig
R4	sw	MPS/TVC ISOL VLV	Open	Provides fluid flow to MPS control valve actuators and TVC actuator	
			Close	Shuts off fluid flow to MPS/TVC actuators	
R4	Indic-ator	MPS/TVC ISOL VLV	Open or Close	Indicates position of the MPS/TVC isolation valve	

Table 3-5. Hydraulic controls and displays (continued)

Panel	Type	Nomenclature	Position	Function	Remarks
R4	sw	BRAKE ISOL VLV	Open	Provides fluid flow to wheel brakes and System 2 nosewheel steering actuators	
			Close	Isolates fluid flow from wheel brakes and System 2 nosewheel steering actuators	
			GPC	Gives software control of isolation valves	
R4	Indic-ator	BRAKE ISOL VLV	Open or Close	Indicates position of the BRAKE isolation valves	
R4	sw	LG RET/CIRC VLV	Open	Routes fluid pressure to the LG external fluid line and return to the retract line	
			Close	Routes fluid pressure to the LG retract line and return to the extend line	Used only during ground operations
			GPC	Software controls the valve to provide thermal conditioning capability	
R4	sw	HYD BRAKE HTRS	AUTO	Maintain brake line temps	
			OFF	No power to brake heaters	
R4	sw	LG EXT ISOL VLV	Open	Provides hydraulic fluid flow to LG EXT VLV	
			Close	Isolates hydraulic fluid flow from LG EXT VLV	
R4	Indic-ator	LG EXT ISOL VLV		Indicates position of LG EXT ISOL VLV	
R4	sw	LG EXT ISOL VLV	GPC	Software controls valve to flow/isolate hydraulic fluid at LG EXT VLV	
R4	sw	LG/NWS HYD SYS	AUTO 1/2	Allows hydraulic flow to NWS switching valve from system 1 or 2	
R4	sw	LG/NWS HYD SYS	SYS 2 INH	Allows hydraulic flow to NWS from System 1 only	

Table 3-5. Hydraulic controls and displays (concluded)

Panel	Type	Nomenclature	Position	Function	Remarks
HYD/ APU	Subsystem Status Display Meter	HYDRAULIC QTY %	1 2 3	Displays hydraulic fluid quantity in reservoir	Red: 0 < % < 40 Green: 40 <= % <= 95 Red: % >= 95
HYD/ APU	Subsystem Status Display Meter	HYDRAULIC PRESS	1 2 3	Displays hydraulic pressure	Red: 0 < psia <= 500 Green: 500 < psia < 1000 Red: 1000 <= psia < 2400 Green: psia >= 2400

3.6.3 DPS Displays

The onboard DPS displays that the crew uses to monitor the hydraulic system are listed below. They have been divided into two categories, ascent/entry DPS displays and orbit DPS displays.

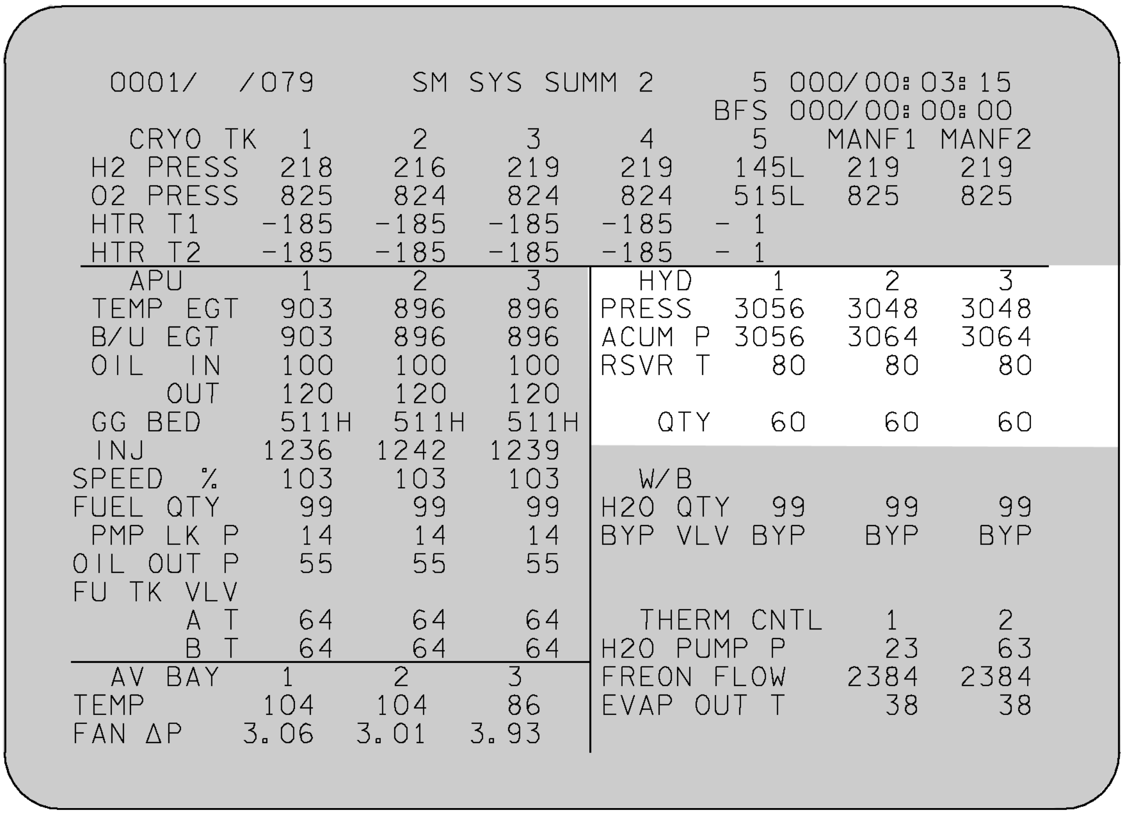
- Ascent/entry DPS displays
  - BFS SM SYS SUMM 2
  - GNC SPEC 51
  - BFS SM THERMAL
- Orbit DPS displays
  - SPEC 86
  - SPEC 87
  - SM SYS SUM 2

3.6.3.1 Ascent/Entry DPS Displays

The following three DPS displays for the APU/HYD/WSB system are available only during ascent and entry.

a. BFS SM SYS SUMM 2

The BFS SM SYS SUMM 2 display (Figure 3-14) allows the crew to monitor HYD parameters (Table 3-6).



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td_312_501

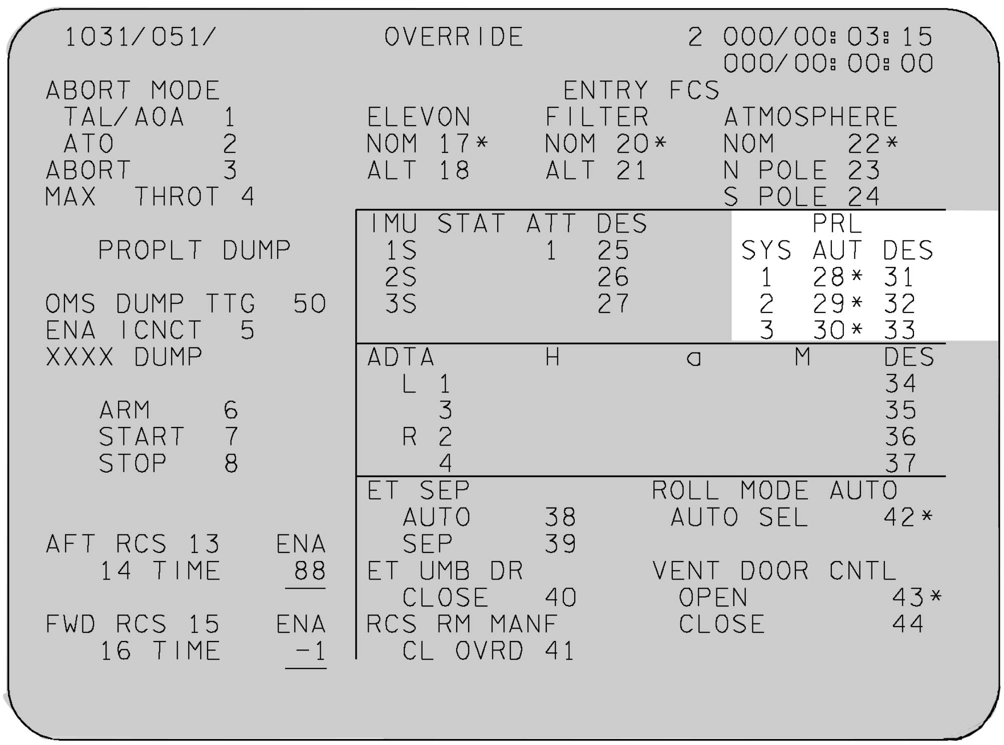
Figure 3-14. BFS SM SYS SUMM 2 display

Table 3-6. BFS SM SYS SUMM 2 HYD parameters

DPS name			Units	Displayed range	Status indicators				
					M	**H**	**L**	**↑**	**↓**
HYD:	PRESS		psia	0 to 4000	M	H	L		↓
	ACCUM	P	psia	0 to 4000	M	H	L	↑	↓
	RSVR	T	deg F	-75 to +300	M	H	L	↑	↓
		QTY	percent	0 to 100	M	H	L	↑	↓

b. GNC SPEC 51

The GNC SPEC 51 (Figure 3-15) display contains PRL information for each hydraulic system. PRL status is displayed on the right-hand side of the display. The information shows the present status of each hydraulic system. If PRL is in the AUTO mode, there will be an asterisk next to the system under the AUT column. If PRL for a system has been deselected, there is an asterisk next to the system under the DES column. There are two status indicators that may appear in the SYS column for off-nominal situation. A "↓" will appear if PRL declares a hydraulic system failed. A "?" will appear if PRL declares a dilemma (see PRL discussion beginning on Page 3-11).

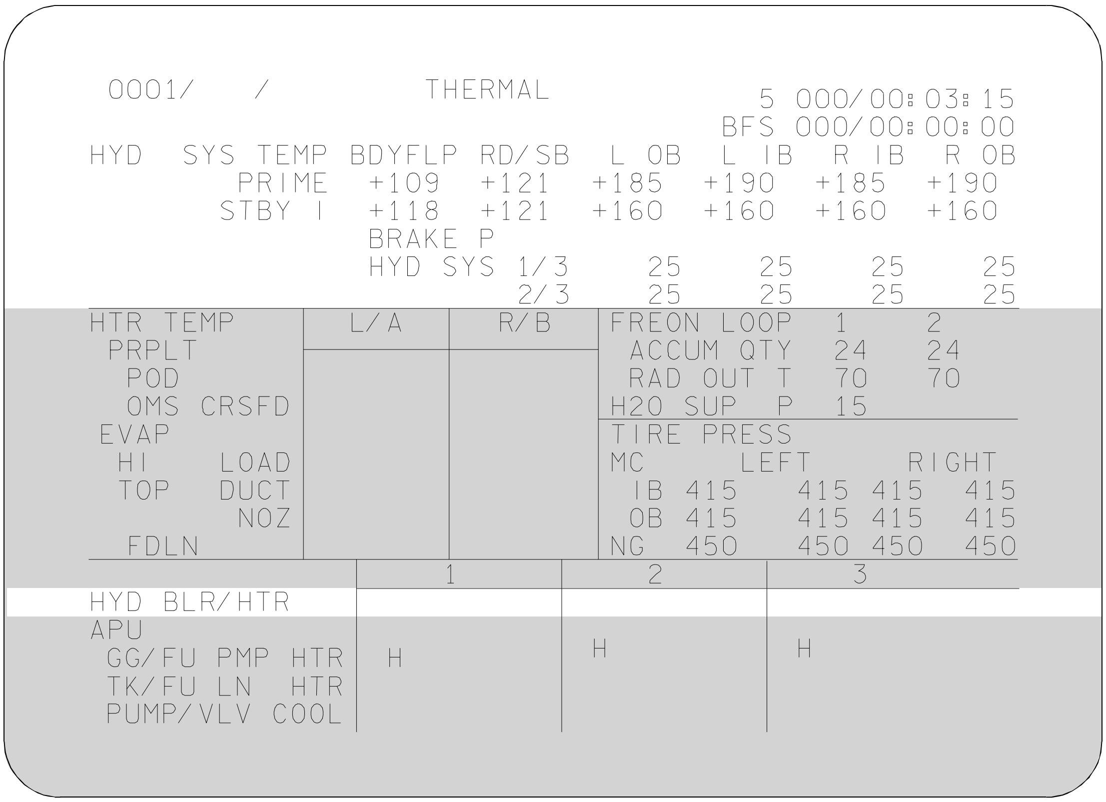


TD3120320.CRT;1
td_312_320

Figure 3-15. GNC SPEC 51 display

c. BFS SM THERMAL

This display (Figure 3-16) monitors hydraulic system temperatures. The parameters are shown in Table 3-7.



TD3120222.CRT;3
td_312b_0222.cv5

Figure 3-16. BFS SM THERMAL display

Table 3-7. BFS SM THERMAL HYD parameters

DPS name	Units	Displayed range	Status indicators				
			M	**H**	**L**	**↑**	**↓**
HYD SYS TEMP (24 Parameters)	deg F	-75 to +300	M	H	L	↑	↓
BRAKE P	psia	0 to 2000	M	H	L		↓
HTR TEMP: PRPLT POD			M	H	L	↑	
OMS CRSFD			M	H	L	↑	↓
EVAP HI LOAD			M	H	L	↑	↓
TOP DUCT			M	H	L	↑	↓
NOZ			M	H	L	↑	↓
FDLN			M	H	L	↑	↓

3.6.3.2 Orbit DPS Displays

The following DPS displays for the hydraulic system are available only on orbit.

a. SPEC 86

SPEC 86 (Figure 3-17) is also known as the APU/HYD display. It is divided into two parts, APU on the left and HYD/WSB on the right. It monitors many of the same parameters seen on the BFS SYS SUMM 2 display (Table 3-8).

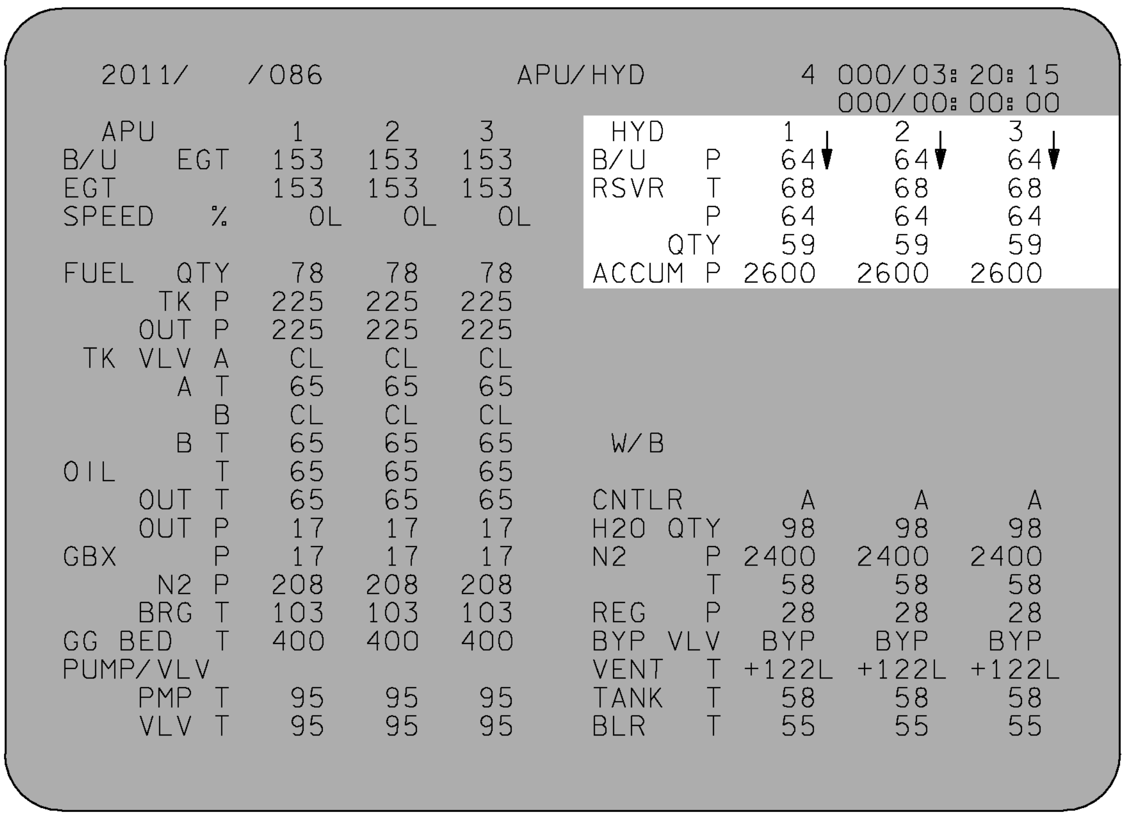


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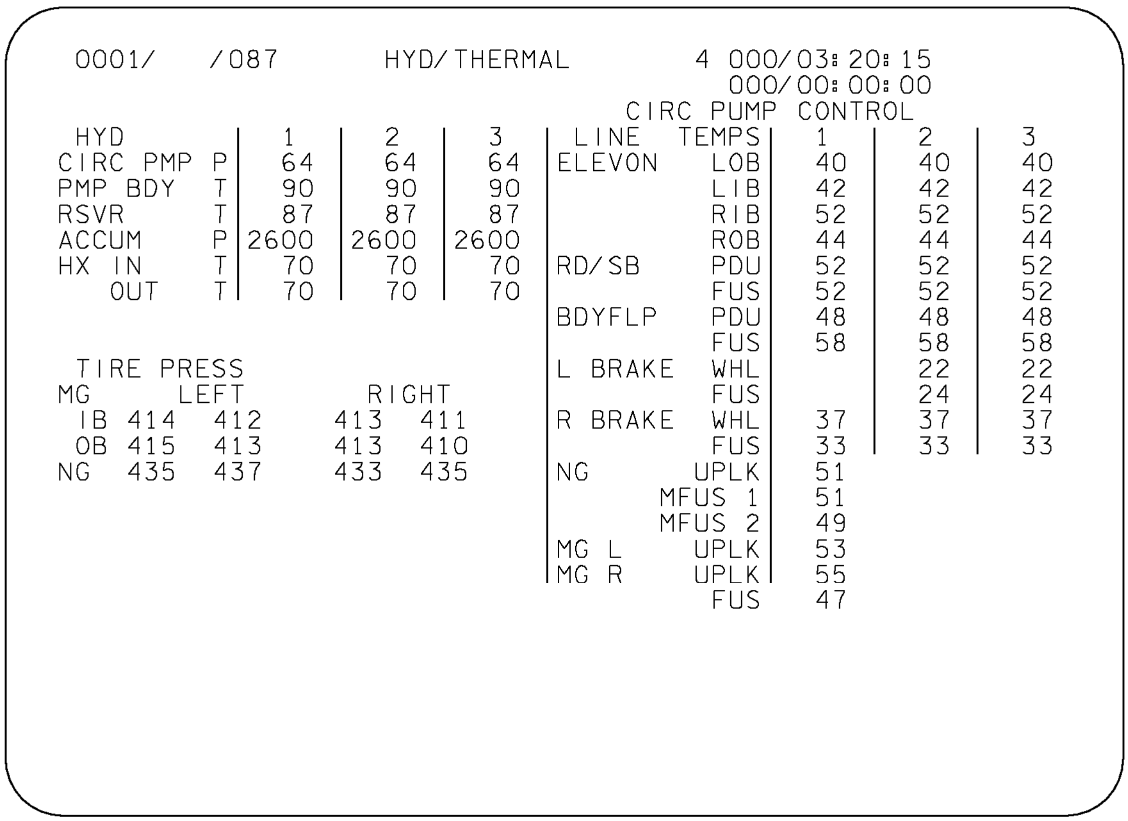
Figure 3-17. SPEC 86 display

Table 3-8. SPEC 86 HYD parameters

DPS name		Units	Displayed range	Status indicators				
				M	**H**	**L**	**↑**	**↓**
HYD:	B/U P	psia	0 to 4000	M	H	L		↓
	RSVR T	deg F	-75 to +300	M	H	L	↑	↓
	P	psia	0 to 250	M	H	L		↓
	QTY	percent	0 to 100	M	H	L	↑	↓
	ACCUM P	psia	0 to 4000	M	H	L		↓

b. SPEC 87

SPEC 87 (Figure 3-18) is known as the HYD/THERMAL display. This display monitors the hydraulic fluid lines and where they interface with the landing gear and aerosurfaces. The parameters are shown in Table 3-9.



TD3120326.CRT;1
td_312_326

Figure 3-18. SPEC 87 display

Table 3-9. SPEC 87 HYD parameters

DPS name			Units	Displayed range	Status indicators				
					M	**H**	**L**	**↑**	**↓**
HYD:	CIRC PMP P		psia	0 to 800	M	H	L	↑	↓
	PMP BDY T		deg F	-75 to +300	M	H	L	↑	↓
	RSVR T		deg F	-75 to +300	M	H	L	↑	↓
	ACCUM P		psia	0 to 4000	M	H	L	↑	↓
	HX IN T		deg F	-75 to +300	M	H	L	↑	↓
		OUT T	deg F	-75 to +300	M	H	L	↑	↓
SW VLV			text	"*" or blank					
TIRE PRESS									
	MG IB	L,R	counts	0 to 150	M	H	L	↑	↓
	OB	L,R	counts	0 to 150	M	H	L	↑	↓
	NG	L,R	counts	0 to 150	M	H	L	↑	↓
CIRC PUMP CONTROL LINE TEMPS									
	ELEVON	LOB	deg F	-75 to +300	M	H	L	↑	↓
		LIB	deg F	-75 to +300	M	H	L	↑	↓
		RIB	deg F	-75 to +300	M	H	L	↑	↓
		ROB	deg F	-75 to +300	M	H	L	↑	↓
	RD/SB	PDU	deg F	-75 to +300	M	H	L	↑	↓
		FUS	deg F	-75 to +300	M	H	L	↑	↓
	BDYFLP	PDU	deg F	-75 to +300	M	H	L	↑	↓
		FUS	deg F	-75 to +300	M	H	L	↑	↓
	L BRAKE	WHL	deg F	-75 to +300	M	H	L	↑	↓
		FUS	deg F	-75 to +300	M	H	L	↑	↓
	R BRAKE	WHL	deg F	-75 to +300	M	H	L	↑	↓
		FUS	deg F	-75 to +300	M	H	L	↑	↓
	NG	UPLK	deg F	-75 to +300	M	H	L	↑	↓
		MFUS 1,2	deg F	-75 to +300	M	H	L	↑	↓
	MG L	UPLK	deg F	-75 to +300	M	H	L	↑	↓
	MG R	UPLK	deg F	-75 to +300	M	H	L	↑	↓
		FUS	deg F	-75 to +300	M	H	L	↑	↓

c. PASS SYS SUMM 2

The PASS SYS SUMM 2 display (Figure 3-19 and Table 3-10) allows the crew to monitor vital hydraulic system parameters. It monitors hydraulic system pressures, various system temperatures, and fluid quantities.

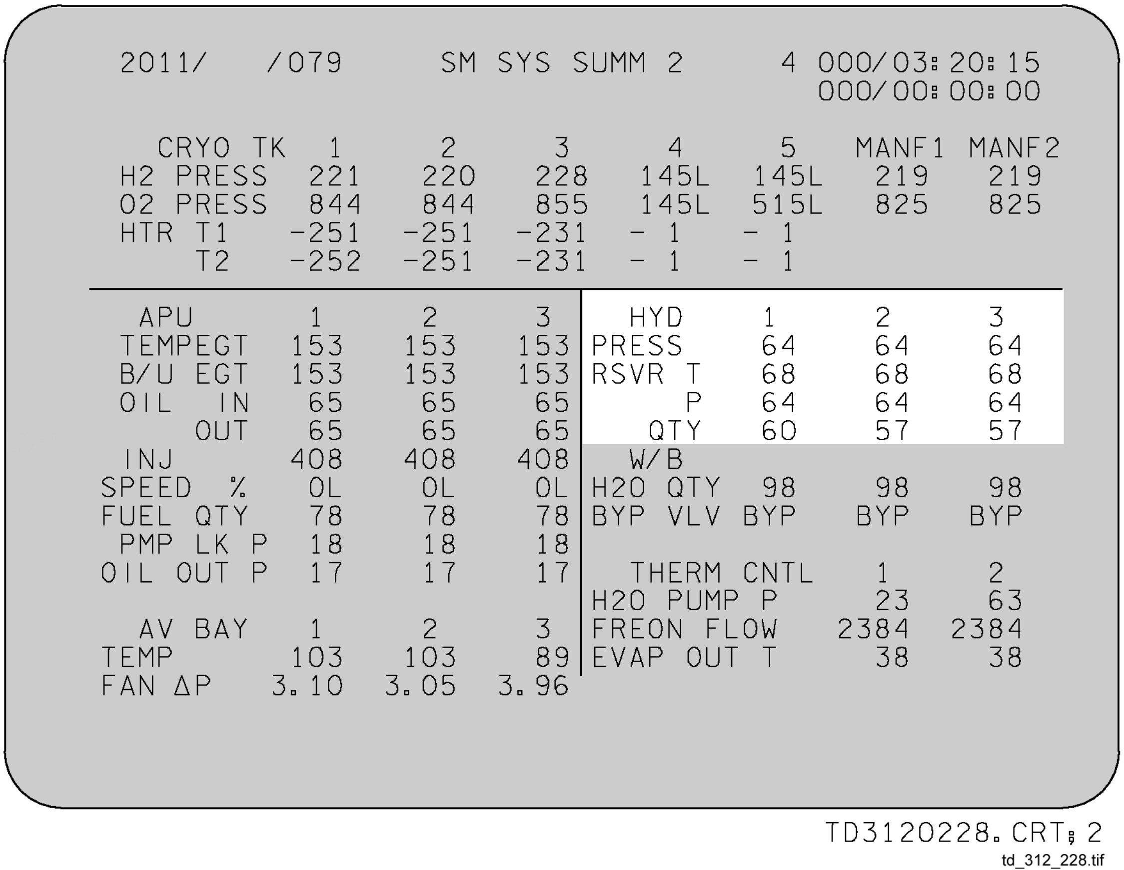


Figure 3-19. PASS SYS SUMM 2 display

Table 3-10. PASS SYS SUMM 2 HYD parameters

DPS name			Units	Displayed range	Status indicators				
					M	**H**	**L**	**↑**	**↓**
HYD:	PRESS		psia	0 to 4000	M	H	L		↓
	RSVR	T	deg F	-75 to +300	M	H	L	↑	↓
		P	psia	0 to 250	M	H	L		↓
		QTY	percent	0 to 100	M	H	L	↑	↓

Questions

1. Where is the orbiter hydraulic system located?

2. The function of the hydraulic system is to provide hydraulic power to

   (a) The OMS and RCS systems

   (b) Deploy the Ku-band antenna, the radiators, and the air data probes

   (c) The power drive units which actuate the mechanical systems

   (d) The main engines, aerosurfaces, landing gear, and ET plates

   (e) None of the above

3. Match each of the following hydraulic system components to its function or functions:

a. Main pump	__________	1. Provides pressure to the reservoir
b. Reservoir	__________	2. Provides hydraulic flow and pressure to system
c. Accumulator	__________	3. Warms hydraulic lines when fluid is not flowing
d. Circulation pump	__________	4. Allows hydraulic fluid to pick up heat from the ECLSS Freon coolant loops
e. Hydraulic/Freon heat exchanger	__________	5. Circulates hydraulic fluid and repressurizes the accumulator while the APU system is inactive
f. Heaters	__________	6. Maintains positive head pressure at the main pump

7. True or false. The hydraulic systems provide for triple redundancy for landing gear deployment and nosewheel steering.

8. What is PRL?

4.0 WATER SPRAY BOILER

4.1 OBJECTIVES

Upon completing this section, you should be able to

- Locate the WSB system in the orbiter
- Recognize the function of the WSB system
- Match WSB system components to their functions

4.2 OVERVIEW

The WSB is used to cool its associated APU lubricating oil and the orbiter hydraulic fluid while the system is active. It cools by the evaporation of water sprayed onto the fluid lines.

The WSB system (Figure 4-1) consists of three identical independent WSBs, one for each APU/hydraulic system. The WSB systems are located near the APUs in the aft compartment of the orbiter.

4.3 SYSTEM DESCRIPTION

In this section, we will discuss the major components of the WSB system

- Electronic controllers
- Water tank
- Boiler

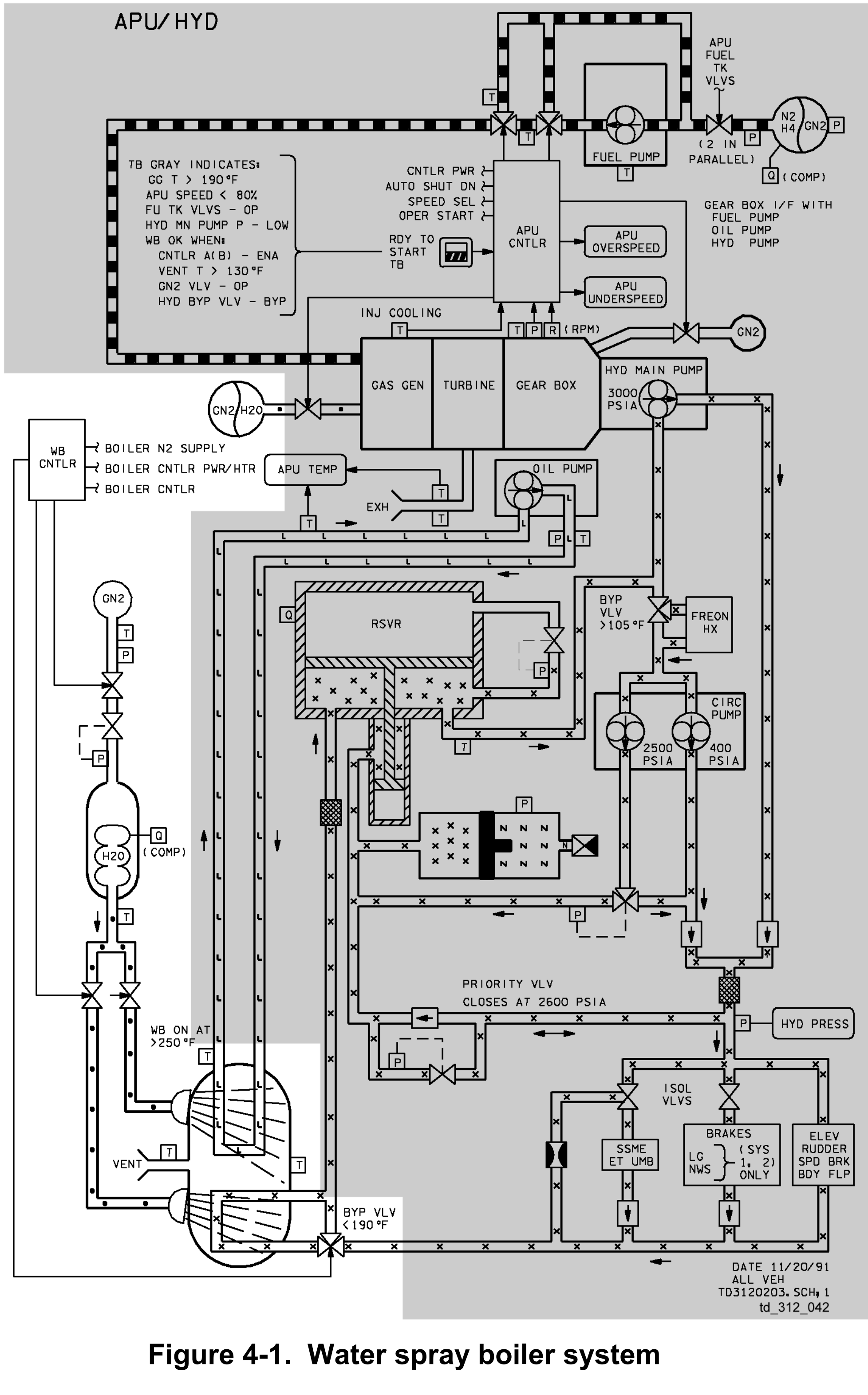


Figure 4-1. Water spray boiler system

4.3.1 Electronic Controller

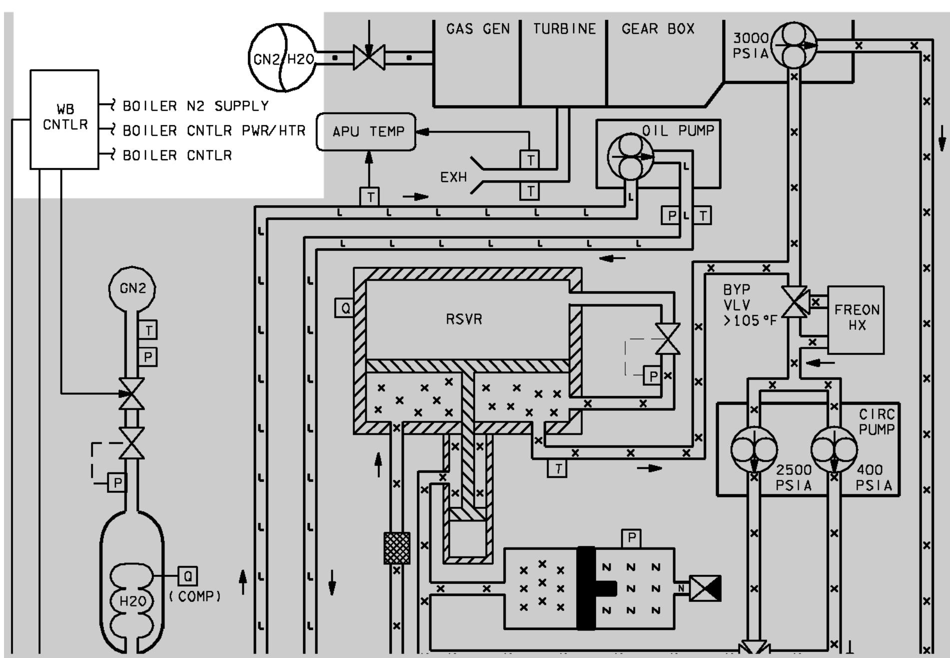
The WSB has two controllers, A and B, which are powered by different electrical buses. Only one controller is used at a time. The controller (Figure 4-2) controls the water spray and the hydraulic fluid bypass valve based on fluid temperatures.

Controller A and controller B are identical and contain spray logic and bypass valve logic as well as signal conditioner power to several transducers. Both controllers provide for the computation of WSB tank quantity based on H_2O tank pressure and temperature transducer readings, and GN_2 tank pressure and temperature transducer readings. The controllers are activated by switches on panel R2.

If you remember from the section on APUs, the “ready” WSB was one of the criteria for the APU controller giving a READY TO START talkback for the APU.

For the WSB to be ready, the following four conditions must be met:

- WSB controller A or B is ENABLED
- WSB steam vent temperature is greater than 130° F
- GN_2 shutoff valve is open, allowing nitrogen to pressurize the water tank
- Hydraulic fluid bypass valve is in the correct position



td_312_043

Figure 4-2. WSB electronic controller

4.3.2 Water Tank and Boiler

Water for the WSB is stored in a bellows-type storage tank which is pressurized by nitrogen (Figure 4-3). The water tank capacity is 142 lbs of water, but normally the tank is filled with only 118 lbs. The nitrogen can be isolated by a GN_2 shutoff valve using the BLR N_2 SUPPLY switch on panel R2.

The hydraulic fluid and APU lubricating oil lines pass through the water boiler and are sprayed with water from three hydraulic fluid water spray bars and two APU lubricating oil water spray bars.

Prelaunch, the boiler is preloaded with water or water mixed with Propylene Glycol Monomethyl Ether (PGME) for what is termed the “pool mode” (Figure 4-4). PGME is an antifreeze additive. This liquid is in addition to the consumables loaded into the storage tank. In the pool mode, the boiler holds enough water mixture to immerse the hydraulic fluid and lubricating oil cooling tubes. This mode is used during ascent and entry.

During ascent, the APU lubricating oil heats up. Eventually, the pooled water boils off and the boiler goes into the spray mode (approximately Mission Elapsed Time (MET) of 10 min) (Figure 4-5). The hydraulic fluid usually does not heat up enough during ascent to require water spray cooling.

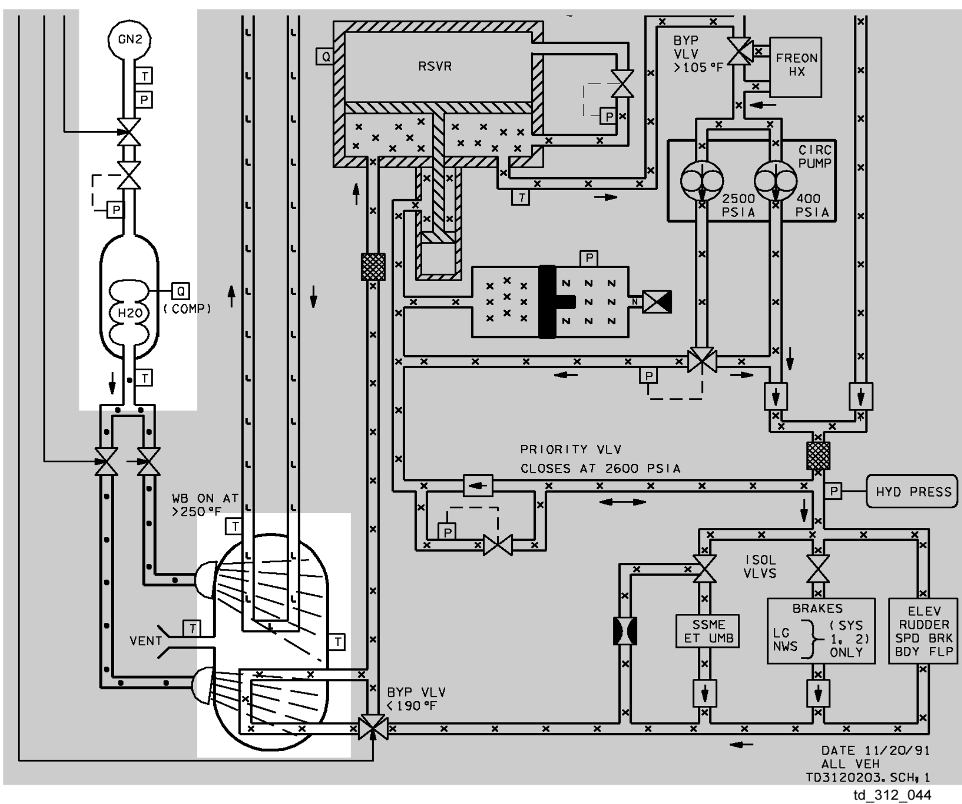


Figure 4-3. Water tank and boiler

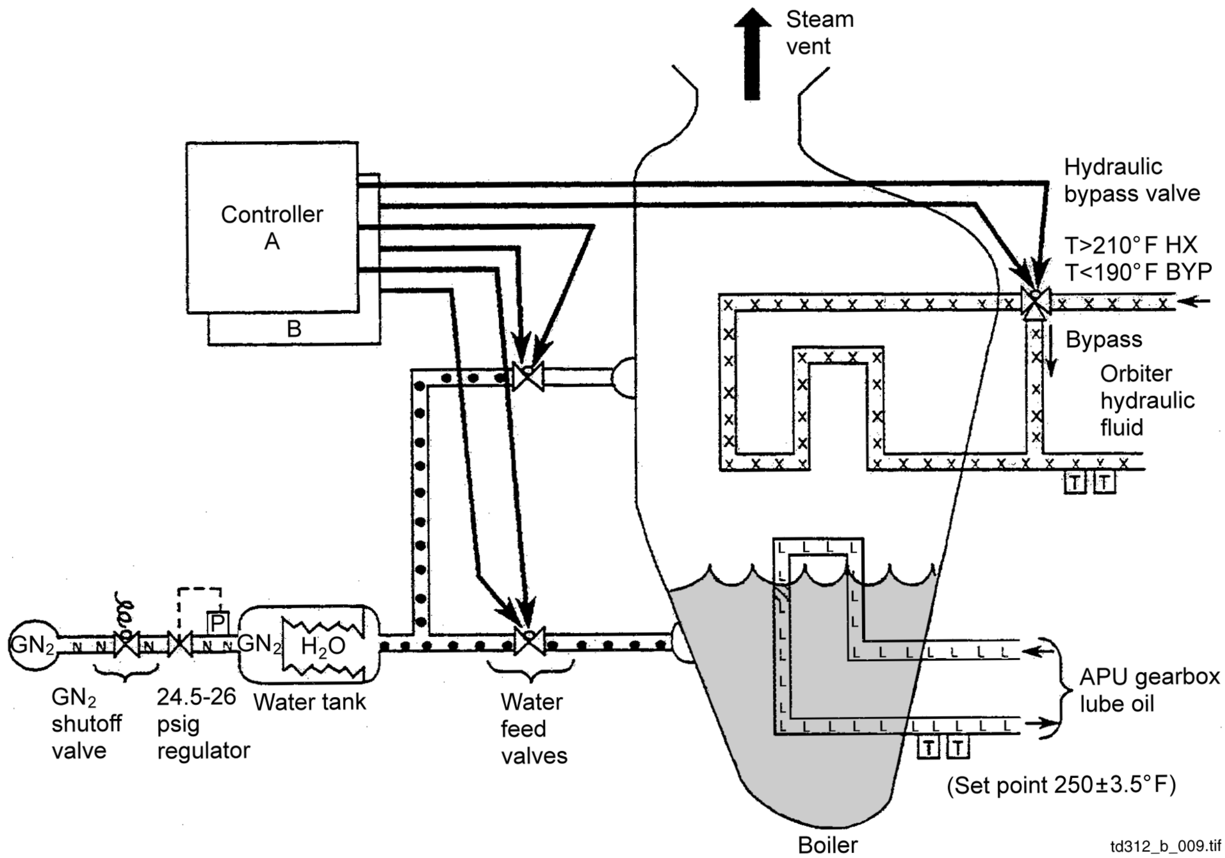


Figure 4-4. WSB ascent pool mode

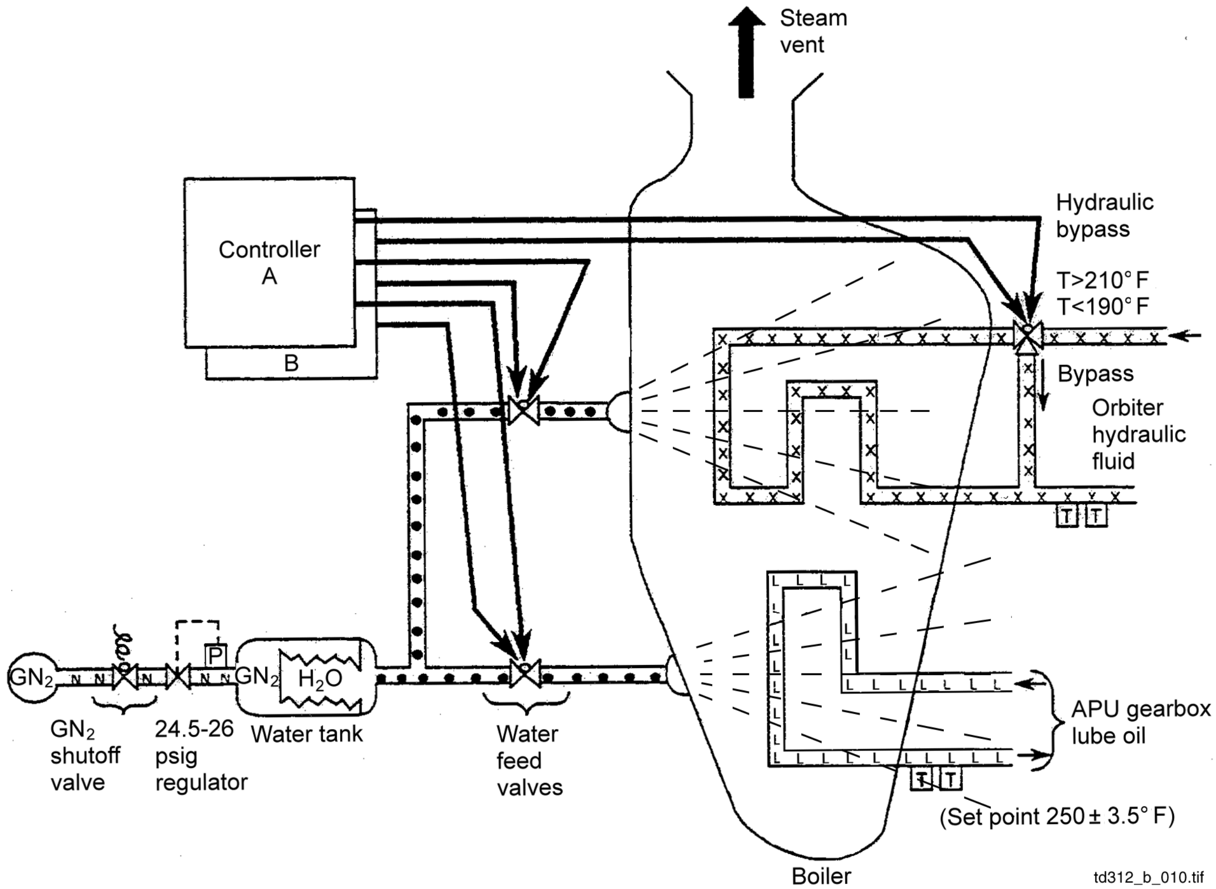


Figure 4-5. WSB spray mode

During the later part of entry (approximately 17 kft), when the boiler core temperature increases to the boiling point of water at the given altitude or internal pressure, the WSB returns to the pool mode (Figure 4-6). When the water reaches the liquid level sensors, the spray is turned off so that the boiler does not overfill. During entry the orbiter is in a different orientation than during ascent, so the boiler can hold up to 14 lbs of water.

The water that is boiled off during WSB operation exits the orbiter through a steam vent located to the right of the vertical stabilizer.

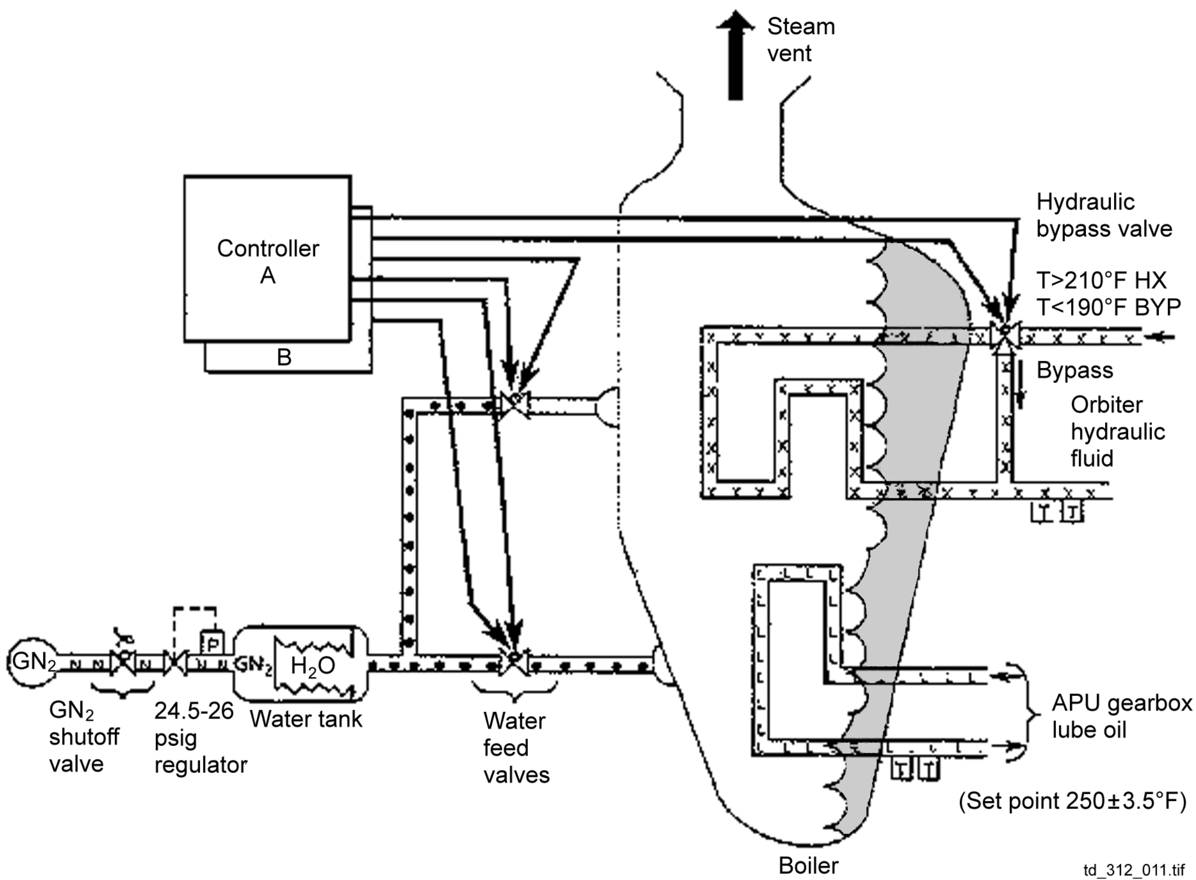


Figure 4-6. WSB entry pool mode

4.3.3 Heaters

The water boiler, water tank, and steam vent are equipped with heaters to prevent freezing on orbit. The heaters are cycled automatically by the WSB controller. Controller B has a separate set of heaters that is completely redundant to the controller A heaters. The Controller A heaters also have continuously powered heaters on the water feedlines coming from the spray valves to the spray bars. Since the Controller A heaters are used for ascent, this added heat helps to prevent the formation of ice on the spray bars that may leak water prior to active spraying.

The steam vent heaters are not run continuously on orbit but are activated about 2 hours prior to APU startup during deorbit prep.

All the heaters can be controlled by switches on panel R2.

4.4 WATER SPRAY BOILER CONTROLS AND DISPLAYS

4.4.1 Panels

The panels that the crew uses to interface with the water spray boiler system are

- R2
- L4

4.4.1.1 Panel R2

Panel R2 (Figure 4-7) is located in the forward flight deck just to the right of the PLT's seat. It lies parallel to the seat so the PLT can simply reach down and move the switches.

The switches on this panel are used primarily for WSB and steam vent activation and deactivation.

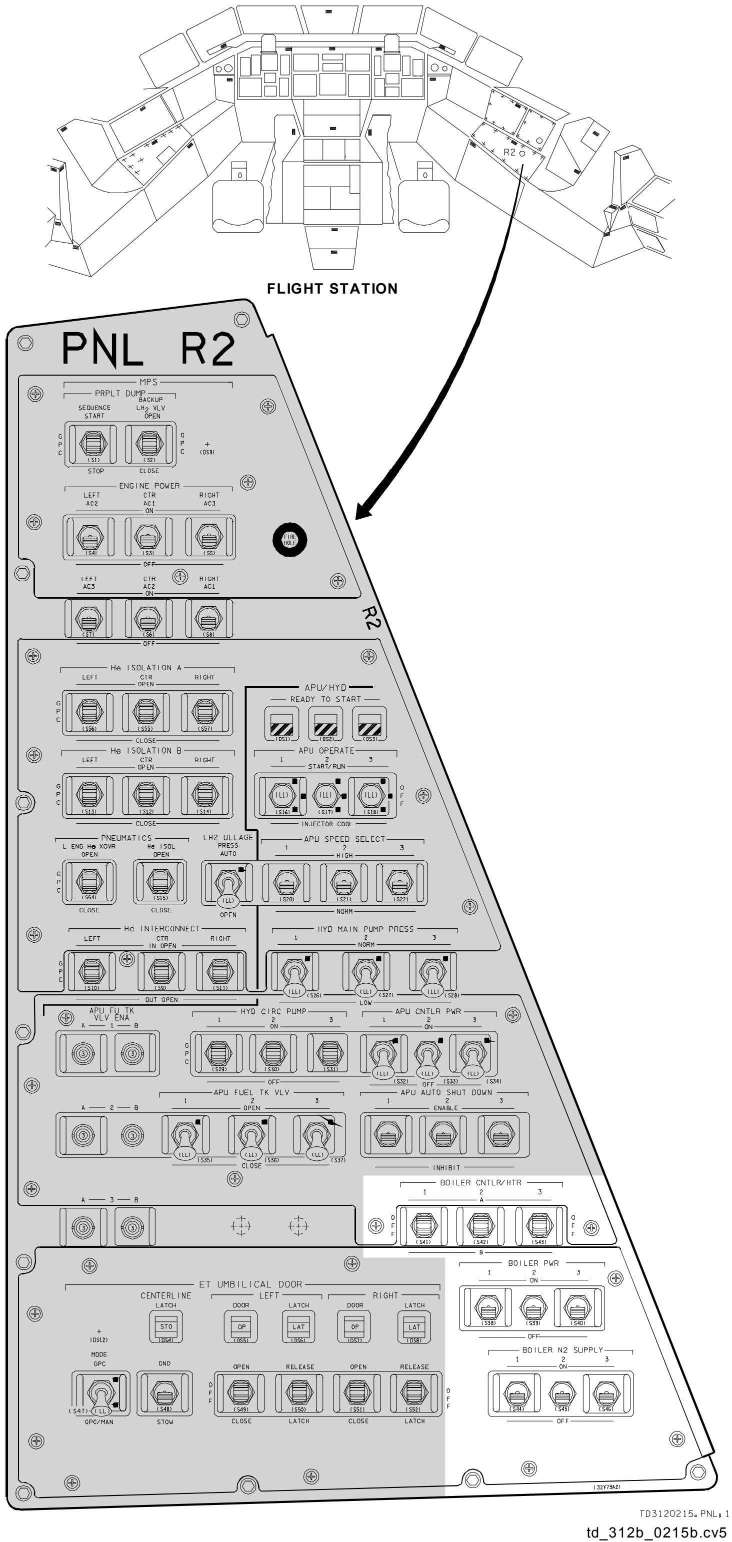


Figure 4-7. Panel R2 and its location

4.4.1.2 Panel L4

Panel L4 (Figure 4-9) is located on the left side of the forward flight deck just behind the commander's seat.

The boiler hydraulic bypass and hydraulic quantity circuit breakers are on this panel.

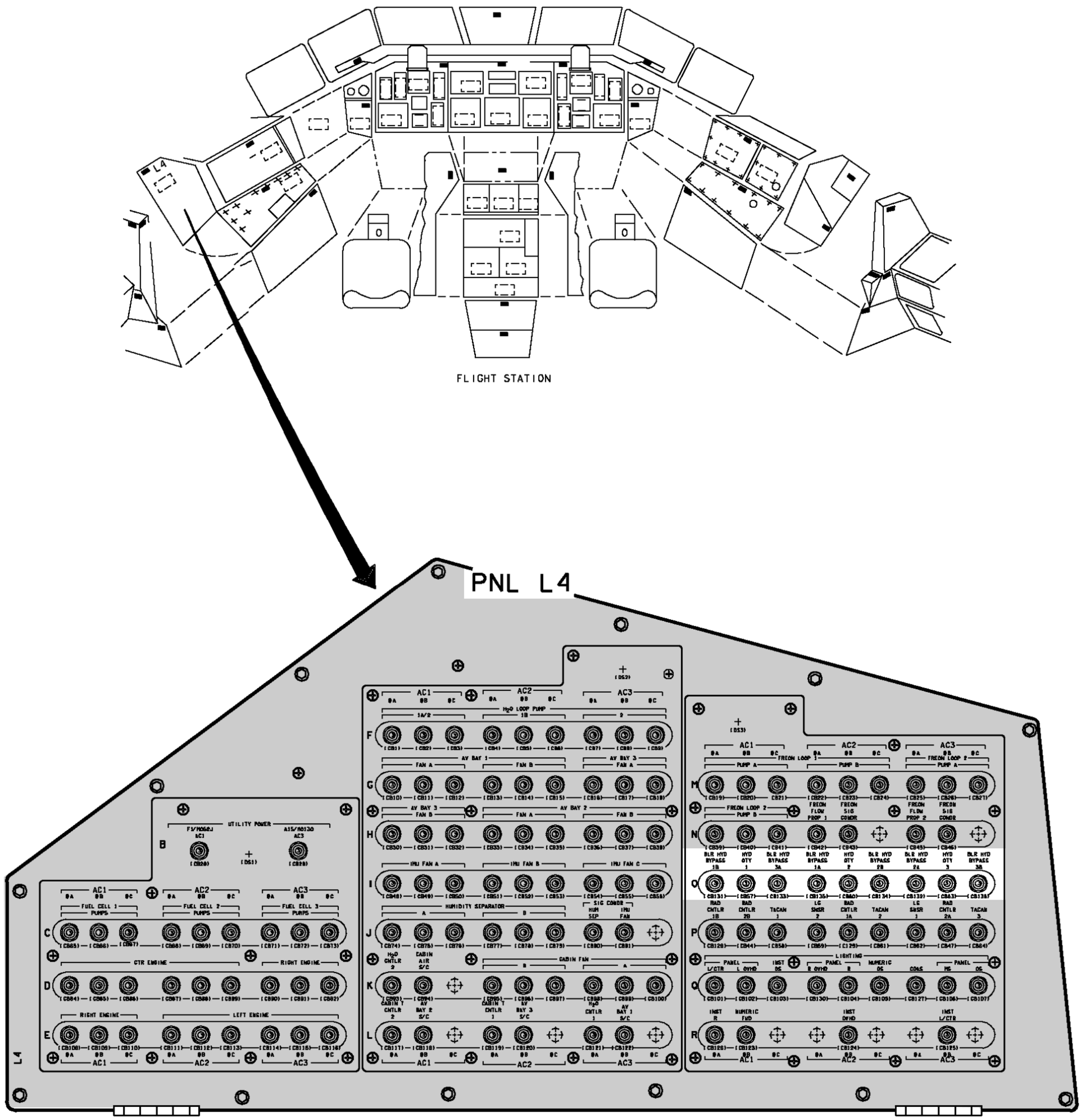


Figure 4-8. Panel L4 and its location

4.4.2 Displays

4.4.2.1 Subsystem Display

The Subsystem display that the crew uses to monitor the water spray boiler system is the HYD/APU Subsystem Status display (Figure 4-9).

The meters give readings of water quantity remaining in the WSB tanks and the temperatures of the oil returning from the WSB.

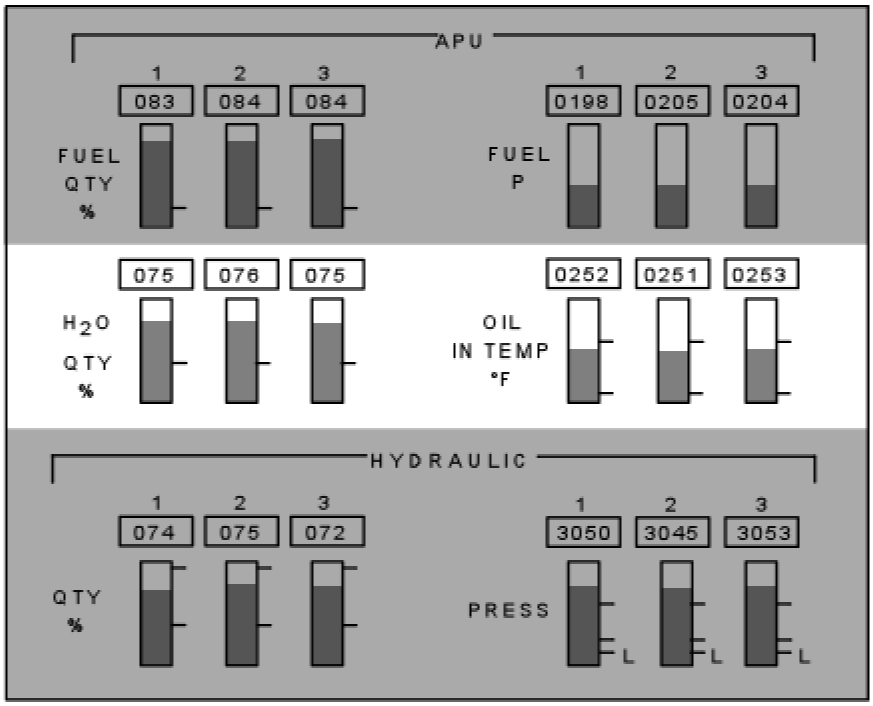


Figure 4-9. HYD/APU Subsystem Status Display meters

Table 4-1 on the following page details the various switches on each panel and describes their functions.

Table 4-1. WSB controls and displays

Panel	Type	Nomenclature	Position	Function	Remarks
L4	cb	BOILER HYD BYPASS 1A, 1B, 2A, 2B, 3A, 3B	Open/ closed	Provides circuit protection from AC bus to controller, AC/DC power converter and bypass motors	
R2	sw	BOILER CNTLR/HTR	A	Selects A controller; puts controller in a passive mode and enables the H_2O tank and boiler heaters	
			B	Selects B controller; puts controller in a passive mode and enables the H_2O tank and boiler heaters	
R2	sw	BOILER PWR	ON	Provides 28 V DC to redundant power supplies in the WSB controller	
			OFF	No power to controller	
R2	sw	BOILER N_2 SUPPLY	ON	Allows N_2 gas from a bottle to pressurize the WSB water tank by electrically opening a valve	
			OFF	Deactivates electrical power to the N_2 gas valve, allowing the valve to close	
HYD/ APU	Subsystem Status Display Meter	APU H_2O QTY %	1 2 3	Indicates percent of water remaining in each of the three WSB water tanks	Red: $0 < \% < 40$ Green: $\% >= 40$
HYD/ APU	Subsystem Status Display Meter	APU OIL TEMP ^oF	1 2 3	Displays inlet lubricating oil temp from the boilers into gearbox in degrees Fahrenheit	Red: $0 < {}^oF < 45$ Green: $45 <= {}^oF <= 290$ Red: ${}^oF > 290$

4.4.3 DPS Displays

The onboard DPS displays that the crew uses to monitor the WSB system are listed below. They have been divided into two categories, ascent/entry DPS displays and orbit DPS displays.

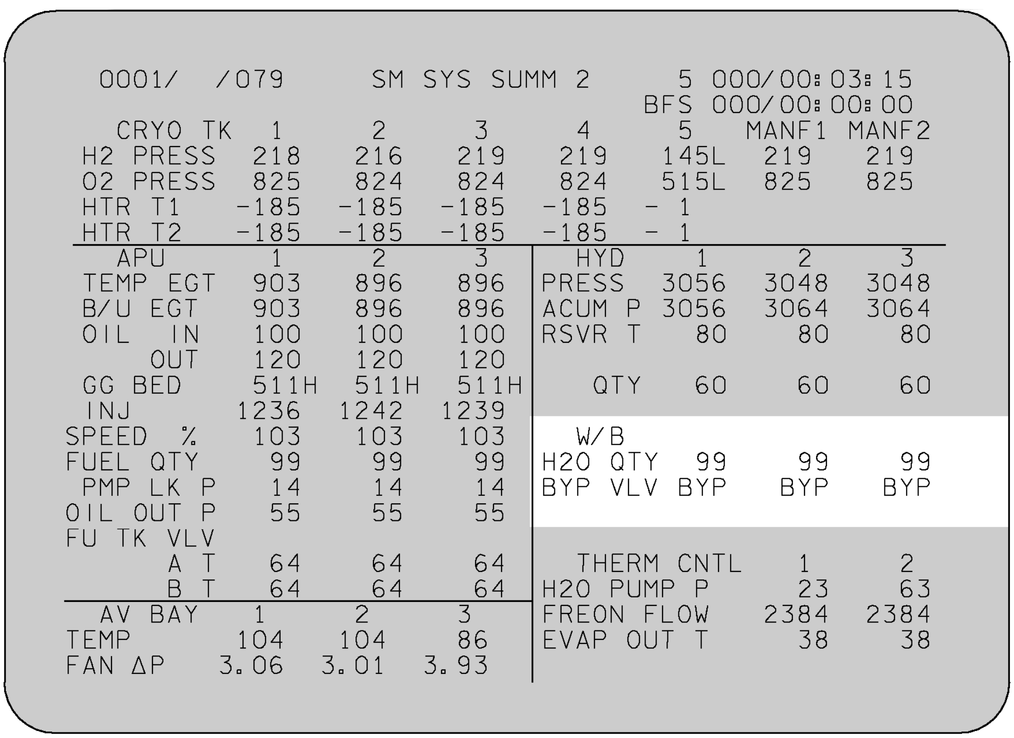
- Ascent/entry DPS displays
  - BFS SM SYS SUMM 2
- Orbit DPS displays
  - SPEC 86
  - PASS SM SYS SUMM 2

4.4.3.1 Ascent/Entry DPS Display

The following DPS display for the APU/HYD/WSB system is available only during ascent and entry.

BFS SM SYS SUMM 2 Display

The BFS SM SYS SUMM 2 display (Figure 4-10) allows the crew to monitor WSB parameters.



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td_312_502.tif

Figure 4-10. BFS SM SYS SUMM 2 display

4.4.3.2 Orbit DPS Displays

The following two DPS displays for the APU/HYD/WSB system are available only on orbit.

a. SPEC 86

SPEC 86 (Figure 4-11) is also known as the APU/HYD display. It is divided into two parts, APU on the left and HYD/WSB on the right. It monitors many of the same parameters seen on the BFS SYS SUMM 2 display (Table 4-2).

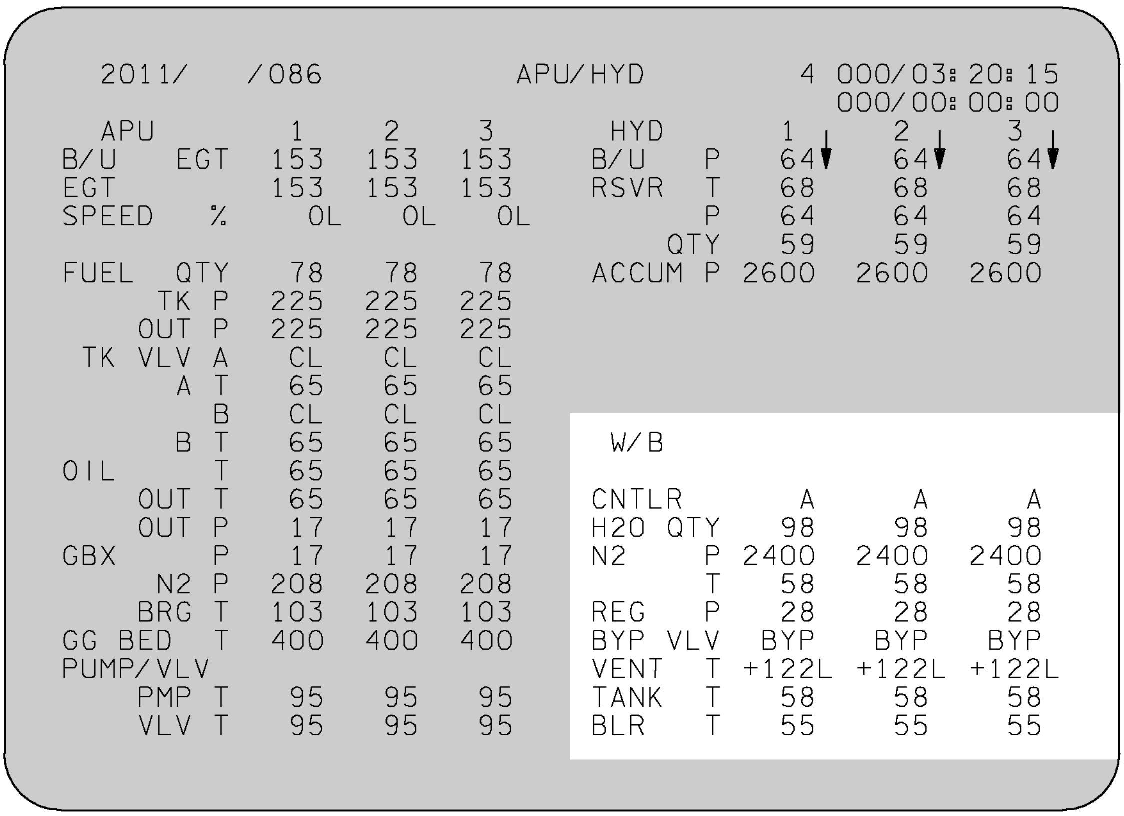

Figure 4-11. SPEC 86 display

Table 4-2. SPEC 86 parameters

DPS name		Units	Displayed range	Status indicators				
				M	**H**	**L**	↑	↓
W/B:	CNTLR	text	‘A,’ ‘B,’ ‘A/B,’ or ‘OFF’					
	H_2O QTY	percent	0 to 100	M	H	L		↓
	N_2P	psia	0 to 3500	M	H	L		↓
	T	deg F	32 to 221	M	H	L		
	REG P	psia	0 to 75	M	H	L	↑	↓
	BYP VLV	text	‘BYP’ or ‘W/B’ or ‘blank’	M				
	VENT T	deg F	122 to 185	M	H	L	↑	
	TANK T	deg F	32 to 221	M	H	L	↑	↓
	BLR T	deg F	32 to 212	M	H	L	↑	↓

b. PASS SM SYS SUMM 2

The Primary Avionics Software System (PASS) SM SYS SUMM 2 display (Figure 4-12. PASS SM SYS SUMM 2 display) contains APU/HYD/WSB parameters for H_2O QTY and the position of the bypass valve.

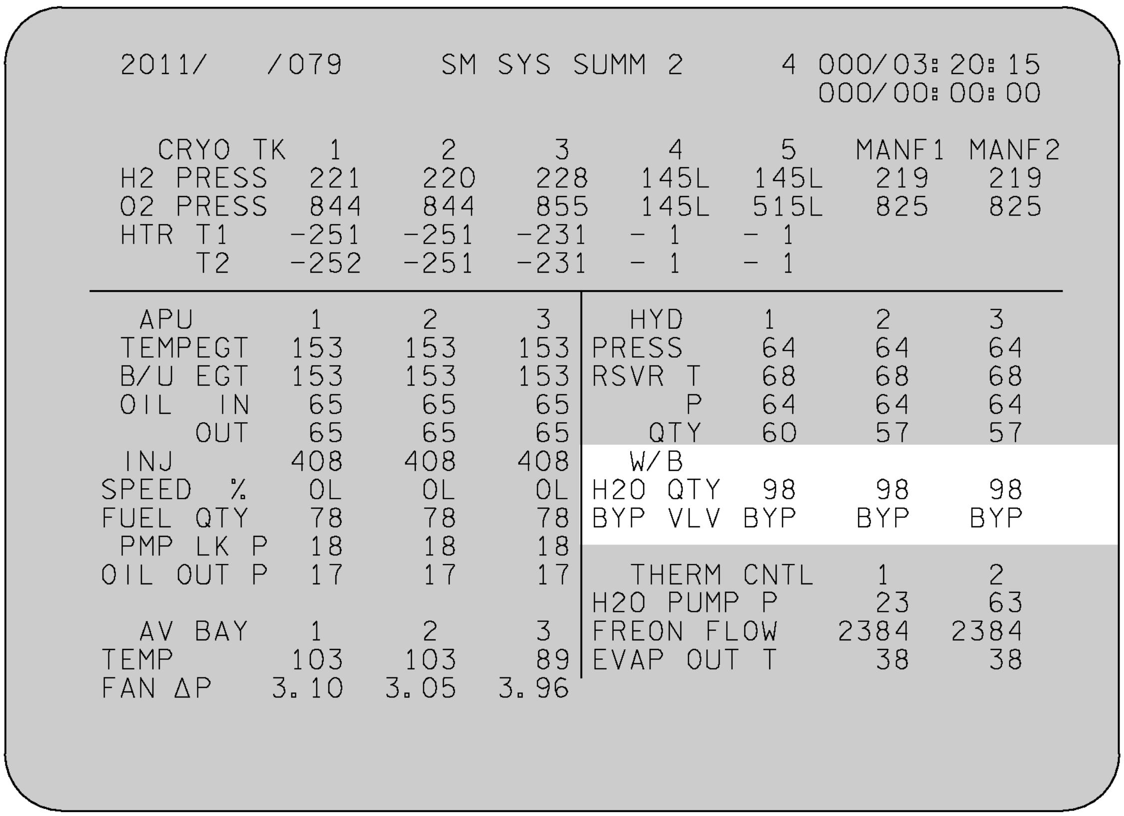

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Figure 4-12. PASS SM SYS SUMM 2 display

Questions

1. Where is the WSB located?

2. What is the function of the WSB?

3. Match each of the following WSB components to its function or functions:

a. electronic controller	__________	1. Used to prevent freezing of water on orbit
b. water tank	__________	2. Commands water spray and controls hydraulic bypass valve based on temperatures
c. boiler	__________	3. Contains the water supply for spraying
d. heaters	__________	4. Is the place where the actual transfer of heat from hydraulic fluid and lubricating oil takes place

5.0 APU/HYD/WSB SYSTEM OPERATION THROUGH MISSION PHASES

5.1 OBJECTIVES

Upon completing this section, you should be able to

- Recognize when the different components of the APU/HYD/WSB system are used in flight

5.2 OVERVIEW

The APU/HYD/WSB system is used throughout the various mission flight phases (Figure 5-1) to provide hydraulic power to the orbiter main engines, aerosurfaces, ET umbilical plates, and landing gear.

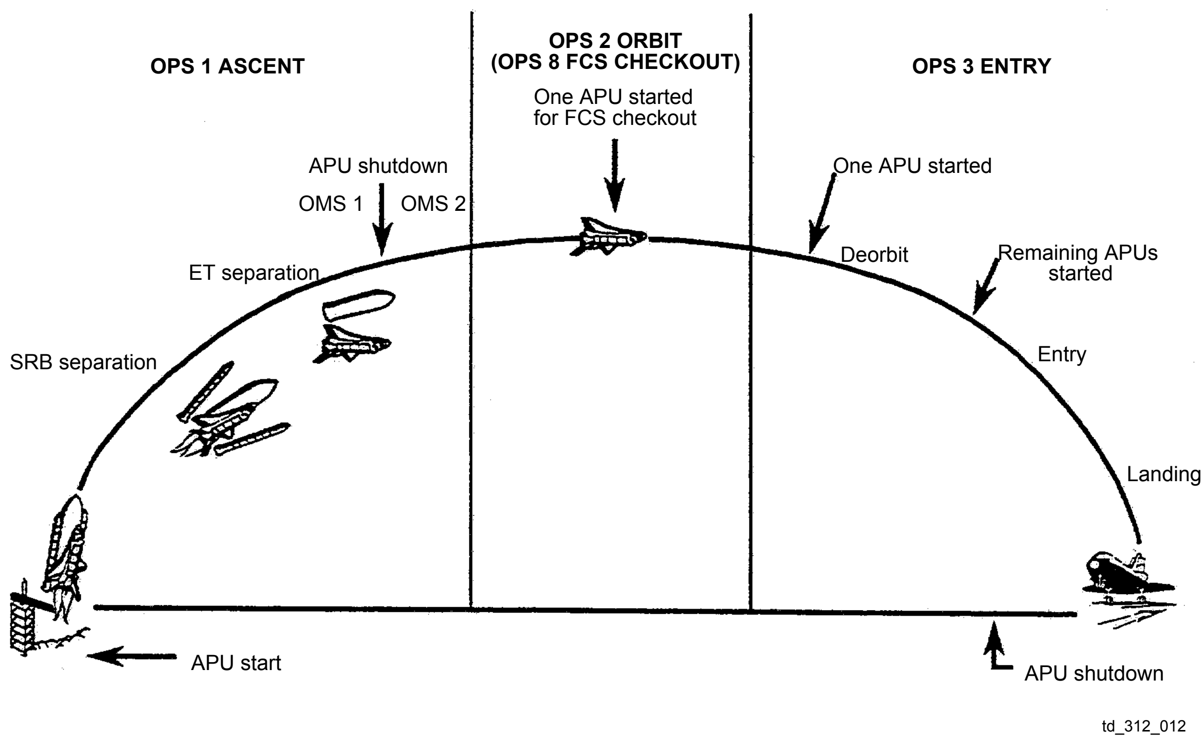


Figure 5-1. Typical mission profile

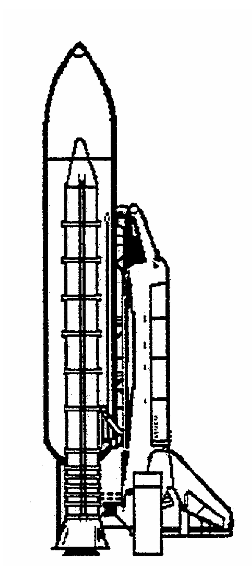
5.3 PRELAUNCH

Several hours prior to launch, the GSE commands the hydraulic circulation pumps on (Figure 5-2). The pumps run continuously, circulating hydraulic fluid throughout the systems to keep the hydraulic lines from getting too cold because of their close proximity to the ET cryogenics.

At T - 10 hours 30 minutes, the Astronaut Support Personnel (ASP) perform the WSB STEAM VENT HEATER ACTIVATION. This procedure turns on the WSB steam vent heaters to prevent freezing of the steam vent during ascent.

At T - 30 minutes, the pilot performs the WSB GN2 SUPPLY ACTIVATION procedure, in which he opens the N_2 supply valve. This action pressurizes the WSB water storage tank so that when the BFS is brought up at T - 19 minutes, it can properly initialize the water quantity computation.

At T - 6 minutes 15 seconds, the pilot performs the APU PRESTART procedure, followed by the APU START procedure at T - 5 minutes. The APUs must be up and running by T - 4 minutes to provide hydraulic power for the main engine purge sequences, gimbal checks, and start sequences. If the APUs are not running and supplying normal hydraulic pressure to the Space Shuttle Main Engines (SSMEs) by T - 4 minutes, an automatic launch hold will occur.



Prelaunch

- Circ pumps run to flow hydraulic fluid through system
- APU prestart at T - 6:15 minutes
- APU start at T - 5 minutes

td_312_013

Figure 5-2. APU/HYD/WSB system use prior to launch

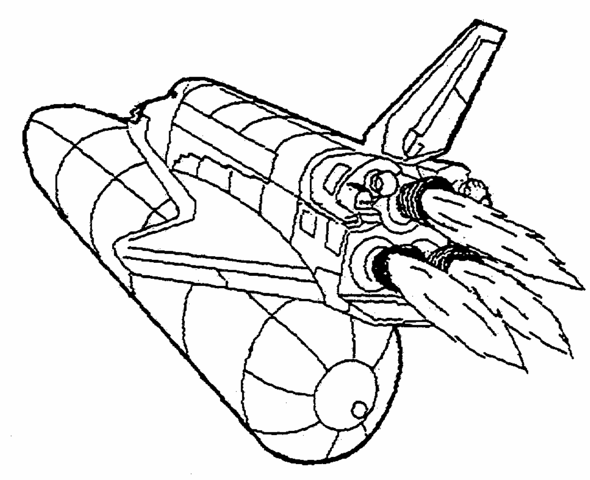
5.4 ASCENT

Prior to Main Engine Cutoff (MECO), there are no nominal procedures for the crew to perform for the APU/HYD/WSB system. The APUs operate during the ascent phase and continue to operate through the OMS-1 orbital insertion burn. For those flight profiles that do not have an OMS-1 burn, the APUs are shut down after the main engines are hydraulically repositioned for orbit.

At the conclusion of the main engine purge, dump, and stow sequences, the APUs and WSBs are shut down. MS1 then turns on the APU fuel tank, fuel line, and water system heaters as part of the FES & HEATER ACTIVATION procedure. This action prevents freezing of these lines on orbit.

The same sequence applies for a delayed OMS-1 burn. If an AOA has been declared, the APUs are left running, but the hydraulic pumps are taken to low pressure to reduce the APU fuel consumption. Leaving the APUs running avoids having to restart hot APUs for deorbit and entry.

Figure 5-3 shows the APU/HYD/WSB system use during ascent.



Ascent

- The HYD system provides hydraulic pressure to
  - Throttle and steer the orbiter main engines
  - Actuate the orbiter aerosurfaces
  - Retract the external tank/umbilical plates
- All APUs are operated from T -5 minutes through the OMS-1. If there is no OMS-1 burn, then APU shutdown comes after repositioning the main engines for orbit

td_312_014

Figure 5-3. APU/HYD/WSB system use during ascent

5.5 POSTINSERTION/ORBIT

At 1 hour into the flight, the crew is working postinsertion procedures. In the AFT STATION CONFIG procedure, they activate the APU lube oil line heaters to keep the lines from freezing.

At approximately 2 hours MET, the crew activates the WSB steam vent heaters to thaw ice that may have formed since WSB deactivation. The heaters are deactivated a few hours later. Also, the WSB Controller A heaters are switched to the Controller B heaters to save orbiter power since Controller A has the added feedline heaters.

At 2 hours 20 minutes MET, the crew places all the hydraulic circulation pump switches in the GPC position. This gives control of the circulation pumps to the GPC pump software, which monitors line temps and accumulator pressures. If the line temps or accumulator pressures drop too low, the GPC will automatically command the associated circulation pump on.

At 2 hours 30 minutes MET, the crew leaves the postinsertion checklist and goes to the flight-specific crew activity plan. At approximately 6 hours MET, the APU GG and fuel pump heaters are activated to prevent freezing of these components.

The day before deorbit, one APU is started in order to have hydraulic pressure to check out the FCSs. Hydraulic pressure is needed to move the orbiter aerosurfaces as part of this checkout.

Figure 5-4 shows the APU/HYD/WSB system use on orbit.

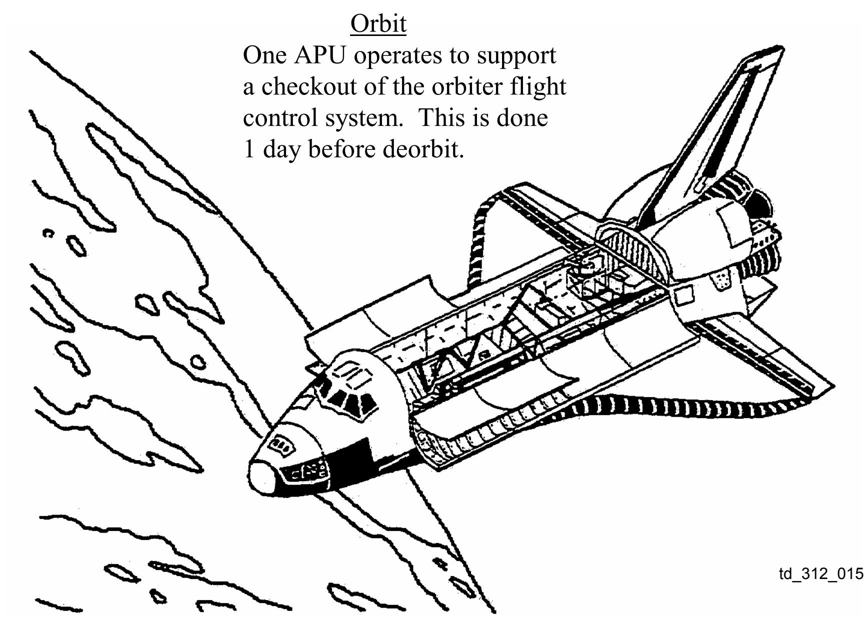


Figure 5-4. APU/HYD/WSB system use on orbit

5.6 DEORBIT AND ENTRY

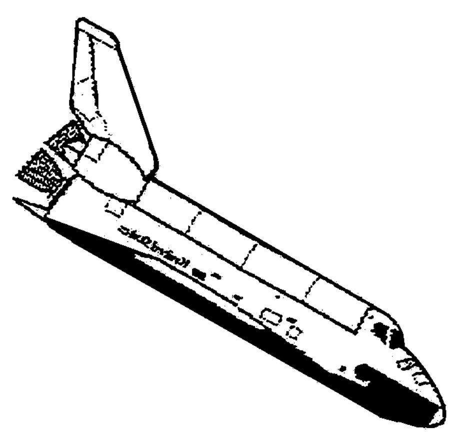
Approximately 2 hours 30 minutes before the Deorbit (D/O) burn, the WSB steam vent heaters are activated to prepare the WSB for operation during entry (Figure 5-5). Automatic control of the circulation pumps is terminated shortly thereafter.

At 46 minutes before D/O, the APU PRESTART procedure is performed. The WSB water tanks are pressurized, the APU controllers are activated, the main hydraulic pumps are taken to low pressure, and the APU fuel tank valves are opened. At this point, all conditions for a ready-to-start talkback should be met, and the talkbacks should be gray. The pilot then closes the fuel tank valves. This procedure is done while in contact with the ground so that flight controllers can observe APU data.

At 5 minutes before the D/O burn, one APU (as selected by the Mission Control Center) is started to ensure that at least one APU will be operating for entry. The hydraulic pump is left in low pressure to conserve fuel since normal pressure is not required at this time.

At 13 minutes before Entry Interface (EI), the other two APUs are started, and all three hydraulic pumps are pressurized to normal pressure.

After landing, a hydraulic load test may be performed to test the response of the APUs and hydraulic pumps under high load (i.e., high flow demand) conditions. This test consists of cycling the orbiter aerosurfaces with one hydraulic system at a time in depressurized mode. This procedure is typically done on the first flight of a new vehicle. After the hydraulic test is complete, the main engine hydraulic isolation valves are opened and the main engine nozzles are moved to the transport (rain drain) position. Since the hydraulic systems are no longer needed after this, the APUs and WSBs are shut down.



Entry

- The HYD system provides hydraulic pressure to
  - Actuate the orbiter aerosurfaces
  - Deploy the landing gear
  - Provide braking
  - Provide nosewheel steering
- At D/O - 5 minutes, one APU is started to ensure that an APU is operating through the entry flight phase
- At El - 13, the remaining two APUs are started and are operated through postlanding

td_312_016

Figure 5-5. APU/HYD/WSB system use for deorbit/entry

Questions

1. Describe briefly when the APUs are used during the different phases of flight, and why.

2. During ascent and entry the WSB operates in _______ mode to take care of high heat loads.

   (a) Auto

   (b) Pool

   (c) GPC

   (d) Spray

   (e) Flash

3. The hydraulic circulation pumps operate during

   (a) Prelaunch

   (b) Ascent

   (c) Orbit

   (d) Entry

   (e) Both a and c

   (f) Both b and d

4. How many APUs support the FCS checkout on orbit?

   (a) One

   (b) Two

   (c) Three

   (d) None

6.0 SUMMARY

Now that you have read each section about the APU/HYD/WSB system on the orbiter, let us quickly review what you have learned.

Section 1 introduced the APU/HYD/WSB system. There are three identical, yet independent, APU/HYD/WSB systems on each orbiter. The APUs provide mechanical power to the hydraulic systems so that they can provide hydraulic fluid flow and pressure. The WSB system provides cooling for the APU/HYD system.

Section 2 discussed the APU, its location, its components, and their functions. The APU converts the chemical energy of liquid hydrazine into mechanical shaft power to turn the hydraulic main pump, fuel pump, and lube oil pump. The APU components covered were

- Fuel tank
- Fuel tank valves
- Fuel pump
- Fuel control valves
- Gas generator
- Lubricating oil system
- Digital controller
- Injector cooling system
- Heaters

APU controls and displays covered were

- Panel R2
- Panel F8
- Panel F7
- Panel A12
- BFS SYS SUMM 2
- BFS THERMAL
- SPEC 86

- SPEC 88
- PASS SYS SUMM 2

Section 3 discussed the hydraulic system. It is responsible for providing hydraulic fluid flow and pressure to the various orbiter systems that need it. Among these are the main engines, the ET umbilical plates, landing gear, brakes, and nosewheel steering. The hydraulic system components discussed were

- Main pump
- Reservoir and accumulator
- Circulation pumps
- Hydraulic/Freon heat exchanger
- Heaters

Hydraulic system redundancy was also covered. Some of the orbiter systems that utilize the hydraulic system are

- Main engine throttle valves
- Main engine thrust vector control
- Elevons
- Rudder/speedbrake and body flap
- ET umbilical plates
- Landing gear

Hydraulic system controls and displays discussed were

- Panel R2
- Panel R4
- Panel F7
- Panel F8
- Panel A12
- Panel L4

- BFS SYS SUMM 2
- GNC SPEC 51
- BFS THERMAL
- SPEC 86
- SPEC 87
- PASS SYS SUMM 2

PRL is a software scheme that manages the loads placed on hydraulic systems when one or more hydraulic systems have been lost.

Section 4 dealt with the WSB system and how it provides cooling for the hydraulic fluid and lubricating oil when needed. The WSB has three different modes of cooling: the ascent pool mode, the spray mode, and the entry pool mode. The WSB components discussed were

- Electronic controller
- Water tank and boiler
- Heaters

WSB controls and displays covered were

- Panel R2
- Panel F8
- Panel A12
- Panel L4
- BFS SYS SUMM 2
- BFS THERMAL
- SPEC 86
- PASS SYS SUMM 2

Section 5 described how the APU/HYD/WSB system is used throughout a typical mission. The APUs are started about 5 minutes prior to launch and operate through the OMS-1 burn, providing hydraulics for the main engines, the aerosurfaces, and the ET umbilical plates. If the flight profile does not require an OMS-1 burn, the APUs operate until the main engines are repositioned for orbit.

On orbit, the circulation pumps and heaters keep the hydraulic lines warm and repressurize the accumulators if needed. One day before deorbit, a single APU is started to support the FCS checkout.

The APUs are started again for deorbit, entry, and landing to provide hydraulics for the aerosurfaces, landing gear deploy, brakes, and nosewheel steering.

This workbook is intended to be only a brief overview of the systems and how they work. For more detailed information, refer to Appendix A, which will give you a list of APU/HYD/WSB reference resources.

Please take the time to complete the workbook evaluation form located at the very back of this book. Your comments will be used to evaluate how effective this book is as a training tool. Write down what you liked and did not like and mail the form to the mail code indicated on the form.

APPENDIX A ACRONYMS AND ABBREVIATIONS

ac	alternating current
actr	actuator
AOA	Abort Once Around
APU	Auxiliary Power Unit
ASP	Astronaut Support Personnel
aut	automatic
av	avionics
B/U	backup
BFS	Backup Flight System
bp	barberpole
byp	bypass
C&W	Caution and Warning
CBT	Computer-Based Training
CDR	Commander
circ	circulation
cmd	command
cntlr	controller
CRT	Cathode-Ray Tube
D/O	Deorbit
DAP	Digital Autopilot
des	deselect
disp	display
DPS	Data Processing System
ECLSS	Environmental Control and Life Support System
EGT	Exhaust Gas Temperature
EI	Entry Interface
environ	environmental
ET	External Tank
ET SEP	External Tank Separation
exch	exchanger
F	Fahrenheit
FCS	Flight Control Surface
FDF	Flight Data File
FPH	Flight Procedures Handbook

g	acceleration due to gravity
gen	generator
GG	Gas Generator
GGVM	Gas Generator Valve Module
GN_2	gaseous nitrogen
GNC	Guidance, Navigation, and Control
GPC	General Purpose Computer
gpm	gallons per minute
H_2	hydrogen
H_2O	water
htr	heater
HX	Heat Exchanger
HYD	Hydraulic
IAPU	Improved APU
inst	instrumentation
isol	isolation
lb	pounds
lg	landing gear
lk	leak
MDM	Multiplexer/Demultiplexer
MECO	Main Engine Cut-off
MET	Mission Elapsed Time
MLG	Main Landing Gear
MM	Major Mode
MPS	Main Propulsion System
MPU	Magnetic Pickup Unit
MS1	Mission Specialist 1
N_2	Nitrogen
N_2H_4	anhydrous hydrazine
NLG	Nose Landing Gear
norm	normal
NWS	Nosewheel Steering
OMS	Orbital Maneuvering System
P	Pressure
PASS	Primary Avionics Software System
PGME	Propylene Glycol Monomethyl Ether
pkgs	packages
PLT	Pilot
pmp	pump
press	pressure

pri	primary
PRD	Program Requirements Document
PRL	Priority Rate Limiting
psi	pounds per square inch
psia	pounds per square inch, absolute
psig	pounds per square inch gauge
PVT	Pressure/Volume/Temperature
RCS	Reaction Control System
RM	Redundancy Management
SEP	separation
SM	Systems Management
SME	Subject Matter Expert
SODB	Shuttle Operations Data Book
SOP	System Operating Program
SSME	Space Shuttle Main Engine
sw	switch
TAMS	Training Administration Management System
TVC	Thrust Vector Control
VLV	Valve
WSB	Water Spray Boiler

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APPENDIX B ANSWERS

Answers to Section 2

1. The orbiter APUs are located in the aft compartment on the 1307 bulkhead below the OMS pods.

2 d. All of the above. The function of an APU is to

a. Provide mechanical shaft power to turn the fuel pump

b. Provide mechanical shaft power to turn the lubricating oil pump

c. Provide mechanical shaft power to turn the hydraulic pump

3. Match each of the following APU components with its function or functions:

i	1.	The heaters prevent freezing of fluid lines.
g	2.	The digital controller provides logic for startup, shutdown, speed control.
b	3.	The fuel pump delivers fuel to the gas generator.
h	4.	Injector cooling provides water cooling to the gas generator.
d	5.	Fuel control valves are valves that pulse or open to control APU speed.
e	6.	The gas generator is the place where hydrazine meets the Shell 405 catalyst.
a	7.	The fuel tank stores liquid hydrazine fuel.
c	8.	Fuel tank valves allow/prevent fuel flow to the fuel pump.
f	9.	Lubricating oil lessens friction between gears in the gearbox and the fuel pump.

Answers to Section 3

1. The hydraulic main pumps are located behind the orbiter aft bulkhead number 1307. The hydraulic lines branch from there to the various orbiter systems that require hydraulic power.

2. d. The function of the hydraulic system is to provide hydraulic power to the main engines, aerosurfaces, landing gear, and ET plates.

3. Match each of the following hydraulic system components to its function or functions:

c	1.	The accumulator provides pressure to the reservoir.
a	2.	The main pump provides hydraulic flow and pressure to system.
f	3.	Heaters warm hydraulic lines when fluid is not flowing.
e	4.	The hydraulic/Freon heat exchanger allows hydraulic fluid to pick up heat from the ECLSS Freon coolant loops.
d	5.	The circulation pump circulates hydraulic fluid and repressurizes the accumulator while the APU system is inactive.
b	6.	The reservoir maintains positive head pressure at the main pump.

7. False. The hydraulic systems do not provide for triple redundancy for landing gear deployment and nosewheel steering. (Hydraulic system redundancy is discussed in the section entitled Orbiter Components Requiring Hydraulic System Pressure.)

8. PRL is a GNC software scheme that provides automatic management of the loads on the hydraulic systems.

Answers to Section 4

1. The WSB is located in the aft compartment of the orbiter.

2. The function of the WSB is to cool APU lubricating oil and hydraulic fluid.

3. Match each of the following WSB components to its function or functions:

    ___d___ 1. Heaters are used to prevent freezing of controller water on orbit.

    ___a___ 2. The electronic controller commands water spray and controls hydraulic bypass valve based on temperatures.

    ___b___ 3. The water tank contains the water supply for spraying.

    ___c___ 4. The boiler is the place where the actual transfer of heat from hydraulic fluid and lubricating oil to water takes place.

Answers to Section 5

1. On ascent, the APUs provide hydraulic power to gimbal and throttle the main engines, move the aerosurfaces, and retract the ET plate after ET SEP. On orbit, one APU/HYD system is used for the FCS checkout. On entry, the APUs provide power to move the aerosurfaces. The system is used for deploying the landing gear for touchdown and providing braking and steering during rollout.

2. b. During ascent and entry the WSB operates in pool mode to take care of high heat loads.

3. a and c. The hydraulic circulation pumps operate during prelaunch and orbit.

4. One APU supports the FCS checkout on orbit.

APPENDIX C REFERENCES

1. The APU/HYD nominal procedures and malfunction procedures can be found in various elements of the **Flight Data File (FDF). Flight Procedures Handbooks (FPHs)** provide explanations of the FDF procedures.

2. The **Space Shuttle Systems Handbook (SSSH)** contains detailed schematics of the APU, HYD, and WSB systems.

3. The **Data Processing System (DPS) Dictionary** contains orbiter DPS displays and parameters.

4. The **Space Shuttle Operational Flight Rules**, in particular section 10 (MMACS), contain planned decisions for failure situations involving the APU/HYD system.

5. The **Shuttle Operations Data Book (SODB)** contains APU/HYD specification data.

6. The **Mechanical Systems Console Handbook** contains detailed information on each different component of the APU/HYD/WSB system.

7. The **Functional Subsystem Software Requirements (FSSR)** document provides detailed descriptions of the primary flight software, including the PRL function.

8. The **BFS Program Requirements Document (PRD)** and the **BFS User's Guide** describe the BFS software.

9. The Software Requirements Specification (SRS) for the Integrated Display Processor (IDP) Software of the Multifunction Electronic Display Subsystem (MEDS) describe the HYD/APU Subsystem Status Display meters.

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