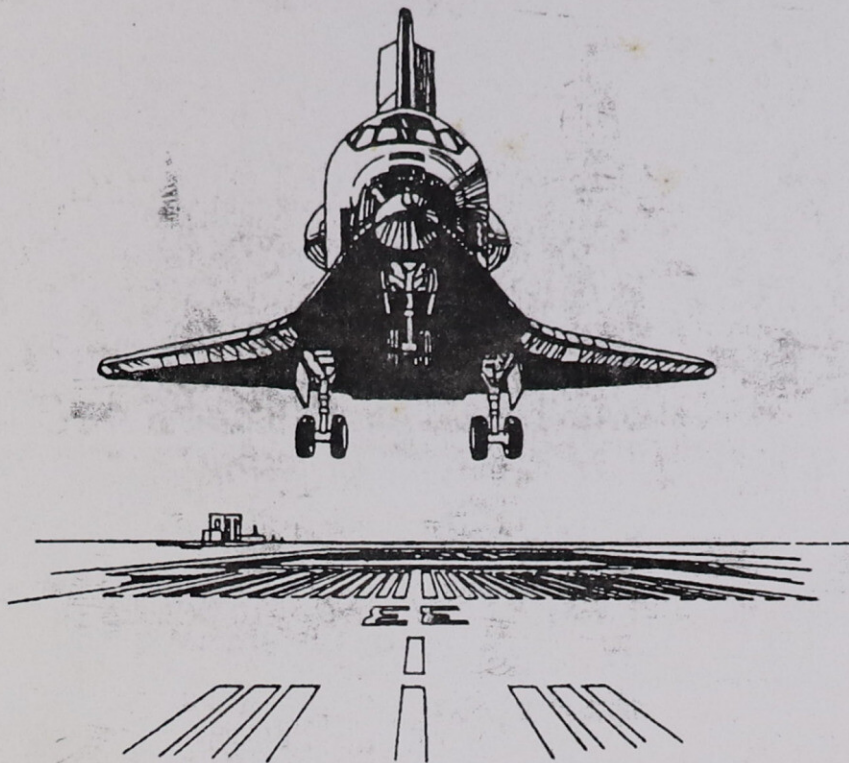




**SHUTTLE  
CREW  
OPERATIONS  
MANUAL**



# SHUTTLE CREW OPERATIONS MANUAL

Prepared by Science Applications International Corporation  
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SCOM 1.0  
November 1991

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## PREFACE

The Shuttle Crew Operations Manual (SCOM) is a unique document containing information about each Shuttle system and every phase of a generic Space Shuttle mission. It was written under the authority of the Director of Flight Crew Operations by Science Applications International Corporation (SAIC) of Houston, Texas, with invaluable technical assistance from Mission Operations Directorate personnel.

The SCOM is a reference document for Space Shuttle crewmembers. The complexity of the Shuttle systems and the unique operational environment, coupled with the numerous malfunction/emergency procedures, necessitated some departures from a Dash1/NATOPS approach. Nonetheless, the SCOM is the only single source document, written specifically for Shuttle astronauts, with comprehensive data about Shuttle systems and operations.

This document contains condensed information from a large number of Space Shuttle publications, including the Flight Data File (FDF), Crew Training workbooks, Flight Procedure Handbooks (FPH), Flight Rules, Shuttle Operational Data Book, and Shuttle Performance Assessment Data Book. The SCOM is not a replacement for any of these documents. It has been carefully reviewed by FCOD and MOD personnel to ensure accuracy of information. In all cases, should a conflict arise between the SCOM and FDF or Flight Rules, the FDF and Flight Rules will govern. If conflicts arise between the SCOM and workbooks or FPH, the conflicts should be resolved with the appropriate book manager or system representative.

Information contained in the SCOM is current as of November 1991 and OI-20. CRT displays documented in the text and in Appendix B, however, are the CRT displays documented in the Level C Functional Subsystem Software Requirements Display and Controls Specification, STS 83-0020F dated February 13, 1991, effectivity OI-21 and subs. It should be noted that several CRT displays provided in the body of this document are for illustrative purposes only; certain CRT displays contain data combined in one illustration that do not appear simultaneously in operational use.

Additional information or clarification is presented in three formats: notes, cautions, and warnings. **Notes** provide amplifying information of a general nature. **Cautions** provide information and instructions necessary to prevent hardware damage or malfunction. **Warnings** provide information and instructions necessary to ensure crew safety. The formats in which this material appears are illustrated below.

### NOTE

A barberpole APU/HYD READY TO START talkback will not inhibit a start.

### CAUTION

After an APU auto shutdown, the APU FUEL TK VLV switch must be taken to CLOSE prior to inhibiting auto shutdown logic. Failure to do so can allow the fuel tank isolation valves to reopen and flow fuel to an APU gas generator bed that is above the temperature limits for safe restart.

### WARNING

The FUEL CELL REAC switches on panel R1 are in a vertical column with FUEL CELL 1 REAC on top, FUEL CELL 3 REAC in the middle, and FUEL CELL 2 REAC on the bottom. This was done to allow the schematic to be placed on the panel. Because the switches are not in numerical order, it is possible to inadvertently close the wrong fuel cell reactant valve when shutting down a fuel cell.

The SCOM will be updated according to the process described in the Configuration Control Plan.

## Configuration Control Plan

Your inputs are vital for the SCOM to remain a useful document. Changes may be submitted via the SCOM Change Request (CR) Form. Corrections, additions, deletions, or other constructive suggestions should be submitted to mail code CB-SCOM on the SCOM CR form. The form should be filled out in its entirety except for the Disposition blocks and the Control Number block. CB-SCOM will assign a control number. The initiator should clearly explain the correction or modification and list the applicable page number(s). Additional pages or annotated copies of the applicable SCOM pages may be submitted with the CR. Each CR should contain only corrections or modifications.

CRs containing recommended corrections will be verified by CB designated personnel and incorporated through pen and ink changes or page change notifications (PCNs). The CB representative will determine whether the number of verified corrections warrant a PCN prior to a semiannual review.

Semiannual reviews will be conducted by a Change Board to consider changes to the SCOM. The CB representative (or his designee) will chair the reviews. CRs recommending modifications will be reviewed and incorporated (with or without additional modification) or disapproved. Disapproved CRs will be returned to the initiator with a brief explanation. Initiators may resubmit the CR at a future review. Approved changes will be promulgated via PCNs subsequent to the reviews or at the direction of CB. Revisions (Rev's) will be published at the direction of CB if substantial changes to the manual are made.

The SCOM is a reference document for the SCOM system. The contents of the SCOM are the only source of information for the SCOM system. The SCOM is not a replacement for any of the documents it has been carefully reviewed by the SCOM and MOD personnel to ensure accuracy in all areas. In all cases, should a conflict arise between the SCOM and the Flight Rules and Flight Rules will govern. A conflict arises between the SCOM and workbooks or the conflict should be resolved with the appropriate manager or system representative.

Information contained in the SCOM is current as of November 1991 and O-30 CRT displays documented in the text and in Appendix B. However, as the CRT displays documented in the SCOM are the CRT displays documented in the SCOM dated February 13, 1991. It should be noted that several CRT displays provided in the body of this document are for illustrative purposes only. CRT displays against data contained in the SCOM do not appear simultaneously.

NASA JOHNSON SPACE CENTER  
SHUTTLE CREW OPERATIONS MANUAL  
CHANGE REQUEST (CR)

DATE	INITIATOR (ORG / NAME / PHONE)	CORRECTION <input type="checkbox"/> MODIFY <input type="checkbox"/>	CONTROL #
<p>RECOMMENDED CHANGE (use additional pages if required) Indicate SCOM page number(s)</p>			
<p>RATIONALE (use additional pages if required)</p>			
<p>INITIAL DISPOSITION</p> <p><input type="checkbox"/> INCORPORATE CORRECTION IN NEXT PCN</p> <p><input type="checkbox"/> HOLD FOR NEXT REVIEW ON ABOUT</p> <p><input type="checkbox"/> RETURN FOR ADDITIONAL INFORMATION</p>		<p>BOARD DISPOSITION</p> <p><input type="checkbox"/> INCORPORATE AS WRITTEN</p> <p><input type="checkbox"/> INCORPORATE WITH MODIFICATION</p> <p><input type="checkbox"/> DISAPPROVED</p>	
CB-SCOM	DATE	PCN/REV #	DATE

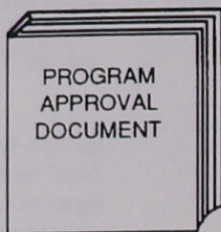
## Program Documentation

There are many hundreds of documents delineating the organization and operation of the Space Shuttle program. Over 100 of these documents have been utilized in the development of the Shuttle Crew Operations Manual. The following flow chart depicts the organization and hierarchy of the

significant documents used in this effort. The level of a document in this "document tree" should not be equated with its relative importance to other Shuttle publications. The level is strictly an indication of the management level that controls the development of the publication and subsequent changes.

### PURPOSE

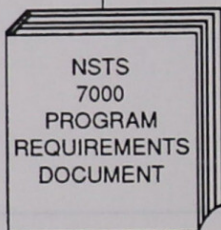
The Program Approval Document (PAD) is the contract between the NASA Administrator and the Associate Administrator for Space Flight for the NSTS objectives and content including top level management, financial and technical aspects.



### APPROVAL AUTHORITY

LEVEL 0  
NASA ADMINISTRATOR  
  
ASSOCIATE ADMINISTRATOR  
FOR SPACE FLIGHT

The Program Requirements Document (PRD) establishes the Level I requirements that are controlled by the NSTS Director and imposed on the NSTS Deputy Directors.



LEVEL I  
NSTS DIRECTOR

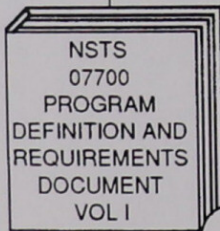
Management  
Requirements

← Appendices

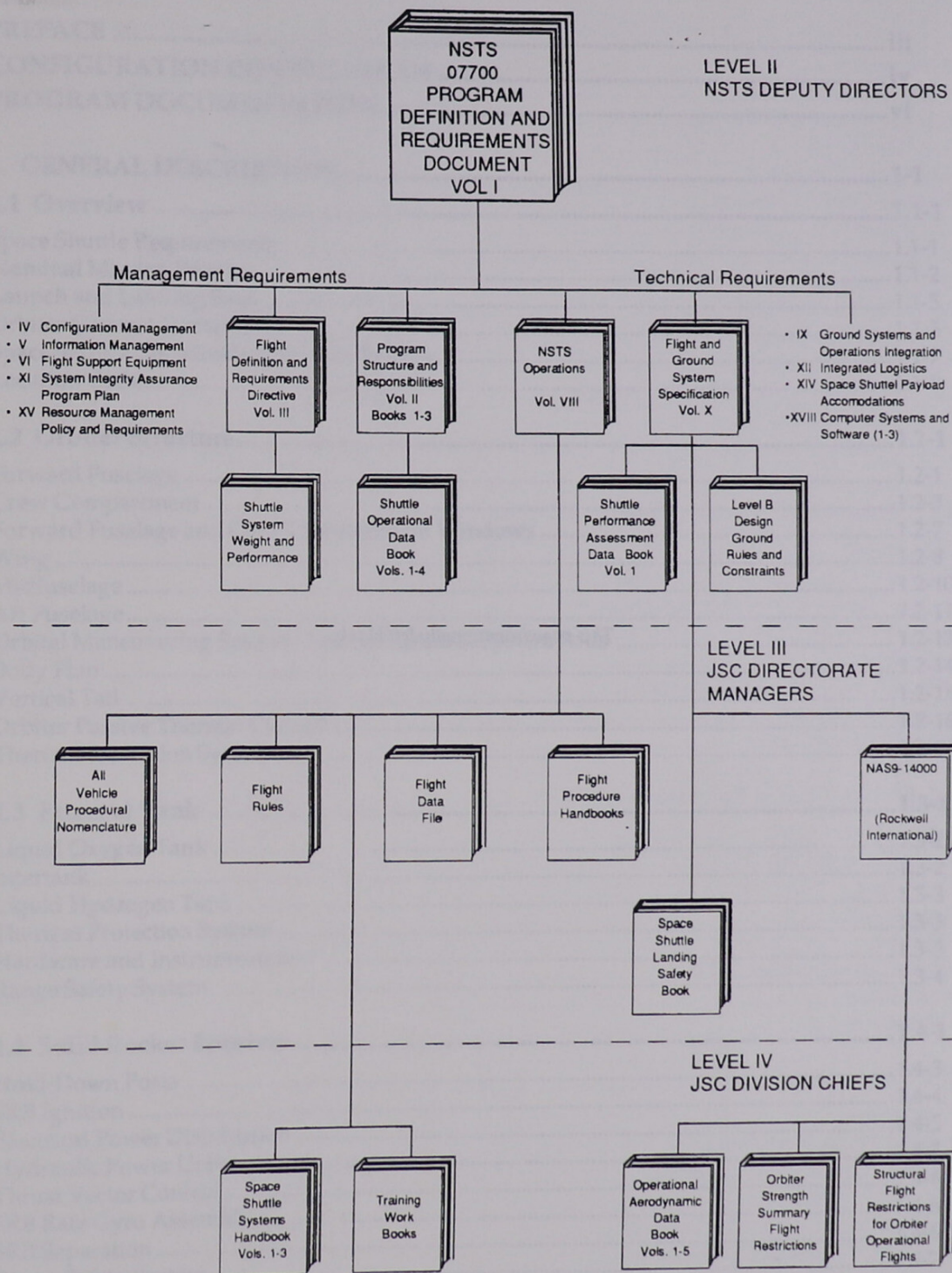
Appendices →

Technical  
Requirements

NSTS 07700 Program Definition and Requirements Document (PDRD) establishes the Level II requirements, controlled by the NSTS Deputy Directors, that incorporate and expand the Level I requirements and are imposed on the Level III Projects and Level II Integration Offices.



LEVEL II  
NSTS DEPUTY DIRECTOR





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# 1. GENERAL DESCRIPTION

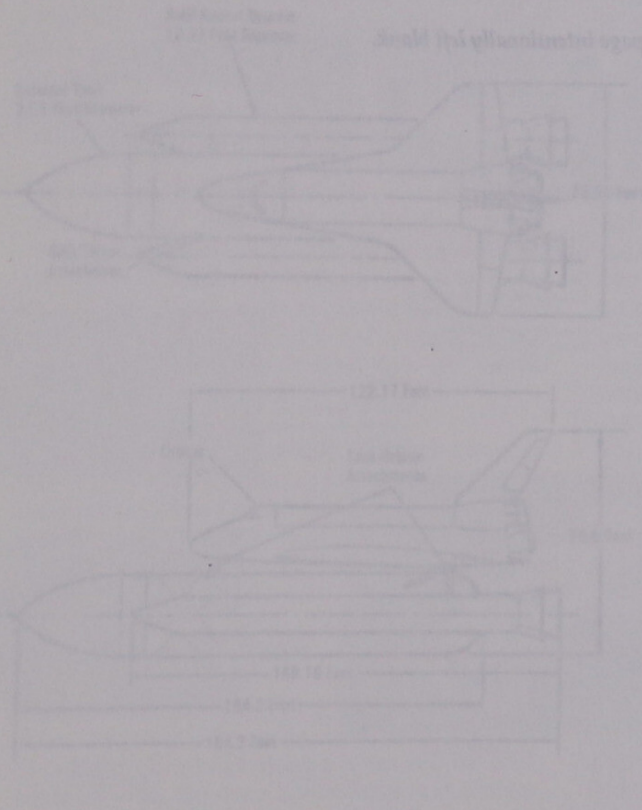
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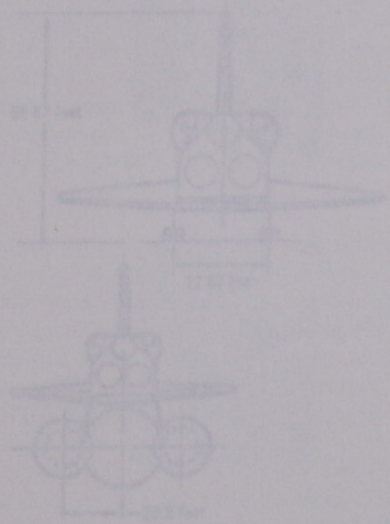
## Space Shuttle Requirements

The Space Shuttle system consists of four primary elements: an orbiter spacecraft, two solid rocket boosters (SRBs), an external tank (ET) to house fuel and oxidizer, and three Space Shuttle main engines (SSMEs). The Shuttle can transport payloads into near Earth orbit 100 to 300 nautical miles above the Earth. Payloads are carried in a bay 15 feet in diameter and 60 feet long. Major system requirements are that the orbiter and the two SRBs be reusable.

The orbiter has carried a flight crew of up to eight persons. The nominal mission is 6 to 16 days in space. The crew compartment has a standard environment, and the acceleration load is never greater than 3 g's. In its return to Earth, the orbiter has a cross-range maneuvering capability of about 1,000 nautical miles.



Requirement	Space Shuttle	Orbiter
Reusable water	Yes	Yes
Reusable solid rocket boosters	Yes	Yes
Reusable external tank	Yes	Yes
Reusable main engines	Yes	Yes
Reusable payload bay	Yes	Yes
Reusable crew compartment	Yes	Yes
Reusable solid rocket boosters	Yes	Yes
Reusable external tank	Yes	Yes
Reusable main engines	Yes	Yes
Reusable payload bay	Yes	Yes
Reusable crew compartment	Yes	Yes



Space Shuttle Products

## 1.1 OVERVIEW

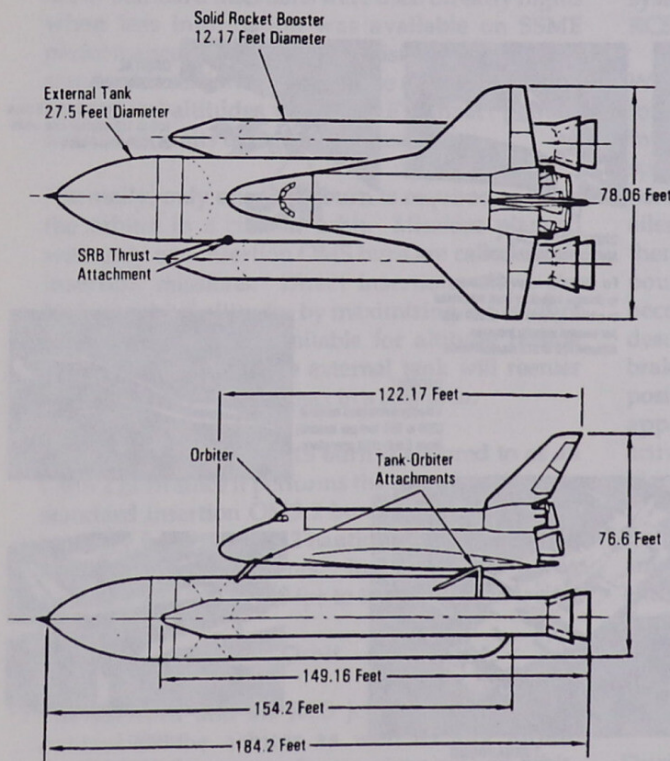
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## Space Shuttle Requirements

The Space Shuttle system consists of four primary elements: an orbiter spacecraft, two solid rocket boosters (SRBs), an external tank (ET) to house fuel and oxidizer, and three Space Shuttle main engines (SSMEs). The Shuttle can transport payloads into near Earth orbit 100 to 312 nautical miles above the Earth. Payloads are carried in a bay 15 feet in diameter and 60 feet long. Major system requirements are that the orbiter and the two SRBs be reusable.

The orbiter has carried a flight crew of up to eight persons. The nominal mission is 4 to 16 days in space. The crew compartment has a shirtsleeve environment, and the acceleration load is never greater than 3 g's. In its return to Earth, the orbiter has a cross-range maneuvering capability of about 1,100 nautical miles.



	Overall Shuttle	Orbiter
Approximate weight	4.5 million pounds	—
• Gross lift-off, which will vary depending on payload weight and onboard consumables	—	230,000 pounds (200,000 pounds typical without payload)
• Nominal end-of-mission landing with payload, which will vary depending on payload return weight	—	—
Thrust (sea level)	3,300,000 pounds of thrust each in vacuum	—
• Solid rocket boosters	—	393,800 pounds of thrust each at sea level at 104 percent
• Orbiter main engines	—	—

Space Shuttle Statistics

## Nominal Mission Profile

### Launch

In the launch configuration, the orbiter and two SRBs are attached to the ET in a vertical (nose-up) position on the launch pad. Each SRB is attached at its aft skirt to the mobile launcher platform by four bolts.

The three SSMEs, fed liquid hydrogen fuel and liquid oxygen oxidizer from the ET, are ignited first. When it has been verified that the engines are operating at the proper thrust level, a signal is sent to ignite the SRBs. At the proper thrust-to-weight ratio, initiators (small explosives) at eight hold-down bolts on the SRBs are fired to release the Space Shuttle for liftoff. Elapsed time is a few seconds.

Maximum dynamic pressure is reached early in the ascent, nominally 30 to 60 seconds after liftoff.

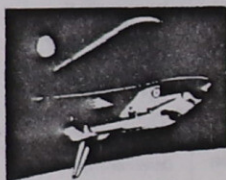
Approximately 1 minute later (2 minutes into the ascent phase), the two SRBs have consumed their propellant and are jettisoned from the ET. This is triggered by a separation signal from the orbiter.

The boosters briefly continue to ascend, while small thrusters fire to carry them away from the Space Shuttle. The boosters then turn and descend, and at a predetermined altitude, parachutes are deployed to decelerate them for a safe splashdown in the ocean. Splashdown occurs approximately 141 nautical miles from the launch site. The boosters are recovered and reused.

The orbiter and ET continue to ascend, using the thrust of the three SSMEs. Approximately 8 minutes after launch and just short of orbital velocity, the three engines are shut down (main engine cutoff or MECO), and the ET is jettisoned on command from the orbiter.

#### MAIN ENGINE CUTOFF EXTERNAL TANK SEPARATION

Altitude: 59 nautical miles  
Velocity: 25,581 feet per second about 8.5 minutes after launch (just before orbit insertion)



#### ORBITAL OPERATIONS

Mission: Nominal 4 to 16 days  
100 to 312 nautical mile orbits  
25,000 feet per second

#### ORBIT INSERTION AND CIRCULARIZATION

For either one or two OMS burns to change trajectory from suborbital to orbital, typically 200 to 550 feet per second velocity increase.  
Altitude: 100 to 312 nautical miles.

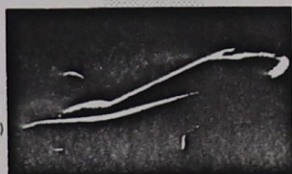


#### SRB SEPARATION

Two minutes after launch

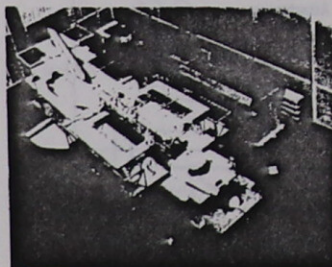
#### DEORBIT

Velocity decreased nominal (200 to 550 feet per second) from Earth orbit operators



#### LAUNCH

Maximum dynamic pressure about 60 seconds after launch



#### TURNAROUND



#### LANDING

Touchdown speed 195 or 205 knots

### Shuttle Mission Profile



The forward and aft reaction control system (RCS) jets provide attitude control, translate the orbiter away from the ET at separation, and maneuver the orbiter to burn attitude prior to the orbital maneuvering system (OMS) burn.

The ET continues on a ballistic trajectory and enters the atmosphere, where it disintegrates. Its nominal impact is in the Indian Ocean for a 28 degree inclination launch.

### Orbit Insertion and Circularization

One type of mission profile, called a standard insertion because it was the standard early in the Shuttle program, uses two OMS burns for orbital insertion. The first OMS burn (OMS 1) raises maximum altitude and occurs just a few minutes after MECO. The second OMS burn (OMS 2) occurs at the highest point of the trajectory after MECO/OMS 1. OMS 2 raises the lowest point of the orbit (perigee) and usually is targeted to achieve a circular orbit. Standard insertions were used on early flights when less information was available on SSME performance and targeting precision. At present, a standard insertion would only be used for flights to low orbital altitudes where the ET impact point is outside of limits using a direct insertion.

Normally, only one OMS burn is required to place the orbiter in a circular orbit. Missions planned with only one insertion OMS burn are called direct insertion missions. Direct insertions allow the highest orbital altitudes by maximizing the amount of OMS propellant available for altitude raising while ensuring that the external tank will reenter the atmosphere and impact in a safe area.

The direct insertion OMS burn is referred to as an OMS 2 burn since it performs the same function as a standard insertion OMS 2 burn. Orbital altitudes can vary from 100 to 312 nautical miles, depending on mission requirements. Insertion OMS burns typically add 200 to 550 fps to the orbiter's velocity.

### Orbit

The forward and aft RCS jets provide attitude control of the orbiter as well as any minor translation maneuvers along a given axis on orbit. While on orbit, the crew fulfills mission objectives, such as payload deployment or retrieval, or scientific experiments.

### Deorbit

At the completion of orbital operations, the RCS is used to orient the orbiter in a tail first attitude. The two OMS engines are burned to slow the orbiter for deorbit. The deorbit burn usually decreases the orbiter's velocity 200 to 550 feet per second depending on orbital altitude. When the deorbit burn is complete, the RCS is used to rotate the orbiter's nose forward for entry. The RCS controls the orbiter until atmospheric density is sufficient for the pitch, roll, and yaw aerodynamic control surfaces to become effective.

### Entry

Entry interface is considered to occur at 400,000 feet altitude approximately 4,200 nautical miles from the landing site and at approximately 25,000 feet per second velocity. The orbiter is maneuvered to zero degrees roll and yaw (wings level) and a 40-degree angle of attack for entry. The flight control system issues the commands to roll, pitch, and yaw RCS jets for rate damping.

Without forward RCS programmed test inputs, the forward RCS jets are inhibited prior to entry interface, and the aft RCS jets maneuver the spacecraft until a dynamic pressure of 10 pounds per square foot is sensed. This is when the orbiter's ailerons become effective. The aft RCS roll jets are then deactivated. At a dynamic pressure of 2 pounds per square foot, the orbiter's elevators become active, and the aft RCS pitch jets are deactivated at a q-bar of 40. The orbiter's speed brake is used below Mach 10 to induce a more positive downward elevator trim deflection. At approximately Mach 5, the rudder becomes activated, and the aft RCS jets are deactivated at Mach 1.

Entry guidance must dissipate the tremendous amount of energy the orbiter possesses when it enters the Earth's atmosphere to assure that the orbiter does not either burn up (entry angle too steep) or skip out of the atmosphere (entry angle too shallow) and that the orbiter is properly positioned to reach the desired touchdown point.

During entry, energy is dissipated by the atmospheric drag on the orbiter's surface. The thermal protection system covering the entire orbiter

## 1. GENERAL DESCRIPTION

### 1.1 Overview

provides the protection necessary for the orbiter to survive the extremely high temperatures encountered. Higher atmospheric drag levels enable faster energy dissipation with a steeper trajectory.

Normally, the angle of attack and bank angle enable the atmospheric drag of any flight vehicle to be controlled. However, for the orbiter, angle of attack was rejected because it creates surface temperatures above the design specification. The angle of attack scheduled during entry is loaded into the orbiter computers as a function of relative velocity, leaving bank angle for energy control. Increasing the bank angle decreases the vertical component of lift, causing a higher sink rate and energy dissipation rate. Increasing the bank angle does raise the surface temperature of the orbiter, but not nearly as drastically as an equal angle of attack increase.

If the orbiter is low on energy (current range-to-go much greater than nominal at current velocity), entry guidance will command lower than nominal drag levels. If the orbiter has too much energy (current range-to-go much less than nominal at the current velocity), entry guidance will command higher-than-nominal drag levels to dissipate the extra energy.

Bank angle is used to control cross range. Azimuth error is the angle between the plane containing the orbiter's position vector and the heading alignment cone tangency point and the plane containing the orbiter's position vector and velocity vector. When the azimuth error exceeds a computer-loaded number, the orbiter's bank angle is reversed.

Thus, descent rate and downranging are controlled by bank angle. The steeper the bank angle, the greater the descent rate and the greater the drag. Conversely, the minimum drag attitude is wings level. Cross range is controlled by bank reversals. The entry thermal control phase is designed to keep the backface temperatures within the design limits. A constant heating rate is established until below 19,000 feet per second.

The equilibrium glide phase shifts the orbiter from the rapidly increasing drag levels of the temperature control phase to the constant drag level of the constant drag phase. The equilibrium glide flight is defined as flight in which the flight path angle, which is the angle between the local horizontal and the local velocity vector, remains constant.

Equilibrium glide flight provides the maximum downrange capability. It lasts until the drag acceleration reaches 33 feet per second squared.

The constant drag phase begins at that point. The angle of attack is initially 40 degrees, but it begins to ramp down to approximately 36 degrees by the end of this phase.

In the transition phase, the angle of attack continues to ramp down, reaching the approximately 14-degree angle of attack at the entry terminal area energy management (TAEM) interface, at approximately 83,000 feet altitude, 2,500 feet per second, and 52 nautical miles from the landing runway. Control is then transferred to TAEM guidance.

During the entry phases described, the orbiter's bank commands keep the orbiter on the drag profile and control cross range.

TAEM guidance steers the orbiter to one of two 18,000-ft radius heading alignment cones (HAC), which are located tangent to and on either side of the runway centerline on the approach end. In TAEM guidance, excess energy is dissipated with an S-turn, and the speed brake can be utilized to control dynamic pressure. This increases the ground track range as the orbiter turns away from the HAC until sufficient energy is dissipated to allow a normal approach and landing guidance phase capture, which begins at 10,000 feet altitude. The orbiter also can be flown near the velocity for maximum lift over drag or wings level for the range stretch case. The spacecraft slows to subsonic velocity at approximately 49,000 feet altitude, about 22 nautical miles from the landing site.

At TAEM acquisition, the orbiter is turned until it is aimed at a point tangent to the HAC and continues until it reaches way point (WP) 1. At WP-1, the TAEM heading alignment phase begins. The HAC is followed until landing runway alignment,  $\pm 20$  degrees, has been achieved. In the TAEM prefinal phase, the orbiter leaves the HAC, pitches down to acquire the steep glide slope, increases airspeed, banks to acquire the runway centerline, and continues until on the runway centerline, on the outer glide slope, and on airspeed. The approach and landing guidance phase begins with the

completion of the TAEM prefinal phase and ends when the spacecraft comes to a complete stop on the runway.

### Landing

The approach and landing trajectory capture phase begins at the TAEM interface and continues to guidance lock-on to the steep outer glide slope. The approach and landing phase begins at about 10,000 feet altitude at an equivalent airspeed of 290 ( $\pm$  12) knots at 6.9 nautical miles from touchdown. Approach and landing guidance is initiated at this point to guide the orbiter to the minus 19- to 17-degree glide slope aimed at a target 7,500 feet short of the runway. The speed brake is positioned to hold the proper velocity. The descent rate in the later portion of TAEM and approach and landing is greater than 10,000 feet per minute.

At 2,000 feet above ground level (AGL), a preflare maneuver is started to position the spacecraft for a 1.25- to 1.5-degree glide slope in preparation for landing with the speed brake positioned as required. The flight crew deploys the landing gear at 300 feet AGL. The final phase reduces the sink rate of the spacecraft to less than 9 feet per second. Touchdown occurs approximately 2,500 feet past the runway threshold at a speed of 195 or 205 knots (195 knots for orbiter landing weight less than 220,000 pounds, 205 knots for weight greater than 220,000 pounds).

### Launch and Landing Sites

The Kennedy Space Center (KSC) in Florida is used for all Shuttle launches.

Edwards Air Force Base in California and KSC are the primary landing sites. With the advent of the drag chute and carbon/carbon brakes, more missions are likely to land at KSC in the future. Contingency landing sites are also provided in the event the orbiter must return to Earth in an emergency.

KSC launches have an allowable launch azimuth from 035 degrees northeast to 120 degrees southeast. These azimuth degree readings are based on due east from KSC as 090 degrees.

A 035-degree azimuth launch places the spacecraft in an orbital inclination of 57 degrees. This inclination means the spacecraft in its orbital trajectories around Earth will never exceed an Earth latitude higher or lower than 57 degrees north or south of the equator.

A launch path from KSC at an azimuth of 120 degrees will place the spacecraft in an orbital inclination of 39 degrees (it will be above or below 39 degrees north or south of the equator).

These two azimuths, 035 and 120 degrees, represent the launch limits from KSC. Any azimuth angles further north or south would launch a spacecraft over a habitable land mass, adversely affect safety provisions for abort or vehicle separation conditions, or present the undesirable possibility that the SRB or external tank could land on inhabited territory.

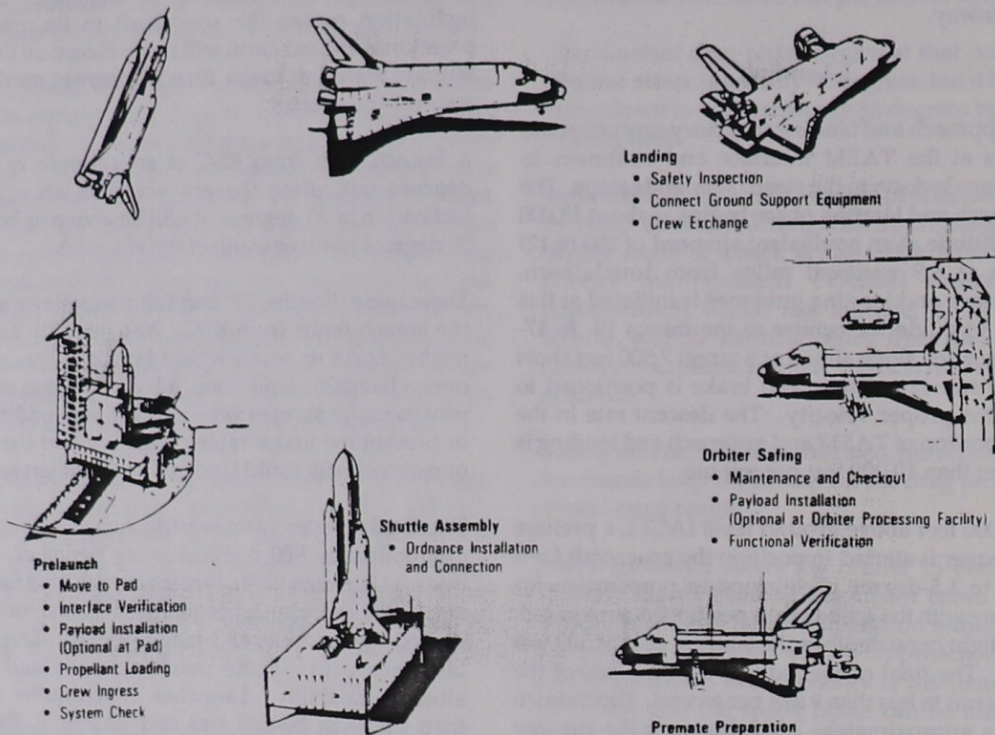
The Earth rotates from west to east at a speed of approximately 900 nautical miles per hour. For due east launches (090 degrees azimuth), the Earth's rotational velocity adds to the velocity increase caused by the SRBs and main engines. Due east launches provide the maximum payload and altitude capability. Launches on azimuths other than due east benefit less and less from Earth's rotation as the launch azimuth approaches north or south. Westerly launches would decrease performance even further. Due east launches result in an orbital inclination of 28.5 degrees.

### Orbiter Ground Turnaround

Spacecraft recovery operations at the nominal end-of-mission landing site are supported by approximately 160 Space Shuttle Launch Operations team members. Ground team members wearing self-contained atmospheric protective ensemble suits that protect them from toxic chemicals approach the spacecraft as soon as it stops rolling. The ground team members take sensor measurements to ensure the atmosphere in the vicinity of the spacecraft is not hazardous. In the event of propellant leaks, a wind machine truck carrying a large fan is moved into the area to create a turbulent airflow that will break up gas concentrations and reduce the potential for an explosion.

# 1. GENERAL DESCRIPTION

## 1.1 Overview



### *Kennedy Space Center Ground Turnaround Sequence*

A ground support equipment (GSE) air-conditioning purge unit is attached to the right-hand orbiter T-0 umbilical so cool air can be directed through the orbiter's aft fuselage, payload bay, forward fuselage, wings, vertical stabilizer, and OMS/RCS pods to dissipate the heat of entry.

A second GSE ground cooling unit is connected to the left-hand orbiter T-0 umbilical spacecraft Freon coolant loops to provide cooling for the flight crew and avionics during the postlanding and system checks. The spacecraft fuel cells remain powered up at this time. The flight crew then exits the spacecraft, and a ground crew powers down the spacecraft.

At KSC, the orbiter and GSE convoy move from the runway to the Orbiter Processing Facility (OPF). If the spacecraft lands at Edwards Air Force Base in

California, the same procedures and GSE are used after the orbiter has stopped on the runway. The orbiter and GSE convoy move from the runway to the orbiter mate and demate facility. After detailed inspection, the spacecraft is prepared to be ferried atop the Shuttle Carrier Aircraft from Edwards Air Force Base to KSC. For ferrying, a tail cone is installed over the aft section of the orbiter.

In the event of a landing at an alternate site, a crew of about eight will move to the landing site to assist the astronaut crew in preparing the orbiter for loading aboard the Shuttle Carrier Aircraft for transport back to KSC. For landings outside the U.S., personnel at the contingency landing sites will be provided minimum training on safe handling of the orbiter with emphasis on crash rescue training, towing the orbiter to a safe area, and prevention of propellant conflagration.

Upon its return to the OPF at KSC, the orbiter is safed (ordnance devices safed), the payload (if any) is removed, and the orbiter payload bay is reconfigured for the next mission. Any required maintenance and inspections are also performed while the orbiter is in the OPF. A payload for the orbiter's next mission may be installed in the orbiter's payload bay in the OPF when the orbiter is at the launch pad.

The spacecraft is then towed to the Vertical Assembly Building and mated to the external tank. The external tank and SRBs are stacked and mated on the mobile launcher platform while the orbiter is being refurbished. Space Shuttle orbiter connections are made, the integrated vehicle is checked, and ordnance is installed.

The mobile launcher platform moves the entire Space Shuttle system on a crawler transporter to the launch pad, where connections are made, and servicing and checkout activities begin. If the payload was not installed in the OPF, it is installed at the launch pad followed by prelaunch activities.

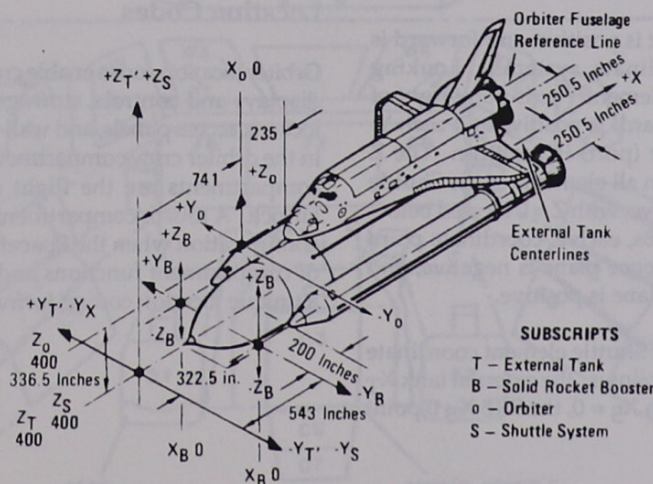
KSC Launch Operations has responsibility for all mating, prelaunch testing, and launch control ground activities until the Space Shuttle vehicle clears the launch pad tower. Responsibility is then turned over to NASA's Johnson Space Center Mission Control Center. Mission Control's responsibility includes ascent, on-orbit operations,

entry, approach, and landing until crew egress, at which time the orbiter is handed over to the postlanding operations at the landing site for turnaround and relaunch. At the launch site, the SRBs and ET are processed for launch, and the SRBs are recycled for reuse.

### Space Shuttle Coordinate Reference System

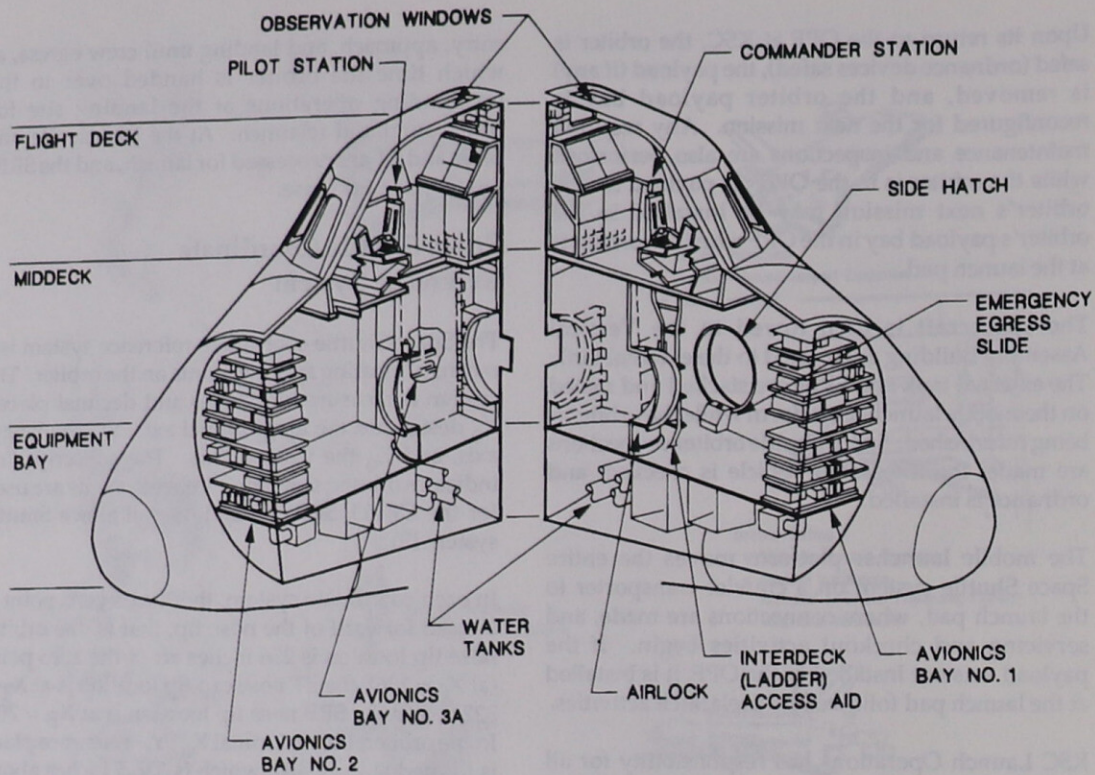
The Space Shuttle coordinate reference system is a means of locating specific points on the orbiter. The system is measured in inches and decimal places;  $X_0$  designates the longitudinal axis,  $Y_0$  the lateral axis, and  $Z_0$  the vertical axis. The subscript "o" indicates orbiter; similar reference systems are used for the ET (T), SRB (B), and overall Space Shuttle system (S).

In each coordinate system, the X-axis zero point is located forward of the nose tip; that is, the orbiter nose tip location is 236 inches aft of the zero point (at  $X_0 = 236$ ), the ET nose cap tip location is at  $X_T = 322.5$ , and the SRB nose tip location is at  $X_B = 200$ . In the orbiter, the horizontal  $X_0, Y_0$  reference plane is located at  $Z_0 = 400$ , which is 336.5 inches above the external tank horizontal  $X_T, Y_T$  reference plane located at  $Z_T = 400$ . The solid rocket booster horizontal  $X_B, Y_B$  reference plane is located at  $Z_B = 0$  and coincident with the external tank horizontal plane at  $Z_T = 400$ . The solid rocket booster vertical



Space Shuttle Coordinate Systems

1. GENERAL DESCRIPTION  
1.1 Overview



Crew Cabin (Cutaway View)

$X_B$ ,  $Z_T$  planes are located at  $+Y_S = 250.5$  and  $-Y_S = 250.5$ . Also, the orbiter, external tank, and Shuttle system center  $X$ ,  $Z$  planes coincide.

From the  $X = 0$  point, aft is positive, and forward is negative for all coordinate systems. Looking forward, each Shuttle element  $Y$ -axis point right of the center plane (starboard) is positive and each  $Y$ -axis point left of center (port) is negative. The  $Z$  axis of each point within all elements of the Shuttle except the SRBs is positive, with  $Z = 0$  located below the element. In the SRBs, each  $Z$ -coordinate point below the  $X_B$ ,  $Y_B$  reference plane is negative, and each point above that plane is positive.

The Shuttle system and Shuttle element coordinate systems are related as follows: the external tank  $X_T = 0$  point coincides with  $X_S = 0$ , the SRB  $X_B = 0$  point

is located 543 inches aft, and the  $Y_O$ ,  $Z_O$  reference plane is 741 inches aft of  $X_S = 0$ .

### Location Codes

Orbiter location codes enable crewmembers to locate displays and controls, stowage compartments and lockers, access panels, and wall-mounted equipment in the orbiter crew compartments. The orbiter crew compartments are the flight deck, middeck, and airlock. A fourth compartment becomes part of the configuration when the Spacelab is flown. Because of compartment functions and geometry, each has a unique location coding format.

### Flight Deck Location Codes

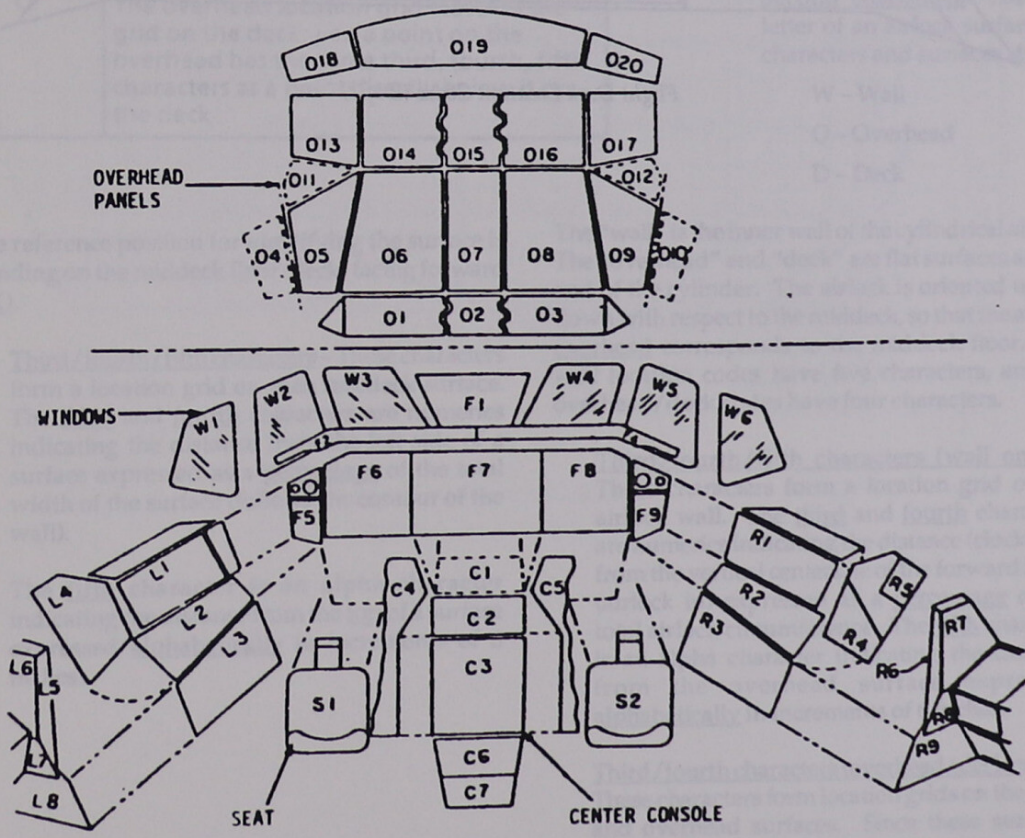
A flight deck location code consists of two or three alphanumeric characters. The first character is the first letter of a flight deck surface as addressed while sitting in the commander/pilot seats. The characters are:

- L — Left
- R — Right
- F — Forward
- A — Aft
- C — Center Console
- O — Overhead
- S — Seats
- W — Windows

Surfaces	General numbering philosophy
L - Left R - Right C - Center console	• Numbered from top to bottom, forward to aft
O - Overhead	• Numbered from left to right, forward to aft
F - Forward A - Aft	• Numbered left to right, top to bottom (facing the surface)
W - Windows	<ul style="list-style-type: none"> <li>• The forward windows are numbered left to right (W1 through W6) facing forward</li> <li>• The overhead windows are numbered left to right (W7 and W8) facing aft</li> <li>• The aft windows are numbered left to right (W9 and W10) facing aft</li> </ul>
S - Seats	• The CDR's seat is <u>S1</u> and the PLT's seat is <u>S2</u>

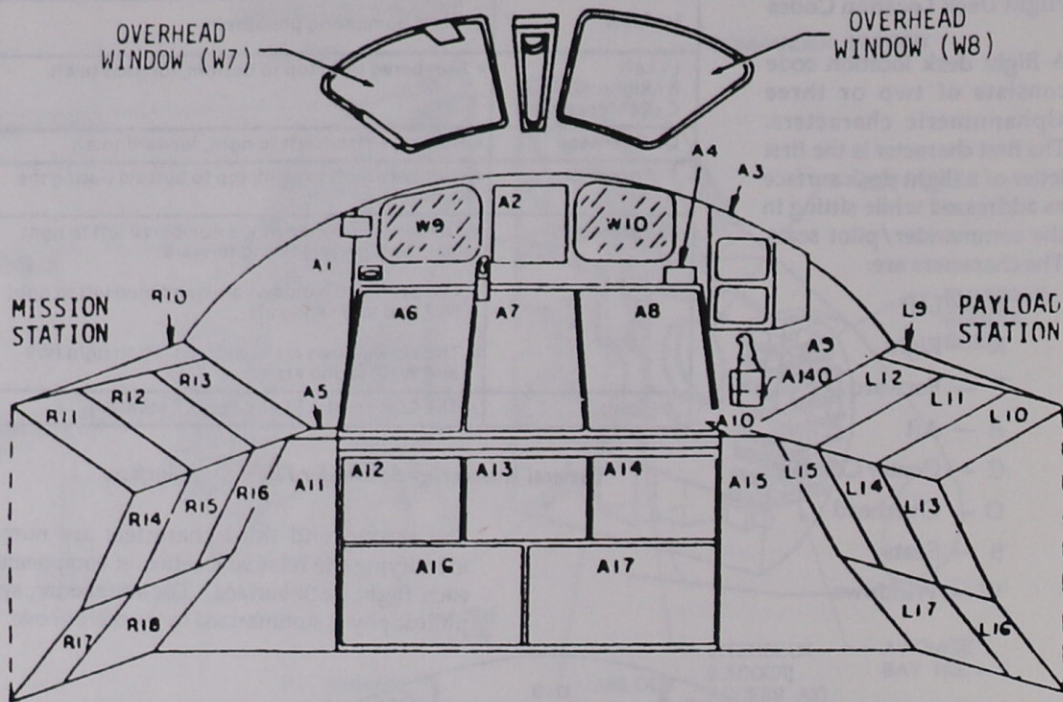
### General Numbering Scheme for Flight Deck Surfaces

The second and third characters are numerics identifying the relative location of components on each flight deck surface. The numbering system philosophy is summarized in the table above.



Flight Deck Location Codes (1 of 2)

1. GENERAL DESCRIPTION  
1.1 Overview



Flight Deck Location Codes (2 of 2)



### Middeck Location Codes

The middeck location codes have five characters specifying the following:

First character - M for middeck

Second character - The first letter of a middeck surface; the characters and surfaces are:

L - Left                      A - Aft  
R - Right                     D - Deck  
F - Forward                 O - Overhead

Surfaces	Reference position
L, R, F, A	Standing on deck facing the surface
D	Standing on deck facing forward (+ X) looking down
O	The overhead location grid matches the grid on the deck; i.e., a point on the overhead has the same third, fourth, fifth characters as a point directly below it on the deck

The reference position for identifying the surface is standing on the middeck floor (deck) facing forward (+X).

Third/fourth/fifth characters - These characters form a location grid on each middeck surface. The third and fourth characters are numerics indicating the distance from the left side of a surface expressed as a percentage of the total width of the surface (follows the contour of the wall).

The fifth character is an alpha character indicating the distance from the top of a surface expressed alphabetically in increments of 6 inches.

### NOTE

The middeck panel numbers are not consistent with the location coding system defined by this document. However, in each case, the location coding, as indicated, is in close proximity to the actual location. Panel numbers were assigned prior to the middeck closeout panel design definition. The starting points for location coding were behind the closeout panels, whereas the starting points used in this document are in front of the closeout panels.

### Airlock Location Codes

An airlock code consists of four or five alphanumeric characters, which specify the following:

First character - A for airlock

Second character - The first letter of an airlock surface; the characters and surfaces are:

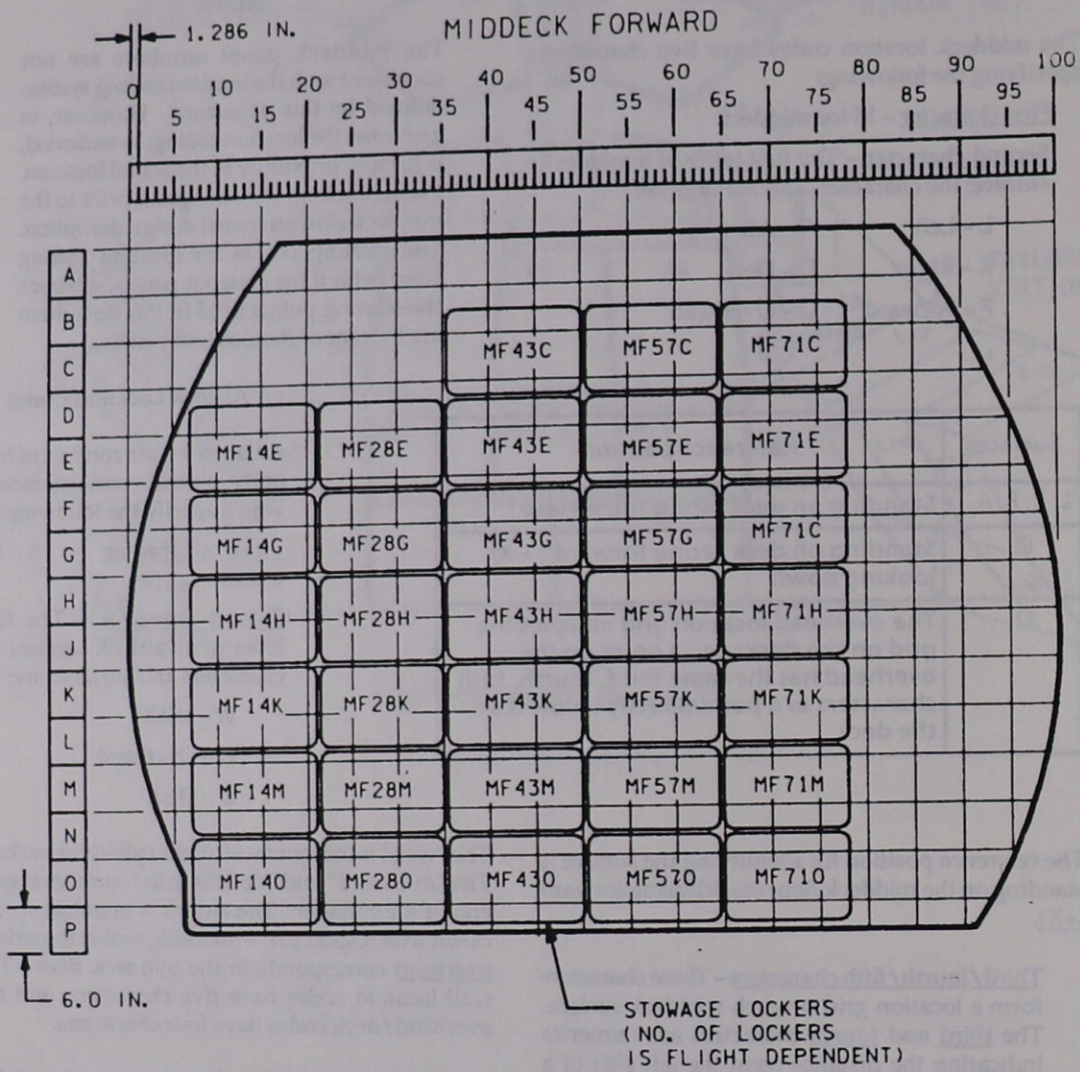
W - Wall  
O - Overhead  
D - Deck

The "wall" is the inner wall of the cylindrical airlock. The "overhead" and "deck" are flat surfaces at each end of the cylinder. The airlock is oriented upside down with respect to the middeck, so that the airlock overhead corresponds to the middeck floor. The wall location codes have five characters, and the overhead/deck codes have four characters.

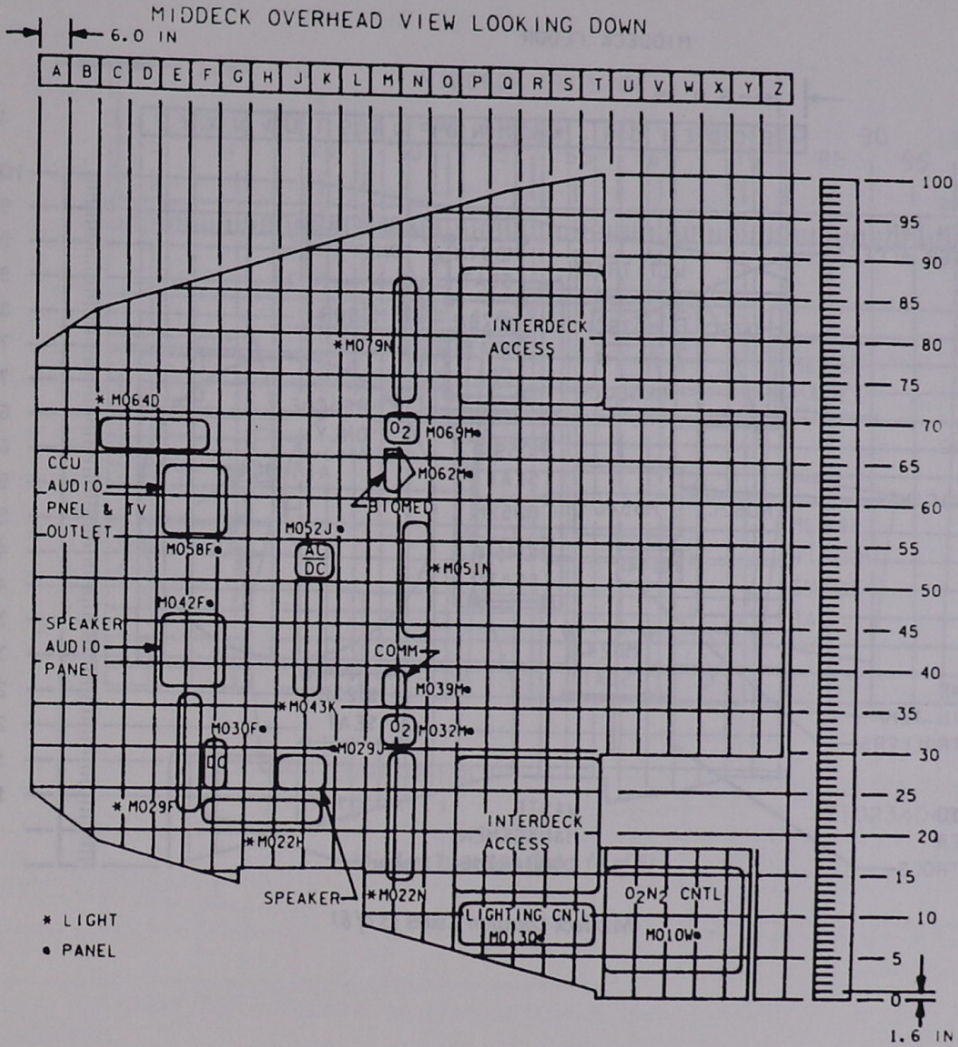
Third/fourth/fifth characters (wall only) - These characters form a location grid on the airlock wall. The third and fourth characters are numerics indicating the distance (clockwise) from the vertical centerline of the forward hatch (airlock in) expressed as a percentage of the total airlock circumference. The fifth character is an alpha character indicating the distance from the overhead surface expressed alphabetically in increments of 6 inches.

Third/fourth characters (overhead/deck only) - These characters form location grids on the deck and overhead surfaces. Since these surfaces are small, items can be easily located without the aid of the location grids.

1. GENERAL DESCRIPTION  
 1.1 Overview



Middeck Location Codes (1 of 8)



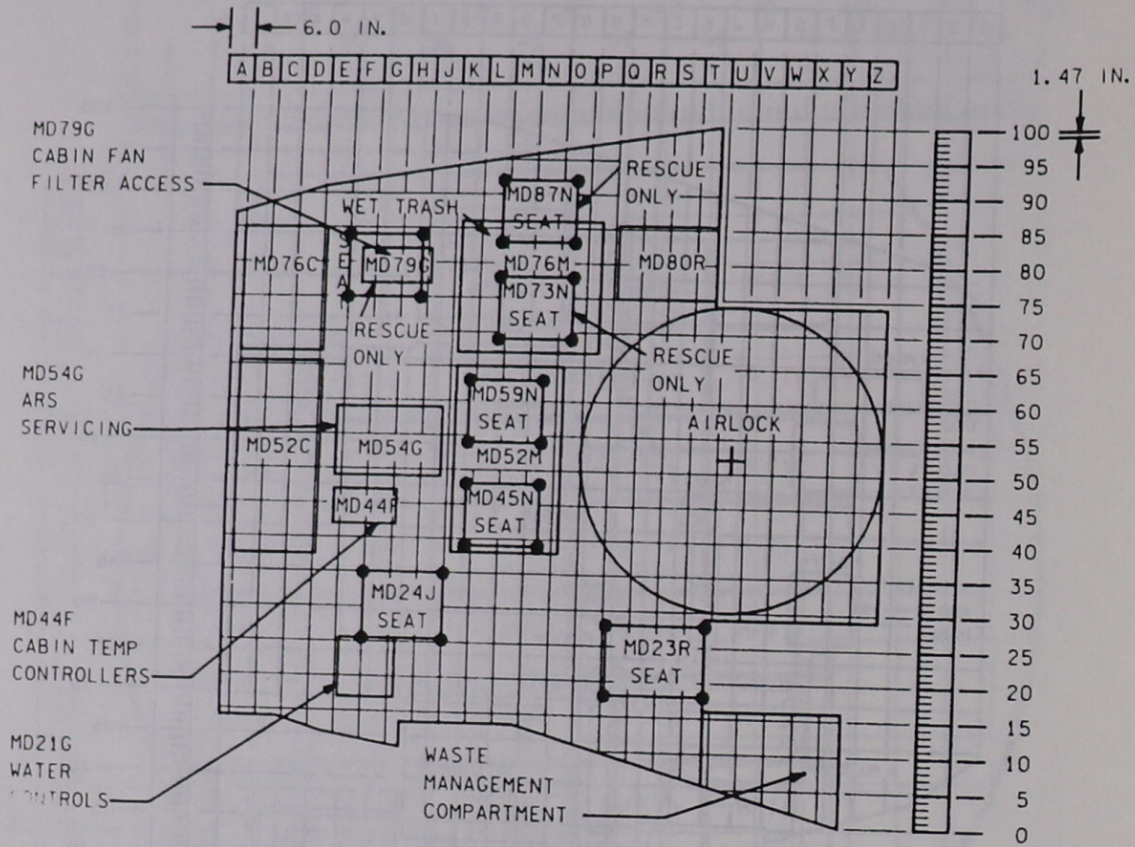
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Middeck Location Codes (2 of 8)

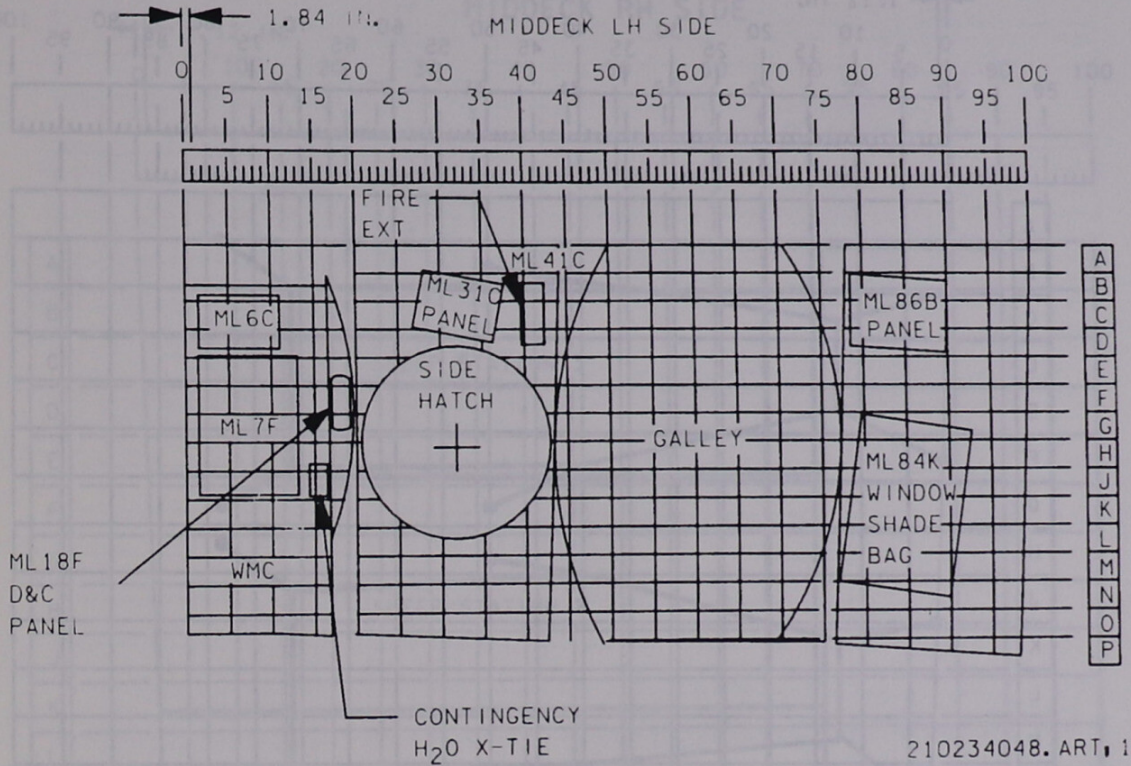
# 1. GENERAL DESCRIPTION

## 1.1 Overview

### MIDDECK FLOOR



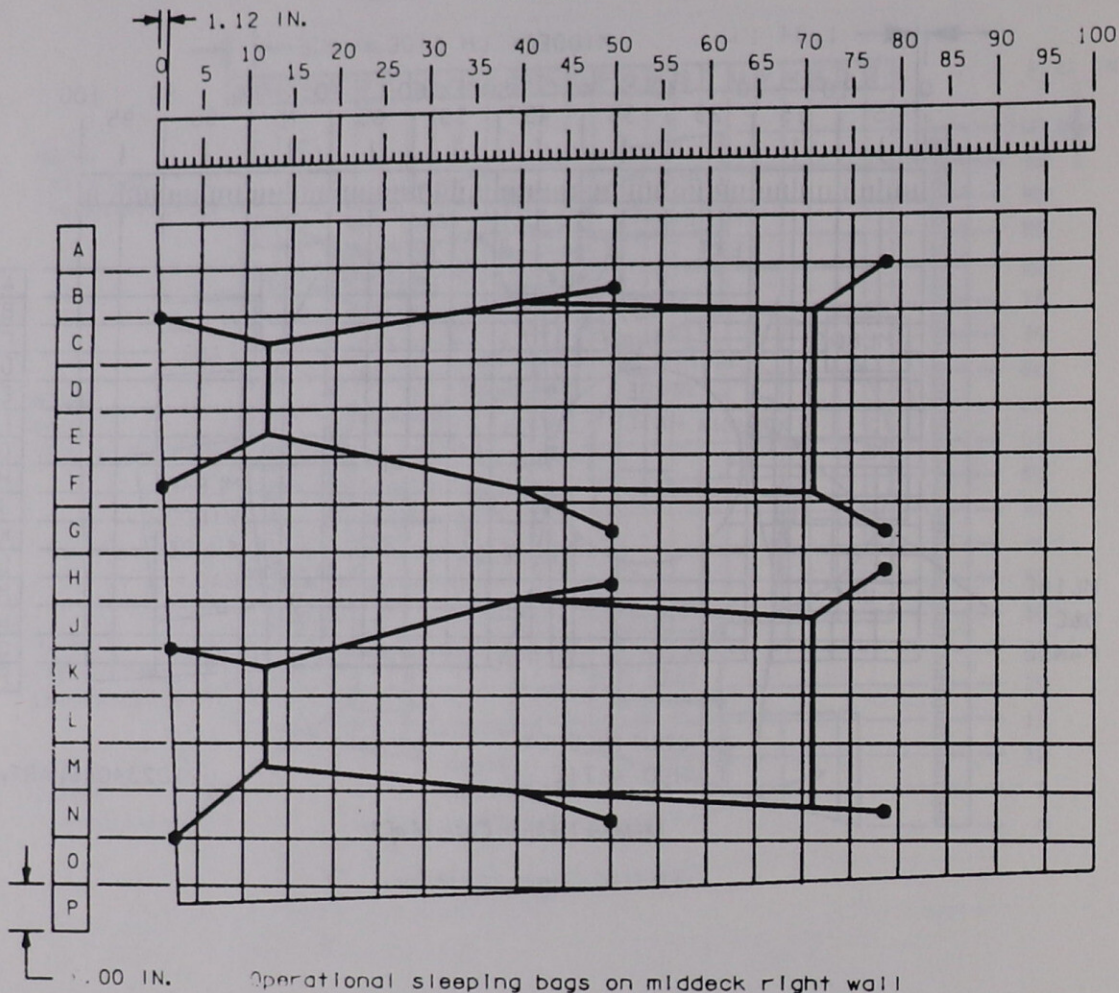
Middeck Location Codes (3 of 8)



Middeck Location Codes (4 of 8)

1. GENERAL DESCRIPTION  
 1.1 Overview

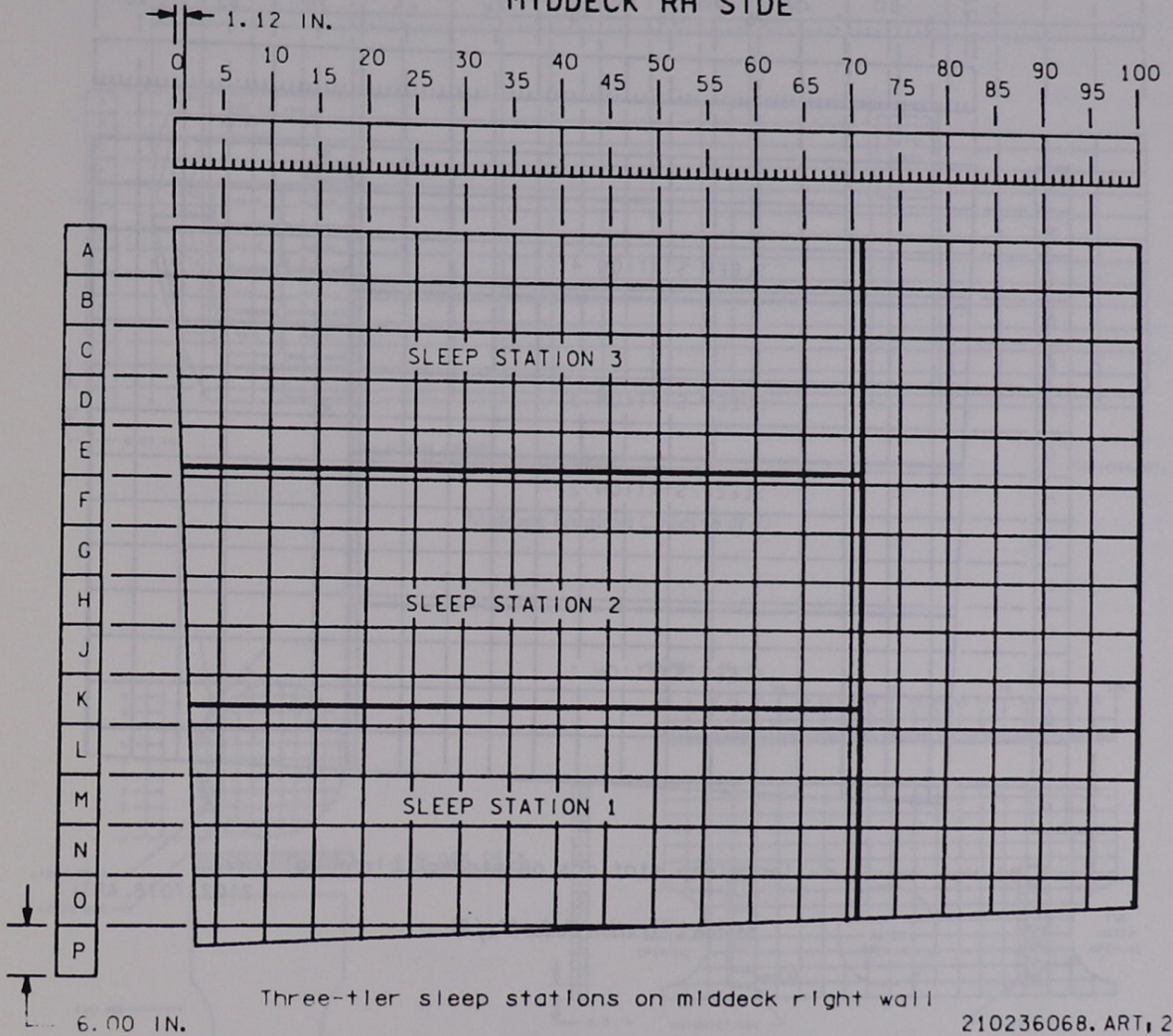
MIDDECK RH SIDE



210235058. ART, 1

Middeck Location Codes (5 of 8)

MIDDECK RH SIDE

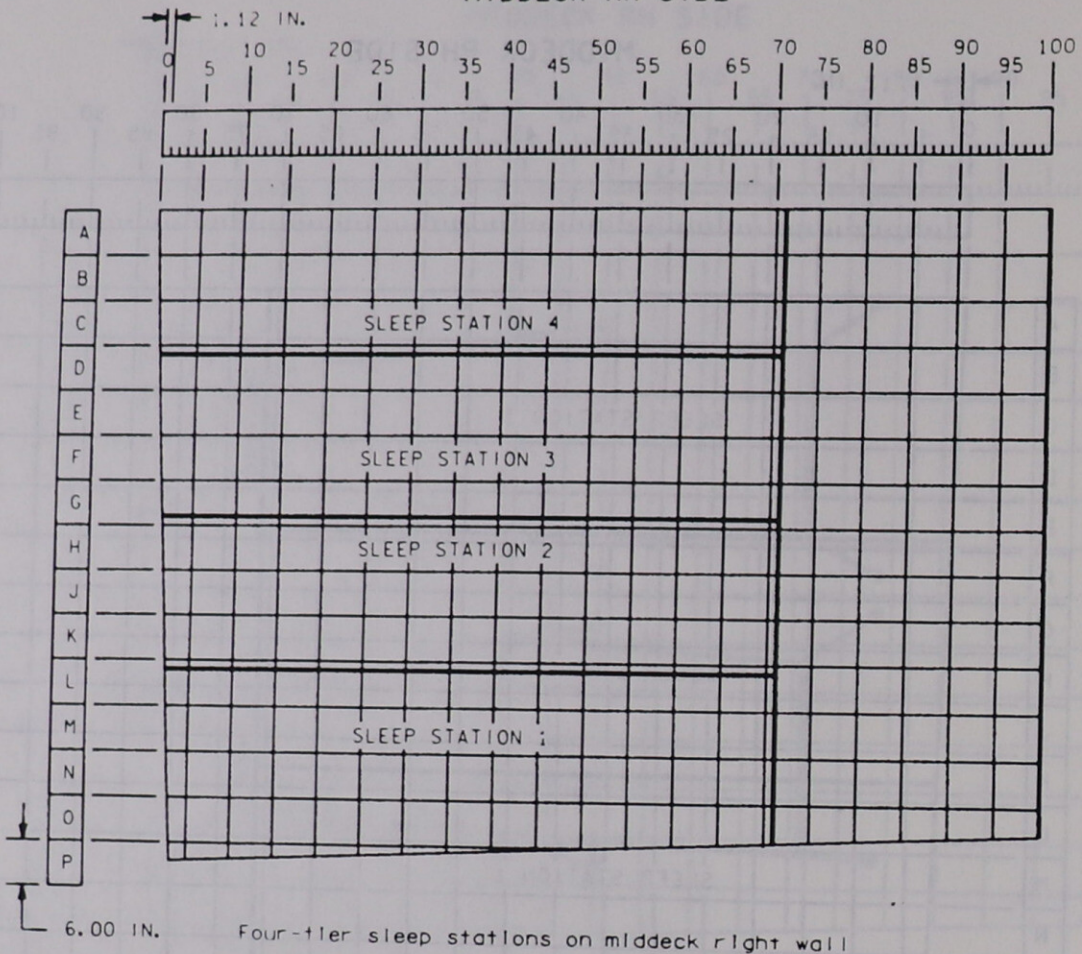


210236068. ART. 2

Middeck Location Codes (6 of 8)

1. GENERAL DESCRIPTION  
 1.1 Overview

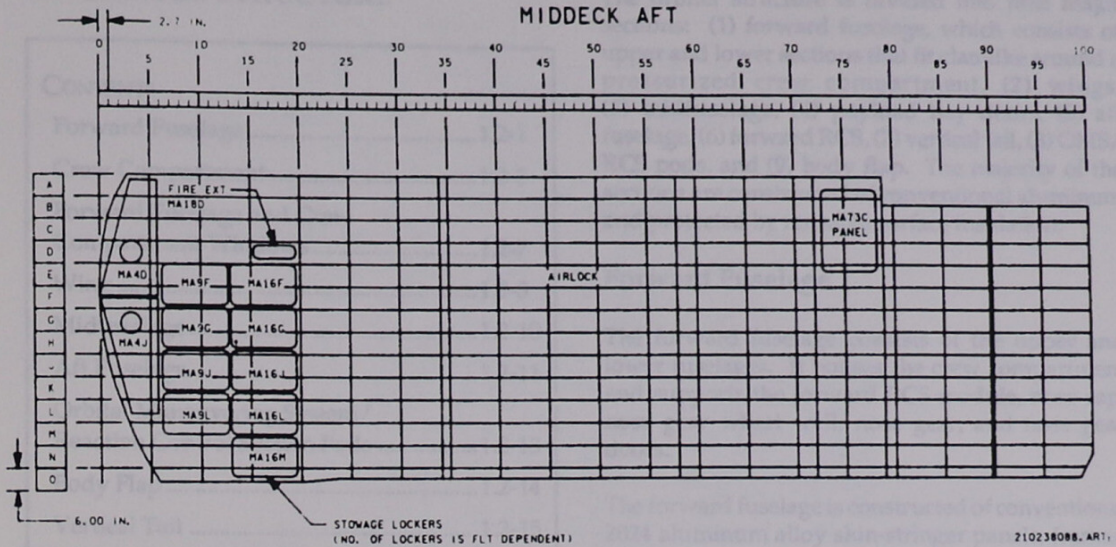
MIDDECK RH SIDE



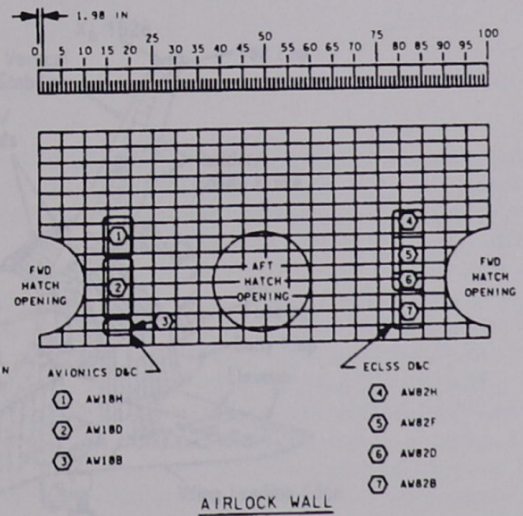
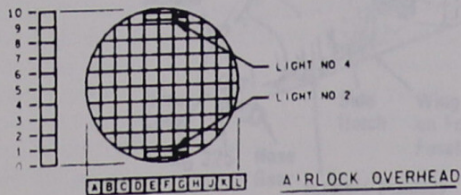
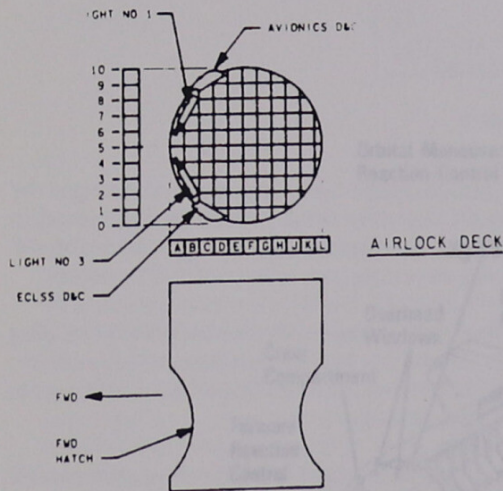
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Middeck Location Codes (7 of 8)





Middeck Location Codes (8 of 8)



AIRLOCK SURFACES

THE AIRLOCK IS SHOWN IN THE MIDDECK (INSIDE) CONFIGURATION. THE LOCATION CODES DO NOT CHANGE IF THE AIRLOCK IS MOVED TO THE PAYLOAD BAY.

21020004L.ART.1

Airlock Location Codes

## 1.2 ORBITER STRUCTURE

### CONTENTS

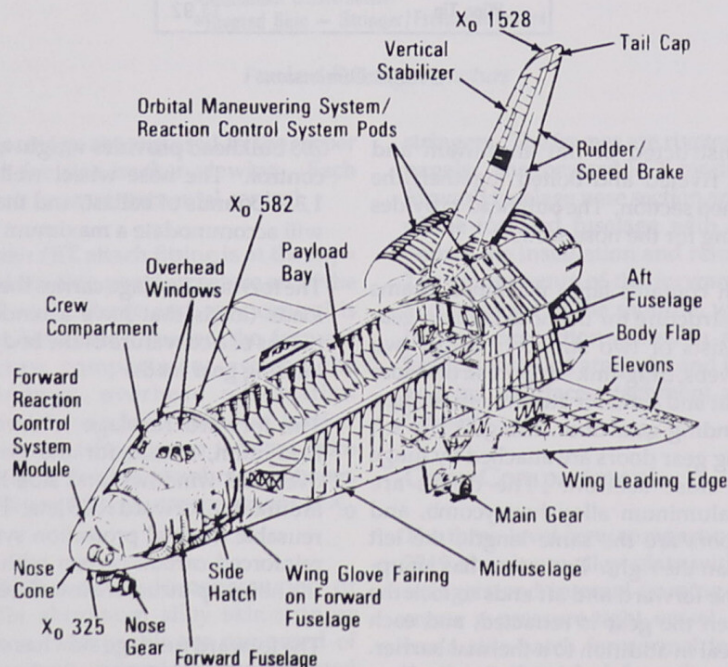
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The orbiter structure is divided into nine major sections: (1) forward fuselage, which consists of upper and lower sections that fit clamlike around a pressurized crew compartment, (2) wings, (3) midfuselage, (4) payload bay doors, (5) aft fuselage, (6) forward RCS, (7) vertical tail, (8) OMS/RCS pods, and (9) body flap. The majority of the sections are constructed of conventional aluminum and protected by reusable surface insulation.

### Forward Fuselage

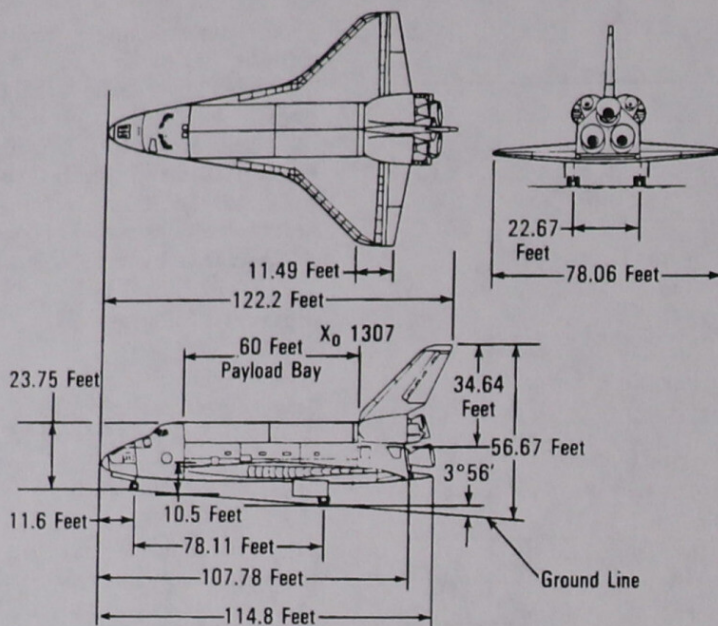
The forward fuselage consists of the upper and lower fuselages. It houses the crew compartment and supports the forward RCS module, nose cap, nose gear wheel well, nose gear, and nose gear doors.

The forward fuselage is constructed of conventional 2024 aluminum alloy skin-stringer panels, frames, and bulkheads. The panels are single curvature, stretch-formed skins with riveted stringers spaced 3 to 5 inches apart. The frames are riveted to the skin-stringer panels. The major frames are spaced 30 to 36 inches apart. The  $Y_0 = 378$  upper forward



Orbiter

1. GENERAL DESCRIPTION  
 1.2 Orbiter Structure



Minimum Ground Clearances	Feet
Body Flap	12.07
Main Gear Door	2.85
Nose Gear Door	2.95
Wing Tip	11.92

Orbiter Dimensions

bulkhead is constructed of flat aluminum and formed sections riveted and bolted together; the lower is a machined section. The bulkhead provides the interface fitting for the nose section.

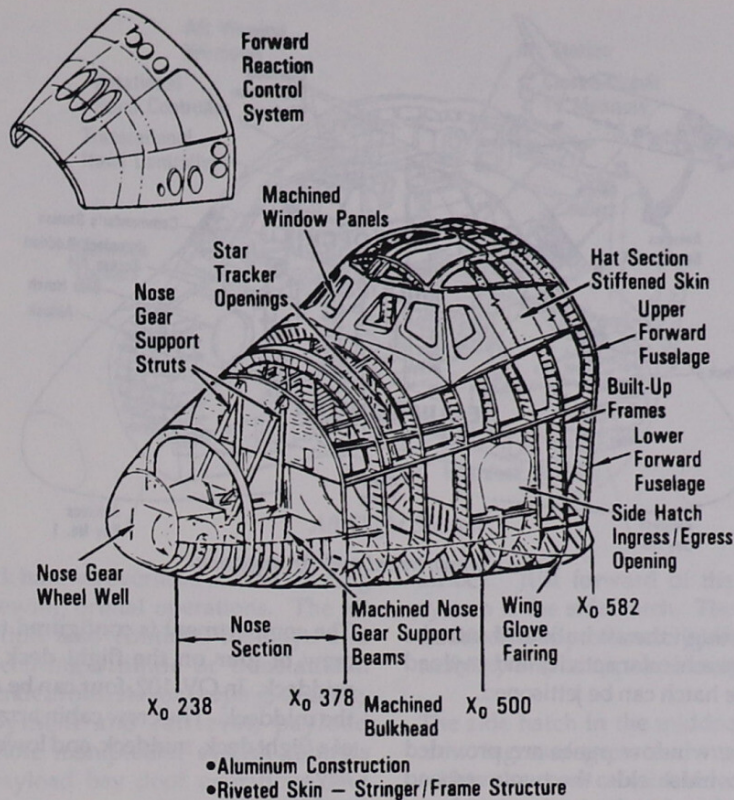
The nose section contains large machined beams and struts. The structure for the nose landing gear wheel well consists of two support beams, two upper closeout webs, drag-link support struts, nose landing gear strut and actuator attachment fittings, and the nose landing gear door fittings. The left and right landing gear doors are attached by hinge fittings in the nose section. The doors are constructed of aluminum alloy honeycomb, and although the doors are the same length, the left door is wider than the right. Each door has an up-latch fitting at the forward and aft ends to lock the door closed when the gear is retracted, and each has a pressure seal in addition to a thermal barrier. Lead ballast in the nose wheel well and on the  $X_0 =$

293 bulkhead provides weight and center-of-gravity control. The nose wheel well will accommodate 1,350 pounds of ballast, and the  $X_0 = 293$  bulkhead will accommodate a maximum of 1,971 pounds.

The forward fuselage carries the basic body-bending loads (loads that have a tendency to change the radius of a curvature of the body) and reacts to nose landing gear loads.

The forward fuselage is covered with reusable insulation, except for the six windshields, two overhead windows, and side hatch window areas around the forward RCS jets. The nose cap is also a reusable thermal protection system constructed of reinforced carbon-carbon with thermal barriers at the nose cap-structure interface.

The forward fuselage skin has structural provisions for installing antennas, deployable air data probes, and the door eyelet openings for the two star



*Forward Fuselage Structure*

trackers. Two openings are required in the upper forward fuselage for star tracker viewing. Each opening has a door for environmental control.

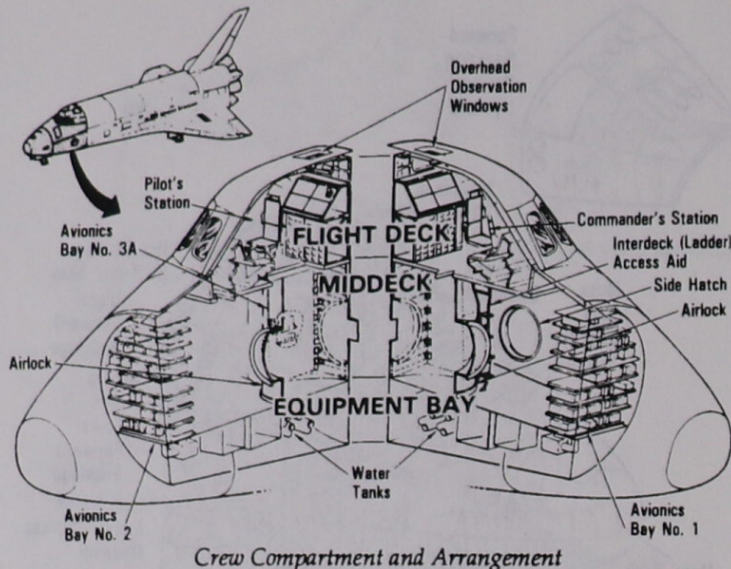
The forward orbiter/ET attach fitting is at the  $X_0 = 378$  bulkhead and the skin panel structure aft of the nose gear wheel well. Purge and vent control is provided by flexible boots between the forward fuselage and crew compartment around the windshield windows, overhead observation window, crew hatch window, and star tracker openings. The forward fuselage is isolated from the payload bay by a flexible membrane between the forward fuselage and crew compartment at  $X_0 = 582$ .

The forward RCS module is constructed of conventional 2024 aluminum alloy skin-stringer panels and frames. The panels are composed of single-curvature, stretch-formed skins with riveted

stringers. The frames are riveted to the skin-stringer panels. The forward RCS module is secured to the forward fuselage nose section and forward bulkhead of the forward fuselage with 16 fasteners, which permit the installation and removal of the module. The components of the forward RCS are mounted and attached to the module, which has a reusable thermal protection cover, in addition to thermal barriers installed around it and the RCS jet interfaces and the interface-attachment area to the forward fuselage.

### Crew Compartment

The three-level crew compartment is constructed of 2219 aluminum alloy plate with integral stiffening stringers and internal framing welded together to create a pressure-tight vessel. The compartment has a side hatch for normal ingress and egress, a hatch into the airlock from the middeck, and a hatch



from the airlock through the aft bulkhead into the payload bay for extravehicular activity and payload bay access. The side hatch can be jettisoned.

Redundant pressure window panes are provided in the six forward windshields, the two overhead viewing windows, the two aft viewing windows, and the side hatch windows. Approximately 300 penetrations in the pressure shell are sealed with plates and fittings. A large removable panel in the aft bulkhead provides access to the interior of the crew compartment during initial fabrication and assembly and provides for airlock installation and removal. The compartment supports the ECLSS, avionics, GNC equipment, inertial measurement units, displays and controls, star trackers, and crew accommodations for sleeping, waste management, seats, and an optional galley.

The crew compartment is supported within the forward fuselage at only four attach points to minimize the thermal conductivity between them. The two major attach points are located at the aft end of the crew compartment at the flight deck floor level. The vertical load reaction link is on the centerline of the forward bulkhead. The lateral load reaction is on the lower segment of the aft bulkhead.

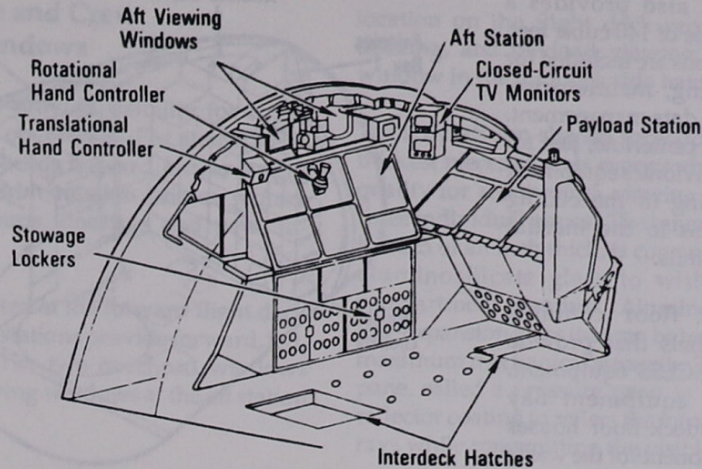
The compartment is configured to accommodate a crew of four on the flight deck and three in the middeck. In OV-102, four can be accommodated in the middeck. The crew cabin arrangement consists of a flight deck, middeck, and lower level equipment bay.

The crew compartment is pressurized to  $14.7 \pm 0.2$  psia and is maintained at an 80-percent nitrogen and 20-percent oxygen composition by the ECLSS, which provides a shirt-sleeve environment for the flight crew. The crew compartment is designed for 16 psia.

The crew compartment's volume with the airlock in the middeck is 2,325 cubic feet. If the airlock is in the payload bay, the crew compartment's cabin volume is 2,625 cubic feet.

### Flight Deck

The flight deck is the uppermost compartment of the cabin. The commander's and pilot's work stations are positioned side by side in the forward portion of the flight deck. These stations have controls and displays for controlling the vehicle throughout all mission phases. Directly behind and to the sides of the commander and pilot centerline are the mission specialist seats.



*Aft Flight Station*

The aft flight deck has two overhead and aft viewing windows for viewing orbital operations. The aft flight deck station also contains displays and controls for executing attitude or translational maneuvers for rendezvous, stationkeeping, docking, payload deployment and retrieval, payload monitoring, remote manipulator system controls and displays, payload bay door operations, and closed-circuit television operations. The aft flight deck is approximately 40 square feet.

The forward flight deck, which includes the center console and seats, is approximately 24 square feet. However, the side console controls and displays add approximately 3.5 more square feet. If the center console is subtracted from the 24 square feet, this would amount to approximately 5.2 square feet.

### Middeck

Directly beneath the flight deck is the middeck. Access to the middeck is through two interdeck openings, which measure 26 by 28 inches. Normally, the right interdeck opening is closed, and the left is open. A ladder attached to the left interdeck access allows easy passage in 1-g conditions. The middeck provides crew accommodations and contains three avionics equipment bays. The two forward avionics bays utilize the complete width of the cabin and extend into the middeck 39 inches from the forward bulkhead. The aft bay extends into the middeck 39 inches from the aft bulkhead on the right side of the

airlock. Just forward of the waste management system is the side hatch. The completely stripped middeck is approximately 160 square feet; the gross mobility area is approximately 100 square feet.

The side hatch in the middeck is used for normal crew ingress/egress and may be operated from within the crew cabin middeck or externally. It is attached to the crew cabin tunnel by hinges, a torque tube, and support fittings. The hatch opens outwardly 90 degrees down with the orbiter horizontal or 90 degrees sideways with the orbiter vertical. It is 40 inches in diameter and has a 10-inch clear-view window in the center of the hatch. The window consists of three panes of glass. The side hatch has a pressure seal that is compressed by the side hatch latch mechanisms when the hatch is locked closed. A thermal barrier of Inconel wire mesh spring with a ceramic fiber braided sleeve is installed between the reusable surface insulation tiles on the forward fuselage and the side hatch. The total weight of the side hatch is 294 pounds.

Depending on the mission requirements, bunk sleep stations and a galley can be installed in the middeck. In addition, three or four seats of the same type as the mission specialists' seats on the flight deck can be installed in the middeck. Three seats over the normal three could be installed in the middeck for rescue missions if the bunk sleep stations were removed.

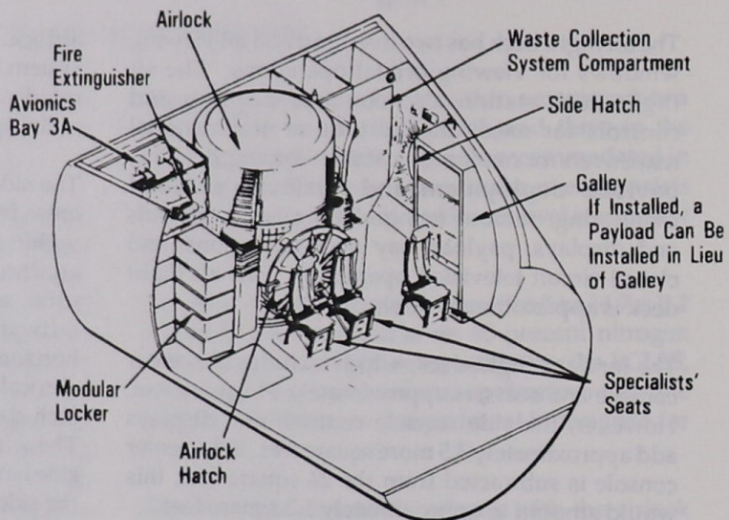
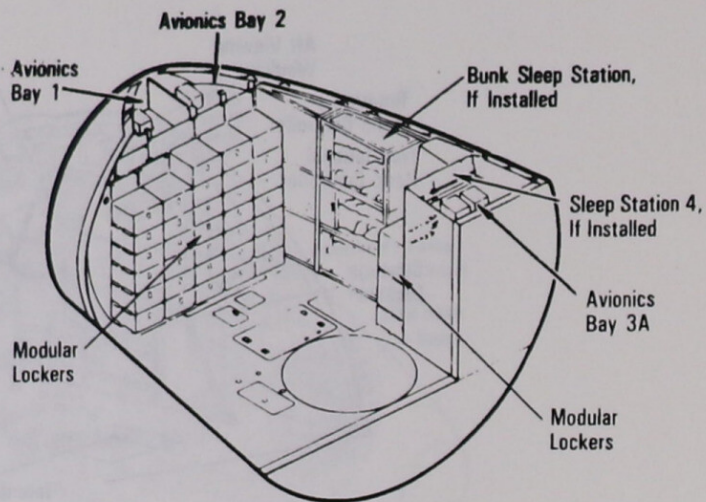
1. GENERAL DESCRIPTION  
1.2 Orbiter Structure

The middeck also provides a stowage volume of 140 cubic feet. Accommodations are included for dining, sleeping, maintenance, exercising, and data management. On the orbiter centerline, just aft of the forward avionics equipment bay, an opening in the ceiling provides access to the inertial measurement units.

The middeck floor contains removable panels that provide access to the ECLSS equipment. The middeck equipment bay below the middeck floor houses the major components of the waste management and air revitalization systems, such as pumps, fans, lithium hydroxide carbon dioxide absorbers, heat exchangers, and ducting. This compartment has space for stowing lithium hydroxide canisters and five separate spaces for crew equipment stowage with a volume of 29.92 cubic feet.

Modular stowage lockers are used to store the flight crew's personal gear, mission-necessary equipment, personal hygiene equipment, and experiments. There are 42 identical boxes, which are 11 by 18 by 21 inches.

An airlock located in the middeck is composed of machined aluminum sections welded together to form a cylinder with hatch mounting flanges. The upper cylindrical section and bulkheads are constructed of aluminum honeycomb. Two semicylindrical aluminum sections are welded to the airlock's primary structure to house the ECLSS and electrical support equipment.



Crew Compartment Middeck

Each semicylindrical section has three feedthrough plates for plumbing and cable routings from the orbiter to the airlock.

Normally, two extravehicular mobility units are stowed in the airlock.

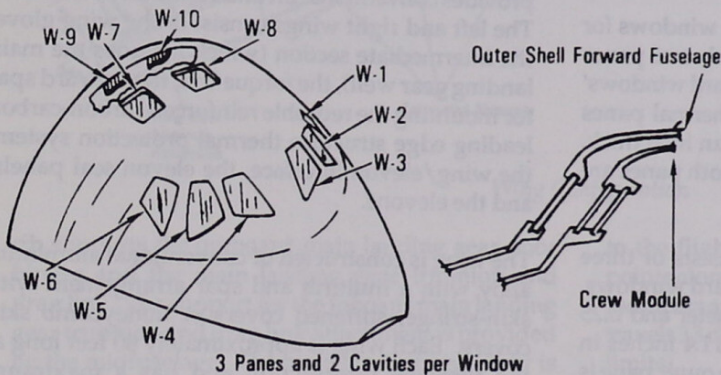
## Forward Fuselage and Crew Compartment Windows

The orbiter windows provide visibility for entry, landing, and on-orbit operations. For atmospheric flight, the flight crew needs forward, left, and right viewing areas. On-orbit mission phases require visibility for rendezvous, docking, and payload-handling operations.

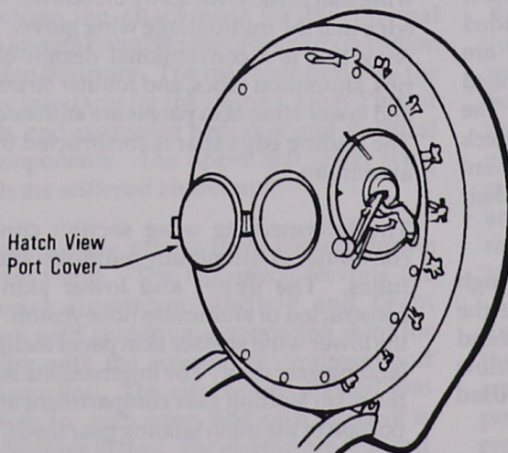
The six windows located at the forward flight deck commander and pilot stations provide forward, left, and right viewing. The two overhead windows and two payload-viewing windows at the aft station

location on the flight deck provide rendezvous, docking, and payload viewing. There is also a window in the middeck side hatch.

The six platform-shaped forward windows are the thickest pieces of glass ever produced in the optical quality for see-through viewing. Each consists of three individual panes. The innermost pane, which is 0.625 of an inch thick, is constructed of tempered aluminosilicate glass to withstand the crew compartment pressure. Aluminosilicate glass is a low-expansion glass that can be tempered to provide maximum mechanical strength. The exterior of this pane, called a pressure pane, is coated with a red reflector coating to reflect the infrared (heat portion) rays while transmitting the visible spectrum.



Flight Deck Windows



Side Hatch (Interior View)

The center pane is constructed of low-expansion, fused silica glass because of its high optical quality and excellent thermal shock resistance. This pane is 1.3 inches thick.

The inner and outer panes are coated with a high-efficiency, anti-reflection coating to improve visible light transmission. These windows withstand a proof pressure of 8,600 psi at 240° F and 0.017 relative humidity.

The outer pane is made of the same material as the center pane and is 0.625 of an inch thick. The exterior is uncoated, but the interior is coated with high-efficiency, anti-reflection coating. The outer surface withstands approximately 800° F.

Each of the six forward windows' outer panes measures 42 inches diagonally, and the center and inner panes each measure 35 inches diagonally. The outer panes of the six forward windows are mounted and attached to the forward fuselage. The center and inner panes are mounted and attached to the crew compartment. Redundant



seals are employed on each window. No sealing/bonding compounds are used.

The two overhead windows at the flight deck aft station are identical in construction to the six forward windows except for thickness. The inner and center panes are 0.45 of an inch thick, and the outer pane is 0.68 of an inch thick. The outer pane is attached to the forward fuselage, and the center and inner panes are attached to the crew compartment. The two overhead windows' clear view area is 20 by 20 inches. The left-hand overhead window provides the crew members with a secondary emergency egress. The inner and center panes open into the crew cabin, and the outer pane is jettisoned up and over the top of the orbiter. This provides a secondary emergency exit area of 20 by 20 inches.

On the aft flight deck, each of the two windows for viewing the payload bay consists of only two panes of glass, which are identical to the forward windows' inner and center panes. The outer thermal panes are not installed. Each pane is 0.3 of an inch thick. The windows are 14.5 by 11 inches. Both panes are attached to the crew compartment.

The side hatch viewing window consists of three panes of glass identical to the six forward windows. The inner pane is 11.4 inches in diameter and 0.25 of an inch thick. The center pane is 11.4 inches in diameter and 0.5 of an inch thick. The outer pane is 15 inches in diameter and 0.3 of an inch thick.

During orbital operations, the large window areas of transparency expose the flight crew to sun glare; therefore, window shades and filters are provided to preclude or minimize exposure. Shades are provided for all windows, and filters are supplied for the aft and overhead viewing windows. The window shades and filters are stored in the middeck of the orbiter crew compartment. Attachment mechanisms and devices are provided for their installation at each window on the flight deck.

The forward station window shades (W-1 through W-6) are rolled up and stowed at the base of the windows. Solid metal shades are used on overhead windows (W-7 and W-8). The overhead window filters are fabricated from Lexan and are used interchangeably with the shades.

The aft window shades (W-9 and W-10) are the same as the overhead window shades except that a 0.63-inch-wide strip of Nomex Velcro has been added around the perimeter of the shade. The shade is attached to the window by pressing the Velcro strip to the pile strip around the window opening. The aft window filters are the same as the overhead window filters except for the addition of the Velcro hook strip. The filters and shades are used interchangeably.

The side hatch window cover is permanently attached to the window frame and is hinged to allow opening and closing.

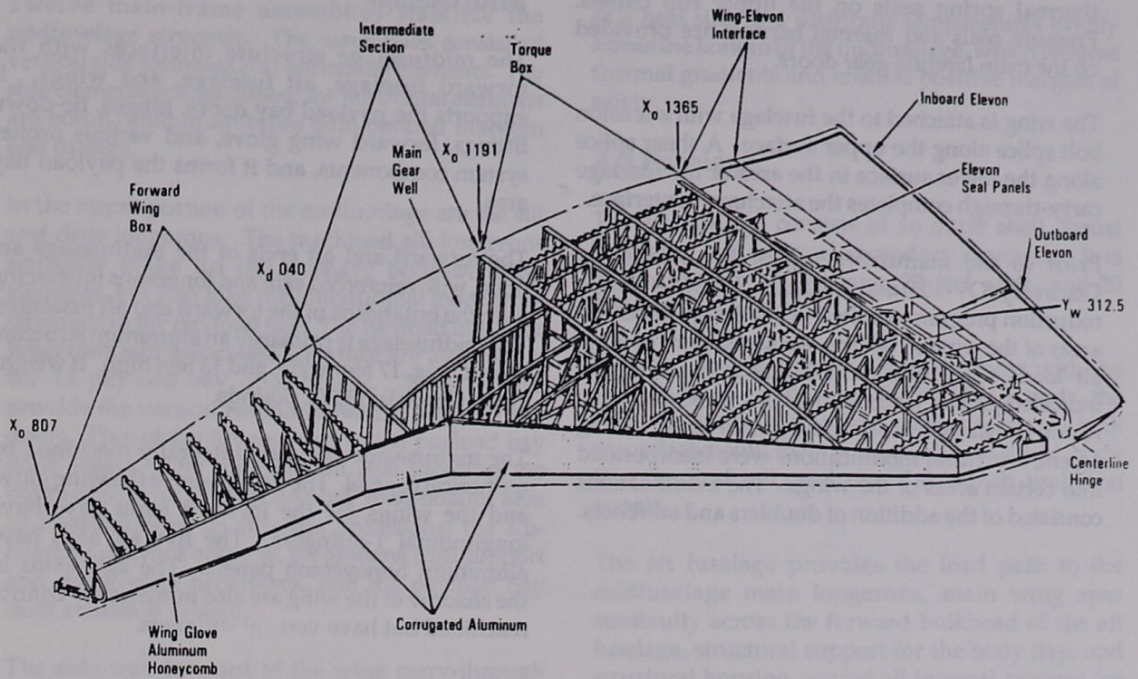
## Wing

The wing is an aerodynamic lifting surface that provides conventional lift and control for the orbiter. The left and right wings consist of the wing glove, the intermediate section (which includes the main landing gear well), the torque box, the forward spar for mounting the reusable reinforced carbon-carbon leading edge structure thermal protection system, the wing/elevon interface, the elevon seal panels, and the elevons.

The wing is constructed of conventional aluminum alloy with a multirib and spar arrangement with skin-stringer-stiffened covers or honeycomb skin covers. Each wing is approximately 60 feet long at the fuselage intersection and has a maximum thickness of 5 feet.

The forward wing box is an extension of the basic wing that aerodynamically blends the wing leading edge into the midfuselage wing glove. The forward wing box is a conventional design of aluminum ribs, aluminum tubes, and tubular struts. The upper and lower wing skin panels are stiffened aluminum. The leading edge spar is constructed of corrugated aluminum.

The intermediate wing section consists of the conventional aluminum multiribs and aluminum tubes. The upper and lower skin covers are constructed of aluminum honeycomb. A portion of the lower wing surface skin panel includes the main landing gear door. The intermediate section houses the main landing gear compartment and reacts to a portion of the main landing gear loads. A structural



*Wing Configuration*

rib supports the outboard main landing gear door hinges and the main landing gear trunnion and drag link. The support for the inboard main landing gear trunnion and drag link attachment is provided by the midfuselage. The main landing gear door is conventional aluminum honeycomb.

The four major spars are constructed of corrugated aluminum to minimize thermal loads. The forward spar provides the attachment for the thermal protection system reusable reinforced carbon-carbon leading edge structure. The rear spar provides the attachment interfaces for the elevons, hinged upper seal panels, and associated hydraulic and electrical system components. The upper and lower wing skin panels are stiffened aluminum.

The elevons provide orbiter flight control during atmospheric flight. The two-piece elevons are conventional aluminum multirib and beam construction with aluminum honeycomb skins for compatibility with the acoustic environment and thermal interaction. The elevons are divided into two segments for each wing, and each segment is supported by three hinges. The elevons are attached

to the flight control system hydraulic actuators at points along their forward extremities, and all hinge moments are reacted to at these points. Each elevon travels 33 degrees up and 18 degrees down (software limits).

The transition area on the upper surface between the torque box and the movable elevon consists of a series of hinged panels that provide a closeout of the wing-to-elevon cavity. These panels are of Inconel honeycomb sandwich construction outboard of wing station  $Y_W = 312.5$  and of titanium honeycomb sandwich construction inboard of wing station  $Y_W = 312.5$ . The upper leading edge of each elevon incorporates titanium rub strips. The rub strips are of titanium honeycomb construction and are not covered with the thermal protection system reusable surface insulation. They provide the sealing surface area for the elevon seal panels.

Except the elevon seal panels, the exposed areas of the wings, main landing gear doors, and elevons are covered with reusable surface insulation thermal protection system materials. Thermal seals are provided on the elevon lower cove area along with

thermal spring seals on the upper rub panels. Pressure seals and thermal barriers are provided on the main landing gear doors.

The wing is attached to the fuselage with a tension bolt splice along the upper surface. A shear splice along the lower surface in the area of the fuselage carry-through completes the attachment interface.

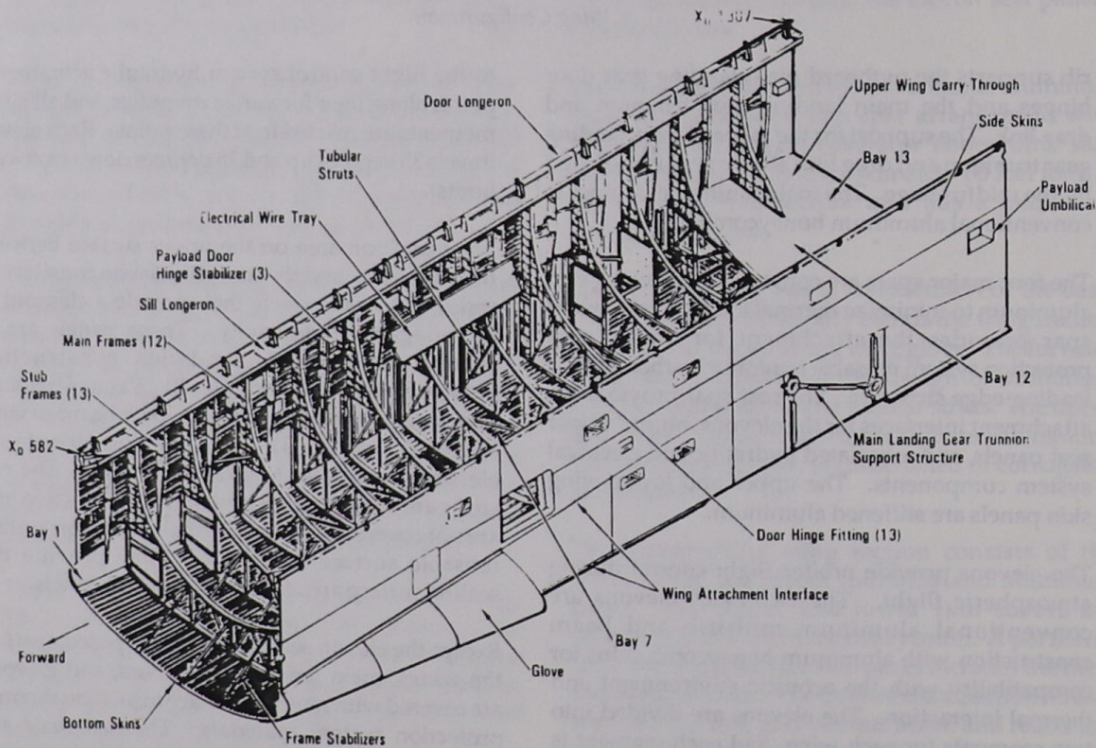
Prior to the manufacturing of the wings for Discovery (OV-103) and Atlantis (OV-104), a weight reduction program resulted in a redesign of certain areas of the wing structure. An assessment of wing air loads was made from actual flight data that indicated greater loads on the wing structure. As a result, to maintain positive margins of safety during ascent, structural modifications were incorporated into certain areas of the wings. The modifications consisted of the addition of doublers and stiffeners.

## Midfuselage

The midfuselage structure interfaces with the forward fuselage, aft fuselage, and wings. It supports the payload bay doors, hinges, tie-down fittings, forward wing glove, and various orbiter system components, and it forms the payload bay area.

The forward and aft ends of the midfuselage are open, with reinforced skin and longerons interfacing with the bulkheads of the forward and aft fuselages. The midfuselage is primarily an aluminum structure 60 feet long, 17 feet wide, and 13 feet high. It weighs approximately 13,502 pounds.

The midfuselage skins are integrally machined by numerical control. The panels above the wing glove and the wings for the forward eight bays have longitudinal T-stringers. The five aft bays have aluminum honeycomb panels. The side skins in the shadow of the wing are also numerically control machined but have vertical stiffeners.



Midfuselage Structure

Twelve main-frame assemblies stabilize the midfuselage structure. The assemblies consist of vertical side elements and horizontal elements. The side elements are machined; the horizontal elements are boron/aluminum tubes with bonded titanium end fittings.

In the upper portion of the midfuselage are the sill and door longerons. The machined sill longerons not only make up the primary body-bending elements, but also take the longitudinal loads from payloads in the payload bay. The payload bay door longerons and associated structure are attached to the 13 payload bay door hinges. These hinges provide the vertical reaction from the payload bay doors. Five of the hinges react to the payload bay door shears. The sill longeron also provides the base support for the payload bay manipulator arm (if installed) and its stowage provisions, the Ku-band rendezvous antenna, the antenna base support and its stowage provisions, and the payload bay door actuation system.

The side wall forward of the wing carry-through structure provides the inboard support for the main landing gear. The total lateral landing gear loads are reacted to by the midfuselage structure.

The midfuselage also supports the two electrical wire trays that contain the wiring between the crew compartment and aft fuselage.

Plumbing and wiring in the lower portion of the midfuselage are supported by fiberglass milk stools.

The other exposed areas of the midfuselage are covered with the reusable surface insulation thermal protection system.

Because of additional detailed analysis of actual flight data concerning descent stress thermal gradient loads, torsional straps were added to the lower midfuselage stringers in bays 1 through 11. The torsional straps tie all stringers together similarly to a box section, which eliminates rotational (torsional) capabilities to provide positive margins of safety.

Also, because of additional detailed analysis of actual flight data during descent, room-temperature vulcanizing silicone rubber material was bonded to the lower midfuselage from bay 4 through 12 to act

as a heat sink and distribute temperatures evenly across the bottom of the midfuselage, which reduces thermal gradients and ensures positive margins of safety.

### Aft Fuselage

The aft fuselage consists of an outer shell, thrust structure, and internal secondary structure. It is approximately 18 feet long, 22 feet wide, and 20 feet high.

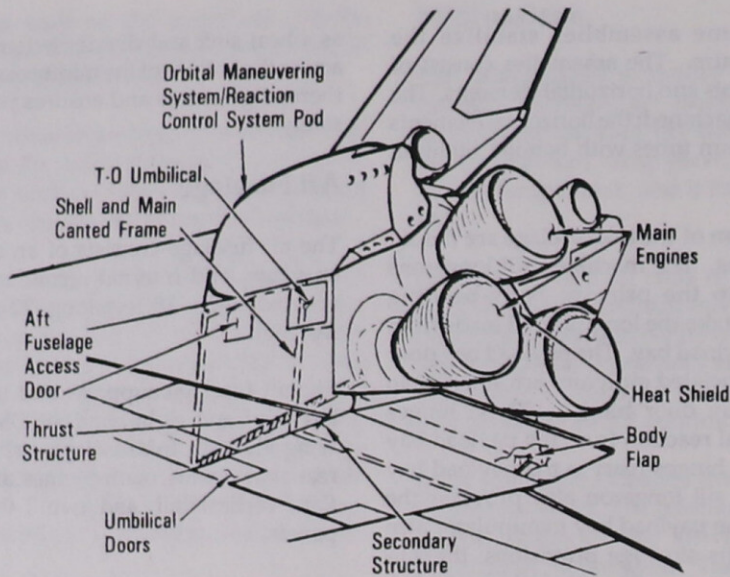
The aft fuselage supports and interfaces with the left-hand and right-hand aft OMS/RCS pods, the wing aft spar, midfuselage, orbiter/external tank rear attachments, main engines, aft heat shield, body flap, vertical tail, and two T-0 launch umbilical panels.

The aft fuselage provides the load path to the midfuselage main longerons, main wing spar continuity across the forward bulkhead of the aft fuselage, structural support for the body flap, and structural housing around all internal systems for protection from operational environments (pressure, thermal, and acoustic) and controlled internal pressures during flight.

The forward bulkhead closes off the aft fuselage from the midfuselage and is composed of machined and beaded sheet metal aluminum segments. The upper portion of the bulkhead attaches to the front spar of the vertical tail.

The internal thrust structure supports the three SSMEs. The upper section of the thrust structure supports the upper SSME, and the lower section of the thrust structure supports the two lower SSMEs. The internal thrust structure includes the SSMEs, load reaction truss structures, engine interface fittings, and the actuator support structure. It supports the SSMEs and the SSME low-pressure turbopumps and propellant lines. The two orbiter/external tank aft attach points interface at the longeron fittings.

The internal thrust structure is composed mainly of 28 machined, diffusion-bonded truss members. In diffusion bonding, titanium strips are bonded together under heat, pressure, and time. This fuses the titanium strips into a single hollow, homogeneous mass that is lighter and stronger than



*Aft Fuselage Structure*

a forged part. In looking at the cross section of a diffusion bond, no weld line is visible. It is a homogeneous parent metal, yet composed of pieces joined by diffusion bonding. (In OV-105, the internal thrust structure is a forging.) In selected areas, the titanium construction is reinforced with boron/epoxy tubular struts to minimize weight and add stiffness.

The upper thrust structure of the aft fuselage is of integral-machined aluminum construction with aluminum frames except for the vertical fin support frame, which is titanium. The skin panels are integrally machined aluminum and attach to each side of the vertical fin to react to drag and torsion loading.

The outer shell of the aft fuselage is constructed of integral-machined aluminum. Various penetrations are provided in the shell for access to installed systems. The exposed outer areas of the aft fuselage are covered with reusable thermal protection system.

The secondary structure of the aft fuselage is of conventional aluminum construction except that titanium and fiberglass are used for thermal isolation of equipment. The aft fuselage secondary structures consist of brackets, buildup webs, truss members,

and machined fittings, as required by system loading and support constraints. Certain system components, such as the avionics shelves, are shock-mounted to the secondary structure. The secondary structure includes support provisions for the auxiliary power units, hydraulics, ammonia boiler, flash evaporator, and electrical wire runs.

The two ET umbilical areas interface with the orbiter's two aft ET attach points and the ET's liquid oxygen and hydrogen feed lines and electrical wire runs. The umbilicals are retracted, and the umbilical areas are closed off after ET separation by an electromechanically operated beryllium door at each umbilical. Thermal barriers are employed at each umbilical door. The exposed area of each closed door is covered with reusable surface insulation.

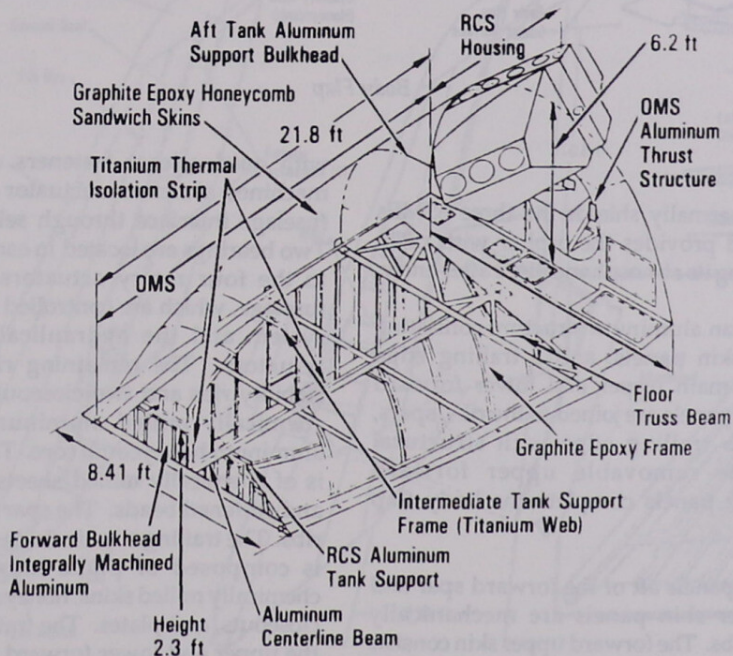
The aft fuselage heat shield and seal provide a closeout of the orbiter aft base area. The aft heat shield consists of a base heat shield of machined aluminum. Attached to the base heat shield are domes of honeycomb construction that support flexible and sliding seal assemblies. The engine-mounted heat shield is of Inconel honeycomb construction and is removable for access to the main engine power heads. The heat shield is covered with a reusable thermal protection system except for the Inconel segments.

### Orbital Maneuvering System/Reaction Control System (OMS/RCS) Pods

The OMS/RCS left- and right-hand pods are attached to the upper aft fuselage left and right sides. Each pod is fabricated primarily of graphite epoxy composite and aluminum. Each pod is 21.8 feet long and 11.37 feet wide at its aft end and 8.41 feet wide at its forward end, with a surface area of approximately 435 square feet. Each pod is divided into two compartments: the OMS and the RCS housings. Each pod houses all the OMS and RCS propulsion components and is attached to the aft fuselage with 11 bolts. The pod skin panels are graphite epoxy honeycomb sandwich. The forward and aft bulkhead aft tank support bulkhead and floor truss beam are machined aluminum 2124. The centerline beam is 2024 aluminum sheet with titanium stiffeners and graphite epoxy frames. The OMS thrust structure is conventional 2124 aluminum construction. The cross braces are

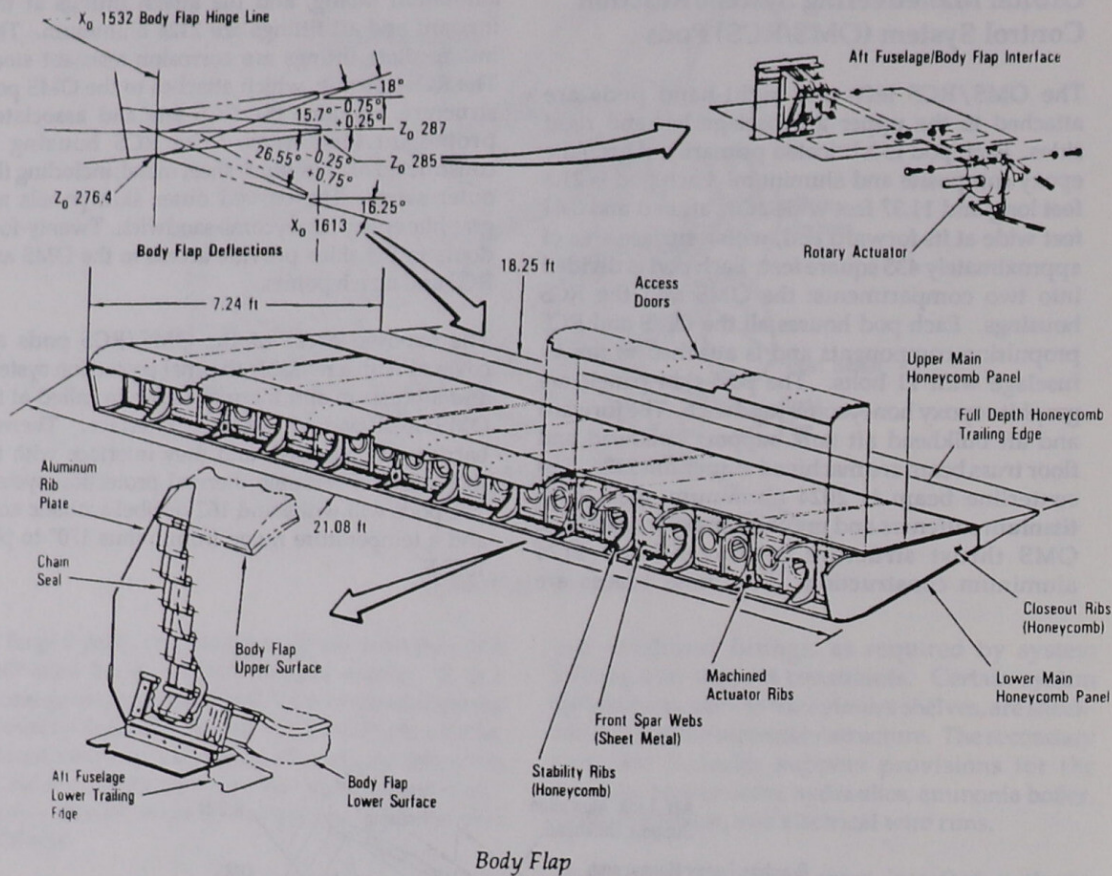
aluminum tubing, and the attach fittings at the forward and aft fittings are 2124 aluminum. The intermediate fittings are corrosion-resistant steel. The RCS housing, which attaches to the OMS pod structure, contains the RCS jets and associated propellant feed lines. The RCS housing is constructed of aluminum sheet metal, including flat outer skins. The curved outer skin panels are graphite epoxy honeycomb sandwich. Twenty-four doors in the skins provide access to the OMS and RCS and attach points.

The exposed areas of the OMS/RCS pods are covered with a reusable thermal protection system, and a pressure and thermal seal is installed at the OMS/RCS pod aft fuselage interface. Thermal barriers are installed, and they interface with the RCS jets and reusable thermal protection system. The pods will withstand 162-decibel acoustic noise and a temperature range from minus 170° to plus 135° F.



Aft Orbital Maneuvering System/Reaction Control System Pod

1. GENERAL DESCRIPTION  
1.2 Orbiter Structure



### Body Flap

The body flap thermally shields the three SSMEs during entry and provides the orbiter with pitch control trim during its atmospheric flight after entry.

The body flap is an aluminum structure consisting of ribs, spars, skin panels, and a trailing edge assembly. The main upper and lower forward honeycomb skin panels are joined to the ribs, spars, and honeycomb trailing edge with structural fasteners. The removable upper forward honeycomb skin panels complete the body flap structure.

The upper skin panels aft of the forward spar and the entire lower skin panels are mechanically attached to the ribs. The forward upper skin consists of five removable access panels attached to the ribs

with quick-release fasteners. The four integral-machined aluminum actuator ribs provide the aft fuselage interface through self-aligning bearings. Two bearings are located in each rib for attachment to the four rotary actuators located in the aft fuselage, which are controlled by the flight control system and the hydraulically actuated rotary actuators. The remaining ribs consist of eight stability ribs and two closeout ribs constructed of chemically milled aluminum webs bonded to aluminum honeycomb core. The forward spar web is of chemically milled sheets with flanged holes and stiffened beads. The spar web is riveted to the ribs. The trailing edge includes the rear spar, which is composed of piano-hinge half-cap angles, chemically milled skins, honeycomb aluminum core, closeouts, and plates. The trailing edge attaches to the upper and lower forward panels by the piano-hinge halves and hinge pins. Two moisture drain

lines and one hydraulic fluid drain line penetrate the trailing edge honeycomb core for horizontal and vertical drainage.

The body flap is covered with a reusable thermal protection system and an articulating pressure and thermal seal to its forward cover area on the lower surface of the body flap to block heat and air flow from the structures.

### Vertical Tail

The vertical tail consists of a structural fin surface, the rudder/speed brake surface, a tip, and a lower trailing edge. The rudder splits into two halves to serve as a speed brake.

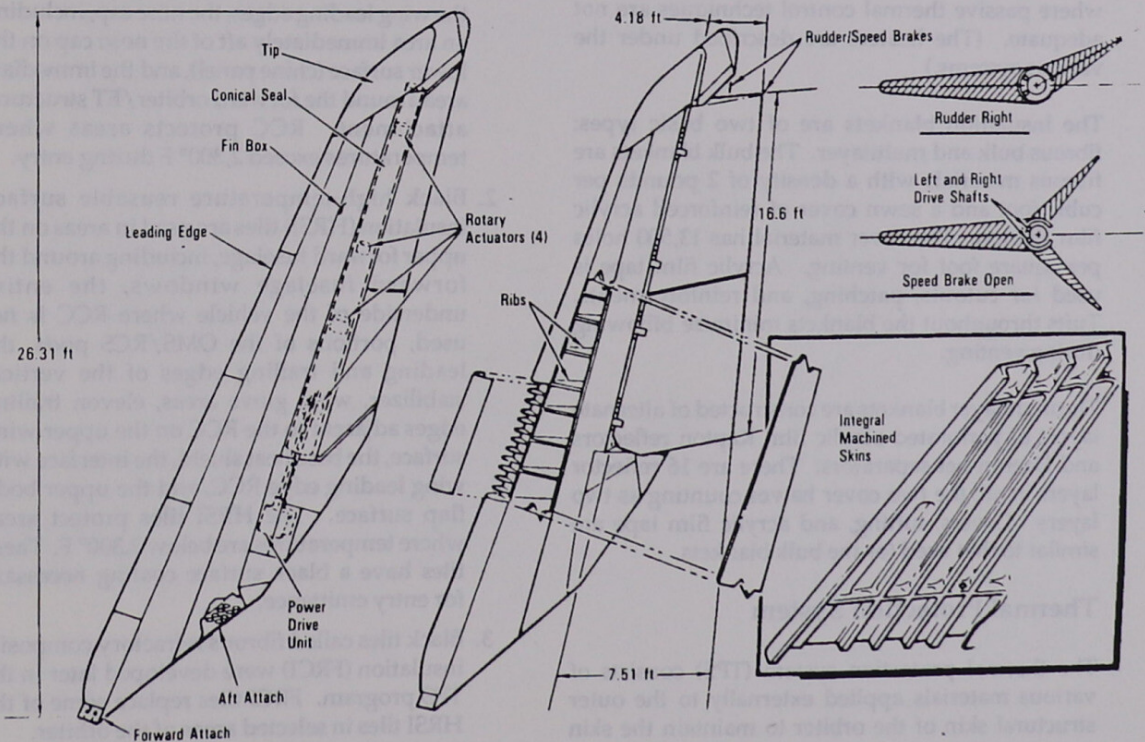
The vertical tail structure fin is made of aluminum. The main torque box is constructed of integral-machined skins and strings, ribs, and two machined spars. The fin is attached by two tension tie bolts at the root of the front spar of the vertical tail to the

forward bulkhead of the aft fuselage and by eight shear bolts at the root of the vertical tail rear spar to the upper structural surface of the aft fuselage.

The rudder/speed brake control surface is made of conventional aluminum ribs and spars with aluminum honeycomb skin panels and is attached through rotating hinge parts to the vertical tail fin.

The lower trailing edge area of the fin, which houses the rudder/speed brake power drive unit, is made of aluminum honeycomb skin.

The hydraulic power drive unit/mechanical rotary actuation system drives left- and right-hand drive shafts in the same direction for rudder control of plus or minus 27 degrees. For speed brake control, the drive shafts turn in opposite directions for a maximum of 49.3 degrees each. The rotary drive actions are also combined for joint rudder/speed brake control. The hydraulic power drive unit is controlled by the orbiter flight control system.



Vertical Tail



## 1. GENERAL DESCRIPTION

### 1.2 Orbiter Structure

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The vertical tail structure is designed for a 163-decibel acoustic environment with a maximum temperature of 350° F.

All-Inconel honeycomb conical seals house the rotary actuators and provide a pressure and thermal seal that withstands a maximum of 1,200° F.

The split halves of the rudder panels and trailing edge contain a thermal barrier seal.

The vertical tail and rudder/speed brake are covered with a reusable thermal protection system. A thermal barrier is also employed at the interface of the vertical stabilizer and aft fuselage.

#### Orbiter Passive Thermal Control

A passive thermal control system helps maintain the temperature of the orbiter spacecraft, systems, and components within their temperature limits. This system uses available orbiter heat sources and sinks supplemented by insulation blankets, thermal coatings, and thermal isolation methods. Heaters are provided on components and systems in areas where passive thermal control techniques are not adequate. (The heaters are described under the various systems.)

The insulation blankets are of two basic types: fibrous bulk and multilayer. The bulk blankets are fibrous materials with a density of 2 pounds per cubic foot and a sewn cover of reinforced acrylic film Kapton. The cover material has 13,500 holes per square foot for venting. Acrylic film tape is used for cutouts, patching, and reinforcements. Tufts throughout the blankets minimize billowing during venting.

The multilayer blankets are constructed of alternate layers of perforated acrylic film Kapton reflectors and Dacron net separators. There are 16 reflector layers in all, the two cover halves counting as two layers. Covers, tufting, and acrylic film tape are similar to that used for the bulk blankets.

#### Thermal Protection System

The thermal protection system (TPS) consists of various materials applied externally to the outer structural skin of the orbiter to maintain the skin within acceptable temperatures, primarily during

the entry phase of the mission. The orbiter's outer structural skin is constructed primarily of aluminum and graphite epoxy.

During entry, the TPS materials protect the orbiter outer skin from temperatures above 350° F. In addition, they are reusable for 100 missions with refurbishment and maintenance. These materials perform in temperature ranges from minus 250° F in the cold soak of space to entry temperatures that reach nearly 3,000° F. The TPS also sustains the forces induced by deflections of the orbiter airframe as it responds to the various external environments. Because the TPS is installed on the outside of the orbiter skin, it establishes the aerodynamics over the vehicle in addition to acting as the heat sink.

Orbiter interior temperatures also are controlled by internal insulation, heaters, and purging techniques in the various phases of the mission.

The TPS is a passive system consisting of materials selected for stability at high temperatures and weight efficiency. These materials are as follows:

1. Reinforced carbon-carbon (RCC) is used on the wing leading edges, the nose cap, including an area immediately aft of the nose cap on the lower surface (chine panel), and the immediate area around the forward orbiter/ET structural attachment. RCC protects areas where temperatures exceed 2,300° F during entry.
2. Black high-temperature reusable surface insulation (HRSI) tiles are used in areas on the upper forward fuselage, including around the forward fuselage windows, the entire underside of the vehicle where RCC is not used, portions of the OMS/RCS pods, the leading and trailing edges of the vertical stabilizer, wing glove areas, elevon trailing edges adjacent to the RCC on the upper wing surface, the base heat shield, the interface with wing leading edge RCC, and the upper body flap surface. The HRSI tiles protect areas where temperatures are below 2,300° F. These tiles have a black surface coating necessary for entry emittance.
3. Black tiles called fibrous refractory composite insulation (FRCI) were developed later in the TPS program. FRCI tiles replace some of the HRSI tiles in selected areas of the orbiter.

4. Low-temperature reusable surface insulation (LRSI) white tiles are used in selected areas of the forward, mid-, and aft fuselages, vertical tail, upper wing, and OMS/RCS pods. These tiles protect areas where temperatures are below 1,200° F. These tiles have a white surface coating to provide better thermal characteristics on orbit.
5. After the initial delivery of Columbia, an advanced flexible reusable surface insulation (AFRSI) was developed. This material consists of sewn composite quilted fabric insulation batting between two layers of white fabric that are sewn together to form a quilted blanket. AFRSI was used on Discovery and Atlantis to replace the vast majority of the LRSI tiles. Following its seventh flight, Columbia also was modified to replace most of the LRSI tiles with AFRSI. The AFRSI blankets provide improved producibility and durability, reduced fabrication and installation time and costs, and a weight reduction over that of the LRSI tiles. The AFRSI blankets protect areas where temperatures are below 1,200° F.
6. White blankets made of coated Nomex felt reusable surface insulation (FRSI) are used on the upper payload bay doors, portions of the midfuselage and aft fuselage sides, portions of the upper wing surface, and a portion of the OMS/RCS pods. The FRSI blankets protect areas where temperatures are below 700° F.
7. Additional materials are used in other special areas. These materials are thermal panes for the windows, metal for the forward RCS fairings and elevon seal panels on the upper wing to elevon interface, a combination of white- and black-pigmented silica cloth for thermal barriers and gap fillers around operable penetrations, such as main and nose landing gear doors, egress and ingress flight crew side hatch, umbilical doors, elevon cove, forward RCS, RCS jets, midfuselage vent doors, payload bay doors, rudder/speed brake, OMS/RCS pods, and gaps between TPS tiles in high differential pressure areas, and room-temperature vulcanizing material for the thick aluminum T-0 umbilicals on the sides of the orbiter aft fuselage.

### 1.3 EXTERNAL TANK

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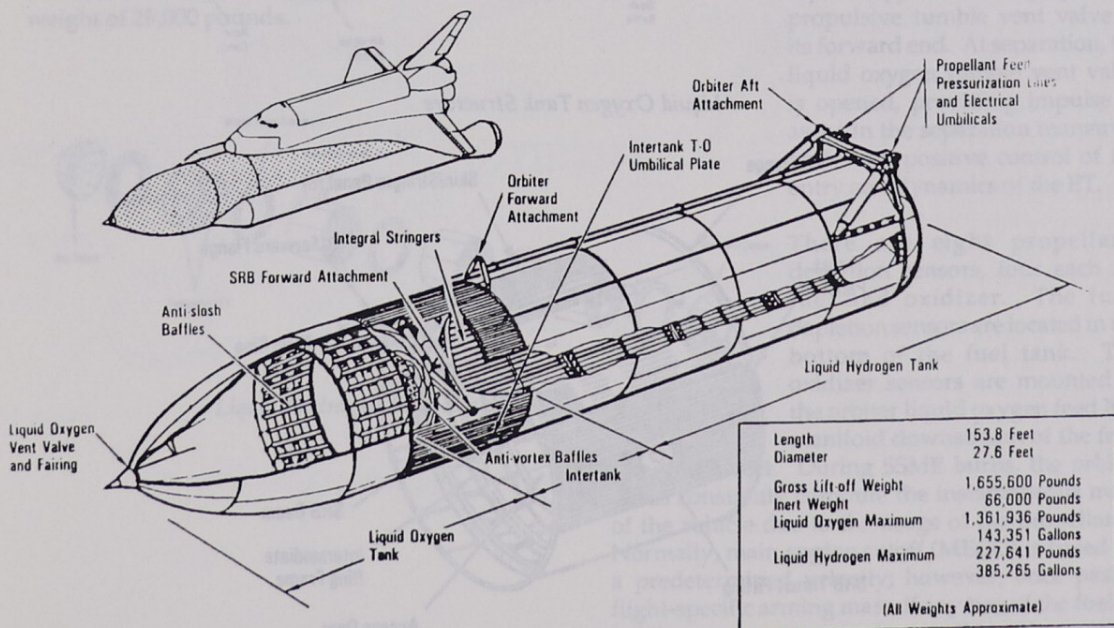
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The external tank (ET) contains the liquid hydrogen fuel and liquid oxygen oxidizer and supplies them under pressure to the three SSMEs in the orbiter during lift-off and ascent. When the SSMEs are shut down, the ET is jettisoned, enters the Earth's atmosphere, breaks up, and impacts in a remote ocean area. It is not recovered. ET impact zones for direct and standard insertion are discussed in Section 1.1.

The largest and heaviest (when loaded) element of the Space Shuttle, the ET has three major components: the forward liquid oxygen tank, an unpressurized intertank that contains most of the electrical components, and the aft liquid hydrogen tank.

Beginning with the STS-6 mission, a lightweight ET was introduced. Although future tanks may vary slightly, each will weigh approximately 66,000 pounds inert. (The last heavyweight tank, flown on STS-7, weighed approximately 77,000 pounds inert.)

The ET is attached to the orbiter at one forward attachment point and two aft points. In the aft attachment area, there are also umbilicals that carry fluids, gases, electrical signals, and electrical power between the tank and the orbiter. Electrical signals and controls between the orbiter and the two SRBs also are routed through those umbilicals.



Lightweight External Tank

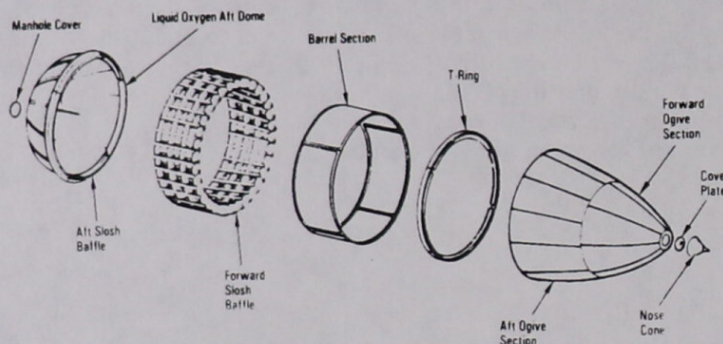
## Liquid Oxygen Tank

The liquid oxygen tank is an aluminum monocoque structure composed of a fusion-welded assembly of preformed, chem-milled gores, panels, machined fittings, and ring chords. It operates in a pressure range of 20 to 22 psig. The tank contains anti-slosh and anti-vortex provisions to minimize liquid residuals and damp fluid motion. The tank feeds into a 17-inch-diameter feed line that conveys the liquid oxygen through the intertank, then outside the ET to the aft right-hand ET/orbiter disconnect umbilical. The 17-inch-diameter feed line permits liquid oxygen to flow at approximately 2,787 pounds per second with the SSMEs operating at 104 percent or permits a maximum flow of 17,592 gallons per minute. The liquid oxygen tank's double-wedge

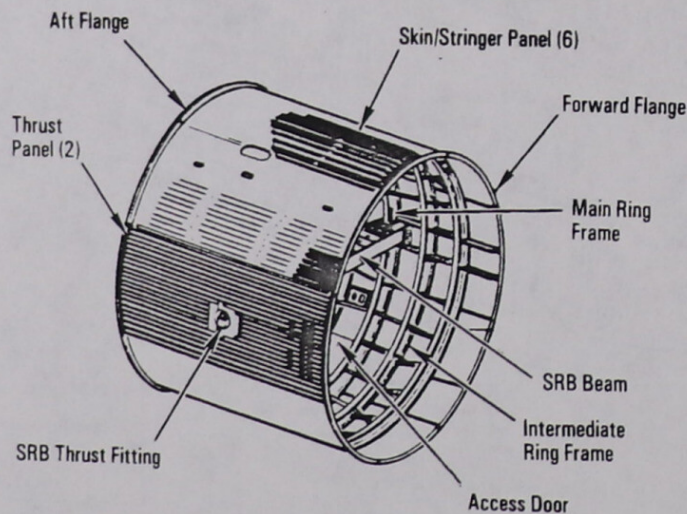
nose cone reduces drag and heating, contains the vehicle's ascent air data system (for nine tanks only) and serves as a lightning rod. The liquid oxygen tank's volume is 19,563 cubic feet. It is 331 inches in diameter, 592 inches long and weighs 12,000 pounds empty.

## Intertank

The intertank is a steel/aluminum semimonocoque cylindrical structure with flanges on each end for joining the liquid oxygen and liquid hydrogen tanks. The intertank houses ET instrumentation components and provides an umbilical plate that interfaces with the ground facility arm for purge gas supply, hazardous gas detection, and hydrogen gas boiloff during ground operations. It consists of



Liquid Oxygen Tank Structure

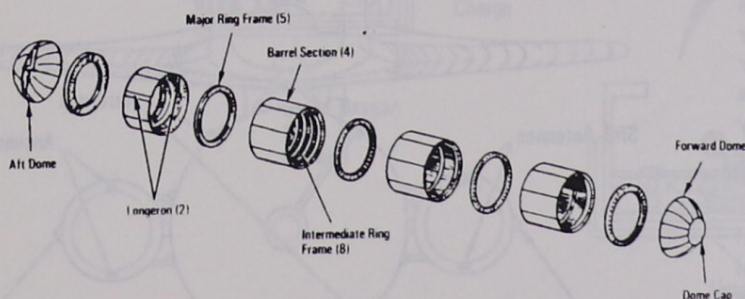


Intertank Structure

mechanically joined skin, stringers, and machined panels of aluminum alloy. The intertank is vented during flight. The intertank contains the forward SRB-ET attach thrust beam and fittings that distribute the SRB loads to the liquid oxygen and liquid hydrogen tanks. The intertank is 270 inches long, 331 inches in diameter, and weighs 12,100 pounds.

## Liquid Hydrogen Tank

The liquid hydrogen tank is an aluminum semimonocoque structure of fusion-welded barrel sections, five major ring frames, and forward and aft ellipsoidal domes. Its operating pressure range is 32 to 34 psia. The tank contains an anti-vortex baffle and siphon outlet to transmit the liquid hydrogen from the tank through a 17-inch line to the left aft umbilical. The liquid hydrogen feed line flow rate is 465 pounds per second with the SSMEs at 104 percent or a maximum flow of 47,365 gallons per minute. At the forward end of the liquid hydrogen tank is the ET/orbiter forward attachment pod strut, and at its aft end are the two ET/orbiter aft attachment ball fittings as well as the aft SRB-ET stabilizing strut attachments. The liquid hydrogen tank is 331 inches in diameter, 1,160 inches long, and has a volume of 53,518 cubic feet and a dry weight of 29,000 pounds.



Liquid Hydrogen Tank Structure

## Thermal Protection System

The ET thermal protection system consists of sprayed-on foam insulation and premolded ablator materials. The system also includes the use of phenolic thermal insulators to preclude air liquefaction. Thermal isolators are required for liquid hydrogen tank attachments to preclude the liquefaction of air-exposed metallic attachments and to reduce heat flow into the liquid hydrogen. The thermal protection system weighs 4,823 pounds.

## Hardware and Instrumentation

The external hardware, ET/orbiter attachment fittings, umbilical fittings, electrical, and range safety system weigh 9,100 pounds.

Each propellant tank has a vent and relief valve at its forward end. This dual-function valve can be opened by ground support equipment for the vent function during prelaunch and can open during flight when the ullage pressure of the liquid hydrogen tank reaches 38 psig, or the ullage pressure of the liquid oxygen tank reaches 25 psig.

The liquid oxygen tank contains a separate, pyrotechnically operated, propulsive tumble vent valve at its forward end. At separation, the liquid oxygen tumble vent valve is opened, providing impulse to assist in the separation maneuver and more positive control of the entry aerodynamics of the ET.

There are eight propellant-depletion sensors, four each for fuel and oxidizer. The fuel-depletion sensors are located in the bottom of the fuel tank. The oxidizer sensors are mounted in the orbiter liquid oxygen feed line manifold downstream of the feed line disconnect. During SSME burns, the orbiter GPCs constantly compute the instantaneous mass of the vehicle due to the usage of the propellants. Normally, main engine cutoff (MECO) is based on a predetermined velocity; however, once past a flight-specific arming mass, if any two of the fuel or oxidizer sensors sense a dry condition, the engines will be shut down.

## 1. GENERAL DESCRIPTION

### 1.3 External Tank

The locations of the liquid oxygen sensors allow the maximum amount of oxidizer to be consumed in the engines, while allowing sufficient time to shut down the engines before the oxidizer pumps cavitate (run dry). In addition, 1,100 pounds of liquid hydrogen are loaded over and above that required by the 6:1 oxidizer/fuel engine mixture ratio. This assures that MECO from the depletion sensors is fuel-rich; oxidizer-rich engine shutdowns can cause burning and severe erosion of engine components.

Four pressure transducers located at the top of the liquid oxygen and liquid hydrogen tanks monitor the ullage pressures.

Each of the two aft ET umbilical plates mate with a corresponding plate on the orbiter. The plates help maintain alignment among the umbilicals. Physical strength at the umbilical plates is provided by bolting corresponding umbilical plates together. When the orbiter GPCs command external tank separation, the bolts are severed by pyrotechnic devices.

The ET has five propellant umbilical valves that interface with orbiter umbilicals: two for the liquid oxygen tank and three for the liquid hydrogen tank. One of the liquid oxygen tank umbilical valves is for liquid oxygen, the other for gaseous oxygen. The liquid hydrogen tank umbilical has two valves for liquid and one for gas. The intermediate-diameter liquid hydrogen umbilical is a recirculation umbilical used only during the liquid hydrogen chill-down sequence during prelaunch.

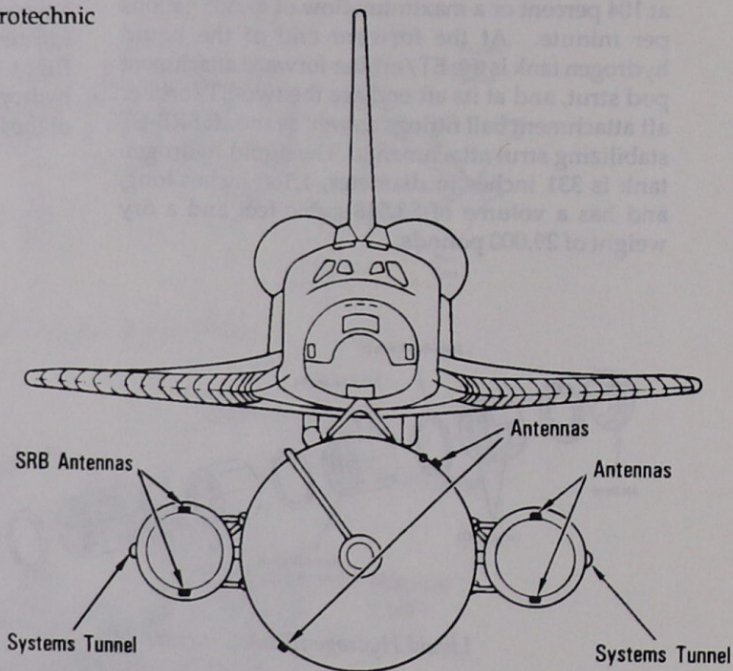
The ET also has two electrical umbilicals that carry electrical power from the orbiter to the tank and the two SRBs and provide information from the SRBs and ET to the orbiter.

A swing-arm-mounted cap to the fixed service structure covers the oxygen tank vent on top of the ET during the countdown and is retracted about two minutes before lift-off. The cap siphons off oxygen vapor that threatens to form ice on the ET, thus protecting the orbiter's TPS during launch.

### Range Safety System

A range safety system provides for dispersing tank propellants if necessary. It includes a battery power source, a receiver/decoder, antennas, and ordnance.

Various parameters are monitored and displayed on the flight deck display and control panel and are transmitted to the ground.



*External Tank Range Safety System Antennas*

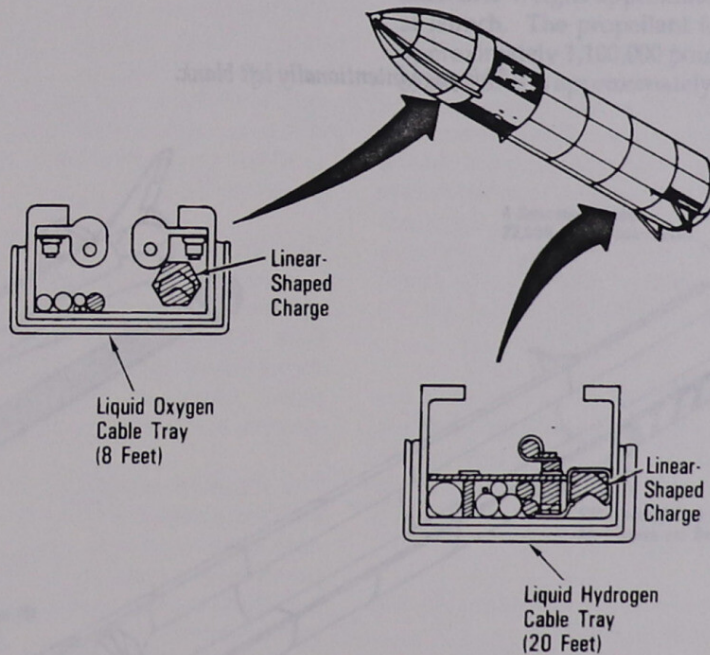
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The two solid rocket boosters (SRBs) provide the main thrust to lift the Space Shuttle off the pad and up to an altitude of about 130,000 feet, or 24 nautical miles. In addition, the two SRBs carry the entire weight of the ET and orbiter and transmit the weight load through their structure to the mobile launcher platform. Each booster has a thrust (at level) of approximately 7,000,000 pounds at launch. They are ignited after the main liftoff thrust level is verified. The two SRBs provide 71.4 percent of the thrust at 1-1/2 off and during first-stage ascent. Seventy-five seconds after SRB separation, SRB ejection occurs at an altitude of approximately 20,000 feet, or 35 nautical miles. SRB impact occurs in the ocean approximately 112 nautical miles downrange.

The SRBs are the largest solid-propellant motors ever flown and the first designed for reuse. Each is 149 feet long and 33 feet in diameter.

Each SRB weighs approximately 7,000,000 pounds. The propellant for each motor weighs 10,000,000 pounds. The inert weight is approximately 170,000 pounds.



External Tank Range Safety System Linear-Shaped Charges

## 1.4 SOLID ROCKET BOOSTERS

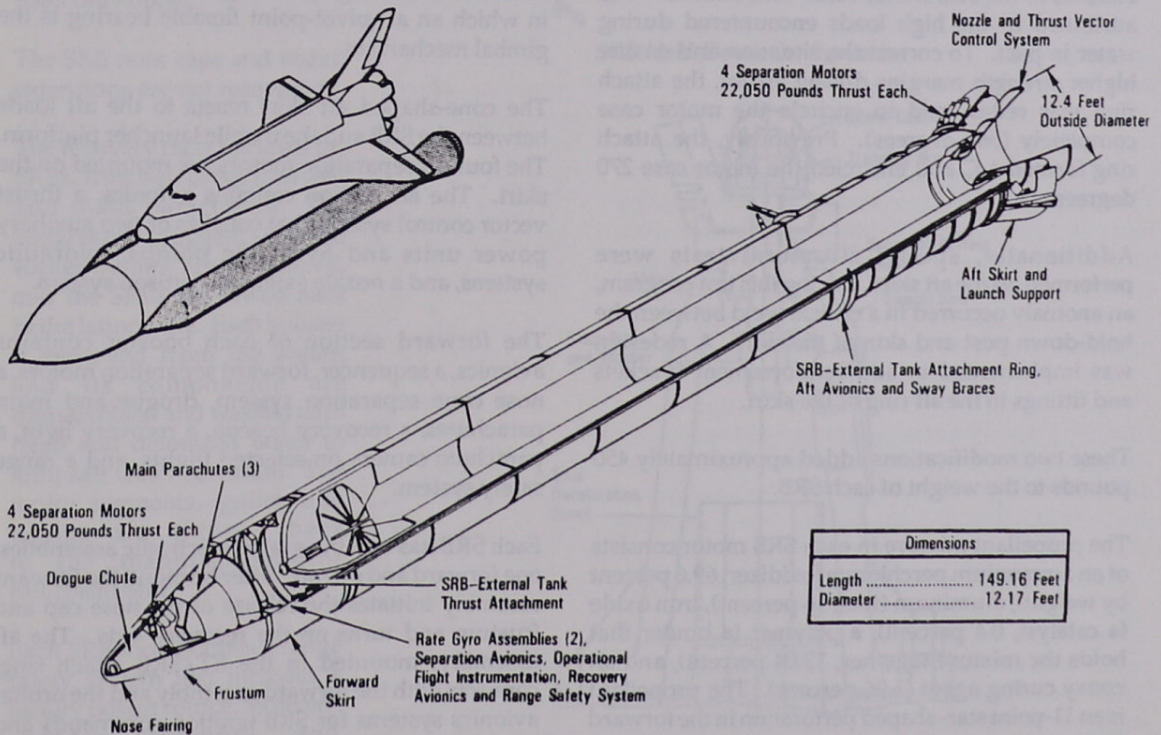
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The two solid rocket boosters (SRBs) provide the main thrust to lift the Space Shuttle off the pad and up to an altitude of about 150,000 feet, or 24 nautical miles. In addition, the two SRBs carry the entire weight of the ET and orbiter and transmit the weight load through their structure to the mobile launcher platform. Each booster has a thrust (sea level) of approximately 3,300,000 pounds at launch. They are ignited after the three SSMEs' thrust level is verified. The two SRBs provide 71.4 percent of the thrust at lift-off and during first-stage ascent. Seventy-five seconds after SRB separation, SRB apogee occurs at an altitude of approximately 220,000 feet, or 35 nautical miles. SRB impact occurs in the ocean approximately 122 nautical miles downrange.

The SRBs are the largest solid-propellant motors ever flown and the first designed for reuse. Each is 149.16 feet long and 12.17 feet in diameter.

Each SRB weighs approximately 1,300,000 pounds at launch. The propellant for each motor weighs approximately 1,100,000 pounds. The inert weight of each SRB is approximately 192,000 pounds.



Solid Rocket Booster



Primary elements of each booster are the motor (including case, propellant, igniter, and nozzle), structure, separation systems, operational flight instrumentation, recovery avionics, pyrotechnics, deceleration system, thrust vector control system, and range safety destruct system.

Each booster is attached to the ET at the SRB's aft frame by two lateral sway braces and a diagonal attachment. The forward end of each SRB is attached to the external tank at the forward end of the SRB's forward skirt. On the launch pad, each booster also is attached to the mobile launcher platform at the aft skirt by four bolts and nuts that are severed by small explosives at lift-off.

During the downtime following the Challenger accident, detailed structural analyses were performed on critical structural elements of the SRB. Analyses were primarily focused in areas where anomalies had been noted during postflight inspection of recovered hardware.

One of the areas was the attach ring where the SRBs are connected to the ET. Areas of distress were noted in some of the fasteners where the ring attaches to the SRB motor case. This situation was attributed to the high loads encountered during water impact. To correct the situation and ensure higher strength margins during ascent, the attach ring was redesigned to encircle the motor case completely (360 degrees). Previously, the attach ring formed a C and encircled the motor case 270 degrees.

Additionally, special structural tests were performed on the aft skirt. During this test program, an anomaly occurred in a critical weld between the hold-down post and skin of the skirt. A redesign was implemented to add reinforcement brackets and fittings in the aft ring of the skirt.

These two modifications added approximately 450 pounds to the weight of each SRB.

The propellant mixture in each SRB motor consists of an ammonium perchlorate (oxidizer, 69.6 percent by weight), aluminum (fuel, 16 percent), iron oxide (a catalyst, 0.4 percent), a polymer (a binder that holds the mixture together, 12.04 percent), and an epoxy curing agent (1.96 percent). The propellant is an 11-point star-shaped perforation in the forward

motor segment and a double-truncated-cone perforation in each of the aft segments and aft closure. This configuration provides high thrust at ignition and then reduces the thrust by approximately a third 50 seconds after lift-off to prevent overstressing the vehicle during maximum dynamic pressure.

The SRBs are used as matched pairs, and each is made up of four solid rocket motor segments. The pairs are matched by loading each of the four motor segments in pairs from the same batches of propellant ingredients to minimize any thrust imbalance. The segmented-casing design assures maximum flexibility in fabrication and ease of transportation and handling. Each segment is shipped to the launch site on a heavy-duty rail car with a specially built cover.

The nozzle expansion ratio of each booster beginning with the STS-8 mission is 7-to-79. The nozzle is gimballed for thrust vector control. Each SRB has its own redundant auxiliary power units and hydraulic pumps. The all-axis gimbaling capability is 8 degrees. Each nozzle has a carbon cloth liner that erodes and chars during firing. The nozzle is a convergent-divergent, movable design in which an aft pivot-point flexible bearing is the gimbal mechanism.

The cone-shaped aft skirt reacts to the aft loads between the SRB and the mobile launcher platform. The four aft separation motors are mounted on the skirt. The aft section contains avionics, a thrust vector control system that consists of two auxiliary power units and hydraulic pumps, hydraulic systems, and a nozzle extension jettison system.

The forward section of each booster contains avionics, a sequencer, forward separation motors, a nose cone separation system, drogue and main parachutes, a recovery beacon, a recovery light, a parachute camera on selected flights, and a range safety system.

Each SRB has two integrated electronic assemblies, one forward and one aft. After burnout, the forward assembly initiates the release of the nose cap and frustum and turns on the recovery aids. The aft assembly, mounted in the ET/SRB attach ring, connects with the forward assembly and the orbiter avionics systems for SRB ignition commands and

nozzle thrust vector control. Each integrated electronic assembly has a multiplexer/demultiplexer, which sends or receives more than one message, signal, or unit of information on a single communication channel.

Eight booster separation motors (four in the nose frustum and four in the aft skirt) of each SRB burn for 1.02 seconds at SRB separation from the ET. Each solid rocket separation motor is 31.1 inches long and 12.8 inches in diameter.

Location aids are provided for each SRB, frustum/drogue chutes, and main parachutes. These include a transmitter, antenna, strobe/converter, battery, and salt water switch electronics. The location aids are designed for a minimum operating life of 72 hours and when refurbished are considered usable up to 20 times. The flashing light is an exception. It has an operating life of 280 hours. The battery is used only once.

The SRB nose caps and nozzle extensions are not recovered.

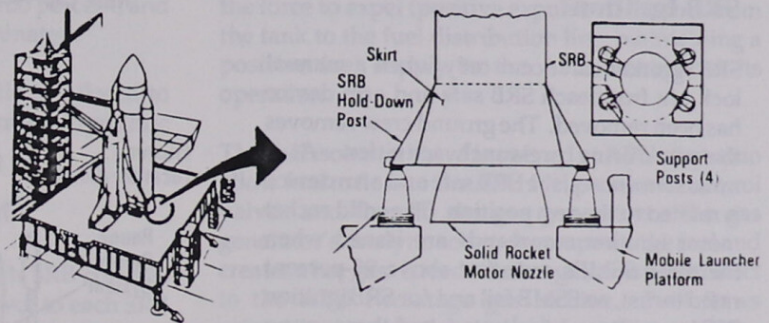
The recovery crew retrieves the SRBs, frustum/drogue chutes, and main parachutes. The nozzles are plugged, the solid rocket motors are dewatered, and the SRBs are towed back to the launch site. Each booster is removed from the water, and its components are disassembled and washed with fresh and deionized water to limit salt water corrosion. The motor segments, igniter, and nozzle are shipped back to the manufacturer for refurbishment.

Each SRB incorporates a range safety system that includes a battery power source, receiver/decoder, antennas, and ordnance.

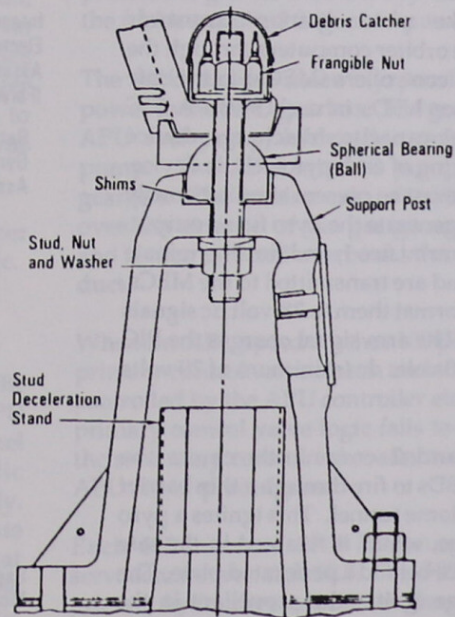
## Hold-Down Posts

Each SRB has four hold-down posts that fit into corresponding support posts on the mobile launcher platform. Hold-down bolts hold the SRB and launcher platform posts together. Each bolt has a nut at each end, but only the top nut is frangible. The top nut contains two NASA standard detonators (NSDs), which are ignited at solid rocket motor ignition commands.

When the two NSDs are ignited at each hold-down, the hold-down bolt travels downward because of the release of tension in the bolt (pretensioned before



SRB Hold-Down Configuration



SRB Support/Hold-Down Post

launch), NSD gas pressure, and gravity. The bolt is stopped by the stud deceleration stand, which contains sand. The SRB bolt is 28 inches long and is 3.5 inches in diameter. The frangible nut is captured in a blast container.

The solid rocket motor ignition commands are issued by the orbiter's computers through the master events controllers to the hold-down pyrotechnic initiator controllers (PICs) on the mobile launcher platform. They provide the ignition to the hold-down NSDs. The launch processing system monitors the SRB hold-down PICs for low voltage during the last 16 seconds before launch. PIC low voltage will initiate a launch hold.

### SRB Ignition

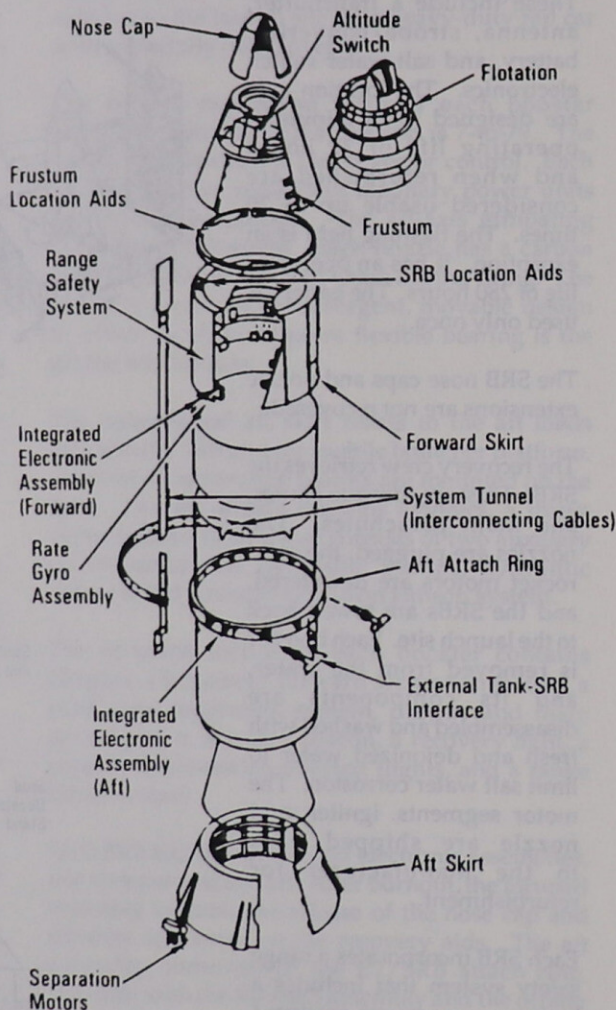
SRB ignition can occur only when a manual lock pin from each SRB safe and arm device has been removed. The ground crew removes the pin during prelaunch activities. At T minus 5 minutes, the SRB safe and arm device is rotated to the arm position. The solid rocket motor ignition commands are issued when the three SSMEs are at or above 90-percent rated thrust, no SSME fail and/or SRB ignition PIC low voltage is indicated, and there are no holds from the launch processing system.

The solid rocket motor ignition commands are sent by the orbiter computers through the master events controllers (MECs) to the safe and arm device NSDs in each SRB. A PIC single-channel capacitor discharge device controls the firing of each pyrotechnic device. Three signals must be present simultaneously for the PIC to generate the pyro firing output. These signals, arm, fire 1, and fire 2, originate in the GPCs and are transmitted to the MECs. The MECs reformat them to 28-volt dc signals for the PICs. The arm signal charges the PIC capacitor to 40 volts dc (minimum of 20 volts dc).

The fire 1 and 2 commands cause the redundant NSDs to fire through a thin barrier seal down a flame tunnel. This ignites a pyro booster charge, which is retained in the safe and arm device behind a perforated plate. The booster charge ignites the propellant in the igniter initiator, and combustion products of

this propellant ignite the solid rocket motor initiator, which fires down the length of the solid rocket motor igniting the solid rocket motor propellant.

The GPC launch sequence also controls certain critical main propulsion system (MPS) valves and monitors the engine-ready indications from the SSMEs. The MPS start commands are issued by the GPCs at T minus 6.6 seconds (staggered start—engine 3, engine 2, engine 1—all approximately within 0.25 second), and the sequence monitors the thrust buildup of each engine. All three SSMEs must reach the required 90-percent thrust within 3 seconds; otherwise, an orderly shutdown is commanded, and safing functions are initiated.



Solid Rocket Booster—Exploded View

Normal thrust buildup to the required 90-percent thrust level will result in the SSMEs being commanded to the lift-off position at T minus 3 seconds as well as the fire 1 command being issued to arm the SRBs. At T minus 3 seconds, the vehicle base bending load modes are allowed to initialize (movement of approximately 25.5 inches measured at the tip of the external tank, with movement towards the external tank).

At T minus 0, the two SRBs are ignited, separation of the four explosive bolts on each SRB is initiated (each bolt is 28 inches long and 3.5 inches in diameter), the two T-0 umbilicals (one on each side of the spacecraft) are retracted, the onboard master timing unit, event timer, and mission event timers are started, the three SSMEs are at 100 percent, and the ground launch sequence is terminated.

The solid rocket motor thrust profile is tailored to reduce thrust during the maximum dynamic pressure region.

### Electrical Power Distribution

Electrical power distribution in each SRB consists of orbiter-supplied main dc bus power to each SRB via SRB buses A, B, and C. Orbiter main dc buses A, B, and C supply main dc bus power to corresponding SRB buses A, B, and C. In addition, orbiter main dc bus C supplies backup power to SRB buses A and B, and orbiter bus B supplies backup power to SRB bus C. This electrical power distribution arrangement allows all SRB buses to remain powered in the event one orbiter main bus fails.

The nominal dc voltage is 28 volts dc, with an upper limit of 32 volts dc and a lower limit of 24 volts dc.

### Hydraulic Power Units

There are two self-contained, independent hydraulic power units (HPUs) on each SRB. Each HPU consists of an auxiliary power unit (APU), fuel supply module, hydraulic pump, hydraulic reservoir, and hydraulic fluid manifold assembly. The APUs are fueled by hydrazine and generate mechanical shaft power to a hydraulic pump that produces hydraulic pressure for the SRB hydraulic system. The two separate HPUs and two hydraulic systems are located on the aft end of each SRB

between the SRB nozzle and aft skirt. The HPU components are mounted on the aft skirt between the rock and tilt actuators. The two systems operate from T minus 28 seconds until SRB separation from the orbiter and external tank. The two independent hydraulic systems are connected to the rock and tilt servoactuators.

The APU controller electronics are located in the SRB aft integrated electronic assemblies on the aft external tank attach rings.

The APUs and their fuel systems are isolated from each other. Each fuel supply module (tank) contains 22 pounds of hydrazine. The fuel tank is pressurized with gaseous nitrogen at 400 psi, which provides the force to expel (positive expulsion) the fuel from the tank to the fuel distribution line, maintaining a positive fuel supply to the APU throughout its operation.

The fuel isolation valve is opened at APU startup to allow fuel to flow to the APU fuel pump and control valves and then to the gas generator. The gas generator's catalytic action decomposes the fuel and creates a hot gas. It feeds the hot gas exhaust product to the APU two-stage gas turbine. Fuel flows primarily through the startup bypass line until the APU speed is such that the fuel pump outlet pressure is greater than the bypass line's. Then all the fuel is supplied to the fuel pump.

The APU turbine assembly provides mechanical power to the APU gearbox. The gearbox drives the APU fuel pump, hydraulic pump, and lube oil pump. The APU lube oil pump lubricates the gearbox. The turbine exhaust of each APU flows over the exterior of the gas generator, cooling it, and is then directed overboard through an exhaust duct.

When the APU speed reaches 100 percent, the APU primary control valve closes, and the APU speed is controlled by the APU controller electronics. If the primary control valve logic fails to the open state, the secondary control valve assumes control of the APU at 113-percent speed.

Each HPU on an SRB is connected to both servoactuators on that SRB. One HPU serves as the primary hydraulic source for the servoactuator, and the other HPU serves as the secondary hydraulics

for the servoactuator. Each servoactuator has a switching valve that allows the secondary hydraulics to power the actuator if the primary hydraulic pressure drops below 2,050 psi. A switch contact on the switching valve will close when the valve is in the secondary position. When the valve is closed, a signal is sent to the APU controller that inhibits the 100-percent APU speed control logic and enables the 113-percent APU speed control logic. The 100-percent APU speed enables one APU/HPU to supply sufficient operating hydraulic pressure to both servoactuators of that SRB.

The APU 100-percent speed corresponds to 72,000 rpm and 113-percent to 81,000 rpm.

The APUs/HPUs and hydraulic systems are reusable for 20 missions.

### Thrust Vector Control

Each SRB has two hydraulic gimbal servoactuators: one for rock and one for tilt. The servoactuators provide the force and control to gimbal the nozzle for thrust vector control.

The Space Shuttle ascent thrust vector control (ATVC) portion of the flight control system directs the thrust of the three SSMEs and the two SRB nozzles to control attitude and trajectory during lift-off and ascent. Commands from the guidance system are transmitted to the ATVC drivers, which transmit signals proportional to the commands to each servoactuator of the main engines and SRBs. Four independent flight control system channels and four ATVC channels control six main engine and four SRB ATVC drivers, with each driver controlling one hydraulic port on each main and SRB servoactuator.

Each SRB servoactuator consists of four independent, two-stage servovalves that receive signals from the drivers. Each servovalve controls one power spool in each actuator, which positions an actuator ram and the nozzle to control the direction of thrust.

The four servovalves in each actuator provide a force-summed majority voting arrangement to position the power spool. With four identical commands to the four servovalves, the actuator force-sum action prevents a single erroneous

command from affecting power ram motion. If the erroneous command persists for more than a predetermined time, differential pressure sensing activates a selector valve to isolate and remove the defective servovalve hydraulic pressure, permitting the remaining channels and servovalves to control the actuator ram spool.

Failure monitors are provided for each channel to indicate which channel has been bypassed. An isolation valve on each channel provides the capability of resetting a failed or bypassed channel.

Each actuator ram is equipped with transducers for position feedback to the thrust vector control system. Within each servoactuator ram is a splashdown load relief assembly to cushion the nozzle at water splashdown and prevent damage to the nozzle flexible bearing.

### SRB Rate Gyro Assemblies

Each SRB contains two rate gyro assemblies (RGAs), with each RGA containing one pitch and one yaw gyro. These provide an output proportional to angular rates about the pitch and yaw axes to the orbiter computers and guidance, navigation, and control system during first-stage ascent flight in conjunction with the orbiter roll rate gyros until SRB separation. At SRB separation, a switchover is made from the SRB RGAs to the orbiter RGAs.

The SRB RGA rates pass through the orbiter flight aft multiplexers/ demultiplexers to the orbiter GPCs. The RGA rates are then interchangeable mid-value-selected in redundancy management to provide SRB pitch and yaw rates to the user software. The RGAs are designed for 20 missions.

### SRB Separation

SRB separation is initiated when the three solid rocket motor chamber pressure transducers are processed in the redundancy management interchangeable middle value select, and the head-end chamber pressure of both SRBs is less than or equal to 50 psi. A backup cue is the time elapsed from booster ignition.

The separation sequence is initiated, commanding the thrust vector control actuators to the null position and putting the main propulsion system

into a second-stage configuration (0.8 second from sequence initialization), which ensures the thrust of each SRB is less than 100,000 pounds. Orbiter yaw attitude is held for 4 seconds, and SRB thrust drops to less than 60,000 pounds.

The SRBs separate from the external tank within 30 milliseconds of the ordnance firing command.

The forward attachment point consists of a ball (SRB) and socket (ET) held together by one bolt. The bolt contains one NSD pressure cartridge at each end. The forward attachment point also carries the range safety system cross-strap wiring connecting each SRB and the ET range safety systems with each other.

The aft attachment points consist of three separate struts: upper, diagonal and lower. Each strut contains one bolt with an NSD pressure cartridge at each end. The upper strut also carries the umbilical interface between its SRB and the external tank and on to the orbiter.

There are four booster separation motors (BSMs) on each end of each SRB. The BSMs separate the SRBs from the external tank. The solid rocket motors

in each cluster of four are ignited by firing redundant NSD pressure cartridges into redundant confined detonating fuse manifolds.

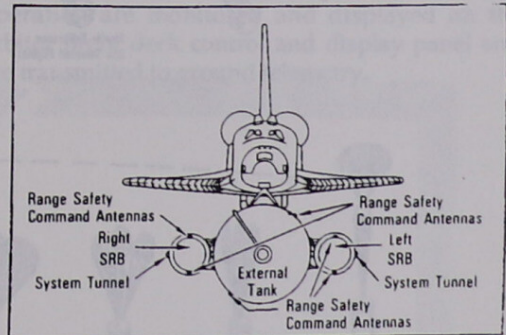
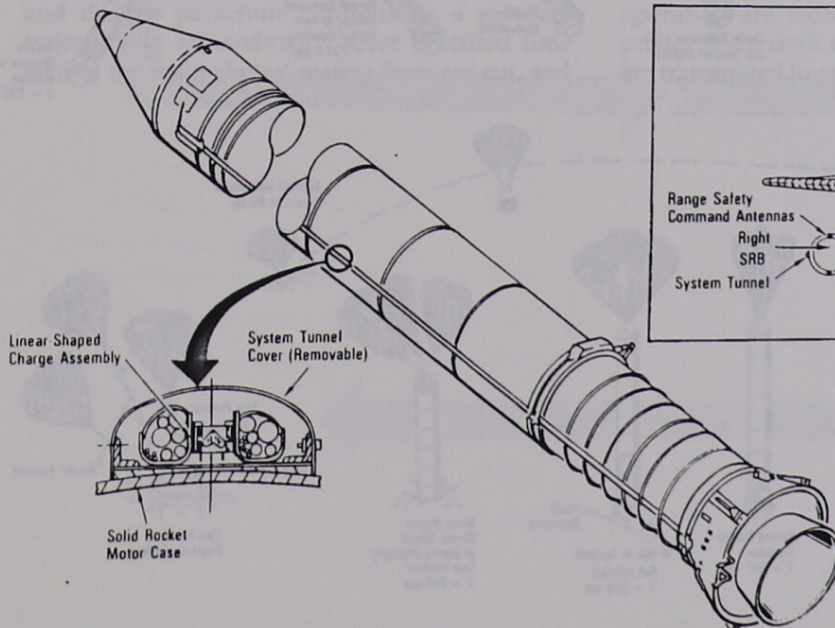
The separation commands issued from the orbiter by the SRB separation sequence initiate the redundant NSD pressure cartridge in each bolt and ignite the BSMs to effect a clean separation.

### Range Safety System

The Shuttle vehicle has three range safety systems (RSSs). One is located in each SRB and one in the external tank. Any one or all three are capable of receiving two command messages (arm and fire) transmitted from the ground station. The RSS is used only when the Shuttle vehicle violates a launch trajectory red line.

An RSS consists of two antenna couplers, command receivers/ decoders, a dual distributor, a safe and arm device with two NSDs, two confined detonating fuse (CDF) manifolds, seven CDF assemblies, and one linear-shaped charge (LSC).

The antenna couplers provide the proper impedance for radio frequency and ground support equipment commands. The command receivers are tuned to



SRB Range Safety System

1. GENERAL DESCRIPTION  
 1.4 Solid Rocket Boosters

RSS command frequencies and provide the input signal to the distributors when an RSS command is sent. The command decoders use a code plug to prevent any command signal other than the proper command signal from getting into the distributors. The distributors contain the logic to supply valid destruct commands to the RSS pyrotechnics.

The NSDs provide the spark to ignite the CDF, which in turn ignites the LSC for Shuttle vehicle destruction. The safe and arm device provides mechanical isolation between the NSDs and the CDF before launch and during the SRB separation sequence.

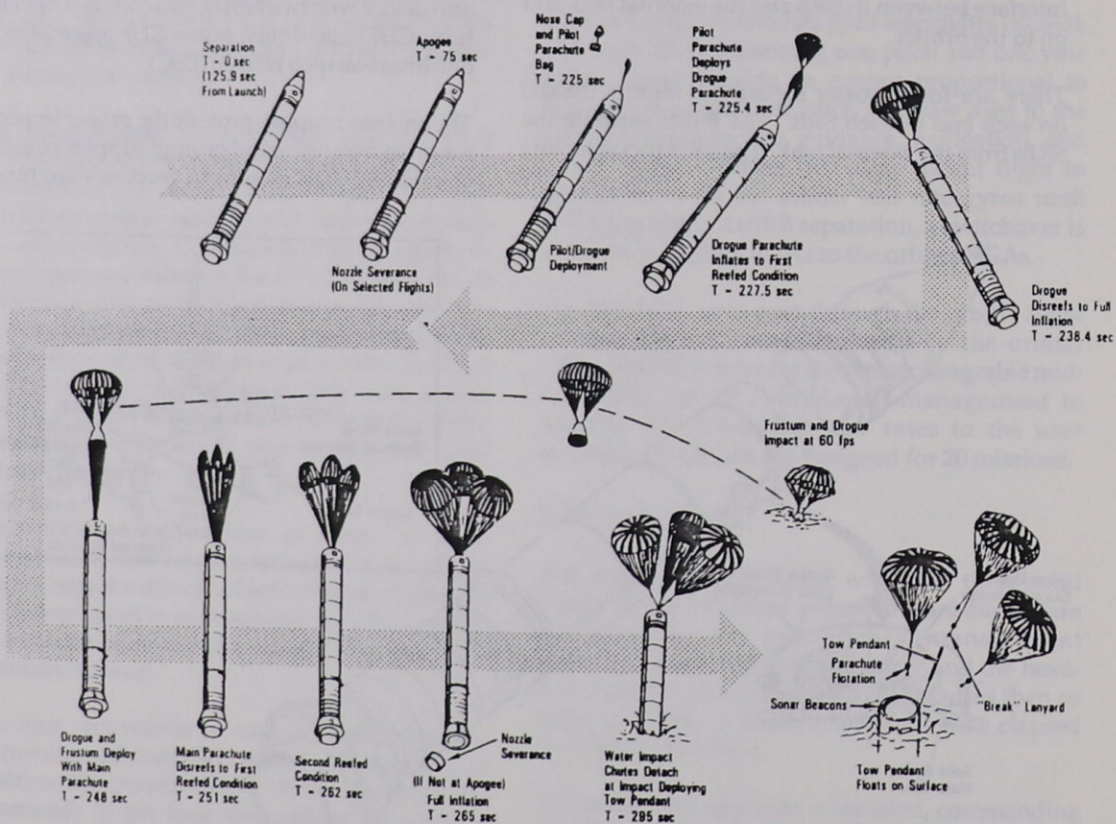
The first message, called arm, allows the onboard logic to enable a destruct and illuminates a light on the flight deck display and control panel at the commander and pilot station. The second message transmitted is the fire command.

The SRB distributors in the SRBs and the ET are cross-strapped together. Thus, if one SRB received an arm or destruct signal, the signal would also be sent to the other SRB and the ET.

Electrical power from the RSS battery in each SRB is routed to RSS system A. The recovery battery in each SRB is used to power RSS system B as well as the recovery system in the SRB. The SRB RSS is powered down during the separation sequence, and the SRB recovery system is powered up. Electrical power for the ET RSS system A and system B is independently supplied by two RSS batteries on the ET.

### SRB Descent and Recovery

The recovery sequence begins with the operation of the high-altitude baroswitch, which triggers the functioning of the pyrotechnic nose cap thrusters.



SRB Descent and Splashdown

This ejects the nose cap, which deploys the pilot parachute. This occurs at 15,704 feet altitude 225 seconds after separation. The 11.5-foot-diameter conical ribbon pilot parachute provides the force to pull the lanyard activating the zero-second cutter, which cuts the loop securing the drogue retention straps. This allows the pilot chute to pull the drogue pack from the SRB, causing the drogue suspension lines to deploy from their stored position. At full extension of the twelve 95-foot suspension lines, the drogue deployment bag is stripped away from the canopy, and the 54-foot-diameter conical ribbon drogue parachute inflates to its initial reefed condition. The drogue disreefs twice after specified time delays, and it reorients/stabilizes the SRB for main chute deployment. The drogue parachute can withstand a load of 270,000 pounds and weighs approximately 1,200 pounds.

After the drogue chute has stabilized the vehicle in a tailfirst attitude, the frustum is separated from the forward skirt by a charge triggered by the low-altitude baroswitch at an altitude of 5,975 feet 248 seconds after separation. It is then pulled away from the SRB by the drogue chute. The main chutes' suspension lines are pulled out from deployment bags that remain in the frustum. At full extension of the lines, which are 204 feet long, the three main chutes are pulled from the deployment bags and inflate to their first reefed condition. The frustum and drogue parachute continue on a separate trajectory to splashdown. After specified time delays, the main chutes' reefing lines are cut, and

the chutes inflate to their second reefed and full open configurations. The main chute cluster decelerates the SRB to terminal conditions. Each of the 136-foot-diameter, 20-degree conical ribbon parachutes can withstand a load of 180,000 pounds and weighs 2,180 pounds. The nozzle extension is severed by pyrotechnic charge either at apogee or 20 seconds after low baroswitch operation.

Water impact occurs 295 seconds after separation at a velocity of 81 feet per second. The water impact range is approximately 140 miles off the eastern coast of Florida. Because the parachutes provide for a nozzlefirst impact, air is trapped in the empty (burned out) motor casing, causing the booster to float with the forward end approximately 30 feet out of the water.

The main chutes are released from the SRB at impact using the parachute release nut ordnance system. Residual loads in the main chutes deploy the parachute attach fittings with the redundant flotation tethered to each fitting. The drogue and frustum, each main chute with its flotation, and the SRB are buoyant. The SRB recovery aids are the radio beacon and flashing lights, which become operable at frustum separation. The radio transponder in each SRB has a range of 8.9 nautical miles, and the flashing light has a nighttime range of 4.9 nautical miles. Various parameters of SRB operation are monitored and displayed on the orbiter flight deck control and display panel and are transmitted to ground telemetry.



## 2. SYSTEMS

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This section discusses in detail each of 23 orbiter systems as listed here in the Table of Contents. The subsections are organized alphabetically, with a detailed internal table of contents provided for each.

Each system subsection begins with descriptive information covering general purpose, function, and location. Relevant elements of each system are then provided in some detail. Where orbiter panels or CRT displays apply, an illustration of such appears as near the reference as possible. In the case of large panels, appropriate fragments are placed in the text, with full panel diagrams provided in Appendix A.

Most system subsections conclude with a summary. Caution and warning summaries and rules of thumb are also provided where appropriate.

## 2.1 AUXILIARY POWER UNIT / HYDRAULICS (APU / HYD)

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### Description

The orbiter has three independent hydraulic systems. Each consists of a main hydraulic pump, hydraulic reservoir, hydraulic bootstrap accumulator, hydraulic filters, control valves, hydraulic/Freon heat exchanger, electrical circulation pump, and electrical heaters.

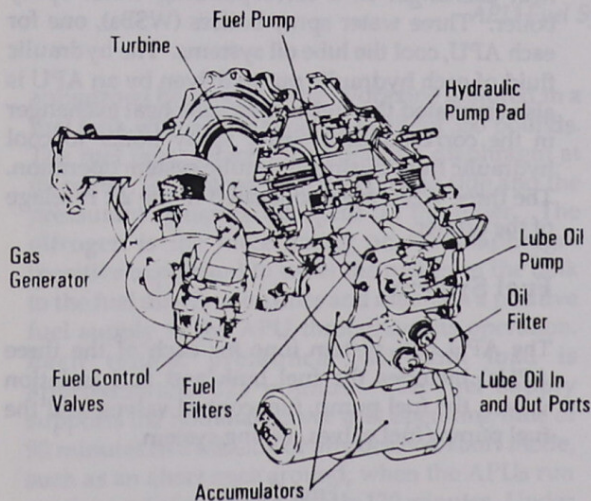
Each system provides hydraulic pressure to position hydraulic actuators for:

1. Thrust vector control of the main engines by gimbaling the three SSMEs
2. Actuation of various control valves on the SSMEs
3. Movement of the orbiter aerosurfaces (elevons, body flap, rudder/speed brake)
4. Retraction of the external tank/orbiter 17-inch liquid oxygen and liquid hydrogen disconnect umbilicals within the orbiter at external tank jettison
5. Main and nose landing gear deployment (system 1)
6. Main landing gear brakes and anti-skid
7. Nose wheel steering (system 1 until improved nose wheel steering, then systems 1 and 2).

Each hydraulic system is capable of operation when exposed to forces or conditions caused by acceleration, deceleration, normal gravity, zero gravity, hard vacuum, and temperatures encountered during on-orbit dormant conditions.

Three identical, but independent, auxiliary power units (APUs) provide power for the orbiter hydraulic systems. The APU is a hydrazine-fueled, turbine-driven power unit that generates mechanical shaft power to drive a hydraulic pump that produces pressure for the orbiter's hydraulic system. Each unit weighs approximately 88 pounds and produces 135 horsepower.

Each APU consists of a fuel tank, a fuel feed system, a system controller, an exhaust duct, lube oil cooling system, and fuel/lube oil vents and drains. Redundant electrical heater systems and insulation thermally control the system above 45° F to prevent fuel from freezing and to

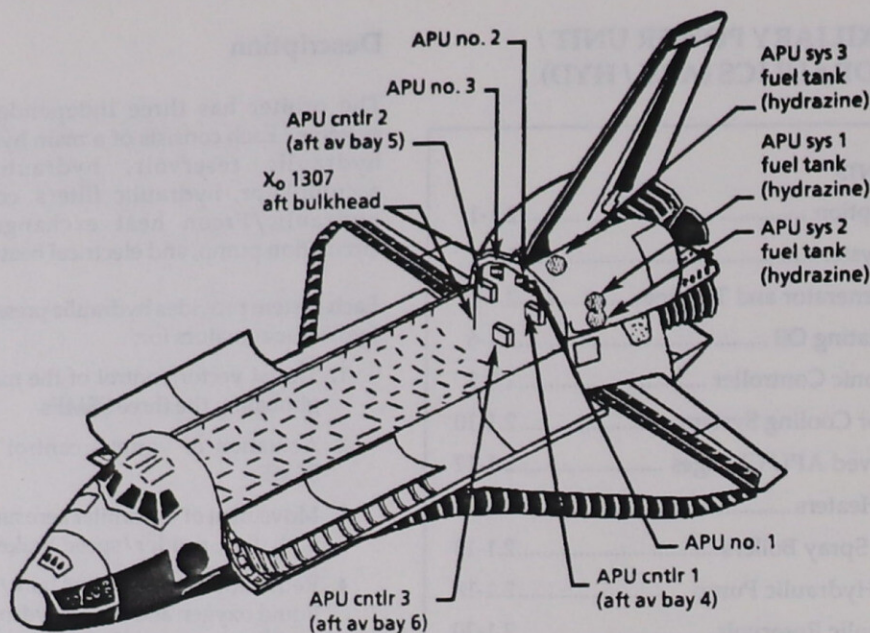


Dimensions: 20 Inches Wide, 21.80 Inches Long,  
18 Inches Deep

*Auxiliary Power Unit*

## 2. SYSTEMS

### 2.1 Auxiliary Power Unit/Hydraulics



*Auxiliary Power Unit Locations*

maintain required lubricating oil viscosity. Insulation is used on components containing hydrazine, lube oil, or water to minimize electrical heater power requirements and to keep high surface temperatures within safe limits on the turbine and exhaust ducts.

The three APUs and fuel systems are located in the aft fuselage. Each APU fuel system supplies storable liquid hydrazine fuel to its respective fuel pump, gas generator valve module, and gas generator, which decomposes the fuel through catalytic action. The resultant hot gas drives a two-stage turbine. The turbine exhaust flow returns over the exterior of the gas generator, cooling it, and is then directed overboard through an exhaust duct at the upper portion of the aft fuselage near the vertical stabilizer.

The turbine assembly provides mechanical power through a shaft to drive reduction gears in the gearbox. The gearbox drives a fuel pump, a hydraulic pump, and a lube oil pump. The hydraulic pump supplies pressure to the hydraulic system. The fuel pump increases the fuel pressure at its outlet to sustain pressurized fuel to the gas generator valve module and gas generator. The lube oil system supplies lubricant to the gearbox reduction gears

and uses the reduction gears as scavenger pumps to supply lube oil to the inlet of the lube oil pump to increase the pressure of the lube oil system.

The lube oil of each APU is circulated through a heat exchanger in a corresponding water spray boiler. Three water spray boilers (WSBs), one for each APU, cool the lube oil systems. The hydraulic fluid of each hydraulic pump driven by an APU is also circulated through a hydraulic heat exchanger in the corresponding water spray boiler to cool hydraulic fluid during hydraulic system operation. The three WSBs are also located in the aft fuselage of the orbiter.

#### Fuel System

The APU fuel system (one for each of the three APUs) includes the fuel tank and fuel isolation valves, the fuel pump, fuel control valves, and the fuel pump/fuel valves cooling system.

#### Fuel Tanks

The APU fuel tanks are mounted on supports cantilevered from the sides of the internal portion of the aft fuselage. The fuel is storable liquid



## 2. SYSTEMS

### 2.1 Auxiliary Power Unit/Hydraulics

panel F8 is positioned to *FUEL*, the quantity in APU fuel tanks 1, 2, and 3 is displayed simultaneously in percent. The fuel quantity of 100 percent on the meter is equivalent to 350 pounds. Fuel pressure (psia) is shown on the FUEL PRESS meter on panel F8. Fuel quantity in percent is also displayed on the BFS SM SYS SUMM 2 display (FUEL QTY).

The gaseous nitrogen pressure in each fuel tank exerts a force on the tank's diaphragm to expel the hydrazine fuel under pressure to the fuel distribution system. Filters are incorporated into each distribution line to remove any particles. The fuel distribution line branches into two parallel paths downstream of the filter. An isolation valve is installed in each parallel path, providing redundant paths to permit fuel flow to the APU or to isolate fuel from the fuel supply tanks.

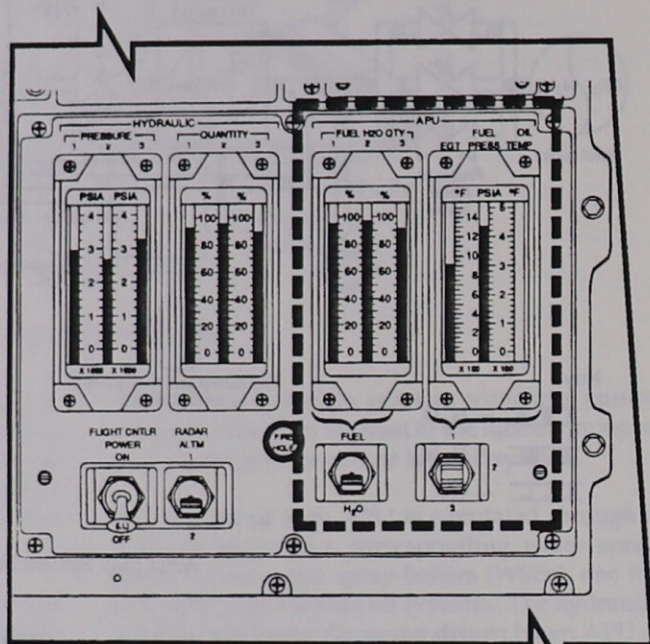
#### Fuel Tank Isolation Valves

Both isolation valves in each APU fuel distribution system are electrically powered solenoid valves, which are controlled by the corresponding *APU FUEL TK VLV* 1, 2, 3 switches on panel R2. They are energized open when the corresponding switch is positioned to *OPEN*; both valves are closed when the switch is positioned to *CLOSE*, or if electrical power is lost.

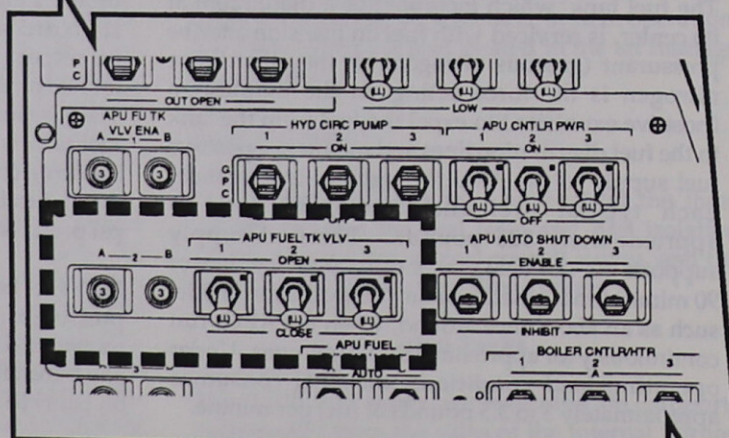
Each valve has a reverse relief function to relieve pressure on fuel trapped in the fuel distribution line downstream of the fuel tank valves when both valves are closed. The valve relieves the downstream pressure when the pressure increases 40 psi to 200 psi above fuel tank pressure due to heat soakback following APU shutdown.

The APU fuel tank isolation valves require fuel flow for cooling when they are powered open.

If an *APU FUEL TK VLV* switch is inadvertently left on after APU shutdown, or if an electrical short occurs within the valve's electrical coil, valve temperatures will increase, and hydrazine detonation may occur if the temperature exceeds 518° F. Redundant temperature measurements (two per valve, four per APU) have been added to redundant electrical valve drivers and individual circuit breakers. Temperature measurements are displayed on the BFS SM SYS SUMM 2 display (FU TK VLV AT and BT). Two circuit breakers (one for



APU Meters and Switches on Panel F8



APU FUEL TK VLV Switches and Circuit Breakers on Panel R2

fuel tank valve A and one for fuel tank valve B) on panel R2 can be pulled to deactivate electrical power from the solenoids. If temperature limits are exceeded, the flight crew responds by turning off the applicable switch or pulling the applicable circuit breaker.

**CAUTION**

The APU fuel tank isolation valves require fuel flow for cooling. If the fuel tank isolation valve fails to close after APU shutdown, or if it is left open more than 5 minutes on orbit, hydrazine detonation could occur.

### Fuel Pump

Each APU fuel pump is a fixed-displacement, gear-type pump that discharges fuel at approximately 1,400 psi to 1,500 psi and operates at approximately 3,918 rpm. A fuel filter is located at the fuel pump outlet, and a relief valve relieves at approximately 1,725 psi back to the pump inlet if the filter becomes clogged.

Each fuel pump is driven by the turbine through the reduction gearbox. The fuel pump reduction gear is located in the lube oil system gearbox, and a shaft from the reduction gear drives the fuel pump. Seals are installed on the shaft to contain any leakage of fuel or lube oil. If leakage occurs through the seals, it is directed to a drain line that runs to a 500-

cubic centimeter catch bottle for each APU. If the catch bottle were overfilled, it would relieve overboard at approximately 28 psia through a drain port. On ascent or entry, the flight crew can monitor the catch bottle's line pressure on the BFS SM SYS SUMM 2 display (PMP LK P).

### Fuel Control Valves

The APU's operating speed is controlled by the primary and secondary fuel control valves, which are installed in series downstream of the fuel pump. These are solenoid-operated pulser-type valves. In the normal APU operating mode, the primary control valve pulses to maintain the APU's speed at about 74,000 rpm (103%), while the secondary control valve is powered fully open. If the APU is taken to high via the *APU SPEED SELECT* switch on panel R2, the primary valve is unpowered and goes to fully open, while the secondary valve begins pulsing, and controls APU speed at about 81,000 rpm (113%). If the secondary valve subsequently fails open, the primary valve will begin pulsing to maintain APU speed at about 83,000 rpm (115%) in the backup speed control mode. If the secondary valve loses power, it goes to the closed position and shuts down the APU. As noted above, the primary valve goes to full open if it loses power, allowing the secondary valve to take over automatically and control at high speed (113%).

The crew can see APU speed on the BFS SM SYS SUMM 2 display (APU SPEED %) in percent (100 percent = 72,000 rpm). The speed fluctuates due to the nature of the pulse-modulated fuel flow system.

For safety reasons, each APU has an automatic shutdown feature that will shut the APU down if the speed falls below 80 percent (57,600 rpm) or rises above 129 percent (92,880 rpm).

XXXX/XXX/079		SM SYS SUMM 2					XX X DDD/HH:MM:SS		
		BFS DDD/HH:MM:SS							
CRYO TK		1	2	3	4	5			
H2 PRESS		XXXX	XXXX	XXXX	XXXX	XXXX			
O2 PRESS		XXXXX	XXXXX	XXXXX	XXXXX	XXXXX			
HTR T1		±XXXX	±XXXX	±XXXX	±XXXX	±XXXX			
T2		±XXXX	±XXXX	±XXXX	±XXXX	±XXXX			
APU		1	2	3					
TEMP EGT		XXXXX	XXXXX	XXXXX	HYD	1	2	3	
BU EGT		XXXXX	XXXXX	XXXXX	PRESS	XXXXX	XXXXX	XXXXX	
OIL IN		XXXX	XXXX	XXXX	ACUM P	XXXXX	XXXXX	XXXXX	
OUT		XXXX	XXXX	XXXX	RSVR T	XXXX	XXXX	XXXX	
GG BED		XXXX	XXXX	XXXX	QTY	XXXX	XXXX	XXXX	
INJ		XXXX	XXXX	XXXX	W/B				
SPEED %		XXS	XXS	XXS	H2O QTY	XXXX	XXXX	XXXX	
FUEL QTY		XXXXX	XXXXX	XXXXX	BYP VLV	XXXX	XXXX	XXXX	
PMP LK P		XXS	XXS	XXS	THERM CNTL			1	2
OIL OUT P		XXXX	XXXX	XXXX	H2O PUMP P			XXXX	XXXX
FU TK VLV					FREON FLOW			XXXXX	XXXXX
A T		XXXX	XXXX	XXXX	EVAP OUT T			XXXX	XXXX
B T		XXXX	XXXX	XXXX					
AV BAY		1	2	3					
TEMP		XXXX	XXXX	XXXX					
FAN ΔP		X.XXS	X.XXS	X.XXS					
									(XX)

APU Information on BFS SM SYS SUMM 2 Display

## Gas Generator and Turbine

Each gas generator consists of a bed of Shell 405 catalyst in a pressure chamber, mounted inside the APU exhaust chamber. When the hydrazine fuel comes into contact with the catalyst, it undergoes an exothermic reaction, decomposing into a hot gas at approximately 1,700° F. The gas expands rapidly and makes two passes through the two-stage turbine wheel, passes over the outside gas generator chamber and exits overboard through its own independent exhaust duct, located near the base of the vertical stabilizer. The temperature of the hot gas at the exhaust duct is approximately 1,000° F.

The shaft power from the spinning turbine is sent to the hydraulic main pump associated with the APU via a speed reduction gearbox. It is also used to drive the APU's fuel pump and lubrication oil pump.

The normal speed of the hydraulic main pump, APU fuel pump, and APU lube oil pump are 3,918 rpm, 3,918 rpm, and 12,215 rpm respectively. The lube oil system is necessary to lubricate the APU gearbox and the fuel pump.

The temperatures of the gas generator bed, the gas generator fuel injector, and the turbine exhaust gas are visible on the BFS SM SYS SUMM 2 CRT display (GG BED, INJ, TEMP EGT). While the APU is running, the gas generator bed temperature transducer goes off-scale high at approximately 500° F. On orbit, when the APU is shut down, the gas generator bed temperature transducer is useful for monitoring the bed temperature when the bed is kept warm by heaters.

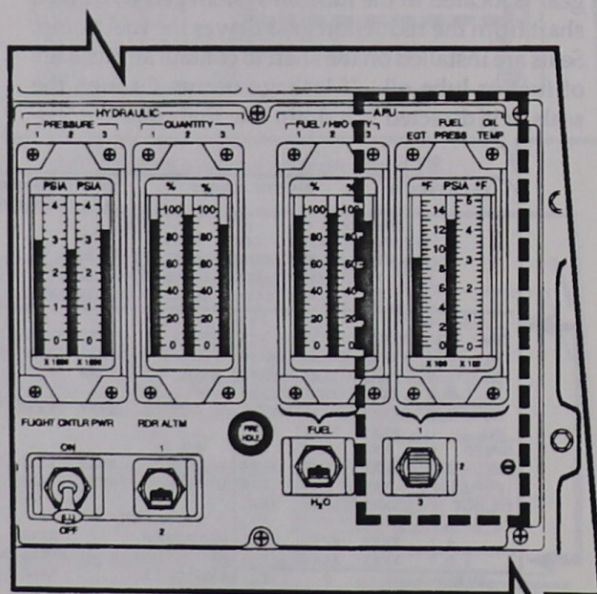
## Lubricating Oil

The APU lube oil system is a scavenger-type system with a fixed-displacement pump. Each APU turbine through its gearbox drives a lube oil pump at 12,215 rpm. The system is pressurized with gaseous nitrogen to provide adequate suction pressure to start the lube oil pump under zero-gravity conditions. Each lube oil system has its own nitrogen gas storage vessel, which is pressurized to approximately 140 psia. The pressurization system for each lube oil system has a valve controlled by its

corresponding APU controller. The gaseous nitrogen pressurization valve for each power unit is energized open by its corresponding controller when the gearbox pressure is below 5.2 psi, plus or minus 1.3 psi, to ensure that gearbox pressure is sufficiently above the requirements for proper scavenging and lube pump operation.

The pump increases the lube oil pressure to approximately 60 psi, directs the lube oil system through the corresponding water spray boiler for cooling, and returns the lube oil to the accumulators and gearbox. The two accumulators in each lube oil system allow thermal expansion of the lube oil, accommodate gas initially trapped in the external lube circuit, maintain lube oil pressure at a minimum of approximately 15 psia, and act as a zero-gravity, all-altitude lube reservoir.

The following information is transmitted to the BFS SM SYS SUMM 2 display by the APU controller via the GPC: lube oil pump outlet pressure (OIL OUT P) at approximately 45 psia, outlet temperature at approximately 270° F and return temperature from the water spray boiler (OIL IN, OUT) at approximately 250° F for each APU. The lube oil temperature of each APU is also monitored on the APU OIL TEMP meter on panel F8. The APU is selected by the switch below the meter.



APU OIL TEMP Meter and Switch on Panel F8

(NOTE: EGT indication on meter is driven by "TEMP EGT" transducer seen on BFS SYS SUMM 2 CRT display.)

## Electronic Controller

Each APU has its own controller. The controller detects malfunctions, controls turbine speed, gearbox pressurization, and fuel pump/gas generator heaters. Each controller is controlled by its corresponding *APU CNTLR PWR* switch on panel R2. When the switch is positioned to *ON*, 28-volt dc power is sent to that controller and APU. The controllers are redundantly powered via dual internal remote power controllers. When the switch is positioned to *OFF*, electrical power is removed from that controller and APU.

### APU Start

An *APU/HYD READY TO START* talkback indicator for each APU is located on panel R2. The talkback signals gray when that APU hydraulic system is ready to start; that is, when the APU gas generator temperature is above 190° F, APU turbine speed is less than 80 percent, APU gearbox pressure is above 5.5 psi, WSB controller is ready, corresponding APU fuel tank isolation valves are open, and corresponding hydraulic main pump is depressurized. When the APU is started, and its turbine speed is greater than 80 percent of normal speed, the corresponding indicator shows barberpole.

### NOTE

A barberpole *APU/HYD READY TO START* talkback will not inhibit a start.

*APU OPERATE 1, 2, 3* switches are located on panel R2. When the switches are positioned to *START/RUN*, the corresponding APU controller activates the start of that unit and removes electrical power automatically from the unit's gas generator and fuel pump heaters.

To start the APU, fuel expelled from the hydrazine tank flows through the open tank valves and filter to the gas generator valve module, which contains a primary and secondary fuel control valve in series. The primary pulse control valve is normally open, and the secondary pulse control valve is energized open. Fuel flowing through the pump bypass valve is directed to the gas generator, because the fuel pump is not being driven at that moment by the APU turbine.

The fuel in the gas generator decomposes through catalytic reaction, creates hot gas, and directs the hot gas to the two-stage turbine, which begins to rotate. The turbine's mechanical shaft drives the reduction gears, rotating the fuel pump, lube oil pump, and hydraulic pump. The fuel pump increases the fuel pressure at its outlet and sustains pressurized fuel to the gas generator valve module and gas generator.

The startup logic delays the APU underspeed logic check for 9.5 seconds after the start command is issued, allowing the APU to reach normal speed before the shutdown logic begins checking for a speed lower than 80 percent. The underspeed logic check can be overridden by taking the *APU AUTO SHUT DOWN* switch on panel R2 to *INHIBIT*.

### CAUTION

After an APU auto shutdown, the *APU FUEL TK VLV* switch must be taken to *CLOSE* prior to inhibiting auto shutdown logic. Failure to do so can allow the fuel tank isolation valves to reopen and flow fuel to an APU gas generator bed that is above the temperature limits for safe restart.

### APU Speed Control

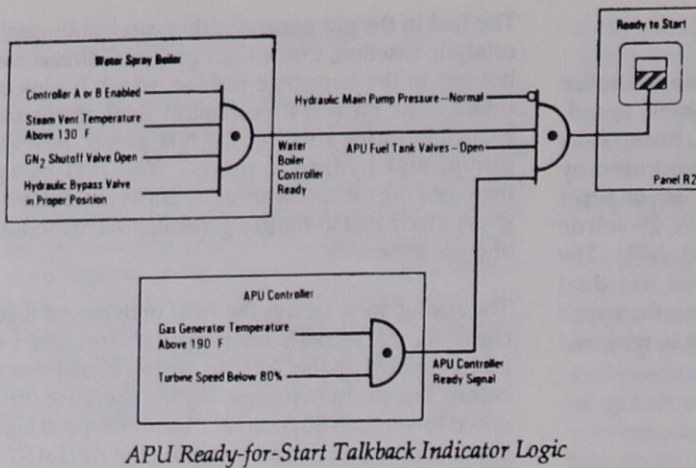
When the upper APU turbine speed is reached, the primary fuel control valve closes the fuel supply off to the gas generator and routes the fuel through the bypass line back to the fuel pump inlet. When the lower turbine speed is reached, the primary fuel control valve opens, permitting fuel to the gas generator, and closes the fuel off to the bypass line. The primary fuel valve pulses to maintain APU speed. The frequency and duration of the primary fuel control valve pulses are functions of the hydraulic load on the unit.

The secondary fuel control valve normally stays fully open during the operation of the primary. If the primary valve loses power, it goes to the fully open position, and the secondary valve begins pulsing and controlling APU speed. If the secondary valve loses power at any time, the APU is shut down. If the auxiliary power unit is taken to a high



## 2. SYSTEMS

### 2.1 Auxiliary Power Unit/Hydraulics



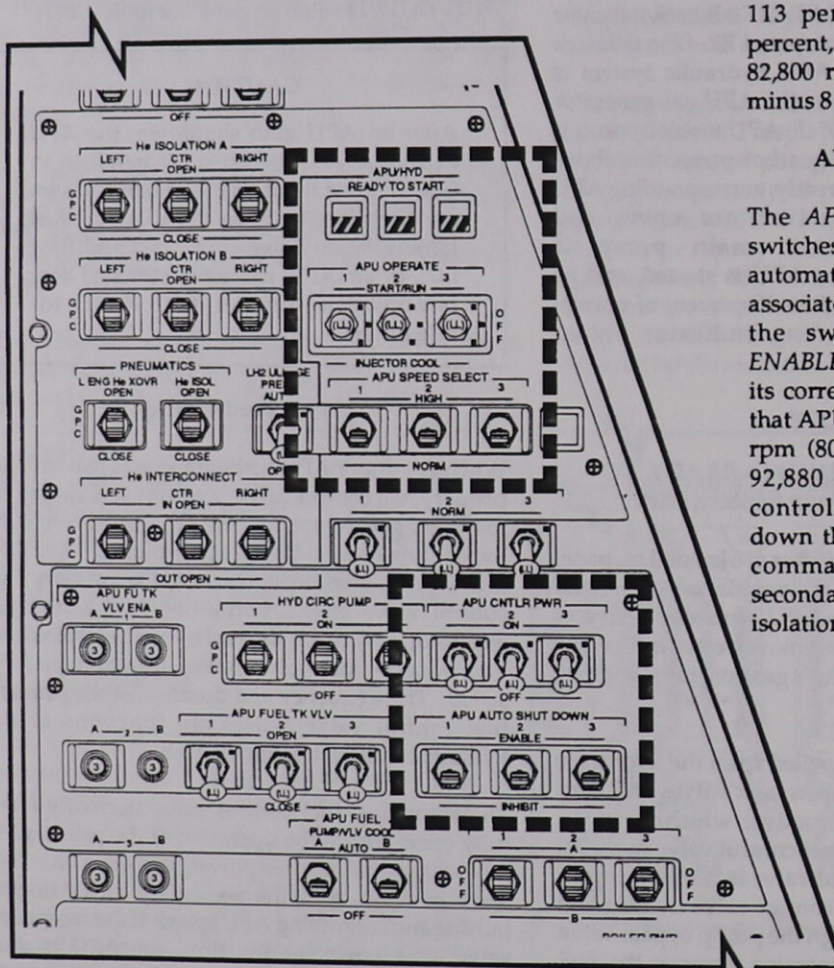
APU Ready-for-Start Talkback Indicator Logic

speed (by the *APU SPEED SELECT* switch on panel R2), the primary valve is unpowered and goes to the fully open position while the secondary valve controls the unit's speed.

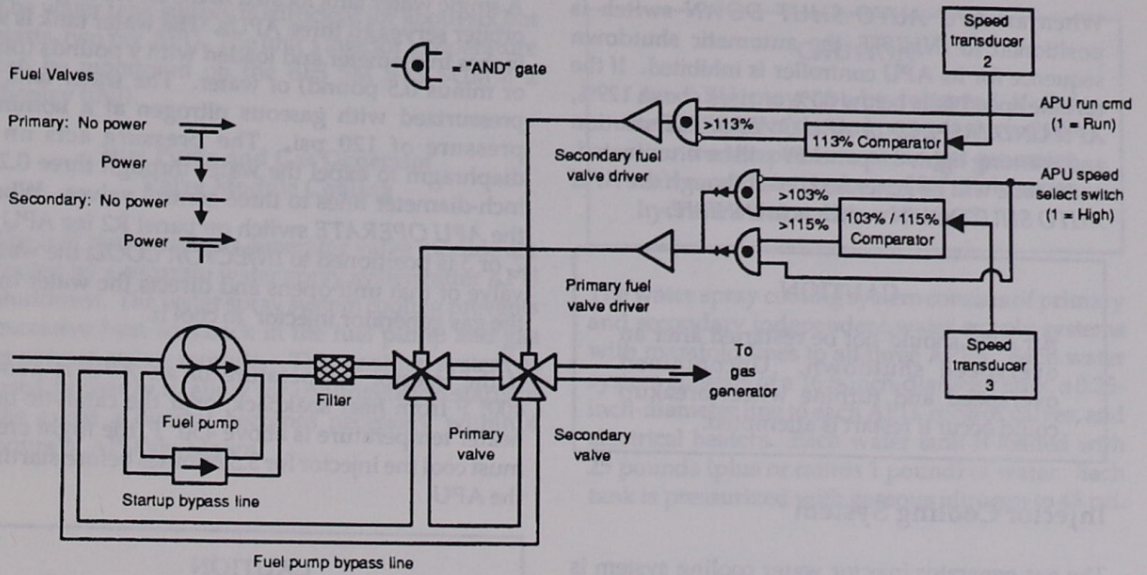
Each APU controller controls the speed of each unit upon the activation of the *APU SPEED SELECT* switch for each APU on panel R2. The *NORM* position controls the speed at 74,160 rpm, 103 percent, plus or minus 8 percent. The *HIGH* position controls the speed at 81,360 rpm, 113 percent, plus or minus 8 percent, with a second backup of 82,800 rpm, 115 percent, plus or minus 8 percent.

#### APU Auto Shutdown

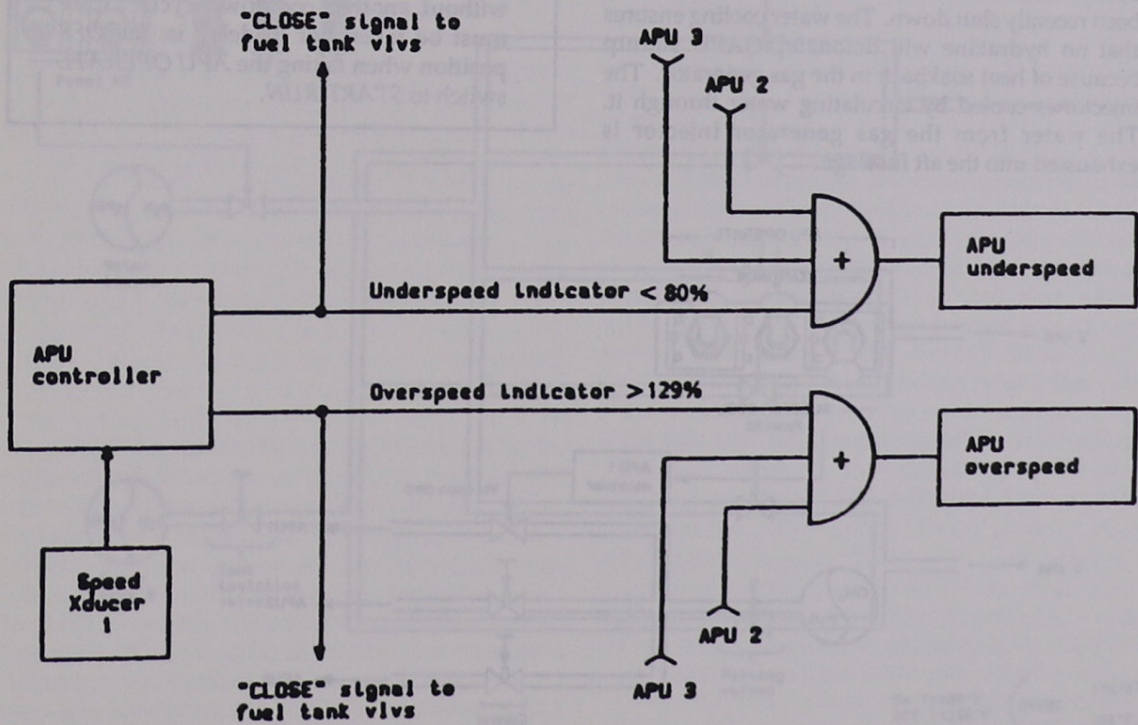
The *APU AUTO SHUTDOWN* switches on panel R2 enable the automatic shutdown feature in the associated APU controllers. When the switch is positioned to *ENABLE*, each controller monitors its corresponding APU speed. If that APU speed falls below 57,600 rpm (80 percent) or rises above 92,880 rpm (129 percent), the controller automatically shuts down that unit. Each shutdown command closes that unit's secondary fuel valve and the tank isolation valves.



APU/HYD READY TO START Talkbacks, APU OPERATE Switches, APU SPEED SELECT Switches, APU CNTLR PWR Switches, and APU AUTO SHUT DOWN Switches on Panel R2



APU Speed Control Logic



APU Overspeed/Underspeed Detection

## 2. SYSTEMS

### 2.1 Auxiliary Power Unit/Hydraulics

When an *APU AUTO SHUT DOWN* switch is positioned to *INHIBIT*, the automatic shutdown sequence for its APU controller is inhibited. If the turbine speed falls below 80% or rises above 129%, *APU UNDERSPEED* or *APU OVERSPEED* caution and warning lights on panel F7 will be illuminated, and a tone will be generated, even though the *APU AUTO SHUTDOWN* switch is in *INHIBIT*.

#### CAUTION

An APU should not be restarted after an overspeed shutdown. Uncontained overspeed and turbine wheel breakup could occur if restart is attempted.

### Injector Cooling System

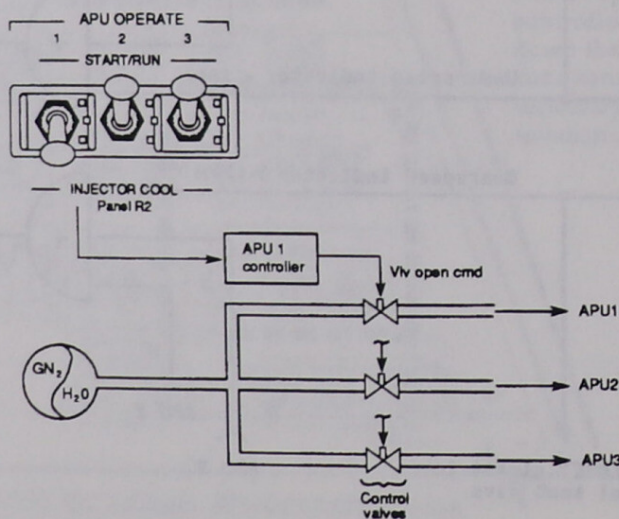
The gas generator injector water cooling system is used only when the normal cool-down period of 180 minutes is not available. The system sprays water to reduce the temperature of the gas generator injector branch passages to less than 400° F in the event that a hot APU must be restarted after it has been recently shut down. The water cooling ensures that no hydrazine will detonate at APU startup because of heat soakback in the gas generator. The injector is cooled by circulating water through it. The water from the gas generator injector is exhausted into the aft fuselage.

A single water tank located in the aft fuselage of the orbiter serves all three APUs. The water tank is 9.4 inches in diameter and loaded with 9 pounds (plus or minus 0.5 pound) of water. The water tank is pressurized with gaseous nitrogen at a nominal pressure of 120 psi. The pressure acts on a diaphragm to expel the water through three 0.25-inch-diameter lines to three control valves. When the *APU OPERATE* switch on panel R2 for APU 1, 2, or 3 is positioned to *INJECTOR COOL*, the water valve of that unit opens and directs the water into the gas generator injector to cool it.

If the injector temperature of an APU is above 400° F from heat soakback, or if the catalytic bed heater temperature is above 430° F, the flight crew must cool the injector for 3.5 minutes before starting the APU.

#### CAUTION

If cooldown is terminated more than 2 to 3 seconds prior to starting the APU, the injector temperature may increase above start limits, and detonation may occur without another cooldown cycle. Care must be taken not to delay in the *OFF* position when taking the *APU OPERATE* switch to *START/RUN*.



APU Injector Cooling

The water tank supply is sufficient for about six hot starts, two per APU. The unit's injector temperature can be monitored on the BFS SM SYS SUMM 2 display (INJ).

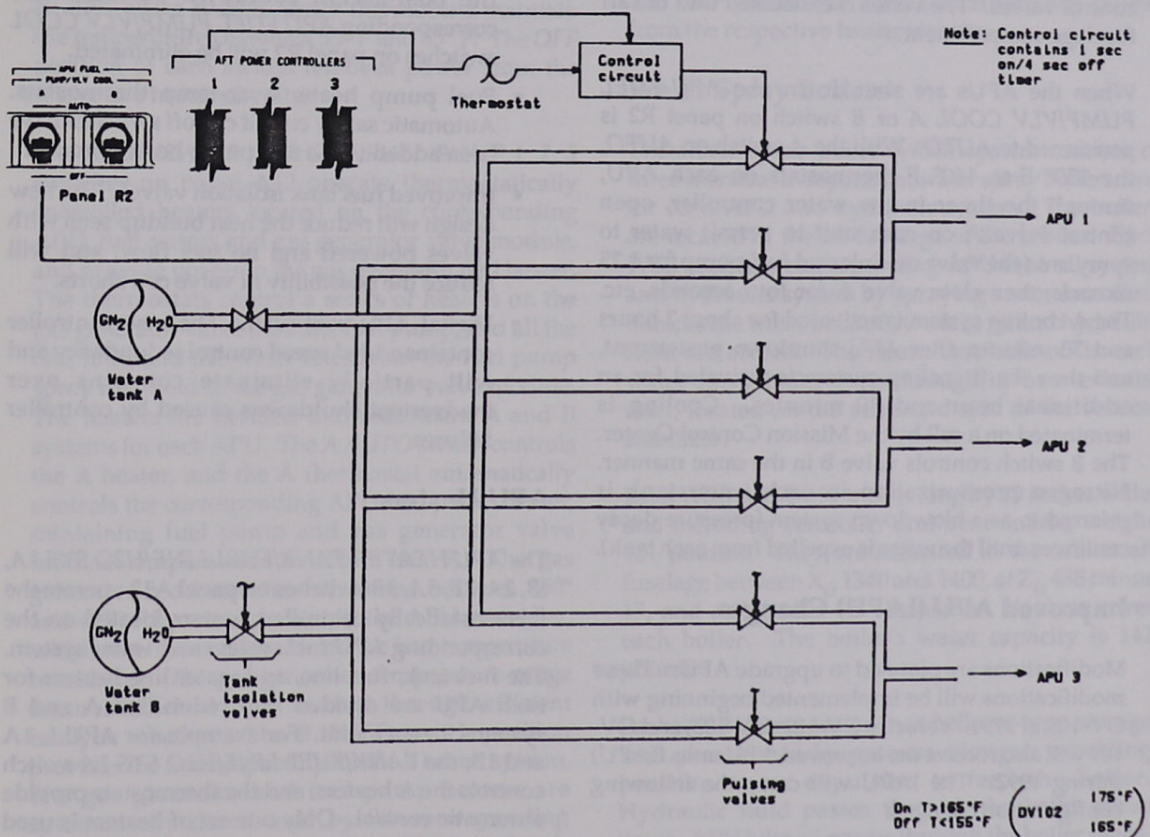
### Fuel Pump and Gas Generator Valve Module Cooling

The fuel pump and gas generator valve module are cooled by a separate water spray system after APU shutdown. The water spray system cooling prevents excessive heat soakback in the fuel pump and gas generator valve module. This cooling system is used primarily to allow for contingency restarts in the event a deorbit becomes necessary within 4 hours of APU shutdown.

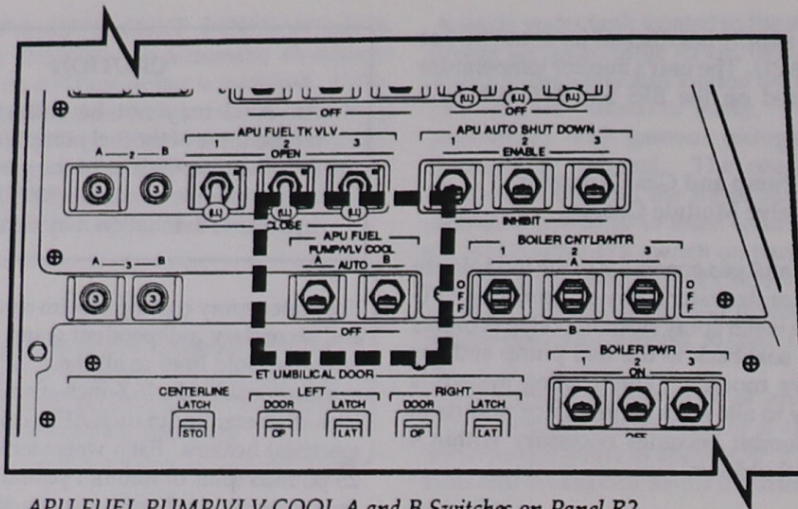
### CAUTION

An APU may not be restarted if the temperature of the fuel pump is above 210° F or the temperature of the gas generator valve module is above 200° F, because hydrazine detonation may occur.

The water spray cooling system consists of primary and secondary independent water supply systems with manifold lines to all three APUs. Each water system consists of a 16.5-inch-diameter tank, a 0.25-inch-diameter line to each APU, control valves, and electrical heaters. Each water tank is loaded with 25 pounds (plus or minus 1 pound) of water. Each tank is pressurized with gaseous nitrogen to 45 psi.



APU Fuel Pump/Valve Cooling



APU FUEL PUMP/VLV COOL A and B Switches on Panel R2

The gaseous nitrogen pressure acts on a diaphragm in each tank to expel the water into the lines to the control valves. The water is exhausted into the aft fuselage compartment.

When the APUs are shut down, the *APU FUEL PUMP/VLV COOL A* or *B* switch on panel R2 is positioned to *AUTO*. With the *A* switch on *AUTO*, the 150° F to 160° F thermostats on each APU, through the timer in the water controller, open control valve A on each unit to permit water to spray onto the valve module and fuel pump for 1.25 seconds, then close valve A for four seconds, etc. The A cooling system is activated for about 2 hours and 30 minutes after APU shutdown post-ascent, and then the B cooling system is activated for an additional hour and 30 minutes. Cooling is terminated on a call by the Mission Control Center. The B switch controls valve B in the same manner. Nitrogen pressurization in each water tank is referred to as a blowdown system (pressure decay continues until the water is expelled from each tank).

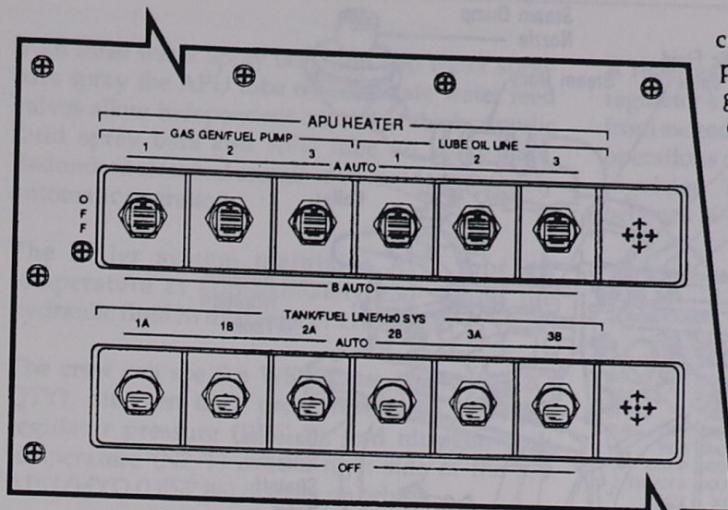
### Improved APU (IAPU) Changes

Modifications are planned to upgrade APUs. These modifications will be implemented beginning with OV-105 in 1991. Vehicles OV-102, OV-103, and OV-104 will also receive the improved APU units (IAPU) during 1992. The IAPU will carry the following configuration changes:

- Deletion of all fuel pump valve module cooling. The IAPU uses passive cooling for the post-ascent cooldown period. The corresponding *APU FUEL PUMP/VLV COOL* switches on panel R2 will be eliminated.
- Fuel pump heater over-temp thermostats. Automatic safety circuit cut-off switches have been added to the fuel pump heater circuits.
- Improved fuel tank isolation valves. The new design will reduce the heat buildup seen with valves powered and no fuel flow, and will reduce the possibility of valve coil shorts.
- Digital APU controller. The new controller contains added speed control redundancy and will partially eliminate concerns over inadvertent shutdowns caused by controller failures.

### APU Heaters

The *APU HEATER TANK/FUEL LINE/H2O SYS 1A, 1B, 2A, 2B, 3A, 3B* switches on panel A12 operate the thermostatically controlled heaters located on the corresponding APU fuel system and water system. The fuel tank, fuel line, and water line heaters for each APU are divided into redundant A and B systems for each unit. For example, for APU 1, 1A and 1B, the *TANK/FUEL LINE/H2O SYS 1A* switch controls the A heaters, and the thermostats provide automatic control. Only one set of heaters is used at a time. The 1B switch controls the 1B heaters, and the thermostats provide automatic control. The



APU HEATER Controls on Panel A12

APU fuel tank and line heater thermostats maintain the temperatures between a nominal 55° F and 65° F. The water system heater thermostats maintain the temperatures between 55° F and 65° F. The OFF position of each switch removes power from the respective heater circuits.

The APU HEATER GAS GEN/FUEL PUMP 1, 2, 3 switches on panel A12 operate thermostatically controlled heaters located on the corresponding APU, fuel pump, and gas generator valve module, and provide power to the gas generator bed heater. The thermostats control a series of heaters on the gas generator valve module, fuel pump, and all the fuel lines and the water lines from the fuel pump spray manifold to the gas generator valve module. The heaters are divided into redundant A and B systems for each APU. The A AUTO switch controls the A heater, and the A thermostat automatically controls the corresponding APU fuel pump heater, maintaining fuel pump and gas generator valve module temperatures at about 100° F. The gas generator bed heater is maintained between 360° and 425° F by a comparator in the APU controller, which receives its signal from the bed temperature transducer. The gas generator temperature range ensures efficient APU startup through efficient catalytic reaction. The B AUTO switch position provides the same capability for the B heater system. The gas generator and fuel pump heaters are automatically deactivated by the corresponding controller at APU start. The OFF position of each switch removes power from the respective heater

circuits. These heater switches also provide redundant power to the gas generator and gearbox pressure signal conditioners for use while the APU controller is off.

The lube oil system lines on each APU also have a heater system. These heaters are controlled by the APU HEATER LUBE OIL LINE 1, 2, 3 switches on panel A12. The lube oil line heaters for each APU are also divided into an A and B system: e.g., for 1, A AUTO and B AUTO. The A AUTO switch controls the A heater, and the thermostat automatically controls the corresponding lube oil system heater, maintaining the lube oil line in the temperature range of 55° F to 65° F. The B AUTO switch position provides the same capability to the B heater system. The OFF position of each switch removes power from the respective heater circuits.

### Water Spray Boilers

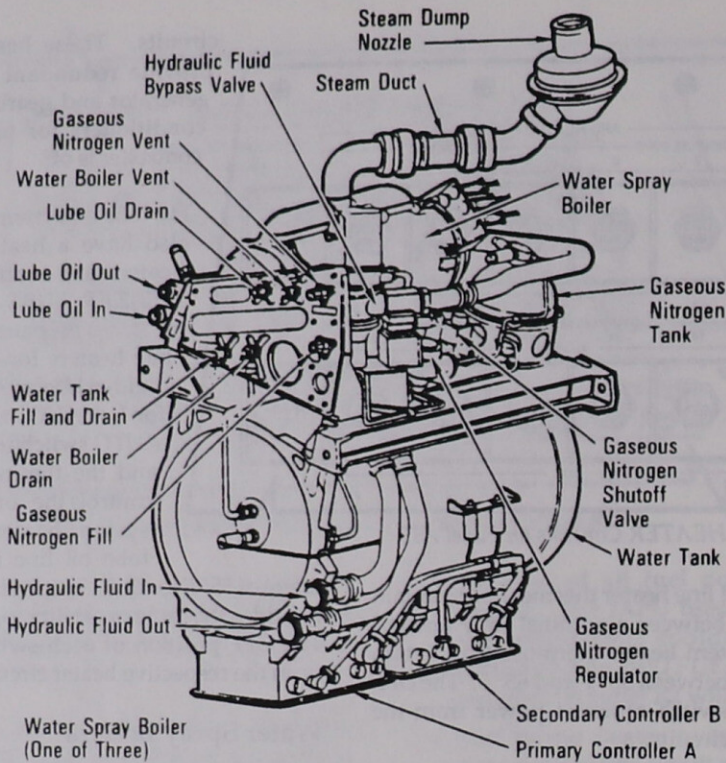
The water spray boiler (WSB) system consists of three identical independent water spray boilers, one for each APU and hydraulic system. The boilers are located in the aft fuselage of the orbiter. Each WSB cools the corresponding APU lube oil system and hydraulic system by spraying water onto their lines; as the water boils off, the lube oil and hydraulic fluid are cooled. The steam that boils off in each water spray boiler exits through its own exhaust duct, located on the starboard side of the vertical stabilizer.

Each WSB is 45 by 31 inches long by 19 inches wide, and including controller and vent nozzle, weighs 181 pounds. They are mounted in the orbiter aft fuselage between X<sub>0</sub> 1340 and 1400, at Z<sub>0</sub> 488 minus 15, and at Y<sub>0</sub> plus 15. Insulation blankets cover each boiler. The boiler's water capacity is 142 pounds.

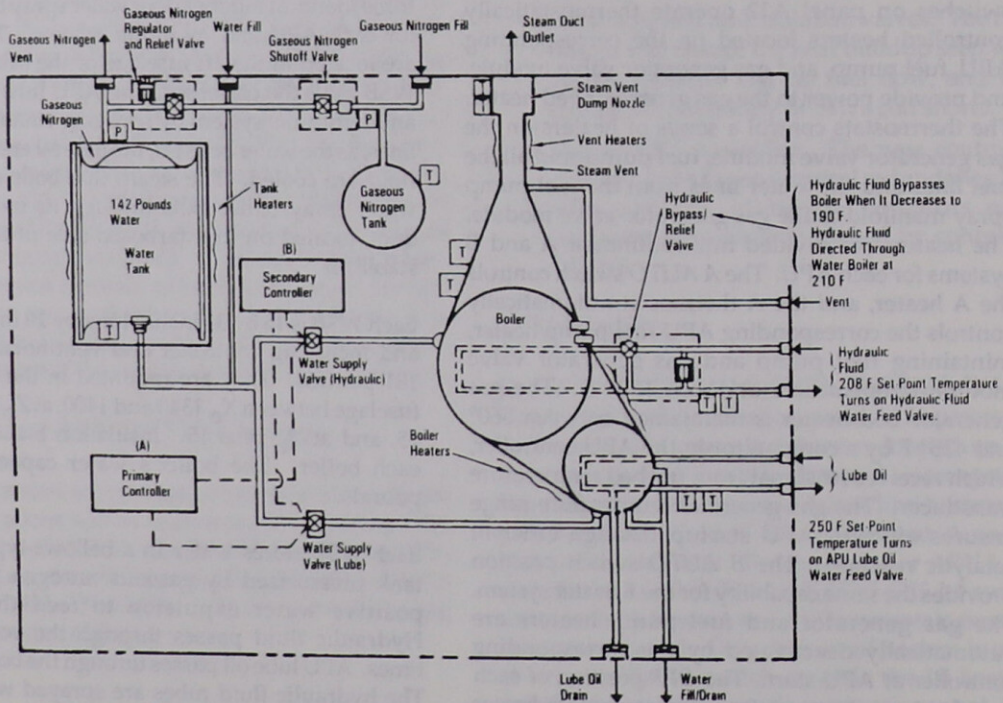
Each WSB stores water in a bellows-type storage tank pressurized by gaseous nitrogen providing positive water expulsion to feed the boiler. Hydraulic fluid passes through the boiler three times. APU lube oil passes through the boiler twice. The hydraulic fluid tubes are sprayed with water

2. SYSTEMS

2.1 Auxiliary Power Unit/Hydraulics



Water Spray Boiler Unit



Water Spray Boiler (One of Three)

from three water spray bars, and two water spray bars spray the APU lube oil. Separate water feed valves allow independent control of the hydraulic fluid spray bars and APU lube oil spray bars. Redundant electrical controllers provide completely automatic operation.

The boiler system maintains APU lube oil temperature at approximately 250° F and the hydraulic fluid in the range of 210° to 220° F.

The crew can see the WSB water quantity (H2O QTY), nitrogen tank pressure (N2 P), nitrogen regulator pressure (REG P), and nitrogen tank temperature (N2 T) on the right side of the SM APU/HYD (DISP 86) display on orbit.

### Nitrogen Supply System

The gaseous nitrogen pressure for each WSB is contained in a corresponding 6-inch spherical pressure vessel. The pressure vessel contains 0.77 pound of nitrogen at a nominal pressure of 2,400 psi at 70° F. The gaseous nitrogen storage system of each WSB is directed to its corresponding water storage tank. Each storage vessel contains sufficient nitrogen gas to expel all the water from the tank and allow for relief valve venting during ascent.

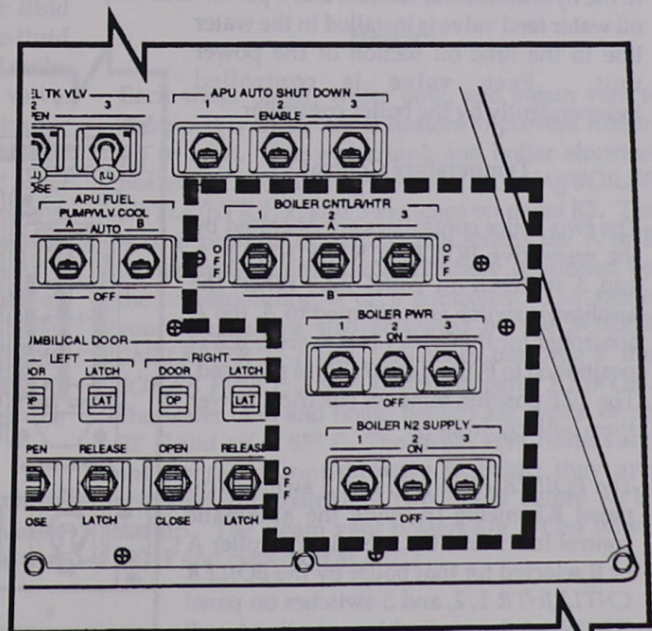
The nitrogen shutoff valve between the pressure valve and water storage tank of each boiler permits the pressure to reach the nitrogen regulator and water tank or isolates the nitrogen supply from the water tank. Each nitrogen valve is controlled by its respective *BOILER N2 SUPPLY 1, 2, or 3* switch on panel R2. The nitrogen shutoff valve, which is latched open or closed, consists of two independent solenoid coils that permit valve control from either the primary or secondary controller.

A single-stage regulator is installed between the nitrogen pressure shutoff valve and the water storage tank. The gaseous nitrogen regulator for each water spray boiler regulates the high-pressure nitrogen between 24.5 and 26 psig as it flows to the water storage tank.

A relief valve is incorporated inside each nitrogen regulator to prevent the water storage tank pressure from exceeding 33.5 psig from heat soakback during operations or in the event of a failed-open nitrogen regulator. The gaseous nitrogen relief valve opens between 30 to 33.5 psig.

APU			HYD		
	1	2	1	2	3
B/U EGT	XXXXX	XXXXX	XXXXX	B/U P	XXXXX XXXXX XXXXX
EGT	XXXXX	XXXXX	XXXXX	RSVR T	XXXXX XXXX XXXX
SPEED %	XXXXX	XXXXX	XXXXX	P	XXXXX XXXX XXXX
FUEL QTY	XXXXX	XXXXX	XXXXX	ACCUM P	XXXXX XXXX XXXX
TK P	XXXXX	XXXXX	XXXXX		
OUT P	XXXXX	XXXXX	XXXXX		
TK VLV A	XXXXX	XXXXX	XXXXX		
A T	XXS	XXS	XXS		
B	XXS	XXS	XXS		
B T	XXXXX	XXXXX	XXXXX	W/B	1 2 3
OIL T	XXXXX	XXXXX	XXXXX		
OUT T	XXXXX	XXXXX	XXXXX	CNTRLR	XXX XXX XXX
OUT P	XXXXX	XXXXX	XXXXX	H2O QTY	XXXXX XXXX XXXX
GBX P	XXXXX	XXXXX	XXXXX	N2 P	XXXXX XXXXX XXXXX
N2 P	XXXXX	XXXXX	XXXXX	T	XXXXX XXXX XXXX
BRG T	XXXXX	XXXXX	XXXXX	REG P	XXXXX XXXX XXXX
GG BED T	XXXXX	XXXXX	XXXXX	BYP VLV	XXXXX XXXX XXXX
PUMP/VLV				VENT T	±XXXX ±XXXX ±XXXX
PMP T	XXXXX	XXXXX	XXXXX	TANK T	±XXXX ±XXXX ±XXXX
VLV T	XXXXX	XXXXX	XXXXX	BLR T	±XXXX ±XXXX ±XXXX

SM APU/HYD Display (DISP 86)



BOILER Switches on Panel R2



### Water Supply System

The water supply for each boiler is stored in a positive-displacement aluminum tank containing a welded metal bellows separating the stored water inside the bellows from the nitrogen expulsion gas.

Redundant pressure and temperature sensors located downstream from the gaseous nitrogen pressure vessel and on the water tank for each boiler transmit the pressures and temperatures through each controller to the systems management general-purpose computer. The computer computes the water tank quantity from the pressure, volume, and temperature, and transmits the water tank quantity to panel F8 for each boiler. The switch below the meter on panel F8 is positioned to  $H_2O$  to allow the water quantity of each boiler to be displayed on the APU FUEL/ $H_2O$  QTY 1, 2, or 3 meter. Water quantity is available when either the A or B controller is powered.

Downstream of the water storage tank, the feed water lines to each water boiler split into two parallel lines: one line goes to the hydraulic fluid flow section and one to the lube oil section of the APU. A hydraulic-fluid water feed valve is installed in the water line to the hydraulic fluid section, and a power unit lube oil water feed valve is installed in the water line to the lube oil section of the power unit. Each valve is controlled independently by the boiler controller.

### Temperature Control

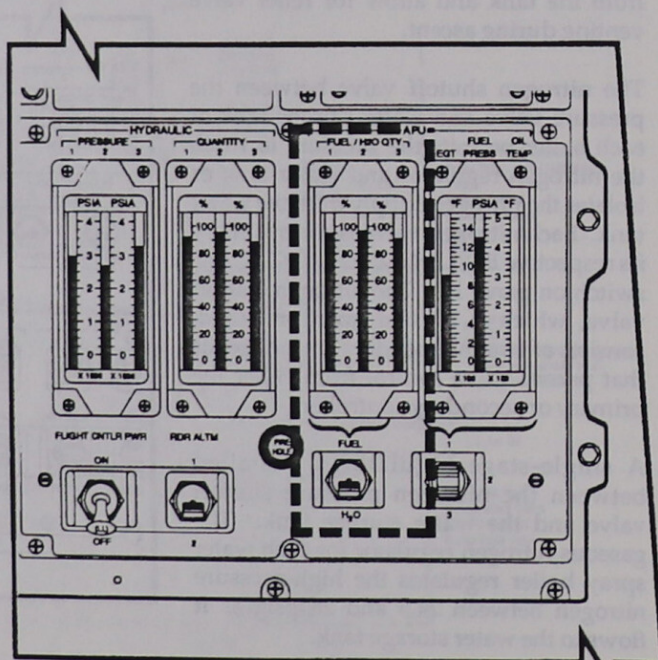
The two boiler controllers are operated by the respective *BOILER CNTLR/HTR* 1, 2, and 3 switches on panel R2. When the applicable switch is positioned to *A*, the *A* controller for that boiler is powered; if it is positioned to *B*, the *B* controller is powered. The *OFF* position removes electrical power from both controllers.

The *BOILER PWR* 1, 2, and 3 switches on panel R2 enable (provide the automatic control functions) the specific controller *A* or *B* selected for that boiler by the *BOILER CNTLR/HTR* 1, 2, and 3 switches on panel R2. When the applicable controller *A* or *B* is enabled for that boiler, a ready signal is transmitted to the corresponding *APU/HYD READY TO START* indicator on panel R2 if

the following additional conditions are met: gaseous nitrogen shutoff valve is open, steam vent nozzle temperature is greater than 130° F, and hydraulic fluid bypass valve is in the correct position with regard to the hydraulic fluid temperature.

The core of each WSB is a stainless steel crimped-tube bundle. The hydraulic fluid section is divided into three 17-inch-long passes of smooth tubes (first pass-234 tubes, second pass-224 tubes, and third pass-214 tubes). The lube oil section of the APU comprises two passes with 103 crimped tubes in its first pass and 81 smooth tubes in the second pass. The tubes are 0.0125 of an inch in diameter with a wall thickness of 0.010 of an inch. Crimps located every 0.24 of an inch break up the internal boundary layer and promote enhanced turbulent heat transfer. Although the second pass is primarily a low-pressure drop return section, approximately 15 percent of the unit's lube oil heat transfer occurs there. Three connected spray bars feed the hydraulic fluid section, while two spray bars feed the power unit's lube oil section in each boiler.

When the orbiter is in the vertical position on the launch pad, each boiler is loaded with up to 3.5 pounds of water, which is referred to as "pool mode" operation. When each APU/hydraulic system and



APU FUEL/ $H_2O$  QTY Meter and Switch on Panel F8

WSB are in operation 5 minutes before lift-off, the APU tube bundle and hydraulic tube bundle are immersed in the boiler water precharge. Liquid level sensors in each water boiler prevent the water feed valves from pulsing to avoid water spillage or loss. As the vehicle ascends during launch, the lube oil system of the APU heats up, eventually the boiler water precharge boils off, and the boiler goes into the spray mode about 8 minutes after launch. The hydraulic fluid usually does not heat up enough during ascent to require spray cooling.

When the APU/hydraulic combination is started for atmospheric entry, the hydraulic fluid and power unit lube oil flow commences, fluid temperatures rise, and spraying is initiated as required. During the lower part of entry, when the boiler temperature reaches 188° F, the water spray boiler returns to the pool mode. The spray bars begin discharging excess water to fill the boiler. When the water reaches the liquid level sensors, the spray is turned off so that the boiler is not overfilled. During entry, because the orbiter's orientation is different from that of launch, the boiler can hold up to 14 pounds of water.

The enabled controller of the operating WSB monitors the hydraulic fluid and lube oil outlet temperature from the APU. The hydraulic fluid outlet temperature controls the hydraulic-fluid water feed valve, and the power unit's lube oil outlet temperature controls the lube oil water feed valve. Signals are based on a comparison of the hydraulic system fluid temperature to its 208° F set point and of the lube oil of the power unit to its 250° F set point. When the respective water feed valve opens, instantaneous flows of 10 pounds per minute maximum through the hydraulic section and 5 pounds per minute maximum through the lube oil section of the power unit enter the water boiler through the corresponding spray bars to begin evaporative cooling of the hydraulic fluid and APU lube oil. The steam is vented out through the overboard steam vent.

The separate water feed valves modulate the water flow to each section of the tube bundle core in each WSB independently in 200-millisecond pulses that

vary from one pulse every 10 seconds to one pulse every 0.25 of a second.

Because of the unique hydraulic system fluid flows, control valves are located in the hydraulic system fluid line section of each WSB. Normally, hydraulic system fluid flows at up to 21 gallons per minute; however, the hydraulic system experiences 1- to 2-second flow spikes at up to 63 gallons per minute. If these spikes were to pass through the boiler, pressure drop would increase ninefold and the boiler would limit the flow of the hydraulic system. To prevent this, a relief function is provided by a spring-loaded poppet valve that opens when the hydraulic fluid pressure drop exceeds 48 psi and is capable of flowing 43 gallons per minute at a differential pressure of 50 psi across the boiler. A temperature controller bypass valve allows the hydraulic fluid to bypass the boiler when the fluid temperature decreases to 190° F. At 210° F, the controller commands the bypass valve to direct the fluid through the boiler. When the hydraulic fluid cools to 190° F, the controller again commands the valve to route the fluid around the boiler. Bypass valve (BYP VLV) status is available on the following displays: SM SYS SUMM 2 (PASS AND BFS) and PASS DISP 86 APU/HYD.

### Heaters

Each water boiler, water tank, and steam vent is equipped with electrical heaters to prevent freeze-up in orbit. The water tank and boiler electrical heaters are activated by the corresponding *BOILER CNTLR/HTR 1, 2, and 3* switches on panel R2. The A or B position of each switch selects the A or B heater system and is automatically controlled by the corresponding A or B controller. The steam vent heaters are also activated by the *BOILER CNTLR/HTR 1, 2 and 3* switches but only if the *BOILER PWR 1, 2 or 3* switch on panel R2 is ON. The water tank and boiler heaters are cycled on at 50° F and off at 55° F. The steam vent heaters are not operated continuously in orbit; they are activated approximately two hours before APU startup. The steam vent heaters are cycled on at 150° F and cycled off at 175° F.

## Main Hydraulic Pump

The main hydraulic pump for each hydraulic system is a variable displacement type. Each operates at approximately 3,900 rpm when driven by the corresponding APU.

Each main hydraulic pump has an electrically operated depressurization valve. The depressurization valve for each pump is controlled by its corresponding *HYD MAIN PUMP PRESS 1, 2, or 3* switch on panel R2. When the switch is positioned to *LOW*, the depressurization valve is energized to reduce the main hydraulic pump discharge pressure from its nominal range of 2,900 to 3,100 psi output to a nominal range of 500 to 1,000 psi to reduce the APU torque requirements during the start of the APU. "APU Press Low" is one of the inputs required to get a gray *READY TO START* talkback.

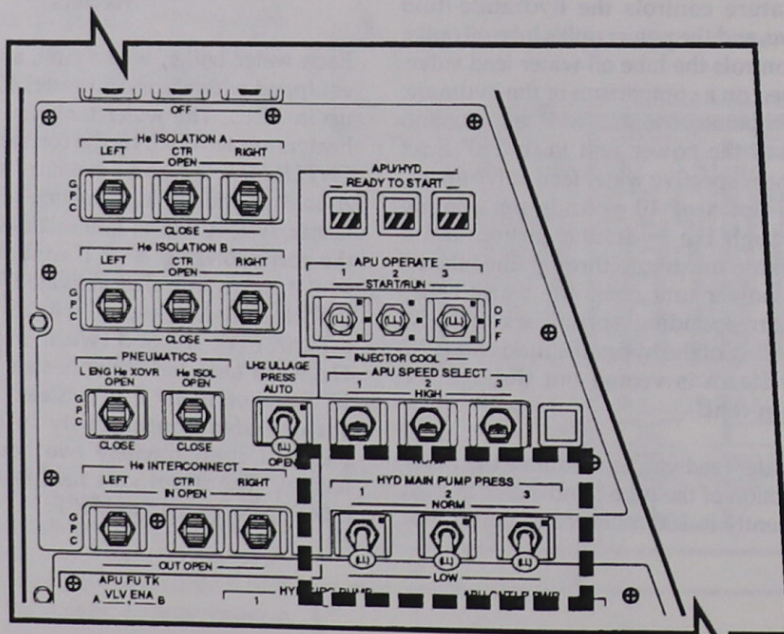
### NOTE

An APU cannot be successfully started with *HYD MAIN PUMP PRESS* positioned to *NORM*.

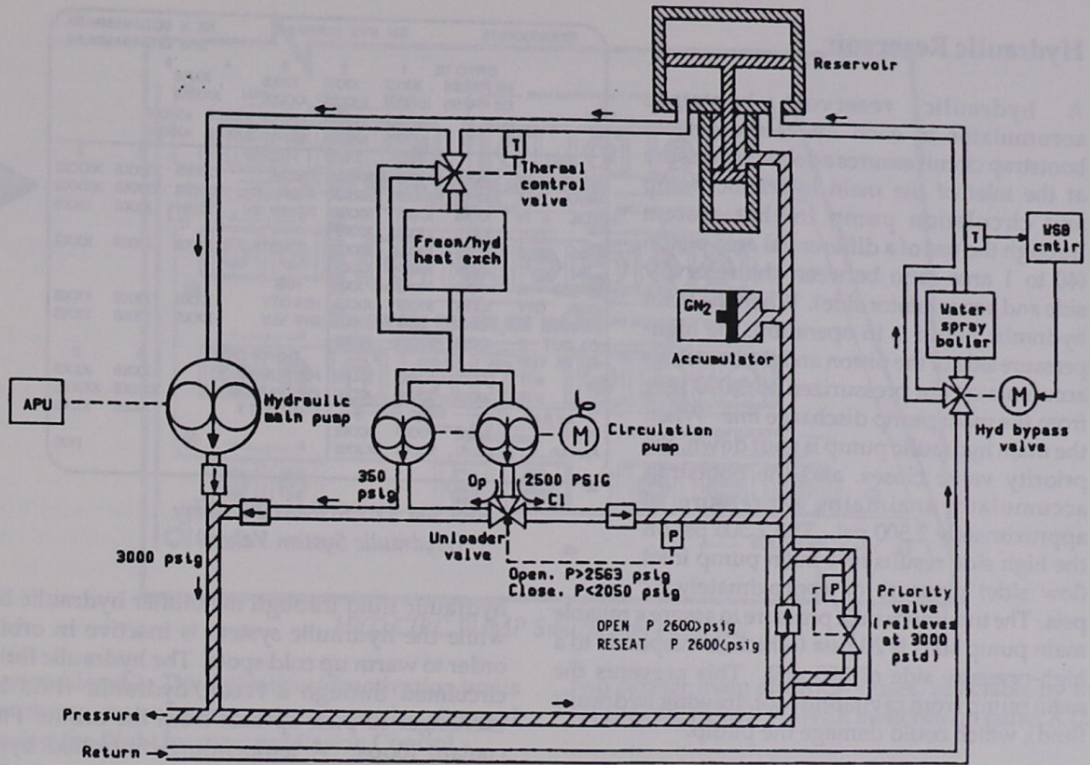
After an APU has been started, the corresponding *HYD MAIN PUMP PRESS* switch is positioned from *LOW* to *NORM*. This de-energizes the respective depressurization valve, allowing that hydraulic pump to increase its outlet pressure from 500 to 1,000 psi to 2,900 to 3,100 psi. Each hydraulic pump is a variable displacement type that provides 0 to 63 gallons per minute at 3,000 psi nominal with the APU at normal speed and 69.6 gallons per minute at 3,000 psi nominal with the APU at high speed.

Main pump outlet pressure (*HYD PRESS*) can be seen by the crew on the *BFS SM SYS SUMM 2* or *PASS DISP 86 APU/HYD* displays. A high-pressure relief valve in the filter module for each hydraulic system also relieves the hydraulic pump supply line pressure into the return line in the event the supply line pressure exceeds 3,850 psid.

A separate pressure sensor (sensor A) in the filter module for each hydraulic system monitors the hydraulic system source pressure and displays the pressure on the *HYDRAULIC PRESSURE 1, 2, and 3* meters on panel F8. This hydraulic pressure sensor also provides an input to the yellow *HYD PRESS* caution and warning light on panel F7 if the hydraulic pressure of system 1, 2, or 3 is below 2,800 psi.



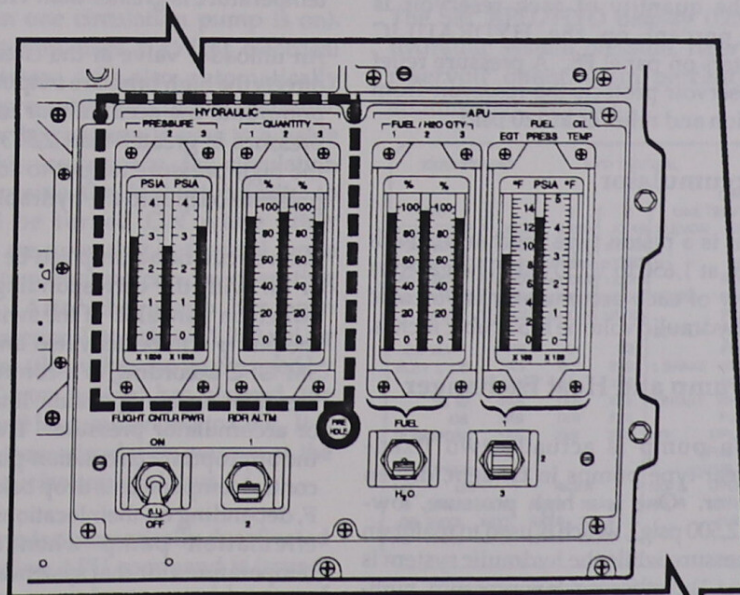
*HYD MAIN PUMP PRESS 1, 2, 3* Switches on Panel R2



NOTE: The system is shown in normal operation  
-APU on  
-Circ pump off

Pressure   
Return

Hydraulic System (Control Section)



HYDRAULIC PRESSURE and QUANTITY Meters on Panel F8  
(Driven by different sensor than CRT.)

## Hydraulic Reservoir

A hydraulic reservoir bootstrap accumulator in each hydraulic system and circulation pump in that system through the use of a differential area piston (40 to 1 area ratio between the reservoir side and accumulator side). When the main hydraulic pump is in operation, the high-pressure side of the piston and the bootstrap accumulator are pressurized to 3,000 psig from the main pump discharge line. When the main hydraulic pump is shut down, the priority valve closes, and the bootstrap accumulator maintains a pressure of approximately 2,500 psi. The 2,500 psi on the high side results in a main pump inlet (low side) pressure of approximately 62 psia. The minimum inlet pressure to assure a reliable main pump start is 20 psia (which corresponds to a high-pressure side of 800 psi). This prevents the main pump from cavitating (not drawing hydraulic fluid), which could damage the pump.

The quantity in each reservoir is 8 gallons. The hydraulic fluid specification is MIL-H-83282, which is a synthetic hydrocarbon (to reduce fire hazards). The reservoir provides for volumetric expansion and contraction. The quantity of each reservoir is monitored in percent on the HYDRAULIC QUANTITY meters on panel F8. A pressure relief valve in each reservoir protects the reservoir from overpressurization and relieves at 120 psid.

## Hydraulic Accumulator

The accumulator is a piston type precharged with gaseous nitrogen at 1,650 to 1,750 psi. The gaseous nitrogen capacity of each accumulator is 96 cubic inches, and the hydraulic volume is 51 cubic inches.

## Circulation Pump and Heat Exchanger

The circulation pump is actually two fixed-displacement gear-type pumps in tandem, driven by a single motor. One is a high pressure, low-volume pump (2,500 psig), which is used to maintain accumulator pressure while the hydraulic system is inactive in orbit. The other is a low pressure, high-volume pump (350 psig), which is used to circulate

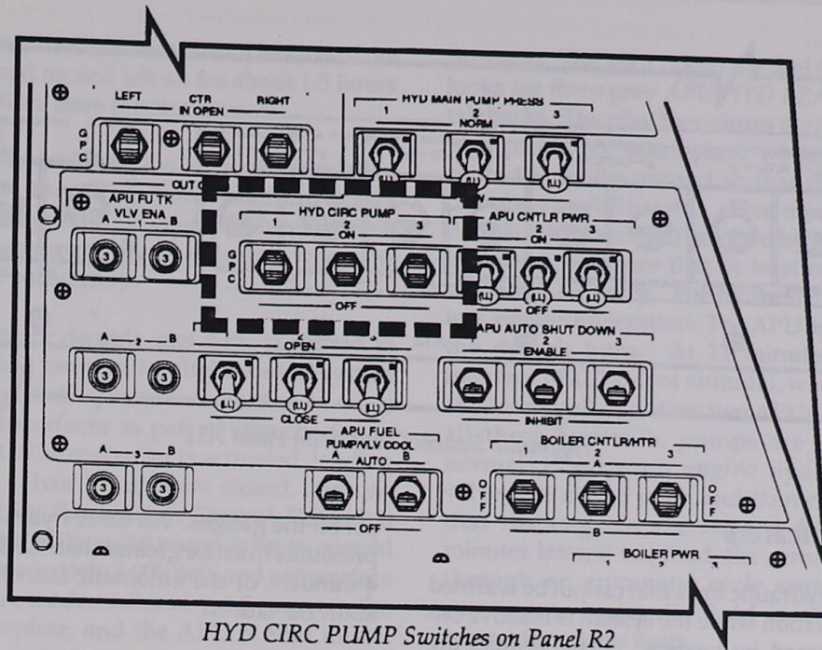
XXXX/XXXX/079				SM SYS SUMM 2				XX X DDD/HH:MM:SS					
				BFS DDD/HH:MM:SS									
CRYO TK				1	2	3	4	5					
H2 PRESS				XXXX	XXXX	XXXX	XXXX	XXXX					
O2 PRESS				XXXXX	XXXXX	XXXXX	XXXXX	XXXXX					
HTR T1				±XXXX	±XXXX	±XXXX	±XXXX	±XXXX					
T2				±XXXX	±XXXX	±XXXX	±XXXX	±XXXX					
AFU				1	2	3	HYD						
TEMP EGT				XXXXX	XXXXX	XXXXX	PRESS	XXXXX	XXXXX	XXXXX			
BAU EGT				XXXXX	XXXXX	XXXXX	ACUM P	XXXXX	XXXXX	XXXXX			
OIL IN				XXXX	XXXX	XXXX	RSVR T	XXXX	XXXX	XXXX			
OUT				XXXX	XXXX	XXXX							
GG BED				XXXX	XXXX	XXXX	QTY	XXXX	XXXX	XXXX			
INJ				XXXX	XXXX	XXXX							
SPEED %				XXS	XXS	XXS	W/B						
FUEL QTY				XXXX	XXXX	XXXX	H2O QTY	XXXX	XXXX	XXXX			
PMP LK P				XXS	XXS	XXS	BYP VLV	XXXX	XXXX	XXXX			
OIL OUT P				XXXX	XXXX	XXXX							
FU TK VLV								THERM CNTL				1	2
A T				XXXX	XXXX	XXXX	H2O PUMP P					XXXX	XXXX
B T				XXXX	XXXX	XXXX	FREON FLOW					XXXXX	XXXXX
AV BAY				1	2	3	EVAP OUT T					XXXX	XXXX
TEMP				XXXX	XXXX	XXXX							(XX)
FAN ΔP				X.XXS	X.XXS	X.XXS							

BFS SM SYS SUMM 2 Display  
(Hydraulic System Values)

hydraulic fluid through the orbiter hydraulic lines while the hydraulic system is inactive in orbit in order to warm up cold spots. The hydraulic fluid is circulated through a Freon/hydraulic fluid heat exchanger to pick up heat from the orbiter Freon coolant 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 bypasses the fluid around the heat exchanger if the temperature is greater than 115° F.

An unloader valve at the circulation pump outlet directs the high pressure output from the circulation pump into the accumulator until the accumulator pressure is greater than 2,563 psia, then redirects the high pressure output to combine with the low pressure output to the hydraulic lines.

Each circulation pump can be manually turned on or off with the corresponding *HYD CIRC PUMP* switch on panel R2. If the switch is placed in *GPC*, the pump will be activated and deactivated by the SM *GPC* according to a control software program based on certain hydraulic line temperatures and/or accumulator pressure. This program activates the appropriate circulation pump when any of the control temperatures drop below either 0° F, or -10° F, depending on their locations, and deactivates the circulation pump when all of the control temperatures for that system are greater than 20° F, or after 15 minutes for system 1 and 10 minutes for



HYD CIRC PUMP Switches on Panel R2

systems 2 and 3. The activation/deactivation limits for these control temperatures can be changed during the flight by crew or Mission Control.

The program also includes a timer to limit the maximum time a circulation pump will run, and a priority system to assure that only one circulation pump is on at a time (because of excessive power usage if more than one circulation pump is on). Each circulation pump uses 2 kW of electrical power. This software will also automatically provide for the repressurization of the hydraulic accumulator when the pressure lowers to a value of 1,960 psi. In this contingency, the circulation pump will first receive the highest priority to operate and will be turned ON while other circulation pumps are operating in thermal mode (this means that two pumps can be operating simultaneously). After the pump has been repressurized, the accumulator above 1,960 psi, or a period of 2 minutes (this value can be changed by Mission Control Center uplink) has elapsed, the circulation pump will be commanded to OFF. It is possible to run all three circulation pumps at the same time to repressurize accumulators.

The circulation pump is automatically deactivated when its corresponding APU command is issued. Each circulation pump can be powered by one of

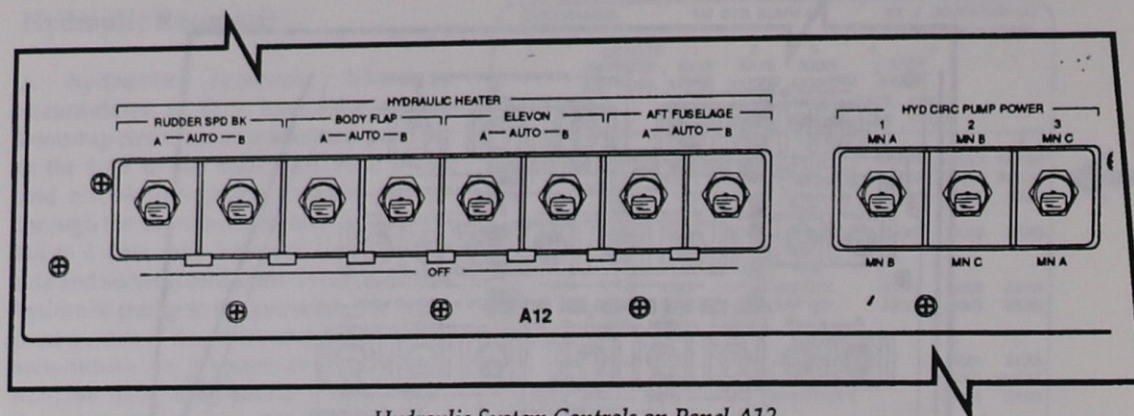
two orbiter main electrical buses, selectable by the *HYD CIRC PUMP POWER* switches on panel A12.

The crew can see circulation pump outlet pressure as well as the hydraulic line and component temperatures on the *PASS SM HYD THERMAL* display, DISP 87.

The *SM APU/HYD* display (DISP 86) shows the hydraulic system pressure, reservoir temperature, reservoir quantity (in percent), and hydraulic accumulator pressure.

XXXX/XXX/087		HYD THERMAL			XX X DDD/HH-MM.SS DDD/HH-MM.SS CONTROL		
HYD	1	2	3	CIRC	1	2	3
CIRC PUMP P	±XXXS	±XXXS	±XXXS	ELEVON	LOB	±XXXS	±XXXS
PMP BDY T	±XXXS	±XXXS	±XXXS		LUB	±XXXS	±XXXS
RSVR T	±XXXS	±XXXS	±XXXS		RIB	±XXXS	±XXXS
ACCUM P	±XXXS	±XXXS	±XXXS		ROB	±XXXS	±XXXS
HX IN T	±XXXS	±XXXS	±XXXS	RD/SB	PDU	±XXXS	±XXXS
OUT T	±XXXS	±XXXS	±XXXS		FUS	±XXXS	±XXXS
				BDYFLP	PDU	±XXXS	±XXXS
SW VLV	PR	S1	S2		FUS	±XXXS	±XXXS
ELEV L	OB	3XS	1XS	2XS	L BRAKE	WHL	±XXXS
	IB	2XS	1XS	3XS		FUS	±XXXS
	R IB	3XS	1XS	2XS	RBRAKE	WHL	±XXXS
	OB	2XS	1XS	3XS		FUS	±XXXS
RUD/SPDBK	1XS	2XS	3XS	NG	UPLX	±XXXS	±XXXS
					MFUS 1	±XXXS	
TIRE PRESS					MFUS 2	±XXXS	
MG	LEFT		RIGHT	MG L	UPLX	±XXXS	
IB	±XXXS	±XXXS	±XXXS	MG R	UPLX	±XXXS	
OB	±XXXS	±XXXS	±XXXS		FUS	±XXXS	
NG	±XXXS	±XXXS	±XXXS				(XX)

SM HYD THERMAL Display (DISP 87)



Hydraulic System Controls on Panel A12

## Hydraulic Heaters

Areas of the hydraulic lines that cannot be warmed by fluid circulation while the system is inactive on-orbit are warmed by heaters. These heaters are automatically controlled by thermostats to maintain the hydraulic line temperatures in a specified range. Each heated area has redundant heaters (A and B), which are controlled by the *HYDRAULIC HEATER* switches on panel A12.

## Operations

The WSB controllers are powered up at launch minus 8 hours, and the boiler water tanks are pressurized in preparation for APU activation. The controllers activate heaters on the water tank, boiler, and steam vent to assure that the water spray boiler is ready to operate for launch.

APU start is delayed as long as possible to save fuel. At T minus 6 minutes, the pilot begins the prestart sequence. The pilot confirms that the WSB is activated, then activates the APU controllers and depressurizes the main hydraulic pump. Depressurizing the main pump reduces the starting torque on the APU. The pilot then opens the fuel tank valves and looks for three APU ready-to-start indications (gray talkbacks). At T minus 5 minutes, the pilot starts the three units by setting the *APU OPERATE* switches to *START/RUN* and checks the hydraulic pressure gauges for an indication of approximately 800 psi. Then the pilot pressurizes the main pump and looks for approximately 3,000

psi on the gauges. All three hydraulic main pump pressures must be greater than 2,800 psi by T minus 4 minutes, or the automatic launch sequencer will abort the launch.

The APUs operate during the ascent phase and continue to operate through the first OMS burn. At the conclusion of the main engine purge, dump, and stow sequence, the APUs and WSBs are shut down. The same sequence applies for a delayed OMS-1 burn. If an abort once around is declared, the APUs are left running, but the hydraulic pumps are depressurized to reduce fuel consumption. The units are left running to avoid having to restart hot APUs for deorbit and re-entry.

Six hours after liftoff, or as soon as they are required, depending on the environment, the gas generator/fuel pump heaters are activated and are in operation for the remainder of the orbital mission. The fuel and water line heaters are activated about 1 hour after lift-off to prevent the lines from freezing as the APUs cool down.

Two hours after liftoff, the landing gear isolation valves on hydraulic systems 2 and 3 are opened so that the pumps can circulate hydraulic fluid through these lines. The valves will not open or close unless the pressure in the line is at least 100 psi, which requires the main hydraulic pump or hydraulic circulation pump to be active. The hydraulic system 1 landing gear isolation valve is left closed because of the danger of inadvertently lowering the landing gear while the vehicle is in orbit.

Two hours after liftoff, the steam vent heaters of the WSBs are turned on and left on for about 1.5 hours to eliminate all ice from the steam vents.

While the vehicle is in orbit, the hydraulic circulation pumps are in the GPC mode—automatically activated when hydraulic line temperatures become too low and automatically deactivated when the lines warm up sufficiently.

On the day before deorbit, one APU is started to supply hydraulic pressure for flight control system checkout. (Hydraulic pressure is needed to move the orbiter aerosurfaces as part of this checkout.) The associated WSB controller is activated, landing gear isolation valves 2 and 3 are closed, and one APU (selected by the Mission Control Center) is started. The hydraulic main pump is set to normal pressure (approximately 3,000 psi), and aerosurface drive checks are made. After about 5 minutes, the checks are complete, and the APU is shut down. Normally, the unit does not run long enough to require WSB operation. The landing gear isolation valves on hydraulic systems 2 and 3 are reopened after the APU is shut down.

At 2.5 hours before the deorbit burn, the boilers' steam vent heaters are activated to prepare the system for operation during atmospheric entry. At about the same time, the landing gear isolation valves on hydraulic systems 2 and 3 are closed, and the circulation pumps are turned off.

At 45 minutes before deorbit, the WSB water tanks are pressurized, the APU controllers are activated, and the main hydraulic pumps are set to low

pressure. The pilot opens the fuel tank valves and looks for three gray *APU/HYD READY TO START* talkbacks. The pilot then closes the fuel tank valves. This procedure takes place while the crew is in contact with the ground so that flight controllers can observe APU status. Five minutes before the deorbit burn, one APU (selected by Mission Control) is started to ensure that at least one unit will be operating for entry. The hydraulic pump is left in low-pressure operation. The APU operates through the deorbit burn. At 13 minutes before entry interface (400,000-foot altitude), while the orbiter is still in free fall, the other two APUs are started, and all three hydraulic pumps are pressurized to normal. Two main engine hydraulic isolation valves are cycled open and then closed to ensure that the engines are stowed for entry. Two minutes later, if required, the aerosurfaces are put through an automatic cycle sequence to make sure warm hydraulic fluid is available in the aerosurface drive units.

After touchdown, a hydraulic load test may be done to test the response of the auxiliary power units and hydraulic pumps under high load (i.e., high flow demand) conditions. This test cycles the orbiter aerosurfaces with one hydraulic system at a time in depressed mode (the remaining two APUs and hydraulic pumps have to drive all the aerosurfaces). This is typically done on the first flight of a new vehicle. Then the main engine hydraulic isolation valves are opened again, and the engines are set to the transport position. At this point, the hydraulic systems are no longer needed; the APUs and WSBs are shut down.



**APU/HYD Caution and Warning Summary**

- The yellow *APU TEMP* caution and warning light on panel F7 is illuminated if the APU 1, 2, or 3 lube oil temperature is above 290° F.
- The yellow *APU OVERSPEED* light is illuminated if APU 1, 2, or 3 turbine speed is more than 92,880 rpm (129%). If the *APU AUTO SHUT DOWN* switch on panel R2 is in *ENABLE*, an automatic shutdown of that APU will occur.
- The yellow *APU UNDERSPEED* light is illuminated if APU 1, 2, or 3 turbine speed is less than 57,600 rpm (80%). If the *APU AUTO SHUT DOWN* switch for that APU is in *ENABLE*, an automatic shutdown will occur.
- Placing the *APU AUTO SHUT DOWN* switch in *INHIBIT* only inhibits the automatic shutdown of that APU if its turbine speed is less than 80% or more than 129%. The *APU UNDERSPEED* or *APU OVERSPEED* light will always illuminate, and a tone will be generated.
- The yellow *HYD PRESS* light illuminates for overspeed or underspeed shutdown, or when hydraulic system 1, 2, or 3 drops below 2,800 psi.
- The blue *SM ALERT* illuminates, and the *C/W* tone is sounded if turbine speed falls below 80% or rises above 129%.
- The red *BACKUP C/W ALARM* illuminates if hydraulic pressure of system 1, 2, or 3 drops below 2,800 psi.

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

APU/HYD Caution and Warning Lights on Panel F7

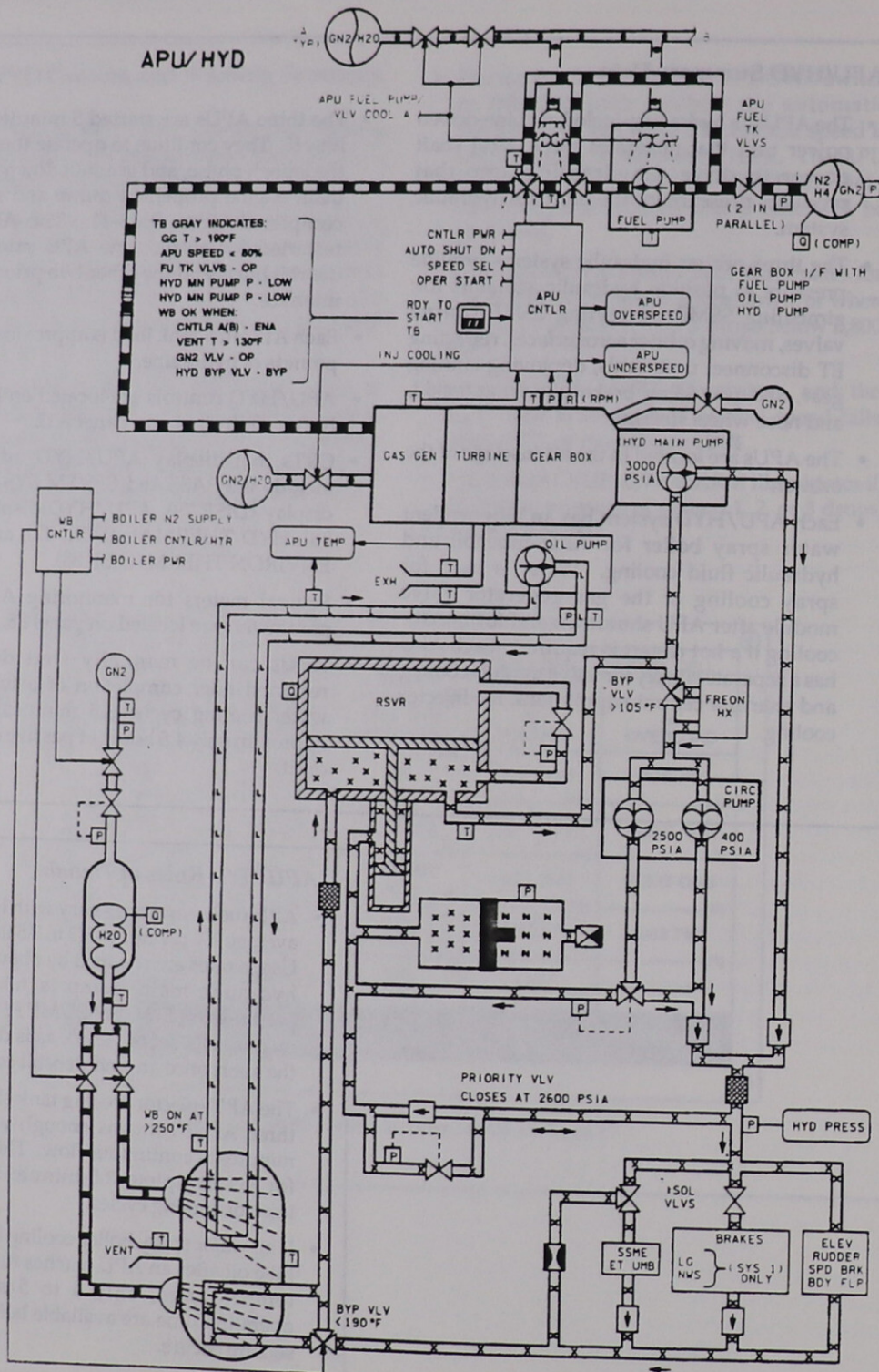
### APU/HYD Summary Data

- The APU is a hydrazine-fueled, turbine-driven power unit that generates mechanical shaft power to drive a hydraulic pump that produces pressure for the orbiter's hydraulic system.
- The three orbiter hydraulic systems provide pressure to position hydraulic actuators for: gimbaling SSMEs, actuating SSME control valves, moving orbiter aerosurfaces, retracting ET disconnect umbilicals, deploying landing gear, and providing brake power, anti-skid, and nose wheel steering.
- The APUs are located in the aft fuselage of the orbiter.
- Each APU/HYD system has an independent water spray boiler for APU lube oil and hydraulic fluid cooling. Water is used for spray cooling of the gas generator valve module after APU shutdown and for injector cooling if a hot restart is required. Each APU has a separate supply for valve module cooling and shares a central supply tank for injector cooling.
- The three APUs are started 5 minutes before lift-off. They continue to operate throughout the launch phase, and are shut down after the main engine propellant dump and stow are completed (post OMS-1). The APUs are restarted for entry: one APU prior to the deorbit burn, and the other two prior to entry interface.
- Each APU fuel tank load is approximately 325 pounds of hydrazine.
- APU/HYD controls are located on Panel R2; heater controls are on panel A12.
- CRTs that display APU/HYD information include the PASS and BFS SM SYS SUMM 2 display (DISP 79), APU/HYD display (DISP 86), HYD THERMAL (DISP 87), and APU/ENVIRON THERM (DISP 88).
- Several meters for monitoring APU/HYD parameters are located on panel F8.
- APUs can be manually shut down and restarted after completion of a full injector water cooling cycle (3.5 minutes), or after approximately 4.5 hours of passive cooling on orbit.

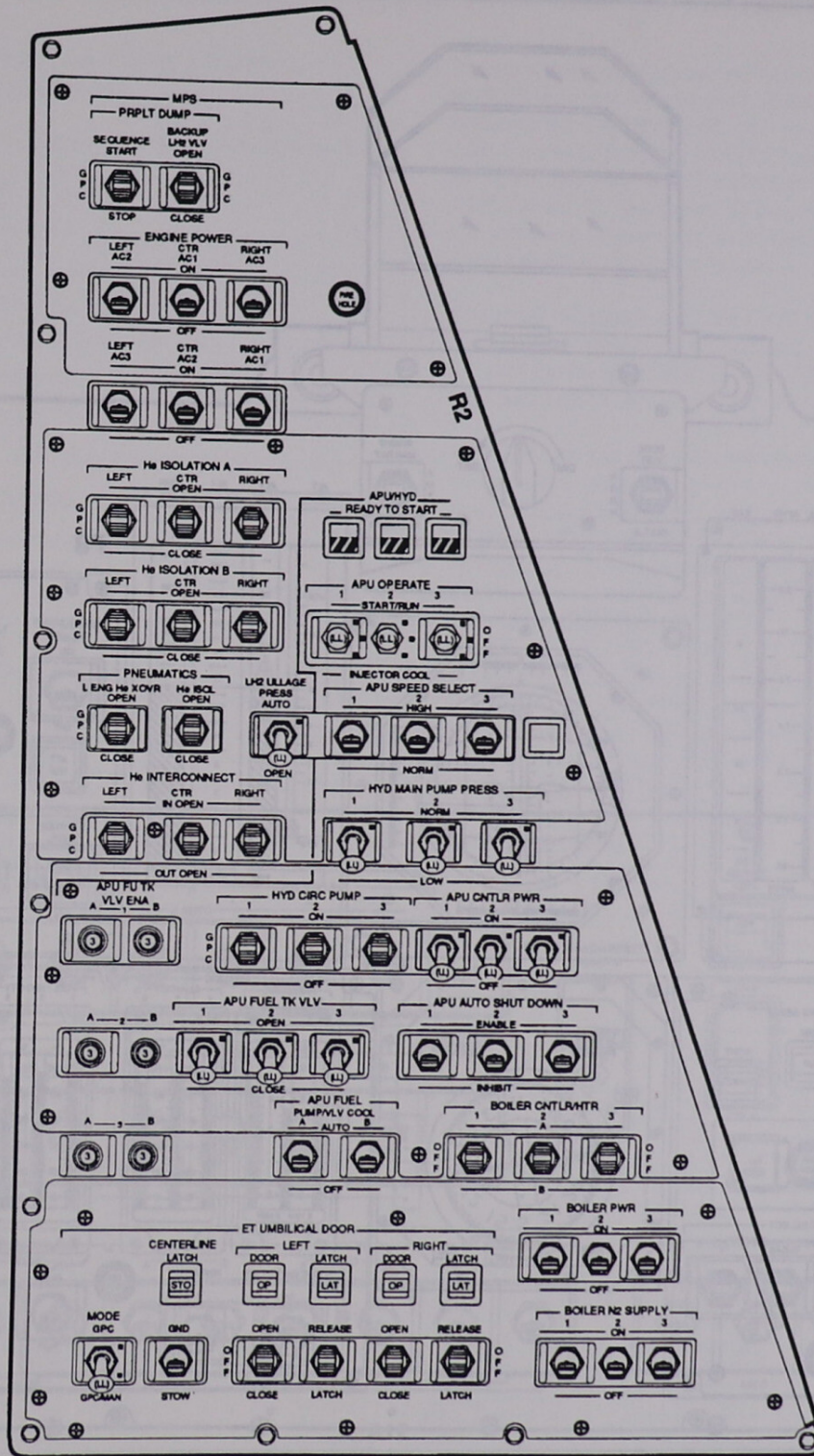
### APU/HYD Rules of Thumb

- APU fuel usage rates vary with loading, but average 1% per minute (3 to 3.5 lbs/minute). Usage rates are reduced by about half if the hydraulic main pump is taken to low pressure (*HYD MAIN PUMP PRESS* switch on panel R2 set to *LOW*), as is done during the abort once around deorbit coast period.
- The APU injector cooling tank shared by all three APUs contains enough water for 21 minutes of continuous flow. This is enough for six complete 3.5-minute hot restart injector cooling cycles.
- If all water spray boiler cooling is lost to the lube oil after an APU reaches full operating temperatures, only 4 to 5 minutes of operating time are available before bearing seizure occurs.

2. SYSTEMS  
2.1 Auxiliary Power Unit/Hydraulics

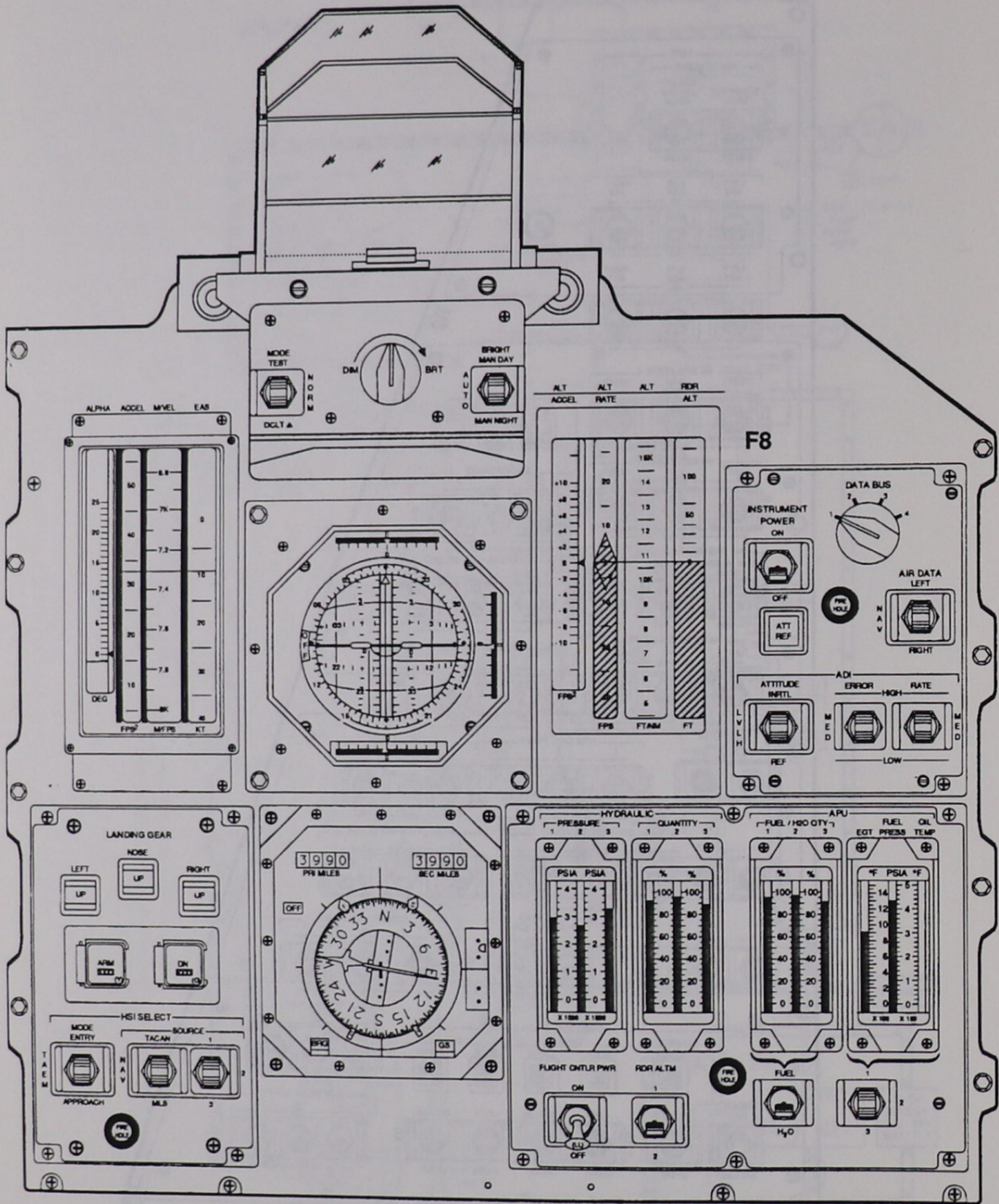


APU/Hydraulic Overview



Panel R2

2. SYSTEMS  
 2.1 Auxiliary Power Unit/Hydraulics



Panel F8

2.2 CAUTION AND WARNING SYSTEM (C/W)

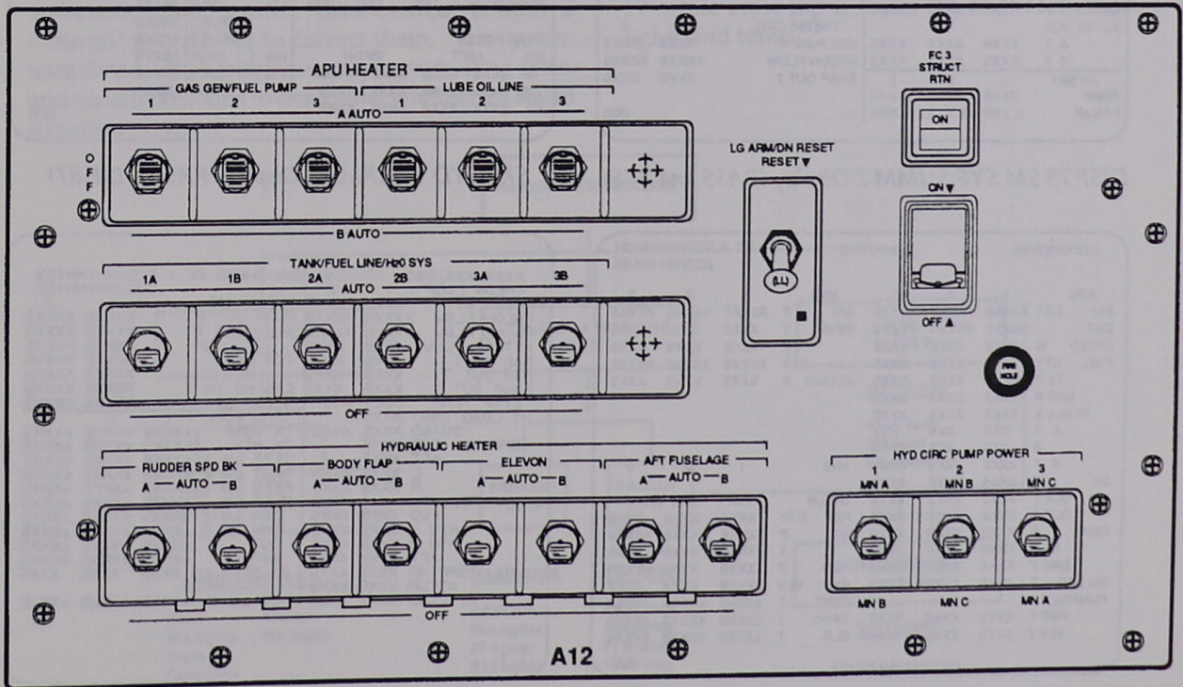
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The system consists of software and electronics that provide the crew with visual and aural cues when a system exceeds predefined operating limits. Visual cues consist of four red MASTER ALARM lights, a 40-light array on panel P7, a 120-light array on panel R13U, and CRT messages. The aural cue is sent to the communication system for distribution to flight crew headsets or speaker boxes.

The crew interfaces with the C/W system through panel R13U, panel C3, CRT displays, panel P7, panel L1, and the four red MASTER ALARM push button indicators on panels P2, P4, P7, and M15C.

The C/W system interfaces with the auxiliary power units, data processing system, environmental control and life support system, electrical power system, fuel system, hydraulic system, and navigation, hydraulic, and programing system.



Panel A12

2. SYSTEMS  
2.1 Auxiliary Power Unit/Hydraulics

XXXX/XXX/079 SM SYS SUMM 2				XX X DDD/HH.MM.SS BFS DDD/HH.MM.SS				
CRYO TK				1	2	3	4	5
H2 PRESS	XXXXS	XXXXS	XXXXS	XXXXS				
O2 PRESS	XXXXS	XXXXS	XXXXS	XXXXS				
HTR T1	±XXXX	±XXXX	±XXXX	±XXXX	±XXXX	±XXXX		
T2	±XXXX	±XXXX	±XXXX	±XXXX	±XXXX			
APU				HYD				
TEMP EGT	XXXXS	XXXXS	XXXXS	PRESS	XXXXS	XXXXS	XXXXS	
B/U EGT	XXXXS	XXXXS	XXXXS	ACUM P	XXXXS	XXXXS	XXXXS	
OIL IN	XXXXS	XXXXS	XXXXS	RSVR T	XXXXS	XXXXS	XXXXS	
OUT	XXXXS	XXXXS	XXXXS					
GG BED	XXXXS	XXXXS	XXXXS	QTY	XXXXS	XXXXS	XXXXS	
INJ	XXXXS	XXXXS	XXXXS					
SPEED %	XXS	XXS	XXS	W/B				
FUEL QTY	XXXXS	XXXXS	XXXXS	H2O QTY	XXXXS	XXXXS	XXXXS	
PMP LK P	XXS	XXS	XXS	BYP VLV	XXXXS	XXXXS	XXXXS	
OIL OUT P	XXXXS	XXXXS	XXXXS					
FU TK VLV				THERM CNTL		1	2	
A T	XXXXS	XXXXS	XXXXS	H2O PUMP P		XXXXS	XXXXS	
B T	XXXXS	XXXXS	XXXXS	FREON FLOW		XXXXS	XXXXS	
AV BAY	1	2	3	EVAP OUT T		XXXXS	XXXXS	
TEMP	XXXXS	XXXXS	XXXXS					
FAN ΔP	X.XXS	X.XXS	X.XXS					(XX)

DISP 79 SM SYS SUMM 2 Display (PASS and BFS)

XXXX/XXX/087 HYD THERMAL				XX X DDD/HH.MM.SS DDD/HH.MM.SS					
HYD				CIRC PUMP			CONTROL		
	1	2	3	LINE TEMPS	1	2	3		
CIRC PUMP P	XXXXS	XXXXS	XXXXS	ELEVON LOB	XXXXS	XXXXS	XXXXS		
PMP BDY T	±XXXX	±XXXX	±XXXX	LIB	±XXXX	±XXXX	±XXXX		
RSVR T	±XXXX	±XXXX	±XXXX	RIB	±XXXX	±XXXX	±XXXX		
ACCUM P	±XXXX	±XXXX	±XXXX	ROB	±XXXX	±XXXX	±XXXX		
HX IN T	±XXXX	±XXXX	±XXXX	RD/SB PDU	±XXXX	±XXXX	±XXXX		
OUT T	±XXXX	±XXXX	±XXXX	FUS	±XXXX	±XXXX	±XXXX		
				BDYFLP PDU	±XXXX	±XXXX	±XXXX		
SW VLV	PR	S1	S2	FUS	±XXXX	±XXXX	±XXXX		
ELEV L OB	3XS	1XS	2XS	L BRAKE WHL	±XXXX	±XXXX	±XXXX		
IB	2XS	1XS	3XS	FUS	±XXXX	±XXXX	±XXXX		
R IB	3XS	1XS	2XS	RBRAKE WHL	±XXXX	±XXXX	±XXXX		
OB	2XS	1XS	3XS	FUS	±XXXX	±XXXX	±XXXX		
RUD/SPDBK	1XS	2XS	3XS	NG UPLK	±XXXX	±XXXX	±XXXX		
				MFUS 1	±XXXX	±XXXX	±XXXX		
TIRE PRESS				MFUS 2	±XXXX	±XXXX	±XXXX		
MG LEFT		RIGHT		MG L UPLK	±XXXX	±XXXX	±XXXX		
IB XXXS	XXXXS	XXXXS	XXXXS	MG R UPLK	±XXXX	±XXXX	±XXXX		
OB XXXS	XXXXS	XXXXS	XXXXS	FUS	±XXXX	±XXXX	±XXXX		
NG XXXS	XXXXS	XXXXS	XXXXS					(XX)	

SM HYD THERMAL Display (PASS DISP 87)

XXXX/XXX/086 APU/HYD				XX X DDD/HH.MM.SS DDD/HH.MM.SS				
APU				HYD				
	1	2	3		1	2	3	
B/U EGT	XXXXS	XXXXS	XXXXS	B/U P	XXXXS	XXXXS	XXXXS	
EGT	XXXXS	XXXXS	XXXXS	RSVR T	XXXXS	XXXXS	XXXXS	
SPEED %	XXXXS	XXXXS	XXXXS	P	XXXXS	XXXXS	XXXXS	
FUEL QTY	XXXXS	XXXXS	XXXXS	QTY	XXXXS	XXXXS	XXXXS	
TK P	XXXXS	XXXXS	XXXXS	ACCUM P	XXXXS	XXXXS	XXXXS	
OUT P	XXXXS	XXXXS	XXXXS					
TK VLV A	XXXXS	XXXXS	XXXXS					
A T	XXS	XXS	XXS					
B T	XXS	XXS	XXS					
B T	XXXXS	XXXXS	XXXXS	W/B	1	2	3	
OIL T	XXXXS	XXXXS	XXXXS					
OUT	XXXXS	XXXXS	XXXXS	CNTRL	XXX	XXX	XXX	
OUT P	XXXXS	XXXXS	XXXXS	H2O QTY	XXXXS	XXXXS	XXXXS	
GBX P	XXXXS	XXXXS	XXXXS	N2 P	XXXXS	XXXXS	XXXXS	
N2 P	XXXXS	XXXXS	XXXXS	T	XXXXS	XXXXS	XXXXS	
BRGT	XXXXS	XXXXS	XXXXS	REG P	XXXXS	XXXXS	XXXXS	
GG BED T	XXXXS	XXXXS	XXXXS	BYP VLV	XXXXS	XXXXS	XXXXS	
PUMP/VLV				VENT T	±XXXX	±XXXX	±XXXX	
PMP T	XXXXS	XXXXS	XXXXS	TANK T	±XXXX	±XXXX	±XXXX	
VLVT	XXXXS	XXXXS	XXXXS	BLR T	±XXXX	±XXXX	±XXXX	(XX)

SM APU/HYD Display (PASS DISP 86)

XXXX/XXX/088 APU/ENVIRON THERM				XX X DDD/HH.MM.SS DDD/HH.MM.SS				
FREON LOOP				H2O LOOP				
	1	2	3		1	2	3	
ACCUM QTY	XXXXS	XXXXS	XXXXS	PUMP OUT P	XXXXS	XXXXS	XXXXS	
FREON FLOW	XXXXS	XXXXS	XXXXS	OUT T	XXXXS	XXXXS	XXXXS	
PL HX FLOW	XXXXS	XXXXS	XXXXS	ΔP	XXXXS	XXXXS	XXXXS	
AFT CP FLOW	XXXXS	XXXXS	XXXXS	ICH FLOW	XXXXS	XXXXS	XXXXS	
RAD IN T	XXXXS	XXXXS	XXXXS	OUT T	XXXXS	XXXXS	XXXXS	
RAD OUT T	XXXXS	XXXXS	XXXXS	CAB HX IN T	XXXXS	XXXXS	XXXXS	
EVAP OUT T	XXXXS	XXXXS	XXXXS	ACCUM QTY	XXXXS	XXXXS	XXXXS	
EVAP TEMP	DUCT	NOZ						
HI LOAD INBD	XXXXS	XXXXS	XXXXS	APU FUEL T	1	2	3	
OUTBD	XXXXS	XXXXS	XXXXS	TK SURF	±XXXX	±XXXX	±XXXX	
TOPPING FWD	XXXXS	XXXXS	XXXXS	TK HTR	±XXXX	±XXXX	±XXXX	
AFT	XXXXS	XXXXS	XXXXS	TEST LN 1	±XXXX	±XXXX	±XXXX	
L	XXXXS	XXXXS	XXXXS	TEST LN 2	±XXXX	±XXXX	±XXXX	
R	XXXXS	XXXXS	XXXXS	FEED LN	±XXXX	±XXXX	±XXXX	
EVAP FOLDN T	A	B		PUMP IN	±XXXX	±XXXX	±XXXX	
				DRN LN 1	±XXXX	±XXXX	±XXXX	
MID 1	XXXXS	XXXXS	XXXXS	DRN LN 2	±XXXX	±XXXX	±XXXX	
MID 2	XXXXS	XXXXS	XXXXS	OUT	±XXXX	±XXXX	±XXXX	
AFT	XXXXS	XXXXS	XXXXS	BYP LN	±XXXX	±XXXX	±XXXX	
TOPPING	XXXXS	XXXXS	XXXXS	GG SPLY LN	XXXXS	XXXXS	XXXXS	
ACCUM	XXXXS	XXXXS	XXXXS					
HI LOAD	XXXXS	XXXXS	XXXXS	H2O LN INJ	±XXXX	±XXXX	±XXXX	(XX)

APU/ENVIRON THERM (PASS DISP 88)

## 2.2 CAUTION AND WARNING SYSTEM (C/W)

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### Description

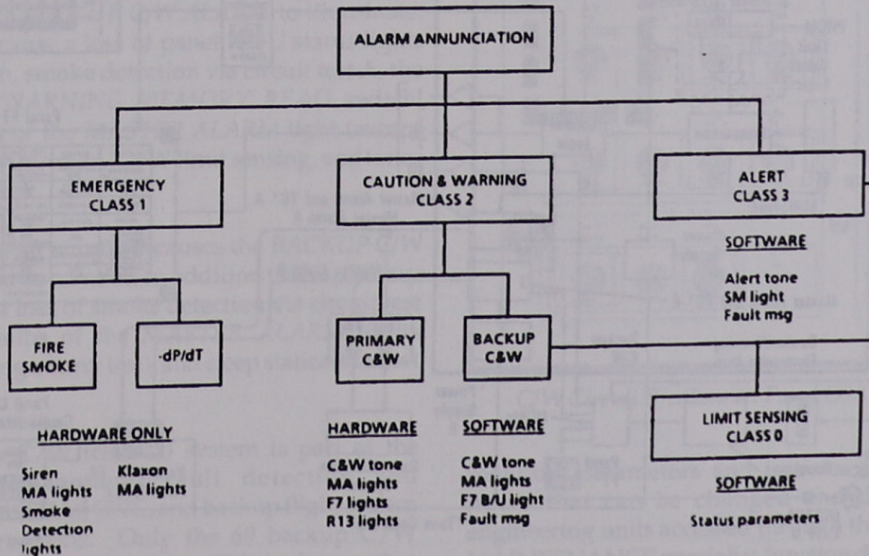
The caution and warning system warns the crew of conditions that may create a hazard to orbiter operation and/or crew. Under certain circumstances, the system also alerts the crew to situations that require time-critical (under 5 minutes) procedures to correct them. The system uses data such as temperature, pressure, flow rates, and switch positions to determine whether an alarm situation exists.

The system consists of software and electronics that provide the crew with visual and aural cues when a system exceeds predefined operating limits. Visual cues consist of four red *MASTER ALARM* lights, a 40-light array on panel F7, a 120-light array on panel R13U, and CRT messages. The aural cue is sent to the communications system for distribution to flight crew headsets or speaker boxes.

The crew interfaces with the C/W system through panel R13U, panel C3, CRT displays, panel F7, panel L1, and the four red *MASTER ALARM* push button indicators on panels F2, F4, A7, and MO52J.

The C/W system interfaces with the auxiliary power units, data processing system, environmental control and life support system, electrical power system, flight control system, guidance and navigation, hydraulics, main propulsion system, reaction control system, orbital maneuvering system, and payloads.

Inputs enter the software C/W logic circuitry from the onboard computers through multiplexers/demultiplexers (MDMs) to activate alarm tones and the *BACKUP C/W ALARM*. Some of these are used to turn on the *BACKUP C/W ALARM* light on panel F7 while crew input resets the *MASTER ALARM* lights and tones.



Caution and Warning Diagram



## Alarms

Four alarm classes constitute the C/W system.

### Class 1 - Emergency

There are two alarms in this class: (1) smoke detection/fire suppression and (2) rapid cabin depressurization. (These systems are discussed in more detail later in this section.) Class 1 is a hardware system only; its input is not processed by any MDMs or software. The system uses hardware, such as hard-wired sensors, to monitor parameters and to issue alarms. Because of the nature of the class 1 alarms, they always receive the highest priority for resolution.

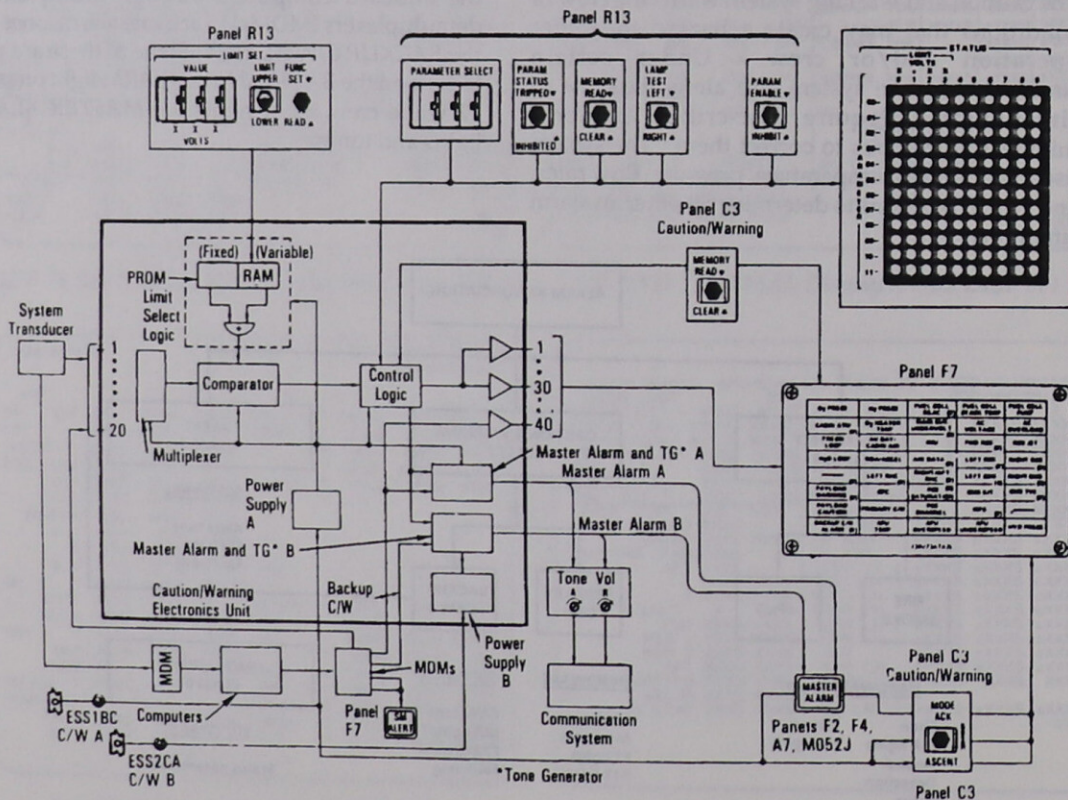
The emergency (class 1) aural alarms consist of a siren (activated by the smoke detection system) and a klaxon (activated by the delta pressure/delta time sensor that recognizes a rapid loss of cabin pressure), and they are announced by hardware. The siren's

frequency varies from 666 to 1,470 hertz and returns at a five-second-per-cycle rate. The klaxon is a 2,500-hertz signal with an on/off cycle of 2.1 milliseconds on and 1.6 milliseconds off, mixed with a 270-hertz signal with a cycle of 215 milliseconds on and 70 milliseconds off.

The emergency alarm visual cues consist of illumination of the four *MASTER ALARM* pushbutton indicators on panels F2, F4, A7, and MO52J. The smoke detection system also illuminates *SMOKE DETECTION* lights on panel L1, displays information on the SM SYS SUMM 1 display (SMOKE), and issues a backup C/W "smoke alarm" message. Similarly, cabin pressure information can be seen on the SM SYS SUMM 1 display (CABIN).

### Class 2 - C/W

This class also consists of two subclasses: primary C/W, which is a hardware system, and backup (B/U) C/W, which is a software system.



Caution and Warning System Overview

The primary C/W system has the capacity to monitor 120 inputs, which are received from transducers through either signal conditioners or flight forward MDMs. Baseline limit values are stored in the C/W electronics unit located in avionics bay 3. These values can be changed by the crew, after the parameters' engineering units are converted to a standard voltage value, through switches on panel R13U; however, if power is lost, the limits will return to their original values. The majority of the original stored values are identical to the backup C/W (software) values. Thirty-nine lights on the panel F7 annunciator matrix are dedicated to the primary C/W; the exception is the **BACKUP C/W ALARM**.

When a primary C/W alarm is issued, the appropriate lamp on the panel F7 annunciator matrix is illuminated, all four **MASTER ALARM** indicators are illuminated, the C/W tone sounds, and the appropriate lamp on the panel R13U parameter status light matrix is illuminated. No CRT fault message is generated by the primary C/W.

The primary C/W system receives power from power supply A from the C/W A circuit breaker powered by **ESS 1BC** on panel O13, and power supply B from C/W B circuit breaker powered by **ESS 2CA** on panel O13.

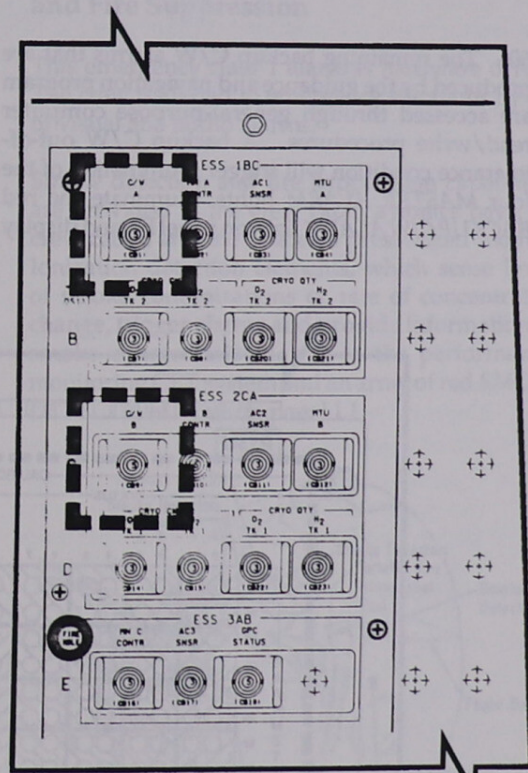
A loss of power supply A will cause all panel F7 lights except **BACKUP C/W ALARM** to illuminate. It will also cause a loss of panel R13U status lights and function, smoke detection via circuit test A, the **CAUTION/WARNING MEMORY READ** switch, lower bulbs of the **MASTER ALARM** light (except for lamp test), primary C/W limit sensing, and tones to the middeck.

A loss of power supply B causes the **BACKUP C/W ALARM** light to come on in addition to the primary C/W light, a loss of smoke detection via circuit test B, upper bulbs of the **MASTER ALARM** lights (except during a lamp test), and sleep station headset tones.

The backup C/W (class 2) system is part of the systems management fault detection and annunciation (FDA), GNC, and backup flight system software programs. Only the 69 backup C/W alarms that are produced by FDA (software that

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

**Caution and Warning Annunciator Matrix on Panel F7**  
(The 39 lights shown unshaded are dedicated to the primary C/W system. The **BACKUP C/W ALARM** light is dedicated to the entire backup C/W system. (R) signifies a red warning light. Red lights take precedence over yellow.)



C/W Circuit Breakers on Panel O13

monitors parameters and initiates alarms) have limits that can be changed and displayed in engineering units accessed through the SM TABLE MAINTENANCE specialist function display (SPEC

2. SYSTEMS

2.2 Caution and Warning System

C/W CH	PARAMETER NAME	C/W CH	PARAMETER NAME	C/W CH	PARAMETER NAME	C/W CH	PARAMETER NAME	C/W CH	PARAMETER NAME
0	CRYO O2 P TK1	25	GPC 3	50	CRYO H2 P TK1	*75	RCS TK P FU- R	100	L RHC
1	CRYO O2 HTR1 TK1	26	RCS LEAK/TK P - F	51	CRYO O2 HTR 2 TK3	76	FC3 STACK T	101	FCS SATURATION
2	FC1 REAC O2	27	OMS ENG - L	52	FC3 REAC H2	*77	AC3 OVLD	102	FC2 COOL PUMP
3	DC VOLT MAIN A	28	APU 3 EGT	53	AC3 VOLT (A, B, C)	78	APU 2 OVERSPEED	103	IMU
4	CAB PRESS	29	MPS HE TK P - R	54	CAB N2 FLOW 1	79	MPS MANF P LH2	104	AV BAY 3 TEMP
5	GPC 1	30	CRYO O2 P TK 4/5	*55		80	CRYO H2 P TK 4/5	105	H2O LOOP 1 PUMP OUT P
6	RCS TK P OX - F	31	CRYO O2 HTR 2 TK2	56	RCS LEAK/TK P - L	*81		106	FREON LOOP 1 FREON FLOW
7	OMS TK P OX - L	32	FC2 REAC H2	57	OMS ENG - R	82	FC3 STACK T	107	FREON LOOP 1 EVAP OUT T
8	APU 1 EGT	33	AC1 VOLT (A, B, C)	58	APU 3 OIL T	83	AC3 OVLD	108	APU 2 UNDERSPEED
9	MPS HE TK P - C	34	CAB PPO2 A	59	MPS HE REG P - R	84	AV BAY 1 TEMP	109	HYD 2 P
10	CRYO O2 P TK2	35	GPC 4	60	CRYO H2 P TK2	*85		110	R/AFT RHC
11	CRYO O2 HTR 2 TK1	36	RCS TK P OX - L	61	CRYO O2 HTR 1 TK4	86	RCS LEAK/TK P - R	111	FCS CH BYPASS
12	FC1 REAC H2	37	OMS TK P OX - R	62	FC1 STACK T	*87		112	FC3 COOL PUMP
13	DC VOLT MAIN B	38	APU 1 OIL T	63	AC1 OVLD	88	APU 3 OVERSPEED	*113	
14	CAB O2 FLOW 1	39	MPS HE REG P - C	64	CAB N2 FLOW 2	*89		114	CAB HX OUT T
15	GPC 2	*40		*65		*90		115	H2O LOOP 2 PUMP OUT P
16	RCS TK P FU - F	41	CRYO O2 HTR 1 TK3	66	RCS TK P OX - R	91	ADTA	116	FREON LOOP 2 FREON FLOW
17	OMS TK P FU - L	42	FC3 REAC O2	67	OMS TVC	92	FC1 COOL PUMP	117	FREON LOOP 2 EVAP OUT T
18	APU 2 EGT	43	AC2 VOLT (A, B, C)	68	APU 1 OVERSPEED	93	RGA/AA	118	APU 3 UNDERSPEED
19	MPS HE TK P - L	44	CAB PPO2 B	69	MPS MANF PL O2	94	AV BAY 2 TEMP	119	HYD 3 P
20	CRYO O2 P TK3	45	GPC 5	70	CRYO H2 P TK3	95	PL WARNING		
21	CRYO O2 HTR 1 TK2	46	RCS TK P FU - L	71	CRYO O2 HTR 2 TK4	96	RCS JET		
22	FC2 REAC O2	47	OMS TK P FU - R	72	FC2 STACK T	97	PL CAUTION		
23	DC VO MAIN C	48	APU 2 OIL T	73	AC2 OVLD	98	APU 1 UNDERSPEED		
24	CAB O2 FLOW 2	49	MPS HE REG P - L	74	CAB FAN ΔP	99	HYD 1 P		

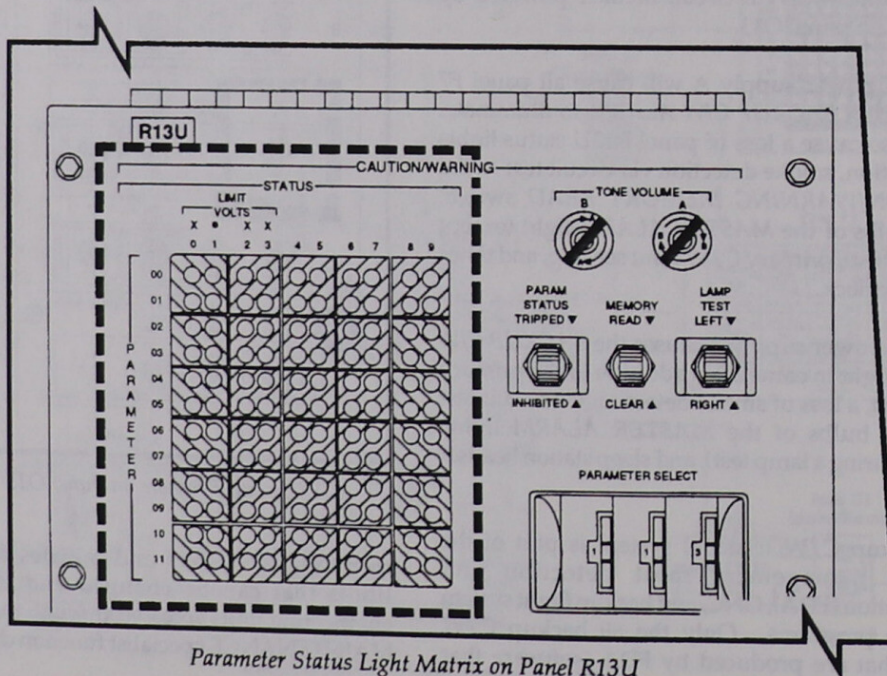
\* Channel not used

Hardware Caution and Warning Table

60). The remaining backup C/W alarms that are produced by the guidance and navigation program are accessed through general-purpose computer read/write procedures. A backup C/W out-of-tolerance condition will trigger illumination of the four MASTER ALARM lights, illuminate the red BACKUP C/W ALARM light on panel F7, and display

a message on the fault message line and fault summary page.

The class 2 (C/W) aural master alarm is activated by the primary (hardware) system, the backup (software) system, or both. The C/W tone is an alternating 375 hertz and 1,000 hertz at a 2.5 hertz rate. The alternating C/W alarm tone is generated



Parameter Status Light Matrix on Panel R13U

when the hardware system detects an out-of-limit condition on any of the 120 parameters it monitors or when the software (backup) system detects a parameter that is out of limits.

Class 2 primary and backup C/W visual cues include a 40-light annunciator matrix on panel F7. This matrix annunciates various system or functional failures. Each light is driven by one or more parameters. With the exception of the *BACKUP C/W ALARM* light, once a lamp has been illuminated, it will not be extinguished until all parameters driving that light are back within limits. THE *BACKUP C/W ALARM* light is extinguished once a *MSG RESET* key is pushed.

Panel R13U is the crew's interface with the primary C/W system. It includes a parameter status light matrix that is used to check the status of a parameter and also to check parameter limits. When used to check the status of parameters, the numbers on the left side of the matrix are read first to obtain the first two numbers of the parameter (row), then the number on the top is read to obtain the third number of the parameter. The matrix can display all 120 parameters (numbered from 000 to 119) of the primary C/W system.

### Class 3 - Alert

This class is a software system operated by the SM software. It would generally receive lower priority than a class 1 or 2 alarm. Class 3 alert is designed to inform the flight crew of a situation leading up to a class 2 alarm or one that may require a long procedure (over 5 minutes) in order to rectify the problem. When an alert parameter exceeds its limits, the blue *SM ALERT* light on panel F7 is illuminated, a discrete is sent to the primary C/W system to turn on the alert tone, and the software displays a fault message on the fault message line and fault summary page.

Both guidance, navigation, and control (GNC) and systems management (SM) software sense out-of-limit conditions. These software systems also serve some less critical parameters and annunciate the systems management alert tone. The SM alert tone is a steady tone of 512 hertz of predefined duration generated in the C/W electronics when activated by inputs from the onboard computers.

### Class 0 - Limit Sensing

Class 0 is a software system consisting of up and down arrows on the CRT displays next to a parameter. It provides no aural annunciation.

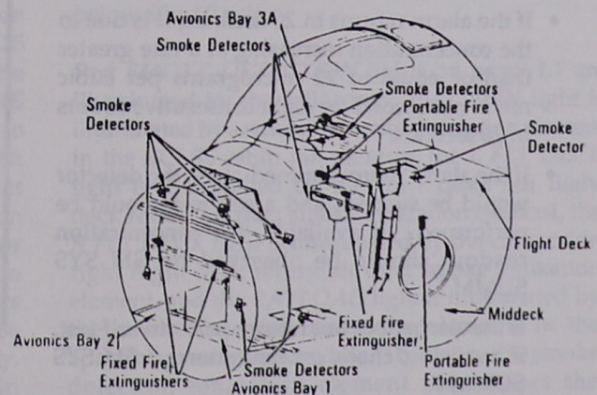
A down arrow displayed next to a parameter would indicate that the low limit for that parameter had been met or violated. In addition, the down arrow is used to indicate a state that does not agree with the nominal state; for example, a fan that is nominally on (e.g., *HUM SEP* fan) is off.

An up arrow displayed next to a parameter would indicate that the upper limit for that parameter has been exceeded.

### Smoke Detection and Fire Suppression

This emergency class 1 alarm is hardware driven. The crew is alerted to emergency situations by use of visual and audio alarms.

Smoke detection and fire suppression capabilities are provided in the crew cabin avionics bays, the crew cabin, and the Spacelab pressurized module. Ionization detection elements, which sense levels of smoke concentrations or rate of concentration change, trigger alarms and provide information on smoke concentration levels to the performance-monitoring CRT system and an array of red *SMOKE DETECTION* lights on panel L1.



Smoke Detection and Fire Suppression System

2. SYSTEMS

2.2 Caution and Warning System

The ionization detection system is divided into two groups: group A and group B. Group A ionization detection elements are located in the environmental control and life support system cabin fan plenum outlet beneath the crew cabin middeck floor and in the left return air duct on the crew cabin flight deck, and one element is located in each of the three forward avionics bays (1, 2, and 3A). Group B ionization detection elements are located in the right return air duct on the crew cabin flight deck and in avionics bays 1, 2, and 3A. On Spacelab missions, ionization detection elements are located in the Spacelab module.

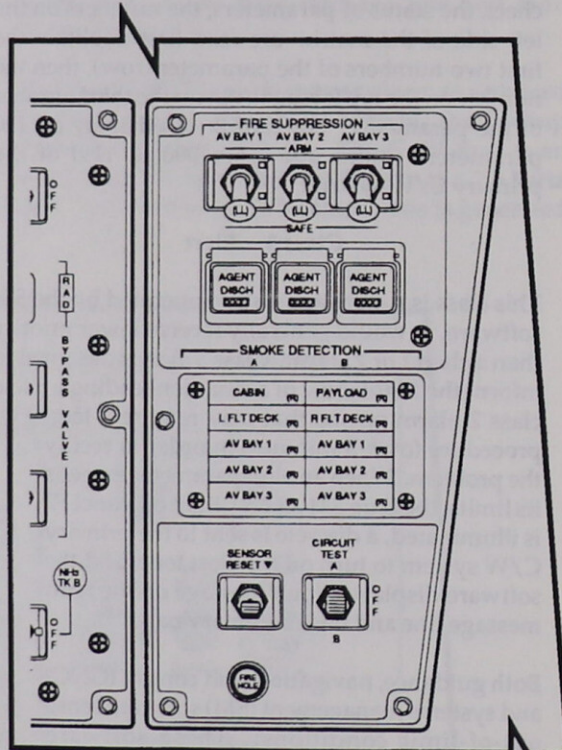
If an ionization detection element senses a smoke particle concentration of 2,000 ( $\pm 200$ ) micrograms per cubic meter for at least 5 seconds and/or a rate of smoke increase of 22 micrograms per cubic meter per second for eight consecutive counts in 20 seconds, a trip signal illuminates the applicable red **SMOKE DETECTION** light on panel L1, illuminates the four red **MASTER ALARM** lights on panels F2, F4, A7, and MO52], and sounds the siren in the crew cabin. The normal reading on the SM SYS SUMM 1 display for the smoke detection elements is 0.3 to 0.4 milligram per cubic meter. A reading on the CRT of 2.0, plus or minus 0.2, corresponds to 2,000 ( $\pm 200$ ) micrograms per cubic meter.

After an alarm and a reset of the detector, the following conditions may be observed:

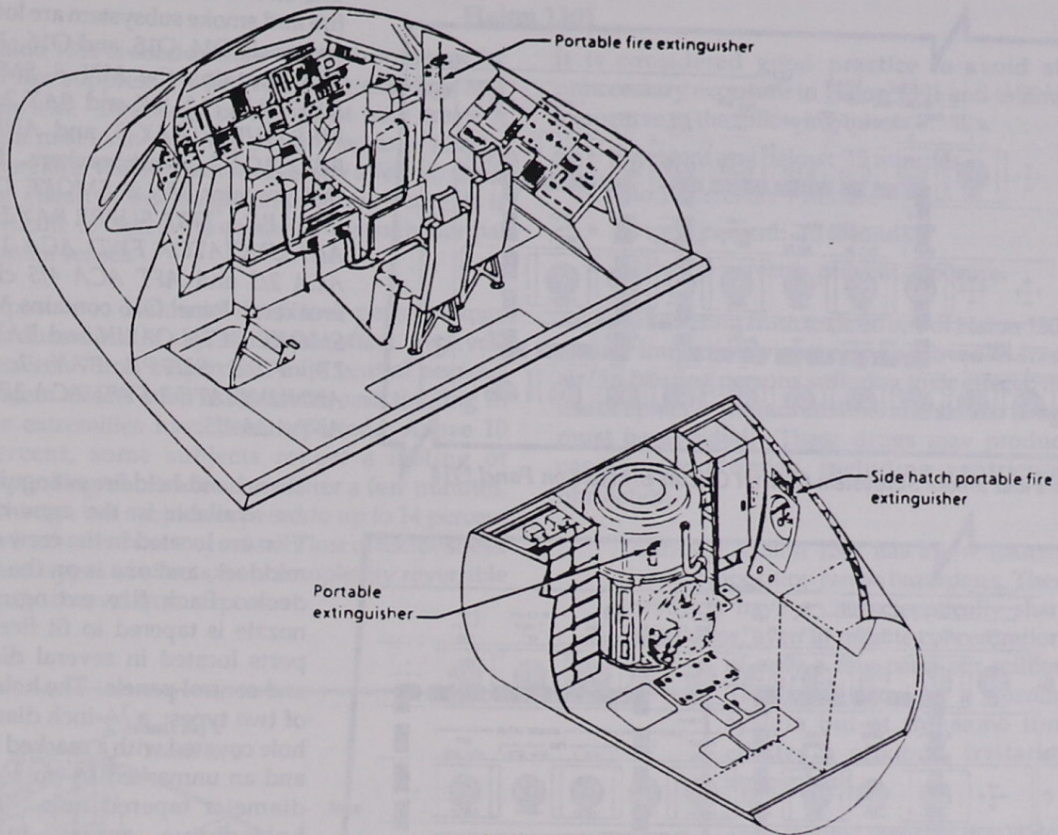
- If the alarm returns in 5 seconds, it is due to the concentration exceeding  $2,000 \pm 200$  micrograms per cubic meter for 5 seconds.
- If the alarm returns in 20 seconds, it is due to the concentration increasing at a rate greater than or equal to 22 micrograms per cubic meter per second for eight consecutive counts in 20 seconds.
- If the alarm returns immediately, the detector would be suspect, and a self test should be performed. If available, the concentration readout should be observed on SM SYS SUMM 1.
- If the alarm does not return, perform self test. If available, check concentration on SM SYS SUMM 1.

XXXX/XXX078			SM SYS SUMM 1			XX X DDD/HH:MM:SS		
						BFS DDD/HH:MM:SS		
SMOKE	1/A	2/B	DC VOLTS	1/A	2/B	3/C		
CABIN	XX.XS		FC	XX.XS	XX.XS	XX.XS		
L/R FD	XX.XS	XX.XS	MAIN	XX.XS	XX.XS	XX.XS		
AV BAY 1	XX.XS	XX.XS	CNTL AB	XX.XS	XX.XS	XX.XS		
2	XX.XS	XX.XS	BC	XX.XS	XX.XS	XX.XS		
3	XX.XS	XX.XS	CA	XX.XS	XX.XS	XX.XS		
CABIN			ESS	XX.XS	XX.XS	XX.XS		
PRESS	XX.XS		AC					
dP/dT	$\pm$ XXS	$\pm$ XXS	VOLT	A	XXXX	XXXX	XXXX	
BU/EQ	$\pm$ XXS		B	XXXX	XXXX	XXXX		
PP02	X.XXS	X.XXS	C	XXXX	XXXX	XXXX		
FAN $\Delta$ P	X.XXS		AMPS	A	XX.XS	XX.XS	XX.XS	
HX OUT T	XXXX		B	XX.XS	XX.XS	XX.XS		
O2 FLOW	X.XS	X.XS	C	XX.XS	XX.XS	XX.XS		
N2 FLOW	X.XS	X.XS	FUEL CELL PH	XXS	XXS	XXS		
IMU FAN $\Delta$ P	X.XXS		AMPS	XXXX	XXXX	XXXX		
$\Delta$ V	FC1	FC2	FC3	XXXX	XXXX	XXXX		
SS1	XXXX	XXXX	XXXX	REAC VLV	XXS	XXS	XXS	
SS2	XXXX	XXXX	XXXX	STACK T	$\pm$ XXXX	$\pm$ XXXX	$\pm$ XXXX	
SS3	XXXX	XXXX	XXXX	EXIT T	XXXX	XXXX	XXXX	
TOTAL AMPS	XXXXXS			COOL P	XXXS	XXXS	XXXS	
KW	XXS			PUMP	XXS	XXS	XXS	
								(XX)

SM SYS SUMM 1 (DISP 78)



FIRE SUPPRESSION Switches and Push Buttons and SMOKE DETECTION Lights on Panel L1



*Fire Extinguisher Locations*

Fire suppression in the crew cabin avionics bays is provided by three Halon extinguisher bottles permanently mounted in avionics bays 1, 2, and 3A. Each bottle contains 3.74 to 3.8 pounds of Halon in a pressure vessel that is 8 inches long and 4.25 inches in diameter. To activate the applicable bottle in an avionics bay, the corresponding *FIRE SUPPRESSION* switch on panel L1 is positioned to *ARM*, and the corresponding *AGENT DISCH* push button indicator on panel L1 is depressed for at least 2 seconds. The *AGENT DISCH* push button indicator activates the corresponding pyro initiator controller, which initiates a pyrotechnic valve on the bottle to discharge the Halon into the avionics bay. The discharge of Halon will produce a noise of approximately 130 decibels in the avionics bay. The discharge will give a Halon concentration in the avionics bay of 7.5 to 9.5 percent. A 4 to 5 percent concentration is required to suppress a fire. This concentration will provide protection for approximately 72 hours. When the bottle is fully

discharged, the push button indicator white light will be illuminated. The white light will be illuminated if the pressure in an avionics bottle falls below  $60 \pm 10$  psig.

Red *SMOKE DETECTION* lights on panel L1 are illuminated by the following: the *CABIN* light is illuminated by a smoke detection ionization element in the *ECLSS* cabin fan plenum, the *L FLT DECK* light is illuminated by the crew cabin left flight deck return air duct smoke ionization element, the *R FLT DECK* light is illuminated by the crew cabin right flight deck return air duct smoke ionization element, and the *PAYLOAD* light is illuminated by the smoke detection ionization elements in the Spacelab pressurized module. The applicable smoke detection ionization element illuminates the applicable red *AV BAY* light on panel L1, activates the *C/W MASTER ALARM* red light, and sounds the siren in the crew cabin.



### Halon 1301

Halon 1301 is used as the extinguishing agent for all fire suppression devices. It is colorless and odorless. Discharge of the agent may create a light mist in the vicinity of the discharge nozzle. Therefore, visibility is not adversely affected. Once the Halon is discharged into an enclosure, it is difficult to detect its presence through normal human senses.

Exposure to Halon in the 5 to 7 percent range produces little, if any, noticeable effect. At levels between 7 and 10 percent, mild central nervous system effects such as dizziness and tingling in the extremities have been reported. Above 10 percent, some subjects report a feeling of impending unconsciousness after a few minutes, although test subjects exposed to up to 14 percent for 5 minutes have not actually lost consciousness. These types of effects were completely reversible upon removal from exposure.

It is considered good practice to avoid all unnecessary exposure to Halon 1301 and to limit exposures to the following times:

- 7 percent and below: 15 minutes
- 7 to 10 percent: 1 minute
- 10 to 15 percent: 30 seconds
- Above 15 percent: prevent exposure.

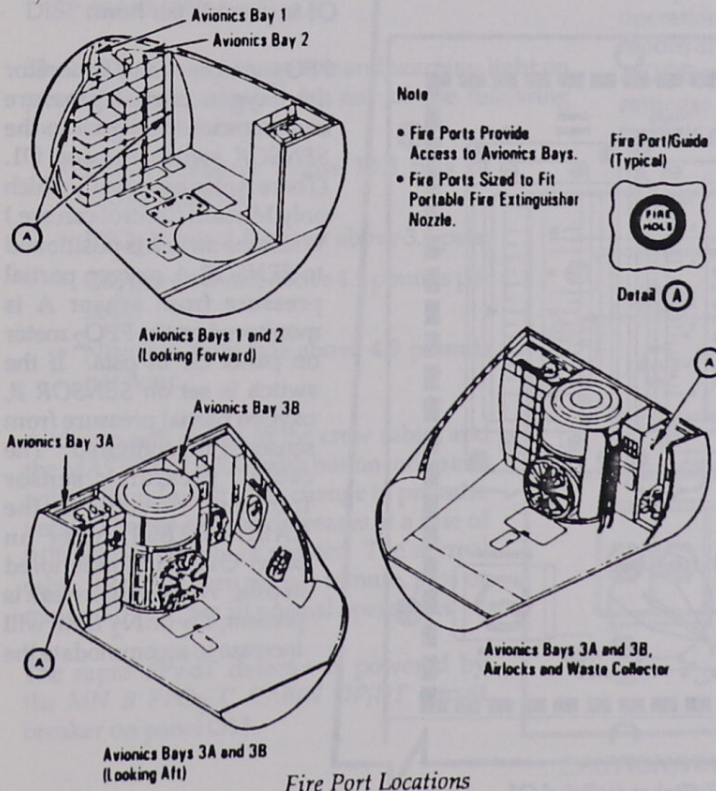
Anyone suffering from toxic effects of Halon 1301 should immediately move or be moved to fresh air. In treating persons suffering toxic effects, the use of epinephrine (adrenaline) and similar drugs must be avoided. These drugs may produce cardiac arrhythmias, including ventricular fibrillation.

Although Halon 1301 has a low toxicity, its decomposition can be hazardous. These products have a characteristically sharp acrid odor, even in minute concentrations of only a few parts per million. This smell provides a warning system but at the same time creates a noxious, irritating atmosphere.

The accepted theory is that Halon must decompose before it is effective in suppressing fire. The decomposition takes place on exposure to a flame or to a hot surface of approximately 900° F.

Depending on the severity of the fire, length of time Halon is exposed to flame, and concentration of Halon, the decomposition products may be extensive or minimal.

The *SMOKE DETECTION CIRCUIT TEST* switch on panel L1 tests the smoke detection system, lights, and alarm circuitry. When the switch is positioned to A or B, electrical power is applied to the ACA channels controlling the *AGENT DISCH* lights, and the white lights are illuminated. Two tests are





completed for both the A and the B circuits to test the complete logic circuitry of the smoke detection system. In the first test, after approximately a 20-second delay, the *SMOKE DETECTION A* or *B* lights are illuminated, and the siren is triggered. In the second test, the *SMOKE DETECTION CIRCUIT TEST* switch is turned off in 5 to 10 seconds, bypassing the 20-second time delay and immediately annunciating a siren and a *SMOKE DETECTION* light (A or B).

Once the alarm system has been triggered, it remains latched until the *SMOKE DETECTION SENSOR* switch on panel L1 is positioned to *RESET*. When the system is latched, the emergency alarm system will not activate an alarm in case of another fire in the same or any other avionics bay.

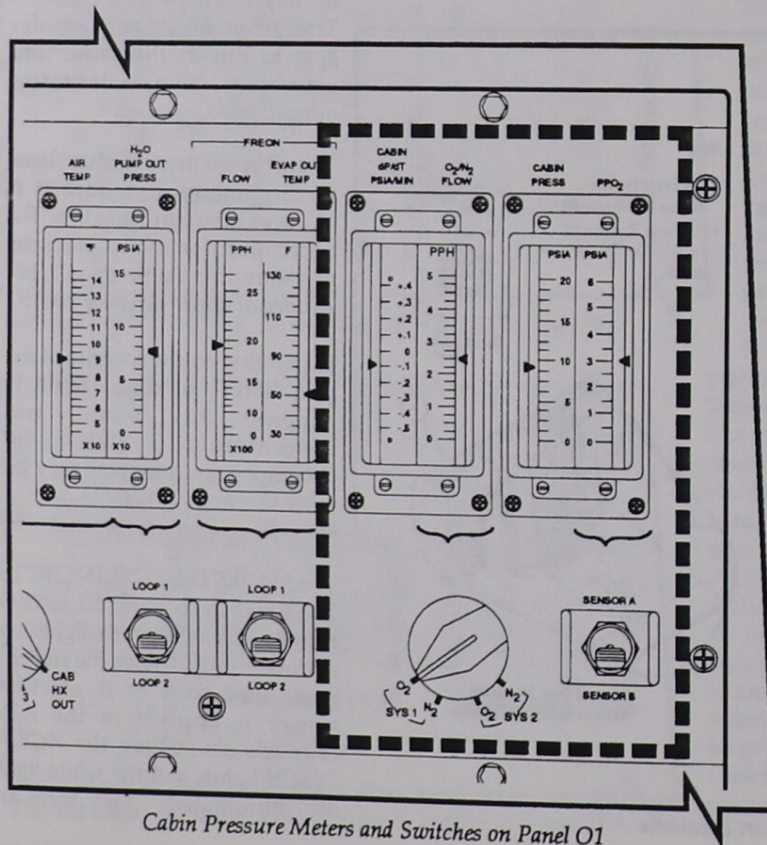
Various parameters of the smoke detection system and remote fire extinguishing agent system are provided to telemetry.

## Cabin Pressure

The cabin pressurization rate,  $dP/dT$ , senses the rate at which atmospheric pressure is changing in the orbiter (in psi/min). There will be an alarm issued only for a rapid cabin depressurization. If a  $dP/dT$  alarm were issued, it would indicate that air was leaking at a rate much higher than normal. The system alerts the crew to a rapid pressure change with respect to time by annunciation of the four *MASTER ALARM* push button indicators and sounding of the klaxon (class 1 alarm). A class 2 alarm system is triggered when cabin pressure reaches a specific value. In addition, a class 3 alarm will annunciate (when the backup flight system is in use) for a change in pressure greater than or equal to 0.12 psia/min.

Cabin pressure parameters can be monitored at several locations. Oxygen and nitrogen systems flows are monitored and sent to the rotary switch on panel O1. The rotary switch permits system 1 oxygen or nitrogen or system 2 oxygen or nitrogen flow to be monitored on the  $O_2/N_2$  FLOW meter on panel O1 in pounds per hour.

PPO<sub>2</sub> sensors A and B monitor the oxygen partial pressure and transmit the signal to the *SENSOR* switch on panel O1. (There is also a sensor C, which only Mission Control can see.) When the switch is positioned to *SENSOR A*, oxygen partial pressure from sensor A is monitored on the PPO<sub>2</sub> meter on panel O1 in psia. If the switch is set to *SENSOR B*, oxygen partial pressure from sensor B is monitored. The cabin pressure sensor transmits directly to the *CABIN PRESS* meter on panel O1 and is monitored in psia. When a cabin leak is present,  $O_2$  or  $N_2$  flow will increase to accommodate the



Cabin Pressure Meters and Switches on Panel O1

XXXX/XXX/066 ENVIRONMENT		XX X	DDD/HHMMSS	DDD/HHMMSS
#P/HT ±	CABIN	AV BAY	1	2
FP02	CABIN P XX.XS	TEMP	XXXXS	XXXXS XXXXS
A X.XXS	AIRLK P XX.XS	FAN ΔP	X.XXS	X.XXS X.XXS
B X.XXS	HK OUT T XXXS	SUPPLY H <sub>2</sub> O	QTY A XXXS	PRESS XXXS
C X.XXS	CABIN T XXXS	WASTE H <sub>2</sub> O	QTY 1 XXXS	PRESS XXXS
PPC02	XX.XS	CO <sub>2</sub> CNTRL	1XS	2XS
O <sub>2</sub> FLOW	X.XS X.XS	FILTER ΔP	X.XXS	
REG P	XXXX XXXS	PPC02	XX.XS	
N <sub>2</sub> FLOW	X.XS X.XS	TEMP	XXX.XS	
REG P	XXXX XXXS	BED A PRESS	XX.XS XX.XS	
O <sub>2</sub> /N <sub>2</sub> CNTL VLV	XXS XXS	B PRESS	XX.XS XX.XS	
-20 TK N <sub>2</sub> P	XXS XXS	ΔP	X.XXS X.XXS	
N <sub>2</sub> QTY	XXXX XXXS	VAC PRESS	X.XS	(XX)
EMER O <sub>2</sub> QTY	XXXX XXXS			
REG P	XXXX			

ENVIRONMENT Display (DISP 66)

loss of pressure. If the leak is large enough, a class 2 alarm will annunciate for high O<sub>2</sub> or N<sub>2</sub> flow.

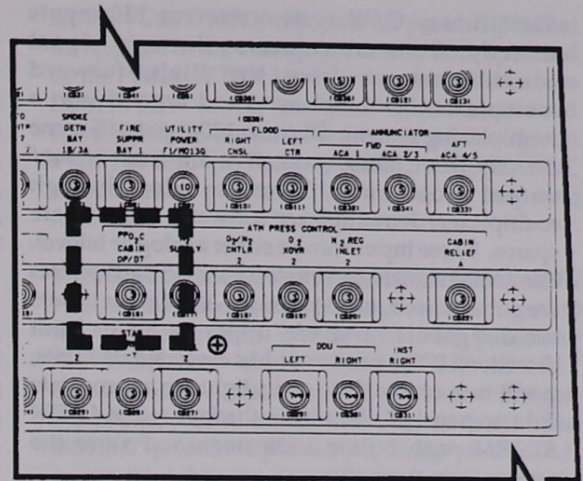
Values for dP/dT can be monitored on the SM SYS SUMM 1 (dP/dT-EQ) and SM ENVIRONMENT DISP 66 (dP/dT) displays.

The red CABIN ATM caution and warning light on panel F7 is illuminated for any of the following monitored parameters:

- Cabin pressure below 13.8 psia or above 15.2 psia.
- PPO<sub>2</sub> below 2.7 psia or above 3.6 psia.
- Oxygen flow rate above 4.9 pounds per hour.
- Nitrogen flow rate above 4.9 pounds per hour.

A klaxon will sound in the crew cabin, and the MASTER ALARM push button indicators will be illuminated if the change in pressure versus change in time decreases at a rate of 0.05 psi per minute or greater. The normal cabin dP/dT is zero psi per minute, plus or minus 0.01 psi, for all normal operations.

The rapid dP/dT detector is powered by the MN B PPO<sub>2</sub> C CABIN DP/DT circuit breaker on panel O15.

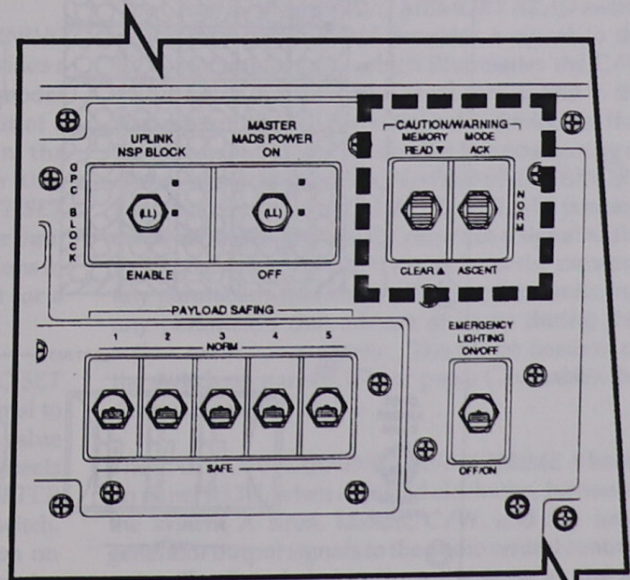


MN B PPO<sub>2</sub> C CABIN DP/DT Circuit Breaker on Panel O15

## Operations

### Primary C/W System

The primary C/W system has three modes of operation: ascent, normal, and acknowledge. These modes are controlled by the CAUTION/WARNING MODE switch on panel C3. The switch has three settings: ASCENT, NORM, and ACK. The normal mode is discussed first.



CAUTION/WARNING MEMORY and MODE Switches on Panel C3

The primary C/W system receives 120 inputs directly from transducers through signal conditioners, or from the flight forward multiplexer/demultiplexers, and are fed into a multiplexing system. Of these 120 inputs, 95 come directly from transducers, five are from input/output processors, 18 are provided through multiplexer/demultiplexer software, and two are spares. These inputs can be either analog or bilevel. The analog signals are zero to 5 volts dc; the discretes are either zero, 5, or 28 volts dc. All of these inputs are designed to provide upper or lower limit detection. If the parameter has exceeded its limits, it will turn on the C/W tone, light the appropriate light on panel F7, illuminate the four red MASTER ALARM push button indicators, and store the parameter in memory.

The C/W tone can be silenced and the MASTER ALARM red light extinguished by depressing any one of the MASTER ALARM push button indicators; however, the C/W light on panel F7 will remain

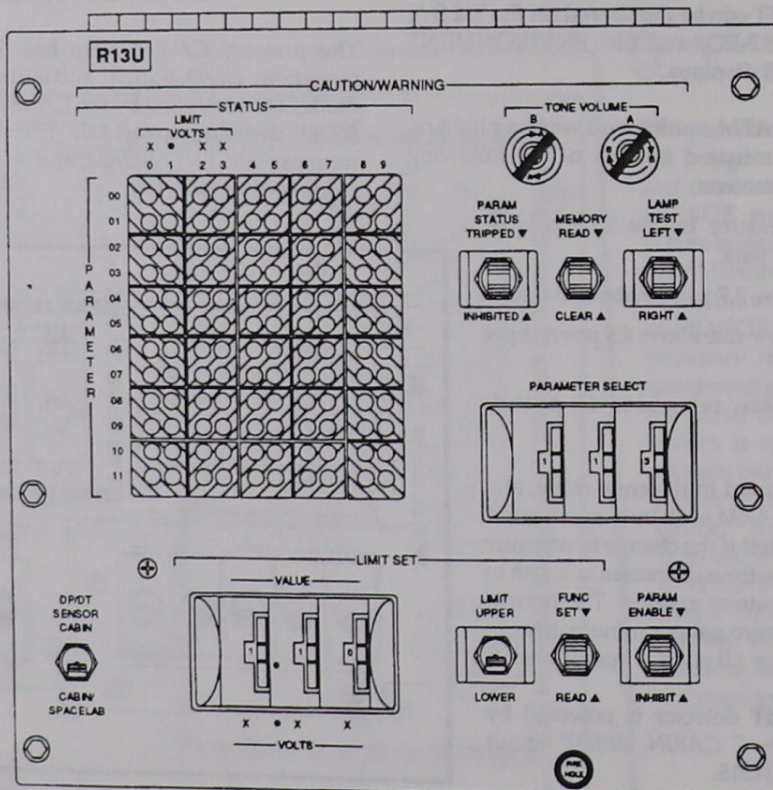
illuminated until the out-of-tolerance condition is corrected. Any one of the MASTER ALARM push button indicators will reset all tones, including the systems management tone.

The C/W ascent mode is the same as the normal mode, except that the commander's red MASTER ALARM push button indicator will not be illuminated.

The C/W acknowledge mode is also the same as the normal mode, except that the 40 annunciator lights on panel F7 will not be illuminated unless one of the red MASTER ALARM push button indicators (on panel F2 for the commander or panel F4 for the pilot) is depressed.

### Panel R13U

Each of the 120 status C/W red parameter lights on panel R13U receives an input from a specific parameter. A primary C/W parameter matrix cue



Panel R13U

card identifies the 120 input channels and correlates them to the panel F7 C/W annunciator light matrix. If an out-of-limit condition exists on a specific parameter that is set on panel R13U, it illuminates the corresponding light on panel F7. If the CAUTION/WARNING PARAM STATUS switch on panel R13U is held in the TRIPPED position when an out-of-limit parameter light on panel F7 is illuminated, the corresponding light on panel R13U will also be illuminated.

Some limits, and the list of parameters monitored, change with flight phase. The crew uses the PARAM ENABLE/INHIBIT and LIMIT switches on panel R13U to tailor the C/W system for their current configuration.

The three CAUTION/WARNING PARAMETER SELECT thumbwheels on panel R13U provide signals to the C/W electronics unit and define the specific parameter for enabling and inhibiting the parameter and setting and reading the parameter's limits.

The CAUTION/WARNING LIMIT SET switch grouping on panel R13U is used to change limits or to read a parameter's limits. The three VALUE thumbwheels provide the signals to the C/W unit, defining the voltage value setting of a parameter's upper or lower limit, X.XX.

The UPPER setting of the CAUTION/WARNING LIMIT SET LIMIT switch on panel R13U provides a signal to the C/W electronics unit, which modes the electronics to set or read the upper limit of a parameter specified by the settings on the PARAMETER SELECT thumbwheels for that parameter. The CAUTION/WARNING LIMIT SET FUNC switch is cycled to set or read the upper limit of that parameter. The LOWER setting functions in the same manner, except for the lower limit for a parameter.

The CAUTION/WARNING LIMIT SET FUNC SET switch position on panel R13U provides a signal to the C/W electronics unit, which sets the value specified by the LIMIT SET VALUE thumbwheels into the parameter as specified by the PARAMETER SELECT thumbwheels and LIMIT SET LIMIT switch. The LIMIT SET FUNC READ switch position on panel R13U provides a signal to the C/W electronics unit, which illuminates the lights under the STATUS

LIMIT VOLTS X.XX columns on panel R13U that correspond to the voltage parameter limit specified by the PARAMETER SELECT thumbwheels and the LIMIT SET LIMIT switch. The value read corresponds to the parameter's full-scale range on a scale of zero to 5 volts dc. The LIMIT SET FUNC switch center position disables the set and read functions.

The ENABLE position of the CAUTION/WARNING PARAM switch on panel R13U provides a signal to the C/W electronics unit to enable the parameter indicated on the PARAMETER SELECT thumbwheels, which allows the parameter to trigger the primary C/W alarm when out of limits. The INHIBIT position operates the same as ENABLE, except it inhibits the parameter from triggering the primary C/W alarm. The center position of the switch disables the enable and inhibit functions.

The TRIPPED position of the CAUTION/WARNING PARAM STATUS switch on panel R13U provides a signal to the C/W electronics unit, which illuminates the C/W status lights that correspond to the parameters that are presently out of limits, including those that are inhibited. The INHIBITED position illuminates those C/W lights on panel R13U that have been inhibited. The center position disables the tripped and inhibited functions.

The CAUTION/WARNING MEMORY READ switch position on panel R13U provides a signal to the C/W electronics unit, which illuminates the C/W status lights on panel R13U that correspond to the parameters that are currently out of limits and that have been out of limits since the last positioning of this switch or the CAUTION/WARNING MEMORY switch on panel C3 to CLEAR. The CLEAR position on panel R13U or panel C3 provides a signal to the C/W electronics unit that clears from the memory any parameters that are presently within limits, but any parameters that are out of limits during this action remain in memory. The center position of the switch on panel R13U or panel C3 disables the clear and read functions.

The CAUTION/WARNING TONE VOLUME A knob on panel R13U, when adjusted clockwise, increases the system A siren, klaxon, C/W, and SM tone generator output signals to the audio central control unit. The B switch functions the same as the A switch for system B tone generators.

The *CAUTION/WARNING LAMP TEST* switch on panel R13U, when positioned to *LEFT*, provides a signal to the C/W electronics unit, which illuminates the left five columns of the C/W status matrix lights on panel R13U. The *RIGHT* position functions the same as the *LEFT*, except for the right five columns of lights. This allows the verification of all 120 lights, making sure that none have burned out.

### Software (Backup) Caution and Warning

When the software caution and warning system detects an out of limits condition, it sounds an aural tone or master alarm, lights the *MASTER ALARM* or *SM ALERT* light, and issues a fault message that is displayed flashing on the CRT fault message line. The master alarm light and tones are reset by depressing a *MASTER ALARM* light push button. The fault message will flash until acknowledged by a depression of the *ACK* key or until the *MSG RESET* key is depressed to erase the message. The *MSG RESET* key will also extinguish the *SM ALERT* light.

The displayed fault message is used to diagnose system failures and frequently is used as the title of the flight data file procedure to be worked by the crew in response to the failure. The text of the fault message identifies the system where limits are being exceeded. A list of individual fault messages is presented in the summary at the end of this section.

For some general classes of fault messages, the first part of the text contains the SPEC number to be consulted to determine the specific parameter that is out of limits. The GPCs declaring the fault are enumerated after the message text. In parentheses at the end of the fault message, software will display the number of other fault messages generated while the current message was being displayed. To view these messages and the time at which they were annunciated, the crew must look at the fault summary page.

After reset of the displayed fault message, the message line will be blank until another new message is generated by the software. To avoid missing messages in a multi-failure scenario, crews should occasionally review all messages on the fault summary page and try to reset messages on the fault line as quickly as possible after reviewing them.

Fault messages for some parameters are issued every time the software completes the required number of data counts with the parameter out of limits. This can result in a steady stream of fault messages and *MASTER ALARMS* that may obscure other important fault messages. If this situation is encountered, the crew or Mission Control can inhibit the affected parameter to prevent nuisance messages and alarms in OPS 2 or OPS 4. In OPS 1, 6, or 3, the crew generally has to tolerate the extra alarms/fault messages and pay extra close attention to the fault summary display.

In order to clear messages from the fault summary page, the crew enters a SPEC 99 PRO on the keyboard. If the fault summary (DISP 99) is called up using a SPEC 99 PRO instead of the *FAULT SUMM* key, the fault summary page will appear, and then immediately clear itself.

Software caution and warning limits for some parameters change depending on the phase of flight. These changes can be entered by the crew via the SPEC 60 TABLE MAINTENANCE display or uplinked from the ground. The ground uplink for limits changes is called a Table Maintenance Block Uplink (TMBU).

### SPEC 60, SM Table Maintenance

The primary avionics software system (PASS) includes three types of applications software, called major functions. The first, systems management (SM), is the function that is active on orbit. The second, guidance, navigation, and control (GNC), is active during all flight phases. The third, payload software, provides operations support to payloads. The backup flight system (BFS), normally used only during ascent and entry, also contains both SM and GNC software.

Modules within both SM and GNC software monitor parameters and initiate alarms. To change the characteristics of the PASS GNC, BFS GNC, and BFS SM parameters, the crew would have to perform a GPC memory read/write procedure. (This procedure is described in the DPS HW/SW 2102 Training Manual.)

```

XXXX/060/          SM TABLE MAINT          XX X DDD/HH:MM:SS
SM COM BUFF XXX          DDD/HH:MM:SS
PARAM
  1 ID XXXXXXXX
    VALUE = [±] XXXXXXXXS
LIMITS
  ALERT
    LOW          HI
  2 [±] XXXXXXXX  3 [±] XXXXX.XX
  4 [±] XXXXXXXX  5 [±] XXXXX.XX
  6 [±] XXXXXXXX  7 [±] XXXXX.XX
    8 FILTER XX
      ENA 9X
      INH 10X
CONSTANT
  16 ID XXXXXXXX
  17 VALUE = [±] XXXXXXXXXXXXXXXX
  CHECKPT XXX:XX:XX:XX          FDA
    INITIATE 18                  ENA 19X
    STATUS XXXX XXXX            INH 20X
    11 [±] XXXXXXXX          12 [±] XXXXX.XX
    13 FILTER XX
      ENA 14X
      INH 15X

```

(XX)

SM TABLE MAINT CRT (SPEC 60)

However, PASS SM parameters can be accessed directly by the crew. Within PASS SM is a module called fault detection and annunciation. This module monitors the backup C/W and alert parameters and initiates alarms.

SPEC 60 SM TABLE MAINT is the crew interface with the PASS SM parameters. Using SPEC 60, the crew can read and change the following for each PASS SM backup C/W or alert parameters: (1) lower and upper limits, (2) noise filter value, and (3) enable/inhibit status. Additionally, the crew can read and change SM program constants, initiate a checkpoint, and enable or inhibit the entire fault detection and annunciation software module.

SPEC 60, which is a PASS SM SPEC, is available during SM OPS 2 and SM OPS 4. When the SM TABLE MAINT display is called up by its SPEC number (SPEC 60 PRO), each field will be blank except CHECKPT time and FDA ENA. When SPEC 60 is called by pressing RESUME, the fields that were previously in use will retain their data. When a legal item entry is made, the new data will be displayed in the appropriate field and will overwrite any previous data.

Any backup C/W parameter may be accessed by entering its software ID number (see page 2.2-4) in item 1 of the SM TABLE MAINT display. The limits, noise filter value, and enable/inhibit status of alert

parameters may be changed with items 2 through 10. The same characteristics of backup C/W parameters are available through items 11 through 15. These CRT parameters are discussed in more detail below.

#### PARAM ID (Item 1) and PARAM Value

The software ID number for the desired fault detection and annunciation (FDA) parameters is entered in item 1. The software IDs are located in the C/W and FDF TABLE of the Flight Data File Reference Data Book.

When a valid ID is entered, the ID number will be displayed in the PARAM ID space, and the current value of the parameter will be displayed in the PARAM VALUE field. The status of the parameter is indicated by the presence or absence of an up or down arrow. The appropriate ALERT or BACKUP C/W data will appear in the LIMITS portion (items 2 through 10 or items 11 through 15 respectively). If the parameter is monitored by both the Alert and B/U C/W systems, then both sections will contain the proper data. Otherwise, one of the LIMITS sections will be blank.

If the PARAM ID is not valid, all associated data fields will be blank, and an ILLEGAL ENTRY message will be displayed.

**Limits Alert Low and Hi (Items 2 through 7)**

These fields contain the upper and lower alert limits of the FDA parameter identified in item 1. The limit values are displayed in engineering units and can be changed by entering the desired data in the appropriate items.

Alert parameters that are preconditioned may have two or three limits sets. All other alert parameters have only one limit set. The SM software selects which set of limits is currently active and places an asterisk next to that set (before item 2, 4, or 6). (There is no item entry that allows the crew to move the asterisk to directly select which set of limits is active. This is done exclusively by software.) If only one set of limits exists for the parameter, this set will be displayed in the first limit set location, and the asterisk will be placed by item 2. If a value is entered in a limit set that does not exist for the selected parameter, an illegal entry message will be displayed.

**Limits Backup C/W Low and Hi (Items 11 and 12)**

The backup C/W system limits for the FDA parameter identified in item 1 are displayed in these fields. The limit values, which are in engineering units, can be changed by entering the new data in the desired item.

Backup C/W parameters have one set of limits. An asterisk next to item 11 indicates that there exists a backup C/W limit set for the parameter.

**Limits Alert Filter (Item 8)**

The Alert parameter noise filter value can be read or changed through item 8. It is the number of consecutive times the parameter has to be sensed out of limits before an alarm annunciates. The reverse is true for returning back into limits. The range of valid values is 1 through 15.

**Limits Backup C/W Filter (Item 13)**

The backup C/W filter functions similarly to the Alert filter (item 8).

**Limits Alert ENA or INH (Items 9 and 10)**

The annunciation of an out-of-limits Alert parameter may be either enabled or inhibited by executing the respective item. The items are mutually exclusive, and an asterisk indicates the current annunciation status by appearing after the more recently selected item.

The class 0 status indicators (up and down arrows) and transducer data symbols (H, L, M, ?) are not affected by this item.

**Limits Backup C/W ENA or INH (Items 14 and 15)**

These backup C/W items operate similarly to the Alert items 9 and 10.

**FDA ENA or INH (Items 19 and 20)**

The PASS FDA software can be either inhibited or enabled by executing the respective item. The items are mutually exclusive, and an asterisk denotes the current state. The display is initialized with FDA enabled.

When FDA is inhibited, the following FDA functions are disabled:

- FDA alarm annunciation. This includes backup C/W (class 2), Alert (class 3), and limit sensing up or down arrows (class 0).
- Limit sensing (class 0). The last value of each out-of-limits parameters status indicator is displayed.
- Precondition steering.
- False alarm avoidance noise filters.

Other parameter status indicators (H, L, M, ?) are not affected because they are not generated by the FDA software.

**Constants**

SM constants may be accessed through items 16 and 17. These constants are primarily involved in SM special processes such as water loop pump cycling, alert preconditioning, and payload deployment.

### Constant ID (Item 16)

When a constant ID number is entered in item 16, both the CONSTANT ID and VALUE fields are filled. If the ID was illegal, both data fields are blanked.

The constant IDs and values are not typically carried onboard the orbiter, although various malfunction procedures contain occasional constants. If a constant must be changed, Mission Control will either provide the crew with the data or directly change the constant through a TMB Uplink. (See TMBU description in this section.)

### Constant Value (Item 17)

This field contains the current value of the constant identified in item 16. The constant value can be changed by entering the new data in item 17.

### TMBU

TMBU is the type of uplink that Mission Control uses to change the following data:

- Parameter limit values
- Parameter noise filter values
- Parameter annunciation enable/inhibit status
- SM constant values.

The use of TMBUs decreases the crew's workload because the changes that are uplinked do not have to be entered on SPEC 60.

SPEC 60 operations and TMBUs are interlocked such that TMBU loads are rejected if SPEC 60 is active. If a TMBU is in progress when SPEC 60 is called, the flashing words UPLINK and UL will be displayed on the display, and all item entries will be prohibited by an ILLEGAL ENTRY message.

### Uplink

The flashing word UPLINK is displayed in the top center of SPEC 60 to indicate that a TMBU is in progress.

### UL

When any two-stage command (including a TMBU) is uplinked, a flashing UL is displayed in the upper right corner of all CRTs associated with the GPC(s) that are being commanded.

### Checkpoints

When a checkpoint is performed, the following information is saved in a mass memory unit:

- Parameter limit values
- Parameter noise filter values
- Parameter annunciation enable/inhibit status
- SM constant values
- Checkpoint timetags.

The checkpoint capability is valuable because changes made through item entries on SPEC 60 affect only the SM GPC software and not the mass memory unit software. If these changes are not saved in a mass memory unit, and the SM GPC fails, flight software will lose the changes that have been made. The changes would then have to be reentered.

When checkpoint retrieval is enabled, the software loaded into an SM GPC from a mass memory unit will contain the most recent version of changes saved during checkpoint.

### Checkpoint Initiate (Item 18), Checkpoint Status, and Time

When item 18 is executed, the STATUS field will go blank. While the checkpoint is being performed, a flashing BSY will be displayed next to SM COMM BUFF at the top left of SPEC 60. This indicates that the SM communications buffer is in use. When the checkpoint is completed, the CHECK PT STATUS field will contain GOOD. If the SM common buffer was not available, CHECK PT STATUS will be FAIL, and item 18 should be executed again.

The mission elapsed time (MET) of the most recent successful checkpoint will be displayed as DD/HH:MM:SS, in the checkpoint time field.



### SM COMM BUFF - BSY, or RDY

Either a flashing BSY or a status RDY is displayed after SM COMM BUFF to indicate the status of the SM Common Buffer. BSY (busy) indicates that the SM COMM BUFF is being used; RDY (ready) means the buffer is available.

Keypad entries are rejected if BSY is flashing.

### CKPT RETRV ENA (SPEC 1, Item 12)

Executing this item will alternately select or deselect CKPT RETRV ENA. An asterisk appears next to item 12 when checkpoint retrieval is enabled.

### MMU Assignment (DPS Utility - SPEC 1, Items 3 and 4)

A checkpoint saves the changes in the mass memory unit assigned to the SM software by item 3 or 4. In order to save the checkpoint in both, two checkpoints must be performed.

### C/W Summary Data

- The C/W system consists of four alarm classes: emergency (class 1), C/W (class 2), alert (class 3), and limit sensing (class 0).
- Emergency alarms cover two situations: smoke detection/fire suppression and cabin pressure.
- Smoke detection and fire suppression capabilities are provided in the crew cabin avionics bays, the crew cabin, and the Spacelab pressurized module.
- Increased smoke particle concentration will illuminate *SMOKE DETECTION* lights on panel L1, illuminate four red *MASTER ALARM* lights on panels F2, F4, A7, and MO52J, and sound the siren in the crew cabin.
- Fire suppression in the crew cabin avionics bay is provided by one permanent Halon extinguisher bottle in avionics bays 1, 2, and 3A. The bottle is operated by switches on panel L1.
- Three portable hand-held extinguishers in the crew cabin are operated by inserting them into fire holes located in several display and control panels.
- A class 1 alarm (four *MASTER ALARM* pushbutton indicators and the sounding of the klaxon) is triggered when there is a rapid change in cabin pressure with respect to time.
- Class 2 alarms include primary (hardware) and backup (software) systems. The crew interfaces with the system primarily through the 40-light annunciator matrix on panel F7 and a 120-parameter monitor on panel R13U.
- Class 3 alerts warn the crew of a situation leading up to a class 2 alarm or of one that may require a long procedure.
- Class 0, a software system, consists of up and down arrows displayed on the CRT displays next to a parameter.
- The SPEC 60 TABLE MAINT display allows the crew to change limits, noise filter values, and status of backup C/W or alert system parameters.
- C/W information can be seen on the SM SYS SUMM 1 (DISP 78), and ENVIRONMENT (DISP 66) displays.
- Pressing the *MASTER ALARM* light will silence the alarm and reset the light.
- Pressing the ACK key will stop the fault messages from flashing.
- Pressing the MSG RESET key will erase fault messages and extinguish the *SM ALERT* light.

### C/W Rules of Thumb

- The *SENSOR RESET* switch on panel L1 should be pressed when smoke concentration goes below 1.8. This prevents masking of alarms.
- When panel R13U is not in use, the *PARAMETER SELECT* thumbwheels should be set to a value greater than 119.
- Crewmembers should reset fault messages as quickly as possible after review to avoid covering other messages.
- The fault summary should be reviewed regularly to avoid missed fault messages.

**F7 Light Summary**

**NOTE**

A Class 2 audible tone and **MASTER ALARM** lights accompany the appropriate C/W light. Most lights are hardware-driven, but many parameters are also software-sensed by the PASS or BFS GPCs. The software provides a CRT message and illuminates the **BACKUP C/W ALARM** light. The hardware channels listed below are the same as the channels on the C/W STATUS light matrix on panel R13U. The color of each light is indicated by (R) for red and (Y) for yellow.

**O<sub>2</sub> PRESS (Y)**: Indicates an O<sub>2</sub> tank 1, 2, 3, or 4 pressure or the O<sub>2</sub> kit (Tank 5) pressure out of limits. The hardware channels are 0, 10, 20, 30, and 40 for Tanks 1, 2, 3, 4, and 5, respectively.

**H<sub>2</sub> PRESS (Y)**: Indicates either an H<sub>2</sub> Tank 1, 2, 3, or 4 pressure or the H<sub>2</sub> kit (Tank 5) pressure out of limits. The hardware channels are 50, 60, 70, 80, and 90 for Tanks 1, 2, 3, 4, and 5, respectively.

**FUEL CELL REAC (R)**: Indicates an O<sub>2</sub> or H<sub>2</sub> Fuel Cell 1, 2, or 3 reactant valve is closed. The hardware channels are 2, 22, 32, 42, and 52 for FC 1, 2, and 3 O<sub>2</sub> and H<sub>2</sub> respectively.

**FUEL CELL STACK TEMP (Y)**: Indicates a Fuel Cell 1, 2, or 3 stack temperature out of limits. The hardware channels are 62, 72, and 82 for FC 1, 2, and 3, respectively.

**FUEL CELL PUMP (Y)**: Indicates a Fuel Cell 1, 2, or 3 pump ΔP out of limits. The hardware channels are 92, 102, and 112 for FC 1, 2, and 3 respectively.

**CABIN ATM (R)**: Indicates either cabin pressure, PPO<sub>2</sub>, O<sub>2</sub> flow rate, or N<sub>2</sub> flow rate out of limits. The hardware channels are 4, 14, 24, 34, 44, 54, and 64 for cabin press, O<sub>2</sub> SYS 1 and 2 flow rate, PPO<sub>2</sub> A and B, and N<sub>2</sub> SYS 1 and 2 flow rate respectively.

**O<sub>2</sub> HEATER TEMP (Y)**: Indicates an O<sub>2</sub> Tank 1, 2, 3, or 4 heater temp or O<sub>2</sub> kit (Tank 5) heater temp out of limits. The hardware channels are 1, 11, 21, 31, 41, 51, 61, 71, and 81 for O<sub>2</sub> Tank 1 HTR 1 and 2, Tank 2 HTR 1 and 2, Tank 3 HTR 1 and 2, Tank 4 HTR 1 and 2, and Tank 5 respectively.

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

Caution and Warning Light Matrix on Panel F7

### F7 Light Summary (continued)

**MAIN BUS UNDERVOLT (R):** Indicates main bus A, B, or C voltage low. The hardware channels are 3, 13, and 23 for main bus A, B, and C respectively.

**AC VOLTAGE (Y):** Indicates AC bus 1, 2, or 3 phase A, B, or C out of limits. The hardware channels are 33, 43, and 53 for AC bus 1, 2, and 3 respectively.

**AC OVERLOAD (Y):** Indicates an inverter 1, 2, or 3 phase A, B, or C output of 225 percent overload for 20 sec or 300 percent for 4 to 6 sec. The hardware channels are 63, 73, and 83 for inverter 1, 2, and 3 respectively.

**FREON LOOP (R):** Indicates a low Freon loop 1 or 2 flow rate or a temperature out of limits. The hardware channels are 106, 116, 107, and 117 for loop 1 and 2 flow rate, and loop 1 and 2 temp respectively.

**AV BAY/CABIN AIR (Y):** Indicates out of limits condition on cabin fan  $\Delta P$ , AV Bay 1, 2, or 3 air out temp, or cabin heat exchanger air temp. The hardware channels are 74, 84, 94, 104, and 114 for cabin fan  $\Delta P$ , AV Bay 1, 2, or 3 Temp, and CAB HX temp respectively.

**IMU (Y):** Indicates detection of an inertial measurement unit (IMU) failure or dilemma. The hardware channel is 103 and is a discrete driven from the GNC software.

**FWD RCS (R):** Indicates detection of an out of limits condition on a forward RCS oxidizer tank ullage pressure, fuel tank ullage pressure, or forward oxidizer or fuel leak. The hardware channels are 6, 16, and 26 for oxidizer tank press, fuel tank press, and leak respectively.

**RCS JET (Y):** Indicates detection of an RCS jet failed on, failed off, or leaking. The hardware channel is 96 and is a discrete driven from the GNC software.

**H<sub>2</sub>O LOOP (Y):** Indicates an out of limits condition on H<sub>2</sub>O loop 1 or 2 pump out pressure. The hardware channels are 105 and 115 for loop 1 and 2 respectively.

**RGA/ACCEL (Y):** Indicates detection of a rate gyro assembly (RGA) 1, 2, 3, or 4 failure, or an accelerometer 1, 2, 3, or 4 failure. The hardware channel is 93 and is a discrete driven from the GNC software.

**AIR DATA (R):** Indicates detection of an air data transducer assembly (ADTA) dilemma. The hardware channel is 91 and is a discrete driven from the GNC software.

**LEFT RCS (R):** Indicates detection of a left RCS oxidizer, fuel tank ullage pressure out of limits, or left oxidizer or fuel leak. The hardware channels are 36, 46, and 56 for oxidizer tank press, fuel tank press, and leak respectively.

**RIGHT RCS (R):** Indicates detection of a right RCS oxidizer, fuel tank ullage pressure out of limits, or right oxidizer or fuel tank leak. The hardware channels are 66, 76, and 86 for oxidizer tank press, fuel tank press, and leak respectively.

**SPARE:** Available for future warning parameter growth.

**LEFT RHC (R):** Indicates detection of a left rotational hand controller (RHC) pitch, roll, and yaw disagree. The hardware channel is 100 and is a discrete driven from the GNC software.

**RIGHT/AFT RHC (R):** Indicates detection of a right or aft RHC pitch, roll, or yaw disagree. The hardware channel is 110 and is a discrete driven from the GNC software.

**LEFT OMS (R):** Indicates detection of a left OMS pod oxidizer, fuel tank ullage pressure out of limits, or an engine abnormal (OMS engine fail to cutoff, fail to ignite, or early shutdown) condition. The hardware channels are 37, 47, and 57 for the oxidizer, fuel tank press, and engine abnormal respectively. The hardware channels are 7, 17, and 27 for the oxidizer, fuel tank press, and engine abnormal respectively.

**F7 Light Summary (continued)**

**RIGHT OMS (R):** Indicates detection of a right OMS pod fuel tank ullage pressure out of limits, or an engine abnormal (OMS engine fail to ignite, or early shutdown) condition.

**PAYLOAD WARNING (R):** Indicates detection of up to five payload parameter inputs out of limits. The hardware channels are 55, 65, 75, 85, and 95.

**GPC (Y):** Indicates GPC 1, 2, 3, 4, or 5 has determined itself failed and issued a self-fail discrete. The hardware channels are 5, 15, 25, 35, and 45 for GPC 1, 2, 3, 4, and 5 respectively.

**FCS SATURATION (Y):** Indicates detection of elevon position or hinge moment saturation. The channel is 101 and is a discrete driven from the GNC software.

**OMS KIT (Y):** Indicates detection of an OMS kit oxidizer or fuel tank ullage pressure out of limits. The hardware channels are 77 and 87 for oxidizer and fuel respectively.

**OMS TVC (R):** Indicates detection of an OMS pitch or yaw gimbal failure. The hardware channel is 67. An OMS TVC failure may also result in a *LEFT* or *RIGHT OMS* light.

**PAYLOAD CAUTION (Y):** Indicates detection of a payload parameter input out of limits. The hardware channel is 97 and is not presently implemented.

**PRIMARY C/W (Y):** Indicates detection of a C/W system self-test failure internal to the C/W EU. The failures include the loss of power supply A or B, loss of A or B timing, or the inability of a C/W self-test parameter to pass limit check. No channel number. The parameter is internal to the C/W unit hardware itself. The light also illuminates each time the ESS 1BC C/W A circuit breaker is closed after being opened and extinguishes when the *MASTER ALARM* push button indicator is depressed.

**FCS CHANNEL (Y):** Indicates detection of an elevon, rudder, or speedbrake actuator failure, SRB rock or tilt actuator failure, or MPS engine pitch and yaw actuator failure. The hardware channel is 111 and is a discrete driven from the GNC software.

**MPS (R):** Indicates detection of an MPS engine He tank press, He regulator out press, LO2 manifold press, or LH2 manifold press out of limits. The hardware channels are 9, 19, 29, 39, 49, 59, 69, and 79 for Engine 1, 2, and 3 He TK, He reg, and LO2 and LH2 pressure respectively.

**SPARE (R):** Available for future warning parameter growth.

**BACKUP C/W ALARM (R):** Indicates detection of a C/W alarm via SM, GNC, or BFS software monitoring. In OPS 2 SM parameter limits can be accessed, changed, enabled, and inhibited through the Table Maintenance display.

**APU TEMP (Y):** Indicates an APU 1, 2, or 3 exhaust gas temp or lube oil temp out of limits. The hardware channels are 8, 18, 28, 38, 48, and 58 for APU 1, 2, and 3 EGT and lube oil temp respectively.

**APU OVERSPEED (Y):** Indicates an APU 1, 2, or 3 speed greater than a specified percentage of the designed speed. The hardware channels are 68, 78, and 88 for APU 1, 2, and 3 respectively.

**APU UNDERSPEED (Y):** Indicates an APU 1, 2, or 3 speed less than a specified percentage of the designed speed. The hardware channels are 98, 108, and 118 for APU 1, 2, and 3 respectively.

**HYD PRESS (Y):** Indicates a hydraulics system 1, 2, or 3 supply pressure out of limits. The hardware channels are 99, 109, and 119 for APU 1, 2, and 3 respectively.

### Fault Message Summary

MESSAGE	OPS AVAIL		CAUSE	COMMENTS
	PASS	BFS		
S67 ACOVLD SM1 AC OVLD	1(2,3)	S2,4	SM	• ACOVLD ↓
S67 AC VOLTS SM1 AC VOLTS	1(2,3)	S2,4	SM	• AC VOLTS ↑↓ • ANY PHASE
AERO DRIVE		GB		• SURFACE CMD/POS MISCOMPARE (I LOAD) • NO MAL • THRESHOLDS: ELEV = 5.8° RUD = 5.5° S/B = 10.9°
ANTENNA		S2,4		• QUAD ANT FAIL ↓ • MSG ONLY DURING AOS - CORRECTIVE ACTION BY MCC
SM2 APU 1(2,3)			SM	• FU QTY ↓ APU OIL OUT T ↑↓ • PUMPK PRESS ↑ • NO MAL
S86 APU/HYD	APU	S2,4		• FU QTY ↓ FU TK P ↑↓ • GG BED T ↓↑ • GBX P ↓ • OIL OUT T ↑↓ • OIL OUT P ↑↓ • FU PMP BDY T ↑ • FU VLV T ↑ • GBX BRG T ↑

MESSAGE	OPS AVAIL		CAUSE	COMMENTS
	PASS	BFS		
S86 APU/HYD	HYD	S2,4		• RSVR T ↑↓ • RSVR P ↓ • RSVR QTY ↑↓ • ACCUM P ↓
	W/B	S2,4		• REG P ↑↓ • N2 P ↓ • H2O QTY ↓ • TK T ↓ • BLRT ↑↓
SM2 APU SPD HI	1(2,3)		SM	• TURBINE OVERSPEED • NO MAL
SM2 APU SPD LO	1(2,3)		SM	• TURBINE UNDERSPEED • NO MAL
S86 APU TEMP SM2 APU TEMP	1(2,3)	S2,4	SM	• BACKUP EGT ↑ • OIL TEMP ↑↓
S66 AV BAY SM2 AV BAY	FAN TEMP	S2,4 S2,4	SM SM	• AV BAY FAN ΔP ↑↓ • AV BAY FAN AIR OUT T ↑

## 2. SYSTEMS

### 2.2 Caution and Warning System

MESSAGE	OPS AVAIL		CAUSE	COMMENTS
	PASS	BFS		
S62 BCE BYP	OA	S2,4	<ul style="list-style-type: none"> <li>• OA1, OA2, or OA3 MDM or MDM CARD FAIL</li> <li>• OF1 or OF2 MDM or MDM CARD FAIL</li> <li>• OF3 or OF4 MDM or MDM CARD FAIL</li> </ul>	<ul style="list-style-type: none"> <li>• MSG OCCURS at SM OPS TRANSITION if PDI POWER OFF</li> </ul>
	OFA	S2,4		
	OFB	S2,4		
	PDI	S2,4	<ul style="list-style-type: none"> <li>• PDI INTERFACE to SM GPC FAIL</li> </ul>	<ul style="list-style-type: none"> <li>• MSG OCCURS at SM OPS TRANSITION if PDI POWER OFF</li> </ul>
	PL	S2,4	<ul style="list-style-type: none"> <li>• PDI SSC or EXC INTERFACE to PCMMU FAIL</li> </ul>	<ul style="list-style-type: none"> <li>• MSG OCCURS at SM OPS TRANSITION if PDI POWER OFF or if SPACELAB and SSC or EXC POWER OFF</li> </ul>
PSP 1(2)	S2,4	<ul style="list-style-type: none"> <li>• PSP 1(2) to PL 1(2) MDM SERIAL I/O FAIL</li> </ul>		
BCE BYP FLEX	S2,4	<ul style="list-style-type: none"> <li>• BCE BYPASS ON FLEX/FLEX PAIR</li> </ul>		
BCE BYP KU	S2,4	<ul style="list-style-type: none"> <li>• PL 1 KU COMM/RADAR S10 FAIL</li> </ul>	<ul style="list-style-type: none"> <li>• RADAR: GPC MODE NOT VALID UNLESS TRACKING, AUTO-TRACK MODE is VALID</li> <li>• NO MAL</li> </ul>	
BCE BYP PL1(2)	S2,4	<ul style="list-style-type: none"> <li>• BCE BYPASS on PL BUSES</li> </ul>		
BCE BYP SCA	S2,4	<ul style="list-style-type: none"> <li>• BCE BYPASS on SCA</li> </ul>		

MESSAGE	OPS AVAIL		CAUSE	COMMENTS			
	PASS	BFS					
BCE STRG 1	A	G1,2,3,6,8	G0,1,2,3,6	<ul style="list-style-type: none"> <li>• ALL GPCs DETECTED PROBLEM RECEIVING DATA FROM INDICATED BCE ELEMENT OF STRING 1 AND HAVE BYPASSED THAT ELEMENT</li> </ul>	<ul style="list-style-type: none"> <li>• BFS PRE-ENGAGE MUST BE IN SYNC WITH (TRACKING) PASS TO ANNUNCIATE</li> </ul>		
		ADTA	G1,3,6,8			G0,1,3,6	
	B	G1,2,3,6,8	G0,1,3,6				
		C	G1,2,3,6,8			G0,1,3,6	
	D	G1,2,3,6,8	G0,1,3,6				
		IMU	G1,2,3,6,8			G0,1,3,6	
	MLS	G1,3,6,8					
	MTU	G1,2,3,6,8,0	G0,1,3,6				
		NSP	G1,2,3,6,8,0			G0,1,3,6	
	STKR	G2,3,8					
	TAC	G1,3,6,8	G0,1,3,6			<ul style="list-style-type: none"> <li>• ALL GPCs DETECTED PROBLEM RECEIVING DATA FROM INDICATED BCE ELEMENT OF STRING 1 AND HAVE BYPASSED THAT ELEMENT</li> </ul>	<ul style="list-style-type: none"> <li>• BFS PRE-ENGAGE MUST BE IN SYNC WITH (TRACKING) PASS TO ANNUNCIATE</li> <li>• RADAR ALTIMETER DATA ALSO LOST</li> </ul>
		PASS	G0,1,3,6				

MESSAGE	OPS AVAIL		CAUSE	COMMENTS			
	PASS	BFS					
BCE STRG 2	A	G1,2,3, 6,8	G0,1, 3,6	<ul style="list-style-type: none"> <li>• ALL GPCs DETECTED PROBLEM RECEIVING DATA FROM INDICATED BCE ELEMENT OF STRING 2 AND HAVE BYPASSED THAT ELEMENT</li> </ul>	<ul style="list-style-type: none"> <li>• BFS PRE-ENGAGE MUST BE IN SYNC WITH (TRACKING) PASS TO ANNUNCIATE</li> </ul>		
	ADTA	G1,3,6, 8	G0,1, 3,6				
	B	G1,2,3, 6,8	G0,1, 3,6				
	C	G1,2,3, 6,8	G0,1, 3,6				
	D	G1,2,3, 6,8	G0,1, 3,6				
	IMU	G1,2,3, 6,8	G0,1, 3,6				
	MLS	G1,3,6, 8					
	MTU	G1,2,3, 6,8,0	G0,1, 3,6				
	TAC	G1,3,6, 8	G0,1, 3,6			<ul style="list-style-type: none"> <li>• ALL GPCs DETECTED PROBLEM RECEIVING DATA FROM INDICATED BCE ELEMENT OF STRING 2 AND HAVE BYPASSED THAT ELEMENT</li> </ul>	<ul style="list-style-type: none"> <li>• BFS PRE-ENGAGE MUST BE IN SYNC WITH (TRACKING) PASS TO ANNUNCIATE</li> <li>• RADAR ALTIMETER DATA ALSO LOST</li> </ul>
	PASS		G0,1, 3,6			<ul style="list-style-type: none"> <li>• BFS FAIL TO TRACK STRING 2</li> </ul>	<ul style="list-style-type: none"> <li>• NO MAL</li> <li>• I/O RESET MAY RESTORE PASS/BFS COMM</li> </ul>

MESSAGE	OPS AVAIL		CAUSE	COMMENTS			
	PASS	BFS					
BCE STRG 3	A	G1,2,3, 6,8	G0,1, 3,6	<ul style="list-style-type: none"> <li>• ALL GPCs DETECTED PROBLEM RECEIVING DATA FROM INDICATED BCE ELEMENT OF STRING 3 AND HAVE BYPASSED THAT ELEMENT</li> </ul>	<ul style="list-style-type: none"> <li>• BFS PRE-ENGAGE MUST BE IN SYNC WITH (TRACKING) PASS TO ANNUNCIATE</li> </ul>		
	ADTA	G1,3,6, 8	G0,1, 3,6				
	B	G1,2,3, 6,8	G0,1, 3,6				
	C	G1,2,3, 6,8	G0,1, 3,6				
	D	G1,2,3, 6,8	G0,1, 3,6				
	IMU	G1,2,3, 6,8	G0,1, 3,6				
	MLS	G1,3,6, 8					
	MTU	G1,2,3, 6,8,0	G0,1, 3,6				
	NSP	G1,2,3, 6,8,0	G0,1, 3,6				
	STKR	G2,3,8					
	TAC	G1,3,6, 8	G0,1, 3,6				
	PASS		G0,1, 3,6			<ul style="list-style-type: none"> <li>• BFS FAIL TO TRACK STRING 3</li> </ul>	<ul style="list-style-type: none"> <li>• NO MAL</li> <li>• I/O RESET MAY RESTORE PASS/BFS COMM</li> </ul>



## 2. SYSTEMS

### 2.2 Caution and Warning System

MESSAGE	OPS AVAIL		CAUSE	COMMENTS	
	PASS	BFS			
BCE STRG 4	A	G1,2,3,6,8	G0,1,3,6	<ul style="list-style-type: none"> <li>ALL GPCs DETECTED PROBLEM RECEIVING DATA FROM INDICATED BCE ELEMENT OF STRING 4 AND HAVE BYPASSED THAT ELEMENT</li> </ul>	<ul style="list-style-type: none"> <li>BFS PRE-ENGAGED MUST BE IN SYNC WITH (TRACKING) PASS TO ANNUNCIATE</li> </ul>
	ADTA	G1,3,6,8	G0,1,3,6		
	B	G1,2,3,6,8	G0,1,3,6		
	C	G1,2,3,6,8	G0,1,3,6		
	D	G1,2,3,6,8	G0,1,3,6		
	PASS		G0,1,3,6	<ul style="list-style-type: none"> <li>BFS FAIL TO TRACK STRING 4</li> </ul>	<ul style="list-style-type: none"> <li>NO MAL</li> <li>I/O RESET MAY RESTORE PASS/BFS COMM</li> </ul>
BDY FLP SW	L(R)	G3,6		<ul style="list-style-type: none"> <li>BODY FLAP DN(UP) SW DISAGREE</li> </ul>	<ul style="list-style-type: none"> <li>NO MAL</li> <li>DEFAULT TO NO OUTPUT</li> </ul>
BODY FLAP FAIL HOLD	CYCL	G1,3,6		<ul style="list-style-type: none"> <li>BODY FLAP LIMIT CYCLING BUT USABLE</li> </ul>	<ul style="list-style-type: none"> <li>NO MAL</li> </ul>
		G1,3,6		<ul style="list-style-type: none"> <li>BODY FLAP STALLED OR RUNAWAY</li> </ul>	
		G1,3,6		<ul style="list-style-type: none"> <li>BODY FLAP ONE CH FAILED BUT USABLE</li> </ul>	
SM0 BRAKE P 1/3			G0,1,3,6	<ul style="list-style-type: none"> <li>PRESSURE &gt; 180 PSI IN BRAKES DRIVEN BY HYDRAULIC SYSTEM 1/3</li> <li>PRESSURE &gt; 180 PSI IN BRAKES DRIVEN BY HYDRAULIC SYSTEM 2/3</li> </ul>	
SM0 BRAKE P 2/3			G0,1,3,6		

MESSAGE	OPS AVAIL		CAUSE	COMMENTS		
	PASS	BFS				
S66 CABIN	S2,4		<ul style="list-style-type: none"> <li>EMER O2 QTY REG P</li> <li>H2O TK N2 P ↓</li> <li>O2 REG P ↑</li> <li>N2 REG P ↓</li> <li>CAB T ↑</li> <li>HUMID SEP ↓ (SPEED)</li> <li>N2 SPLY QTY ↓</li> <li>AIRLOCK P ↑</li> </ul>	<ul style="list-style-type: none"> <li>EMER O2 MSG ONLY WHEN EMER O2 TK MANIFESTED</li> </ul>		
S66 CABIN or SM1 CABIN	O2	S2,4	SM	<ul style="list-style-type: none"> <li>O2 FLOW ↑</li> </ul>	<ul style="list-style-type: none"> <li>A,E PKT C/L - CAB P LK</li> </ul>	
		PCO2	S2,4		<ul style="list-style-type: none"> <li>PCO2 ↑</li> </ul>	<ul style="list-style-type: none"> <li>NO MAL</li> </ul>
		PRES	S2,4	SM	<ul style="list-style-type: none"> <li>CAB P ↓</li> </ul>	
		PPO2	S2,4	SM	<ul style="list-style-type: none"> <li>PPO2 ↓</li> </ul>	
		N2	S2,4	SM	<ul style="list-style-type: none"> <li>N2 FLOW ↑</li> </ul>	<ul style="list-style-type: none"> <li>A,E PKT C/L - CAB P LK</li> </ul>
		FAN	S2,4	SM	<ul style="list-style-type: none"> <li>FAN Δ P ↑</li> </ul>	
		HX T	S2,4		<ul style="list-style-type: none"> <li>CAB HX OUT T</li> </ul>	<ul style="list-style-type: none"> <li>NO MAL - LIMITS OSL AND OSH</li> </ul>
		IMU	S2,4	SM	<ul style="list-style-type: none"> <li>CAB IMU ↓</li> </ul>	<ul style="list-style-type: none"> <li>IMU FAN Δ P (PASS ONLY)/SPEED (PASS AND BFS)</li> </ul>
		O2 CONC	S2,4		<ul style="list-style-type: none"> <li>O2 CONC ↑</li> </ul>	
		dP/dT EQ	S2,4		<ul style="list-style-type: none"> <li>CABIN PRESS RATE OF CHANGE ↓</li> </ul>	<ul style="list-style-type: none"> <li>O,E PKT - O2(N2) FLOW HIGH/CAB FLOW/dP/dT</li> </ul>
S60CHECKPT FAIL	S2,4		<ul style="list-style-type: none"> <li>SM CHECKPOINT FAILED ON WRITE OR RESTORE DUE TO AN I/O FAILURE BETWEEN THE GPC AND MMU, OR MMU WAS OFF/BUSY</li> </ul>	<ul style="list-style-type: none"> <li>ATTEMPT RECOVERY USING MMU MALS</li> </ul>		
CIRC PUMP	S2,4		<ul style="list-style-type: none"> <li>CIRC PUMP FAILS TO TURN OFF</li> </ul>	<ul style="list-style-type: none"> <li>INHIBITS CONTINUATION OF PUMP CYCLING SEQ</li> </ul>		

MESSAGE	OPS AVAIL		CAUSE	COMMENTS
	PASS	BFS		
S67 CNTL/ESS V SM1 CNTL/ESS V	S2.4	SM	<ul style="list-style-type: none"> <li>• DC VOLT CNTL ↓</li> <li>• DC VOLT ESS ↓</li> </ul>	
S76 COMM	S2.4		<ul style="list-style-type: none"> <li>• GCIL CONFIG - PNL ↓</li> <li>• CAMERA OVERTEMP - YES</li> <li>• KUGMBL TEMP A ↑</li> <li>• B ↑</li> <li>• GYRO TEMP ↑</li> </ul>	
CRT BITE 1(2,3,4)	ALL	ALL	• A BITE ERROR DETECTED IN INDICATED DEU	
S68 CRYO H2	S2.4		<ul style="list-style-type: none"> <li>• TK P ↑↓</li> <li>• HTR T ↑</li> <li>• MANF P ↓</li> <li>• VLV = CL</li> </ul>	
S68 CYRO H2 or SM2 CRYO H2	PRES S2.4	SM	• TK HTR CNTL P ↑↓	
S68 CRYO O2	S2.4		<ul style="list-style-type: none"> <li>• TK P ↑↓</li> <li>• MANF P ↓</li> <li>• VLV = CL</li> <li>• HTR CURSNSR = TRIP</li> </ul>	
S68 CRYO O2 or SM2 CRYO O2	HTR S2.4 PRES S2.4	SM	<ul style="list-style-type: none"> <li>• TK HTR T ↑</li> <li>• TK HTR CNTL P ↑↓</li> </ul>	

MESSAGE	OPS AVAIL		CAUSE	COMMENTS
	PASS	BFS		
DAP RECONF	G2.8		• DESELECTION OF ONE OR MORE DOWNFIRING VERNIER JETS	<ul style="list-style-type: none"> <li>• IF USING PRI RCS, MSG INDICATES FAILURE OF DOWNFIRING VERN JET W/O DOWNMODING</li> <li>• IF USING VERN RCS, OR UPON TRANS FROM PRI TO VERN RCS, DAP WILL DOWNMODE TO FREE DRIFT</li> </ul>
SM1 DC VOLT FC 1(2,3)		SM	• FC VOLT ↑↓	
> 3 DEU	ALL		• TOO MANY DEUs IN COMMON SET	• NO MAL
DISPLAY SW	A G2.8		<ul style="list-style-type: none"> <li>• AFT ADI ERROR/RATE SW</li> <li>• ATT SEL SW</li> </ul>	<ul style="list-style-type: none"> <li>• NO MAL</li> <li>• MAY BE TRIGGERED BY COMM FAULT OR I/O RESET</li> <li>• MOVE APPROPRIATE SW TO GREEN DOT DEFAULT POS</li> <li>• AIR DATA/RADAR ALT SW NOT READ IN OPS 1, 2 OR 8 FOR PASS</li> </ul>
	L G1.2.3, 6.8		<ul style="list-style-type: none"> <li>• LH ADI ERROR/RATE SW</li> <li>• ATT SEL SW</li> <li>• AIR DATA SW</li> <li>• HSI MODE/SOURCE/TRAN SW</li> <li>• RADAR ALT SW</li> </ul>	
	R G1.2.3, 6.8		<ul style="list-style-type: none"> <li>• RH ADI ERROR/RATE SW</li> <li>• ATT SEL SW</li> <li>• AIR DATA SW</li> <li>• HSI MODE/SOURCE/TRAN SW</li> <li>• RADAR ALT SW</li> </ul>	

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MESSAGE	OPS AVAIL		CAUSE	COMMENTS	
	PASS	BFS			
SM1 EMER dP/dT BU		SM	<ul style="list-style-type: none"> <li>CAB LEAK</li> </ul>	<ul style="list-style-type: none"> <li>SW CABIN PRESSURE RATE-OF-CHANGE COMP</li> <li>NO MAL</li> <li>NOT IN PRELAUNCH OPS 0</li> </ul>	
ET SEP	AUTO	G6	<ul style="list-style-type: none"> <li>ET SEP MODE SW FAIL</li> </ul>	<ul style="list-style-type: none"> <li>NO MAL</li> <li>SW DEFAULTS TO AUTO IN G6</li> </ul>	
	INH	G1,6	G1,6	<ul style="list-style-type: none"> <li>AUTO SEP INH</li> <li>G1 = BODY RATES &amp; FDLN DISC VLVS</li> <li>G6 = BODY RATES, <math>\alpha</math> and <math>\beta</math></li> </ul>	<ul style="list-style-type: none"> <li>NO MAL</li> <li>USE CUE CARDS FOR DISC VLVS</li> </ul>
	MAN	G1		<ul style="list-style-type: none"> <li>ET SEP SW FAIL (RM)</li> </ul>	<ul style="list-style-type: none"> <li>NO MAL</li> <li>USE SPEC 51 OVERRIDE</li> </ul>
S77 EVA-MMU T PORT STBD	S2,4		<ul style="list-style-type: none"> <li>MMU/FSS TEMP OUT OF LIMITS</li> </ul>		
S88 EVAP OUT T SM2 EVAP OUT T	1(2) S2,4	SM	<ul style="list-style-type: none"> <li>OUT T <math>\uparrow\downarrow</math></li> </ul>		
G23 EXCESS FU AAPS	G2		<ul style="list-style-type: none"> <li>EXCESSIVE FUEL AAPS JET FIRING</li> </ul>		

MESSAGE	OPS AVAIL		CAUSE	COMMENTS	
	PASS	BFS			
SM1 FC AMPS 1(2,3)		SM	<ul style="list-style-type: none"> <li>FC AMPS <math>\uparrow\downarrow</math></li> </ul>		
SM1 FC COOL P 1(2,3)		SM	<ul style="list-style-type: none"> <li>FC COOL P <math>\uparrow\downarrow</math></li> </ul>		
SM1 FC DELTA V 1(2,3)		SM	<ul style="list-style-type: none"> <li>FC SUBSTACK <math>\Delta V &gt; 150</math> MV</li> </ul>		
S69 FC END HTR SM0 FC END HTR	S2,4		<ul style="list-style-type: none"> <li>FC END CELL HTR FAIL ON</li> </ul>		
		SM			
SM1 FC EXIT T 1(2,3)		SM	<ul style="list-style-type: none"> <li>FC EXIT T <math>\uparrow\downarrow</math></li> </ul>		
SM1 FC PH 1(2,3)		SM	<ul style="list-style-type: none"> <li>FC PH HIGH</li> </ul>		
S69 FC PUMP SM1 FC PUMP	S2,4		<ul style="list-style-type: none"> <li>FC COOL PUMP <math>\Delta P \downarrow</math></li> </ul>		
		SM			
FC PURGE	1(2,3)	S2,4	<ul style="list-style-type: none"> <li>FAILS FLOW CHECK AT PURGES AT END OF PURGE</li> </ul>	<ul style="list-style-type: none"> <li>USE MAN FC PURGE PROC</li> </ul>	
		SEQ	S2,4	<ul style="list-style-type: none"> <li>LOSS OF PWR TO PURGE LN HTRS AFTER AUTO SEQ INIT OR LOSS OF SWITCH FUNCTION</li> </ul>	<ul style="list-style-type: none"> <li>USE MAN FC PURGE PROC</li> <li>SEQ FAIL FLAG TERMINATES AUTO PURGE SEQ</li> </ul>
		TEMP	S2,4	<ul style="list-style-type: none"> <li>FC PURGE LINE TEMP TOO LOW TO PERFORM AUTO PURGE</li> </ul>	<ul style="list-style-type: none"> <li>TERMINATES AUTO PURGE</li> <li>USE MAN FC PURGE PROC</li> </ul>

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MESSAGE	OPS AVAIL		CAUSE	COMMENTS	
	PASS	BFS			
S69 FC REAC SM1 FC REAC	1(2,3)	S2,4	SM	<ul style="list-style-type: none"> <li>FC REAC ↓</li> </ul>	<ul style="list-style-type: none"> <li>FC REAC VLV - CL</li> </ul>
FCS CH	1(2,3,4)	G1	G1	<ul style="list-style-type: none"> <li>SRB CHANNEL BYPASS</li> </ul>	<ul style="list-style-type: none"> <li>NO MAL</li> <li>ROCK &amp; TILT ACT A(B,C,D) CH FAIL</li> </ul>
		G1	G1,6	<ul style="list-style-type: none"> <li>MPS CHANNEL BYPASS</li> </ul>	<ul style="list-style-type: none"> <li>NO MAL</li> <li>MPS ENG PITCH (YAW) CH FAIL</li> </ul>
		G1,3,6	G1,3,6	<ul style="list-style-type: none"> <li>AERO CHANNEL BYPASS</li> </ul>	<ul style="list-style-type: none"> <li>NO MAL</li> <li>ELEV (RUD,S/B) ACT CH FAIL</li> </ul>
FCS SAT	POS	G3,6	G3,6	<ul style="list-style-type: none"> <li>L/R IB/OB ELEVON POSITION SATURATION</li> </ul>	<ul style="list-style-type: none"> <li>NO MAL</li> <li>ELEVON SAT (&gt; +12 OR &lt; -15 DEG) SEE ENT C/L, ENT MON NOTES</li> </ul>
	MOM	G3,6	G3,6	<ul style="list-style-type: none"> <li>L/R IB/OB PRI DELTA PRESS</li> </ul>	<ul style="list-style-type: none"> <li>NO MAL</li> <li>IN RTLS EXPECT HINGE MOM &gt; 2400 psi (80% SYS MAX). SEE ENT C/L, ENT MON NOTES</li> </ul>
S69 FC STACK T SM1 FC STACK T	1(2,3)	S2,4	SM	<ul style="list-style-type: none"> <li>FC STACK T ↑ ↓</li> </ul>	

MESSAGE	OPS AVAIL		CAUSE	COMMENTS	
	PASS	BFS			
F RCS	JET		G1,3,6	<ul style="list-style-type: none"> <li>F JET MANF 1(2,3,4) FAIL ON/OFF</li> </ul>	<ul style="list-style-type: none"> <li>NO FAIL LK DETECTION IN BFS</li> </ul>
	DJET	G1,2,3, 6,8		<ul style="list-style-type: none"> <li>F DOWN JET 1(2,3,4) FAIL ON/OFF/LK</li> </ul>	<ul style="list-style-type: none"> <li>NO MAL</li> </ul>
	FJET	G1,2,3, 6,8		<ul style="list-style-type: none"> <li>F FWD JET 1(2,3) FAIL ON/OFF/LK</li> </ul>	<ul style="list-style-type: none"> <li>FAIL OFF DETECTION NOT PERFORMED IN MM 101 &amp; 102 FOR PASS</li> </ul>
	LJET	G1,2,3, 6,8		<ul style="list-style-type: none"> <li>F LEFT JET 1(3,5) FAIL ON/OFF/LK</li> </ul>	
	RJET	G1,2,3, 6,8		<ul style="list-style-type: none"> <li>F RIGHT JET 2(4,5) FAIL ON/OFF/LK</li> </ul>	
	UJET	G1,2,3, 6,8		<ul style="list-style-type: none"> <li>F UP JET 1(2,3) FAIL ON/OFF/LK</li> </ul>	
	He P	G2,8	G1,3,6	<ul style="list-style-type: none"> <li>F He (FU OR OX) TK P 2 LOW</li> </ul>	<ul style="list-style-type: none"> <li>PKT C/L - RCS LEAK ISOL</li> </ul>
	LEAK	G2,3,8	G1,3,6	<ul style="list-style-type: none"> <li>PROP/He LEAK</li> </ul>	<ul style="list-style-type: none"> <li>OX/FU Δ QTY &gt; 12.6%</li> </ul>
	PVT	G2,3,8		<ul style="list-style-type: none"> <li>LOSS OF PORT DATA FOR RCS QTY CALC</li> </ul>	<ul style="list-style-type: none"> <li>NO MAL/QTY CALC SUSPENDED</li> </ul>
	TK P	G2,8	G1,3,6	<ul style="list-style-type: none"> <li>FWD RCS (FU OR OX) TK ULL PRESS HI/LOW</li> </ul>	<ul style="list-style-type: none"> <li>QTY CALC SUSPENDED</li> </ul>
S88 FREON FLOW SM2 FREON FLOW	1(2)	S2,4	SM	<ul style="list-style-type: none"> <li>FLOW ↓</li> </ul>	<ul style="list-style-type: none"> <li>FCL ICH FLOW</li> </ul>

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MESSAGE	OPS AVAIL		CAUSE	COMMENTS
	PASS	BFS		
S69 FUEL CELL	S2,4		<ul style="list-style-type: none"> <li>• FC VOLT ↑↓</li> <li>• AMPS ↑↓</li> <li>• EXIT T ↑↓</li> <li>• COOL P ↑↓</li> <li>• O2(H2) FLOW ↑</li> <li>• H2O LNT ↑↓</li> <li>• pH - pH ↓</li> <li>• H2O VLV T ↑↓</li> <li>• RLF LNT ↑↓</li> <li>• O2 PURGE LNT ↑</li> <li>• H2 PURGE LNT 1(2) ↑</li> <li>• SUBSTACK ΔV &gt; 150 MV</li> <li>• H2O LINE pH ↓</li> <li>• FC H2 PUMP STATUS ↑↓</li> <li>• H2O RLF HEATER STATUS ↓</li> <li>• READY ↓</li> <li>• ALTH2O RLF TEMP ↑↓</li> </ul>	<ul style="list-style-type: none"> <li>• pH &gt; 9 BILEVEL</li> <li>• pH &gt; 9 BILEVEL</li> </ul>
H2O	S2,4		<ul style="list-style-type: none"> <li>• FC H2O RLF NOZ T A(B) ↑↓</li> </ul>	
S86 FU TK VLV APU	S2,4		<ul style="list-style-type: none"> <li>• APU FUEL TANK VLV TEMP ↑↓</li> </ul>	
SM2 FU TK VLV APU		SM	<ul style="list-style-type: none"> <li>• APU FUEL TANK VLV TEMP ↑↓</li> </ul>	

MESSAGE		OPS AVAIL		CAUSE	COMMENTS
		PASS	BFS		
GPC	BITE	ALL	ALL	<ul style="list-style-type: none"> <li>• SW FORCED CLOSED PROCESS DUE TO GPC H/W (SW) FAULT</li> <li>• BFS RESTART INDICATION</li> </ul>	<ul style="list-style-type: none"> <li>• IN PASS</li> <li>• IN BFS</li> </ul>
	CONF	ALL		<ul style="list-style-type: none"> <li>• NBAT TGT GPCS NOT IN RUN OR NOT SPECIFIED</li> </ul>	<ul style="list-style-type: none"> <li>• NO MAL</li> <li>• PROCEDURAL ERROR OPS W/TC-ERROR</li> </ul>
	SUM		ALL	<ul style="list-style-type: none"> <li>• BFS GPC FAIL: CHECKSUM</li> </ul>	
	1	ALL		<ul style="list-style-type: none"> <li>• INDICATED GPC HAS FAILED</li> </ul>	
	2	ALL			
	3	ALL			
	4	ALL			
	5	ALL			
GPC PWR			ALL	<ul style="list-style-type: none"> <li>• PWR TRANSITIONS TO BFS GPC</li> </ul>	<ul style="list-style-type: none"> <li>• BFS WILL DISENGAGE</li> <li>• SW DOES AUTO RESTART</li> </ul>

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MESSAGE	OPS AVAIL		CAUSE	COMMENTS
	PASS	BFS		
S66 H2O	S2,4		<ul style="list-style-type: none"> <li>• SPLY QTY TK A(B,C,D) ↓, C(D) ↑</li> <li>• SPLY (WASTE) DUMP LNT ↑↓</li> <li>• WASTE P ↑↓</li> <li>• SPLY (WASTE) NOZ T A(B) ↑</li> <li>• VAC VENT NOZ T</li> <li>• WASTE QTY 1 ↓↑</li> </ul>	<ul style="list-style-type: none"> <li>• NO MAL- LIMITS OSL AND OSH</li> <li>• NO MAL FOR QTY HIGH</li> </ul>
PRES	S2,4		<ul style="list-style-type: none"> <li>• SUPPLY H2O IN P ↑↑</li> </ul>	
S88 H2O PUMP P SM2 H2O PUMP P	1(2) S2,4	SM	<ul style="list-style-type: none"> <li>• P 1(2) ↑↓</li> </ul>	
HIGH G	G3,6		<ul style="list-style-type: none"> <li>• HIGH G</li> </ul>	<ul style="list-style-type: none"> <li>• NO MAL</li> </ul>
SM2 HYD ACUM P	1(2,3)	SM	<ul style="list-style-type: none"> <li>• ACCUM P ↓</li> </ul>	
S86 HYD PRESS SM2 HYD PRESS	1(2,3) S2,4	SM	<ul style="list-style-type: none"> <li>• HYD SYS SPLY P ↑↓</li> </ul>	<ul style="list-style-type: none"> <li>• NO MAL</li> </ul>
SM2 HYD QTY	1(2,3)	SM	<ul style="list-style-type: none"> <li>• RSVR QTY ↑↓</li> </ul>	<ul style="list-style-type: none"> <li>• NO MAL</li> </ul>
SM2 HYD RSVR T	1(2,3)	SM	<ul style="list-style-type: none"> <li>• RSVR T ↑↑</li> </ul>	
ILLEGAL ENTRY	ALL	ALL	<ul style="list-style-type: none"> <li>• ILLEGAL KYBD ENTRY WITH RESPECT TO OPS SELECT/TRANSITION, DATA LOAD, INITIALIZATION, MEM RECONFIG, GPC ASSIGN, KYBD SYNTAX, FREEZE DRY LOAD, ETC</li> </ul>	<ul style="list-style-type: none"> <li>• NO MAL</li> <li>• IF APPROPRIATE, KYBD INPUT SHOULD BE REENTERED</li> </ul>

MESSAGE	OPS AVAIL		CAUSE	COMMENTS
	PASS	BFS		
I/O ERROR	CRT1 ALL CRT2 ALL CRT3 ALL CRT4 ALL D/L ALL	ALL ALL ALL ALL ALL	<ul style="list-style-type: none"> <li>• ERROR IN DEU 1(2,3,4) MSG (I/O OR CHECKSUM)</li> </ul>	
FA1	G1,2,3, 6,8	G0,1, 3,6	<ul style="list-style-type: none"> <li>• INPUT/OUTPUT ERROR ON INDICATED UNIT HAS BEEN DETECTED</li> </ul>	<ul style="list-style-type: none"> <li>• BFS PRE-ENGAGE MUST BE IN SYNC WITH (TRACKING) PASS TO ANNUNCIATE</li> </ul>
FA2	G1,2,3, 6,8	G0,1, 3,6		
FA3	G1,2,3, 6,8	G0,1, 3,6		
FA4	G1,2,3, 6,8	G0,1, 3,6		
FF1	G1,2,3, 6,8	G0,1, 3,6		
FF2	G1,2,3, 6,8	G0,1, 3,6		
FF3	G1,2,3, 6,8	G0,1, 3,6		
FF4	G1,2,3, 6,8	G0,1, 3,6		
FLEX	S2,4		<ul style="list-style-type: none"> <li>• I/O ERROR FLEX/FLEX PAIR</li> </ul>	

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MESSAGE	OPS AVAIL		CAUSE	COMMENTS	
	PASS	BFS			
I/O ERROR MMU 1(2)	ALL		<ul style="list-style-type: none"> <li>CHECKSUM ERROR OR I/O ERROR ON MMU TRANSACTION, OR GPC-GPC OL FAILURE</li> <li>TFL FORMAT NOT FOUND IN BUFFER FOLLOWING RETRIEVAL FROM MMU</li> <li>I/O ERROR DURING DEU 1(2,3,4) LOAD</li> </ul>	<ul style="list-style-type: none"> <li>MAY OCCUR WHILE EXPANDING REDUNDANT SET AS NEW GPC TAKES COMMAND OF MMU</li> </ul>	
PCM PL1 PL2	S2,4	SM	<ul style="list-style-type: none"> <li>I/O ERROR ON PCMMU</li> </ul>		
	S2,4	SM	<ul style="list-style-type: none"> <li>I/O ERROR ON PL BUS 1/2</li> </ul>		
	S2,4	SM			
IMU BITE/T 1(2,3)	G1,2,3, 6,8		<ul style="list-style-type: none"> <li>IMU 1,2,3 PLATFORM TEMP SAFE, CAPRI TEMP SAFE, OR IMU BITE</li> </ul>	<ul style="list-style-type: none"> <li>BITE PARAMETERS CAN BE MASKED VIA CREW R/W</li> <li>BFS ONLY USES H/W BITE</li> <li>DAP DOWNMODES TO MAN PULSE FOR BITE IN SINGLE IMU CASE (OPS 2 &amp; 8 ONLY)</li> </ul>	
ITEM R/CT PSP	S2,4		<ul style="list-style-type: none"> <li>PCP CC CMD REJECTED DUE TO PSP CMD DATA TRANSMISSION IN PROGRESS</li> </ul>	<ul style="list-style-type: none"> <li>NO MAL</li> </ul>	
L OMS	GMBL	G1,2,3	G1,3	<ul style="list-style-type: none"> <li>PITCH (YAW) CMD/FEEDBACK <math>\Delta 2^\circ</math> FOR 3.8 SEC</li> </ul>	<ul style="list-style-type: none"> <li>NO MAL</li> </ul>
	PC	G1,2,3, 6	G1,3,6	<ul style="list-style-type: none"> <li>ENG CHAMBER PRESS LOW</li> </ul>	

MESSAGE	OPS AVAIL		CAUSE	COMMENTS	
	PASS	BFS			
L OMS	QTY	G1,2,3, 6,8		<ul style="list-style-type: none"> <li>ENG FU OR OX TK LEVEL LOW</li> </ul>	
			G1,3	<ul style="list-style-type: none"> <li>ENG FU INJ T HI</li> </ul>	<ul style="list-style-type: none"> <li>NO MAL</li> </ul>
	TEMP TK P	G2,8	G1,3	<ul style="list-style-type: none"> <li>FU OR OX TK ULLAGE P HI/LOW</li> </ul>	
			G1,3,6	<ul style="list-style-type: none"> <li>He OR N2 TK P LOW</li> <li>N2 REG P HI/LOW</li> </ul>	
VLV	G2		<ul style="list-style-type: none"> <li>He P/VAP ISOL VLV MISMATCH</li> </ul>	<ul style="list-style-type: none"> <li>NO MAL</li> </ul>	
S89 L OMS TEMP	S2,4		<ul style="list-style-type: none"> <li>ENG FU INJ T HI/LOW</li> </ul>	<ul style="list-style-type: none"> <li>NO MAL</li> </ul>	
L RCS	JET		G1,3,6	<ul style="list-style-type: none"> <li>LEFT JET MANF 1(2,3,4) FAIL ON/OFF</li> </ul>	<ul style="list-style-type: none"> <li>NO FAIL LK DETECTION IN BFS</li> </ul>
	AJET	G1,2,3, 6,8		<ul style="list-style-type: none"> <li>L AFT JET 1(3) FAIL ON/OFF/LK</li> </ul>	<ul style="list-style-type: none"> <li>FAIL OFF DETECTION NOT PERFORMED IN MM101 &amp; 102 FOR PASS</li> </ul>
	DJET	G1,2,3, 6,8		<ul style="list-style-type: none"> <li>L DOWN JET 2(3,4,5) FAIL ON/OFF/LK</li> </ul>	
	LJET	G1,2,3, 6,8		<ul style="list-style-type: none"> <li>L LEFT JET 1(2,3,4,5) FAIL ON/OFF/LK</li> </ul>	
	UJET	G1,2,3, 6,8		<ul style="list-style-type: none"> <li>L UP JET 1(2,4) FAIL ON/OFF/LK</li> </ul>	
	He P LEAK	G2,8	G1,3,6	<ul style="list-style-type: none"> <li>L RCS AFT He (FU OR OX) TK PRESS-2 LOW</li> </ul>	<ul style="list-style-type: none"> <li>PKT C/L - RCS LEAK ISOL</li> </ul>
	PVT	G2,3,8	G1,3,6	<ul style="list-style-type: none"> <li>PROP/He LEAK</li> </ul>	<ul style="list-style-type: none"> <li>OX/FU <math>\Delta</math>QTY &gt; 12.6%</li> </ul>
	TK P	G2,3,8		<ul style="list-style-type: none"> <li>LOSS OF PORT DATA FOR RCS QTY CALC</li> </ul>	<ul style="list-style-type: none"> <li>NO MAL/QTY CALC SUSPENDED</li> </ul>
	G2,8	G1,2,3, 6	<ul style="list-style-type: none"> <li>L RCS AFT (FU OR OX) TK ULL PRESS HI/LOW</li> </ul>		

MESSAGE	OPS AVAIL		CAUSE	COMMENTS
	PASS	BFS		
S67 MAIN BUS V A(B,C) SM1 MAIN BUS V	S2,4	SM	• V ↑ ↓	
MDM OUTPUT FF1 2 3 4 FA1 2 3 4 PL1 2	ALL		• MDM RETURN WORD FAILURE (ON MDM OUTPUT)	

MESSAGE	OPS AVAIL		CAUSE	COMMENTS
	PASS	BFS		
ME SHDN SW C(L,R)	G1,6		• SW CONTACT DISAGREE	• SHUTDOWN FUNCTION OF SWITCH NO LONGER WORKS
MPS CMD C(L,R)	G1,6	G1,6	• MPS C(L,R) CMD PATH FAIL	• REF AESP CUE CARDS • BFS DOES NOT SUPPORT CMD PATH FAIL ANNUNCIATION PRE-ENGAGED
MPS DATA C(L,R)	G1,6	G1,6	• DATA PATH FAIL	• REF AESP CUE CARDS
MPS ELEC C(L,R)	G1,6	G1,6	• ELECTRONIC LOCKUP MODE FAIL	• REF AESP CUE CARDS
MPS HYD C(L,R)	G1,6	G1,6	• HYD LOCKUP MODE FAIL	• REF AESP CUE CARDS
MPS He P C(L,R)		G1,6	• MPS He TK P HI/LOW • INDICATED REG P HI/LOW • HI LEAK RATE dP/dT	
MPS LH2/O2 MANF		G1,6	• MPS LH2 ENG MANF P HI • LOX ENG MANF P HI	
ULL		G1,6	• ET ULL P HI/LO	
MPS PNEU ACUM		G1,6	• MPS PNEU ACUM PRESS LOW	• REF AESP CUE CARDS
REG		G1,6	• MPS PNEU REG PRESS HI/LOW	• REF AESP CUE CARDS
TK		G1,6	• MPS PNEU TANK PRESS LOW	• REF AESP CUE CARDS



2. SYSTEMS  
2.2 Caution and Warning System

MESSAGE	OPS AVAIL		CAUSE	COMMENTS
	PASS	BFS		
NAV EDIT  ALT  TAC	G2		• RNDZ NAV EDIT	
		G3,6	• DRAG H, ADTA, OR TACAN NAV EDIT	• BFS DOES NOT SUPPORT MLS
	G3,6		• ADTA ALT DATA NOT PROCESSING < M2.5 • DRAG H DATA NOT PROCESSING 85 2k FT < H < 140k FT	• MLS NAV EDIT MESSAGE (MLSNV) SEEN ONLY ON HUD
	G3,6		• TACAN DATA NOT PROCESSING < 140k FT	
G23 NEED JETS AAPS	G2		• NEED MORE JETS TO SATISFY COMMAND	
OFF/BUSY MMU 1(2)	ALL		• AN MMU TRANSACTION IS REQUESTED WHEN THE MMU IS OFF/BUSY, FAILED OFF, OR SELECTED FOR IPL	
G23 OMS/RCS	QTY	G2	• L(R) OMS TO RCS PROP TRANSFER EXCEEDS LIMIT	• NO MAL
OTT ST IN	G3,6	G3,6	• INDICATED EW LVL LESS THAN LVL REQD FOR OVHD APPROACH	• NO MAL • MSG TERMINATES < 45 NM FROM LDG OR EW LVL AGAIN MATCHES PROFILE

MESSAGE	OPS AVAIL		CAUSE	COMMENTS
	PASS	BFS		
PBD CONFIG 563 PBD CONFIG	S2,4	SM	• PLBD OUT-OF-SEQUENCE CONFIG	• CAUSES TERMINATION OF AUTO SEQUENCE
PBD SEQ FAIL 563 PBD SEQ FAIL	S2,4	SM	• PLBD AUTO SEQ FAIL	• CAUSES TERMINATION OF AUTO SEQUENCE
562 PDI DECOM FAIL	S2,4		• DECOM 1 FMT ↑ • 2 FMT ↑ • 3 FMT ↑ • 4 FMT ↑	• MSG OCCURS IF DECOM FDA ENA AND PL TLM FAIL OR PDI DECOM FAILS • MSG ALSO OCCURS IF PL DEPLOYED, PI FAIL OR PSP FAIL
596 PDRS ABE COMM JPC1 JPC2 SY SP EP WP WY WR	S2,4		• ABE/MCIU MISCOMPARE	
	S2,4		• SHOULDER JPC FAIL	
	S2,4		• WRIST JPC FAIL	
	S2,4		• SPA PWR (COMMUTATOR, MDA) FAIL • TACH/PHASE LOCK LOOP FAIL	• AUTO BRAKES APPLIED

## 2. SYSTEMS

## 2.2 Caution and Warning System

MESSAGE	OPS AVAIL		CAUSE	COMMENTS
	PASS	BFS		
S96 PDRS CKCRT D SY SP EP WP WY WR EE T CK FS HC	S2.4		<ul style="list-style-type: none"> <li>• D&amp;C COMM FAIL</li> </ul>	<ul style="list-style-type: none"> <li>• AUTO BRAKES APPLIED</li> </ul>
	S2.4		<ul style="list-style-type: none"> <li>• TACH/ENCODER DATA FAIL</li> <li>• JOINT ENCODER FAIL</li> </ul>	<ul style="list-style-type: none"> <li>• DNMODE TO IDLE IF IN AUTO MODE</li> </ul>
	S2.4		<ul style="list-style-type: none"> <li>• EE CMDS +, EE FLAG +, EEEU FAIL +</li> </ul>	
	S2.4		<ul style="list-style-type: none"> <li>• MCIU TEMP MONITOR CIRCUIT FAIL</li> </ul>	
	S2.4		<ul style="list-style-type: none"> <li>• MCIU EXTERNAL FRAME SYNC BITE OR BITE VERIFICATION FAILURE</li> </ul>	
	S2.4		<ul style="list-style-type: none"> <li>• RHC (THC) HARDOVER (ANY AXIS)</li> <li>• MCIU HC + (MULTIPLEXER MISMATCH)</li> </ul>	<ul style="list-style-type: none"> <li>• S/W DOWNMODE TO IDLE IF IN MANUAL (TEST)</li> </ul>
	S2.4		<ul style="list-style-type: none"> <li>• MCIU BITE VERIFICATION TEST FAILURE</li> </ul>	
PDRS TEST BRK C/W NMI FS LOSS	S2.4		<ul style="list-style-type: none"> <li>• MCIU BITE VERIFICATION TEST FAILURE</li> </ul>	
PDRS CNTL SY SP EP WP WY WR	S2.4		<ul style="list-style-type: none"> <li>• CONSISTENCY CK - JOINT RUNAWAY</li> <li>• TACH DATA FAIL</li> </ul>	<ul style="list-style-type: none"> <li>• AUTO BRAKES APPLIED</li> </ul>
PDRS DERIG	S2.4		<ul style="list-style-type: none"> <li>• UNCOMMANDED DERIGIDIZE</li> </ul>	<ul style="list-style-type: none"> <li>• POSSIBLE EE STRUCT FAIL</li> </ul>

MESSAGE	OPS AVAIL		CAUSE	COMMENTS
	PASS	BFS		
S94 PDRS GPC	S2.4		<ul style="list-style-type: none"> <li>• MCIU-DETECTED GPC COMM FAIL</li> </ul>	<ul style="list-style-type: none"> <li>• MCIU SAFING COMMANDED</li> <li>• S/W DNMODE TO 'SUSPEND'</li> </ul>
BCE BYP MCIU	S2.4		<ul style="list-style-type: none"> <li>• GPC DETECTED I/O LOSS WITH MCIU</li> </ul>	
S96 PDRS MCIU MADC MCPC ICF	S2.4		<ul style="list-style-type: none"> <li>• MADC REF VOLT TEST FAIL</li> </ul>	<ul style="list-style-type: none"> <li>• AUTO BRAKES APPLIED</li> </ul>
	S2.4		<ul style="list-style-type: none"> <li>• MCPC REF VOLT TEST FAIL</li> </ul>	<ul style="list-style-type: none"> <li>• AUTO BRAKES APPLIED</li> </ul>
	S2.4		<ul style="list-style-type: none"> <li>• ICF FAIL</li> </ul>	<ul style="list-style-type: none"> <li>• AUTO BRAKES APPLIED (MAY NOT BE IND)</li> </ul>
PDRS RCH SY SP EP WP WY WR	S2.4		<ul style="list-style-type: none"> <li>• JOINT EXCEEDS POS OR NEG RCH LIMIT</li> </ul>	<ul style="list-style-type: none"> <li>• APPROX 2° PRIOR TO S/W STOP</li> <li>• 4° PRIOR TO HARDSTOP</li> </ul>
PDRS REL	S2.4		<ul style="list-style-type: none"> <li>• UNCOMMANDED P/L RELEASE</li> </ul>	<ul style="list-style-type: none"> <li>• POSSIBLE EE STRUCT FAIL</li> </ul>
PDRS SING SY EP WY	S2.4		<ul style="list-style-type: none"> <li>• SY/WY WITHIN 3 FT OF COALIGNMENT</li> </ul>	<ul style="list-style-type: none"> <li>• LOSE ± Y DEG OF FREEDOM AT SINGULARITY</li> </ul>
	S2.4		<ul style="list-style-type: none"> <li>• EP &gt; -7.6°</li> </ul>	<ul style="list-style-type: none"> <li>• LOSE -X DEG OF FREEDOM AT SINGULARITY</li> </ul>
	S2.4		<ul style="list-style-type: none"> <li>• WY WITHIN ± 15° OF ± 90° SING</li> </ul>	<ul style="list-style-type: none"> <li>• LOSE ROLL DEG OF FREEDOM AT SINGULARITY</li> </ul>

2. SYSTEMS  
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MESSAGE	OPS AVAIL		CAUSE	COMMENTS
	PASS	BFS		
S96 PDRS SLIP SY SP EP WP WY WR ALL	S2.4		<ul style="list-style-type: none"> <li>JOINT SLIPPAGE WITH THE BRAKES ON AND NOT IN DIRECT MODE</li> </ul>	<ul style="list-style-type: none"> <li>SLIPPAGE GREATER THAN 0.5° PER JOINT OR SUM OF 2.0" FOR ALL JOINTS</li> </ul>
PDRS TEMP PORT STBD	S2.4		<ul style="list-style-type: none"> <li>JOINT/EE TEMP OUT OF LIMITS</li> </ul>	
S94 PDRS WR R	S2.4		<ul style="list-style-type: none"> <li>PDRS WRIST ROLL RANGE CHECK FAILURE</li> </ul>	
PL ALERT	G2.3		<ul style="list-style-type: none"> <li>GENERAL ANNUNCIATION BY GNC OF SPECIFIC SM PAYLOAD ALERT</li> </ul>	<ul style="list-style-type: none"> <li>NO MAL</li> </ul>
206 PL CL2		SM	<ul style="list-style-type: none"> <li>AV FAN ΔP ↑↓</li> <li>H2O PUMPS ΔP STAT ↓</li> </ul>	<ul style="list-style-type: none"> <li>SEE ASCENT/ENTRY SYSTEMS PROCEDURES (SPACELAB MODULE CONFIGURATION ONLY)</li> </ul>
PL CL3		SM	<ul style="list-style-type: none"> <li>AUX BUS A/B U/V ↓</li> <li>SS INV IN AMPS ↑</li> <li>TEMP ↑</li> <li>EXP INV IN AMPS ↑</li> <li>TEMP ↑</li> <li>SS AC φ(A,B,C) V ↑↓</li> <li>MAIN BUS V</li> </ul>	<ul style="list-style-type: none"> <li>SEE ASCENT/ENTRY SYSTEMS PROCEDURES</li> </ul>
PL C/W	G2.3		<ul style="list-style-type: none"> <li>GENERAL ANNUNCIATION BY GNC OF SPECIFIC SM PAYLOAD C/W</li> </ul>	<ul style="list-style-type: none"> <li>SPECIFIC MESSAGE AVAILABLE ON SM FAULT DISPLAY</li> </ul>

MESSAGE	OPS AVAIL		CAUSE	COMMENTS
	PASS	BFS		
PL MSG	G2.3		<ul style="list-style-type: none"> <li>GENERAL ANNUNCIATION BY GNC OF SPECIFIC SM PAYLOAD CLASS 4 (MESSAGE ONLY) ANNUNCIATION</li> </ul>	
PNL TRIM L(R)	G3.6		<ul style="list-style-type: none"> <li>LH(RH) +/- P/R/Y TRIM SW DISAGREE</li> </ul>	<ul style="list-style-type: none"> <li>NO MAL</li> </ul>
PROBES	G3.6		<ul style="list-style-type: none"> <li>EITHER ADTA PROBE NOT DEPLOYED DURING 1 &lt; M &lt; 2.5</li> </ul>	<ul style="list-style-type: none"> <li>NO MAL</li> </ul>
S89 PRPLT THRM OMS POD RCS	S2.4		<ul style="list-style-type: none"> <li>OX(FU) LN STRUCT T HI/LOW</li> </ul>	
	S2.4		<ul style="list-style-type: none"> <li>PROP AND STRUCT T HI/LOW</li> </ul>	
	S2.4		<ul style="list-style-type: none"> <li>FWD AND L/R RCS STRUCT T HI/LOW</li> </ul>	
G23 RCS SYSTEM F(L,R)	G2.8		<ul style="list-style-type: none"> <li>F(L,R) RCS FU OR OX TK TEMP</li> </ul>	
	G2.8		<ul style="list-style-type: none"> <li>F(L,R) RCS FU OR OX TK OUT PRESS</li> </ul>	
RCS PWR FAIL	G1.2,3,6.8		<ul style="list-style-type: none"> <li>LOSS OF VLV LOGIC PWR TO MANF ISOL VLVs</li> </ul>	<ul style="list-style-type: none"> <li>✓RCS VLV tb If bp VLV PWR FAIL, VLV POS CANNOT BE CHANGED</li> </ul>
RHC A L R	G2.8		<ul style="list-style-type: none"> <li>CHANNEL FAIL</li> <li>R(P,Y) DISAGREE</li> </ul>	<ul style="list-style-type: none"> <li>FAIL = SM ALERT</li> <li>RHC LOST FOR DISAGREE</li> </ul>
	G2.3.8		<ul style="list-style-type: none"> <li>CHANNEL FAIL</li> <li>R(P,Y) DISAGREE</li> </ul>	
	G2.3.8		<ul style="list-style-type: none"> <li>CHANNEL FAIL</li> <li>R(P,Y) DISAGREE</li> </ul>	
G51 RL MODE SW	G3.6		<ul style="list-style-type: none"> <li>ENTRY ROLL MODE SW FAIL</li> </ul>	<ul style="list-style-type: none"> <li>NO MAL</li> </ul>

MESSAGE		OPS AVAIL		CAUSE	COMMENTS
		PASS	BFS		
RM DLMA	ADTA	G3,6		• DELAYED ADTA DILEMMA FLAG	• NO MAL • DES/SEL AVAILABLE • CONDITION NOT RESET UNTIL DATA GOOD FLAG RETURNS TO VALID
	IMU	G1,2,3,6,8		• DILEMMA	• DES/SEL AVAILABLE
	MLS	G3		• EL, RNG OR AZ DISAGREE	• NO MAL • DES/SEL AVAILABLE OPS 8 ONLY • PWR-OFF/CHANGE CHANNEL • NO CRT DATA OPS 3 HSI MAY IDENTIFY BAD UNIT
	TAC	G3,6		• DILEMMA	• NO MAL • DES/SEL AVAILABLE
	PRL	G1,3,6		• HYD SYS 1(2,3) DISAGREE	• NO MAL • APCL, EPCL - HYD P LOW • OPCL - HYD ACCUM (RSVR) P LOW
	WOW	G3,6		• A/N GATE LATCHED TO NULL	• NO MAL • BOTH WOW AT TRANSACTION OR WOWS DISAGREE
	MANF	G1,2,3,6,8		• RCS MANF DILEMMA FLAG MANF VLV STATUS SET 'CLOSE'	

MESSAGE		OPS AVAIL		CAUSE	COMMENTS
		PASS	BFS		
RM FAIL	ACC	G1,3,6		• FAIL	• NO MAL • DES/SEL AVAILABLE OPS 3,8 ONLY
	ADTA	G3,6	G3,6	• FAIL	• NO MAL • DES/SEL AVAILABLE
	IMU	G1,2,3,6,8	G1,3,6	• FAIL • COMMFault CAUSES BFS RM FAIL	• DES/SEL AVAILABLE
	MLS	G3		• FAIL	• NO MAL • DES/SEL AVAILABLE OPS 8 ONLY • NO CRT DATA OPS 3
	RGA	G1,3,6		• FAIL	• NO MAL • DES/SEL AVAILABLE OPS 3,8 ONLY
	TAC	G3,6		• FAIL	• NO MAL • DES/SEL AVAILABLE
	XFER		G1,3,6	• BFS NOT RECEIVE STATE VECTOR OR REFSMAT	• NO MAL
G33 RNDZ RADAR		G2	• KU-BAND BREAKS TRACK WITH RADAR TARGET (GPC ANT STEERING MODE ONLY)	• NO MAL	
ROLL REF		G3	G3	• REF ROLL STATUS FAIL	• NO MAL

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MESSAGE		OPS AVAIL		CAUSE	COMMENTS	
		PASS	BFS			
R OMS	GMBL	G1,2,3	G1,3	● PITCH (YAW) CMD/FEEDBACK Δ2° FOR 3.8 SEC	● NO MAL	
	PC	G1,2,3,6	G1,3,6	● ENG CHAMBER PRESS LOW		
	QTY	G1,2,3,6,8		● FU OR OX TK LEVEL LOW		
	TEMP		G1,3	● ENG FU INJ T HI		
	TK P	G2,8	G1,3	● FU OR OX TK ULLAGE P HI/LOW		
			G1,3,6	● He OR N2 TK P LOW ● N2 REG P HI/LOW		
	VLV	G2		● OMS R POD He/P VAP ISOL VLV MISMATCH	● NO MAL	
S89 R OMS TEMP		S2,4		● ENG FU INJ T HI/LOW	● NO MAL	
R RCS	JET		G1,3,6	● RIGHT JET MANF 1(2,3,4) FAIL ON/OFF	● NO FAIL LK DETECTION IN BFS ● FAILED OFF DETECTION NOT PERFORMED IN MM101 & 102 FOR PASS	
	AJET	G1,2,3,6,8		● R AFT JET 1(3) FAIL ON/OFF/LK		
	DJET	G1,2,3,6,8		● R DOWN JET 2(3,4,5) FAIL ON/OFF/LK		
	RJET	G1,2,3,6,8		● R RIGHT JET 1(2,3,4,5) FAIL ON/OFF/LK		
	UJET	G1,2,3,6,8		● R UP JET 1(2,4) FAIL ON/OFF/LK		
	He P	G2,8	G1,3,6	● R RCS AFT He (FU OR OX) TK PRESS - 2 LOW		● PKT C/L - RCS LEAK ISOL
	LEAK	G2,3,8	G1,3,6	● PROP/He LEAK		● OX/FU ΔQTY > 12.6%
	PVT	G2,3,8		● LOSS OF PORT DATA FOR RCS QTY CALC		● NO MAL/QTY CALC SUSPENDED
TK P	G2,8	G1,3,6	● R RCS AFT (FU OR OX) TK ULL PRESS HI/LOW			

MESSAGE		OPS AVAIL		CAUSE	COMMENTS
		PASS	BFS		
SBTC/THC	A	G2,8		● AFT THC POS/NEG X/Y/Z OUTPUT A/B/C FAIL ● AFT THC POS/NEG X/Y/Z OUTPUT DISAGREE	
	L	G3		● L SBTC CMD A(B,C) FAIL ● DISAGREE	
	L	G2,3,8		● FWD THC POS/NEG X/Y/Z OUTPUT A/B/C FAIL ● FWD THC POS/NEG X/Y/Z OUTPUT DISAGREE	
	R	G3		● R SBTC CMD A(B,C) FAIL ● DISAGREE	
SEL AUTO		G2		● UNIV PTG MNVR T-30 & NOT AUTO	● NO MAL
SENSE SW		G2		● AFT SENSE SW DEFAULT	● NO MAL ● DEFAULT POS IS '-Z'
212 SL LINK ERR		S2,4		ANY OF THE FOLLOWING MDM SERIAL I/O LINK ERROR CONDITIONS OCCURRED FOR SSC OR EXC: NO SL RESP ↓ GPC NO MATCH ↓ SL LENGTH ↓ AR NO MATCH ↓ SR NO MATCH ↓ MSG REJECT (ITEM OR GNC) ↓ LINK BUSY ↓ DSBL ↓	● SL MAL, <u>CDMS</u> , MDM/MTU/PCMMU

MESSAGE	OPS AVAIL		CAUSE	COMMENTS
	PASS	BFS		
212 SL LINK TERM	S2.4		MDM SERIAL I/O LINK TO SPACELAB TERMINATED CAUSED BY ANY OF THE FOLLOWING FOR SSC OR EXC: NOP IND ↓ COMM ↓ LINK INTRPT ↓	• SL MAL, <u>CDMS</u> , MDM/MTU/PCMMU
SM1 SMOKE ALARM	S2.4	SM	• ANY SMOKE SENSOR CONCEN ↑	
SPD BRK	G3.6		• SPEED BRAKE POSITION > 20% FROM AUTO SCHEDULE DURING 0.95 < M < 9.8	
SSME FAIL C(L,R)	G1.6	G1.6	• PREMATURE ME SHUTDOWN	• IN MM101, MSG ANNUNCIATED BY BFS ONLY
SUMWORD ICC 1(2,3,4,5)	ALL		• SUMWORD MISCOMPARE IN DATA FROM INDICATED GPC	
SW TO MEP	G3.6	G3	• MEP ALERT	• NO MAL

MESSAGE	OPS AVAIL		CAUSE	COMMENTS
	PASS	BFS		
TFL LOAD FAIL	S2.4	ALL	• READ COMPARE ERROR • UNSUCCESSFUL LOAD	• NO MAL • MAY BE RESULT OF GROUND UPLINK
TGT ΔT	G2		• REQUESTED TRANSFER TIME CAUSED SINGULARITY IN TARGETING ALGORITHM	
TGT EL ANG	G2		• EXCEEDED MAX NUMBER OF ITERATIONS ON TPTIG FOR GIVEN ELEVATION ANGLE	• NO MAL
TGT ITER	G2		• LAMBERT TGT TRANSFER ANGLE NEAR SINGULARITY POINT • PARABOLIC TRANSFER • MAX NUMBER OF ITERATIONS	

2. SYSTEMS  
2.2 Caution and Warning System

MESSAGE		OPS AVAIL		CAUSE	COMMENTS
		PASS	BFS		
S88 THERMAL	APU	S2,4		<ul style="list-style-type: none"> <li>• APU TK SURF T, (TK HTR T, TEST LN T1, T2, FEED LN T, PUMP LN T (OUT T), PUMP DRN LN T1, T2, PUMP BYP LN T, H2O LN PRI (SEC) T, H2O LN INJ T) ↑↓</li> </ul>	<ul style="list-style-type: none"> <li>• ACTIVE LOOP ONLY</li> <li>• ΔP HIGH ONLY FOR INACTIVE LOOP</li> <li>• ΔP HIGH OR LOW ACTIVE LOOP ONLY</li> </ul>
	EVAP	S2,4		<ul style="list-style-type: none"> <li>• FES NOZ, DUCT OR FDLN T ↑↓</li> </ul>	
	FRN	S2,4		<ul style="list-style-type: none"> <li>• PL HX FLOW ↓</li> <li>• AFT CP FLOW ↓</li> <li>• ACCUM QTY ↓</li> <li>• CNTL OUT T 1(2) ↓</li> </ul>	
	H2O	S2,4		<ul style="list-style-type: none"> <li>• ACCUM QTY ↑↓</li> <li>• PUMP OUT T ↑↓</li> <li>• CAB HX IN T ↓</li> <li>• ICH OUT T ↓</li> <li>• FLOW ↓</li> <li>• PUMP ΔP ↑↓</li> </ul>	
S87 THERMAL	CNTL	S2,4		<ul style="list-style-type: none"> <li>• LN T ELEV RD/SPBK/BDY FLP ↑↓</li> <li>• BRK NLG, L(R) MG T ↑↓</li> </ul>	<ul style="list-style-type: none"> <li>• HYD CIRC PUMP NOT MAINTAINING HYD THERMAL ENVIR</li> </ul>
	HYD	S2,4		<ul style="list-style-type: none"> <li>• CIRC PUMP P ↓</li> <li>• HX OUT T ↓</li> </ul>	

MESSAGE		OPS AVAIL		CAUSE	COMMENTS
		PASS	BFS		
SM0 THRM	APU		SM	<ul style="list-style-type: none"> <li>• GG BED ↓, APU INJ T ↓</li> </ul>	<ul style="list-style-type: none"> <li>• NO MAL</li> <li>• APCL, EPCL - THERM HTR</li> </ul>
	APU		SM	<ul style="list-style-type: none"> <li>• APU FU FEED LN T ↑↓, PUMP IN T ↑↓, PUMP OUT T ↑↓, FU TEST LN T ↑↓, PUMP DRN LN T ↑↓, PUMP BYP LN T ↑↓</li> </ul>	<ul style="list-style-type: none"> <li>• NO MAL</li> </ul>
EVAP	FRN		MM104 TO 106, ORB	<ul style="list-style-type: none"> <li>• FES NOZ, DUCT OR FDLN T ↑↓</li> <li>• ACCUM QTY ↓</li> <li>• RAD IN T ↑</li> </ul>	<ul style="list-style-type: none"> <li>• ONLY SELECTED DUCTS AND FDLN T's ARE SENSED FOR STATUS</li> <li>• NO ASC/ENT PKT C/L</li> </ul>
	H2O		OPS 0, MM301 TO 303	<ul style="list-style-type: none"> <li>• H2O SPLY IN P ↑↓</li> </ul>	
	HYD			<ul style="list-style-type: none"> <li>• H2O BLR T ↑↓</li> </ul>	<ul style="list-style-type: none"> <li>• NO MAL</li> <li>• APCL, EPCL - THERM HTR</li> </ul>
SM0 THRM PRPLT			MM104 TO 106, ORB OPS 0, MM301 TO 303	<ul style="list-style-type: none"> <li>• OMS FU/OX BLD/DRAIN LN T</li> <li>• POD RCS HOUSING</li> <li>• RCS STRUCT T</li> <li>• OX ENG IN OR ENG FU FDLN T</li> </ul>	
TIME	MTU TONE	ALL		<ul style="list-style-type: none"> <li>• AUTOMATIC TIME SOURCE CHANGE</li> </ul>	
		ALL		<ul style="list-style-type: none"> <li>• TIME MGT TIME TONE</li> </ul>	<ul style="list-style-type: none"> <li>• NO MAL</li> </ul>
SM0 TIRE PRESS			G3,6	<ul style="list-style-type: none"> <li>• NOSE GEAR/MLG TIRE PRESS ↓</li> </ul>	
SM2 W/B QTY	1(2,3)		SM	<ul style="list-style-type: none"> <li>• HYD SYS H2O BOILER FLUID QTY 40%</li> </ul>	

## 2.3 CLOSED CIRCUIT TELEVISION (CCTV)

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### Description

The closed circuit television (CCTV) system is used on orbit to support orbiter and payload activities with real time and recorded video that can be transmitted (downlinked) to the ground.

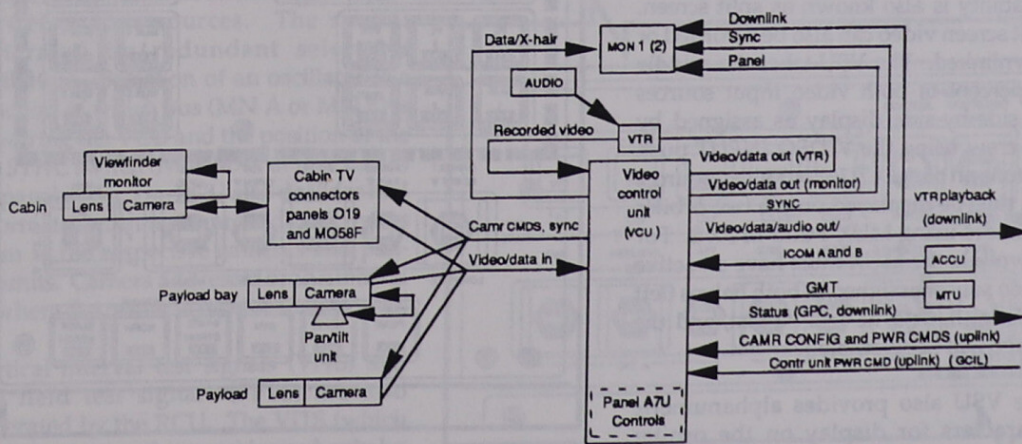
The system includes TV cameras, lenses, pan and tilt units (PTUs), video tape recorder (VTR), TV monitors, video processing components, and accessories. All the camera functions of the CCTV system can be controlled by the crew or, via uplink commands, by the Instrumentation and Communications Officer (INCO) in Mission Control.

With the rapid growth in "user-friendly" high quality consumer video components, 8 mm camcorders (camera and recorder in one unit) and VHS tape recorders are being used on Shuttle missions to augment the CCTV system or as part of detailed test objectives (DTOs).

All integral CCTV components operate on 28 V dc orbiter power (MN A or MN B, with exceptions noted in the equipment descriptions). All CCTV component circuit breakers are located on panel R15, except for the video tape recorder circuit breaker, which is located on the recorder. CCTV panel A7U push button lights are tested and controlled by the ANNUNCIATOR light switches on panel A6U.

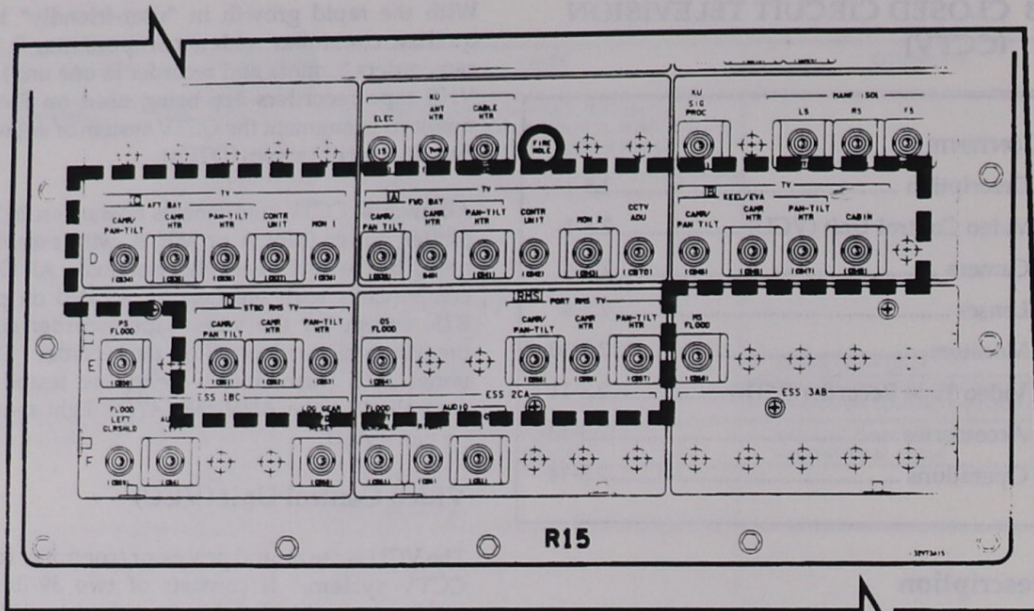
### Video Control Unit (VCU)

The VCU is the central processor/controller for the CCTV system. It consists of two 39-lb line-replaceable units: the video switching unit (VSU), and the remote control unit (RCU). Both units are located behind panels R17 and R18 on the aft flight deck. The units are cooled by forced air from cabin fans; however, neither component contains temperature sensors. The VSU contains a microprocessor that can accommodate up to 12 video sources and eight video outputs in accordance with push button commands from the A7U panel or from Mission Control. An input may be connected to a single output or multiple outputs (with the exception of multiplex (MUX)), but each



CCTV System Overview



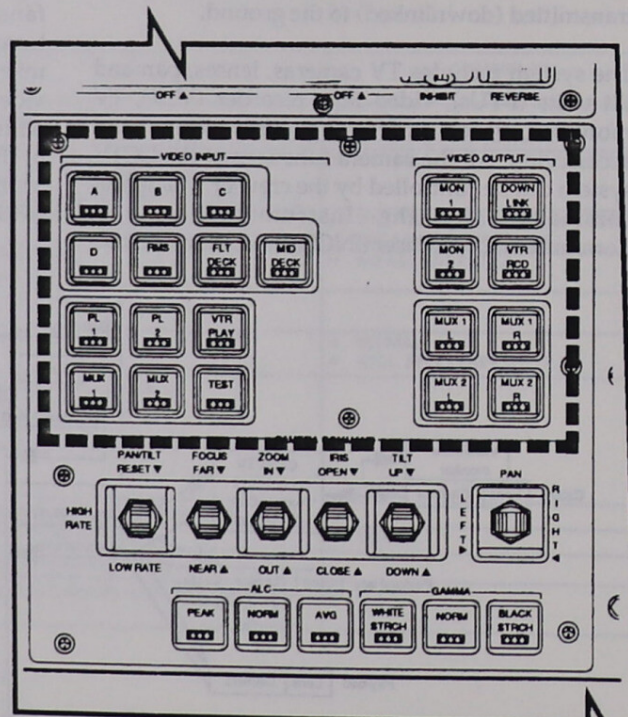


CCTV Circuit Breakers on Panel R15

output can accommodate only a single input. When the CCTV system is powered down, all video configurations (output/input assignments) are lost.

Because of the number of video sources that are desired at the same time, the VSU incorporates the capability to simultaneously display two video inputs (MUX) on a single monitor. This capability is also known as split screen. Split screen video can also be recorded or downlinked. The VSU takes the middle 50 percent of both video input sources for side-by-side display as assigned by the crew using the VIDEO INPUT push buttons on panel A7U. Four video sources can thus be displayed on the two orbiter monitors using MUX 1 and MUX 2. For downlink, the MUX must have an active video source assigned to both halves (left and right), or sync will be lost, and the image will be scrambled.

The VSU also provides alphanumeric characters for display on the orbiter monitors. The characters provide



VIDEO INPUT and OUTPUT Push Buttons on Panel A7U

crewmembers with camera identification, PTU angles, and camera temperature. (The temperature is only of the camera displayed and is only displayed when any powered camera's temperature exceeds 45° C.) Camera configuration and temperature are interleaved into the video signal. The VSU strips this information and displays it on the monitor if camera data is selected. The overtemp signal is also routed to Mission Control. The data stripping function can be inhibited by selection of the asynchronous mode on the INCO's console.

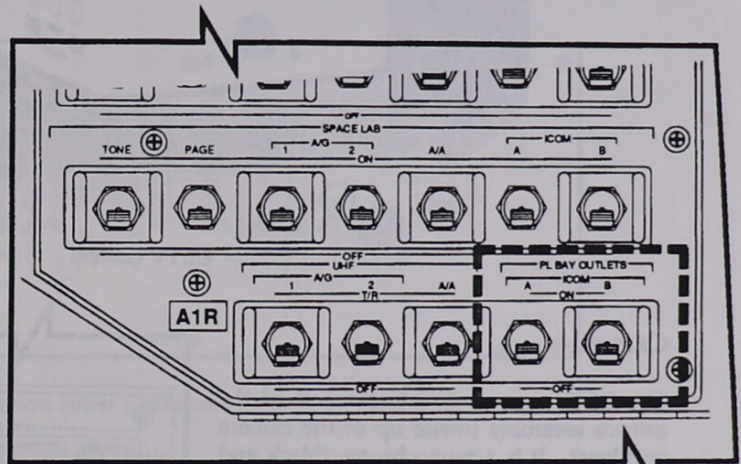
test pattern, is used by the crew to adjust the brightness and contrast of the onboard monitors. The FFTS is also often selected for downlink prior to or after video downlinks.

Within the RCU are a large number of latching relays that provide 28 V dc discrete outputs to the various panel A7U lights and flags, camera cue lights, payload bay cameras (as power logic), and the pulse code modulation master unit (PCMMU), via OF4 multiplexer/demultiplexer (MDM).

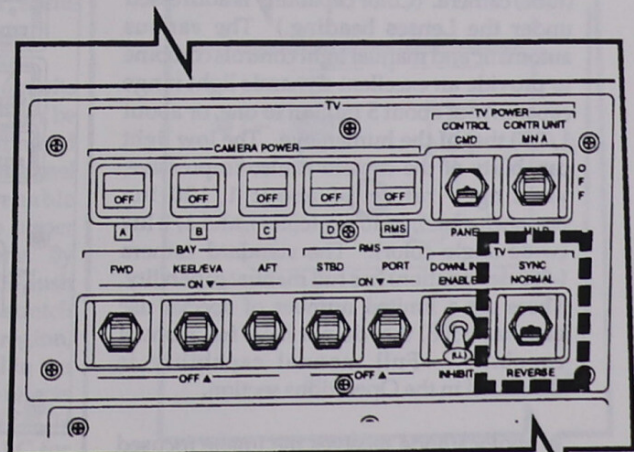
The VSU can also digitize voice from the orbiter audio system and interleave it with downlinked video for "lip sync." (The audio functions will be disabled if the *PL BAY OUTLETS ICOM A/B* switches on panel A1R are both OFF.) Greenwich Mean Time (GMT), provided by the orbiter's master timing unit, is also inserted into unused video lines by the VSU for aid in locating specific segments of mission video.

The remote control unit (RCU) generates the common time base (sync) to which all the CCTV components are slaved. Exceptions are the orbiter interim VTR, camcorders, and DTO VTRs. Slaving the components to the RCU sync eliminates momentary loss of usable imagery when switching between video sources. The sync is generated by redundant selectable oscillators. Selection of an oscillator is a function of which bus (MN A or MN B) is powering the VCU and the position of the *TV SYNC* switch (*NORMAL* or *REVERSE*) on panel A7U. The RCU also decodes and reformats incoming commands and routes them to the respective cameras and pan-tilt units. Camera addresses are a function of where the cameras receive their power.

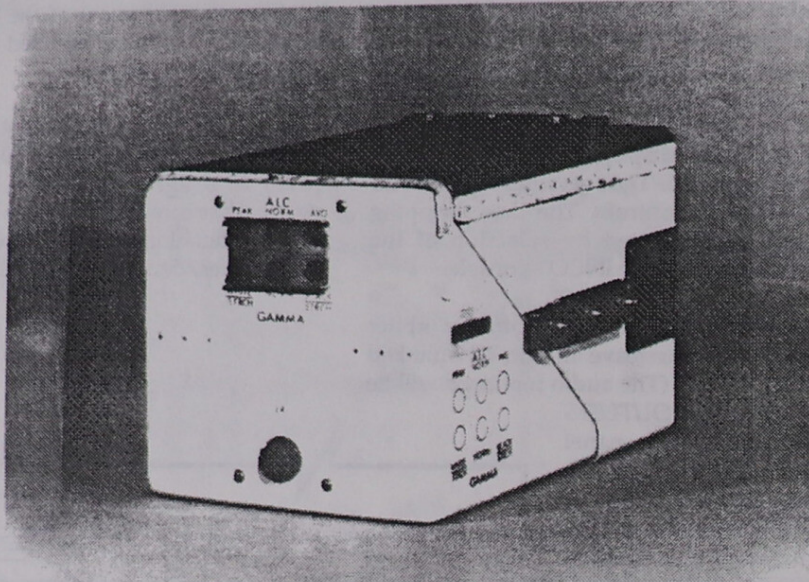
Vertical interval test signals (VITS) and full field test signals (FFTS) are also generated by the RCU. The VITS (which is transparent to the crew) is used only by ground technicians, whereas the FFTS, or



PL BAY OUTLETS ICOM Switches on Panel A1R



TV SYNC Switch on Panel A7U .

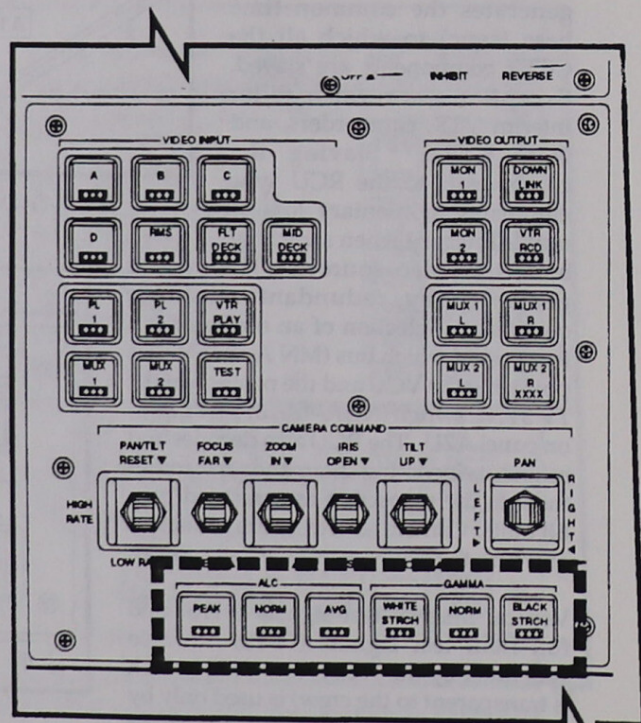


CCTV Camera

### Camera

The CCTV camera is the rear half of the camera assembly (made up of the camera and lens). It is a monochrome (black and white), silicon intensified target, vidicon (tube) camera. (Color capability is addressed under the Lenses heading.) The various automatic and manual light controls combine to provide an excellent dynamic light range capability of about 5 million to one, or about 1/200 that of the human eye. The low light capability of the camera is also impressive, yielding a rating of about 1/100 lux (monochrome), 1/10 lux (color), and 1/2 lux (wide angle color). The standard camera (-508 designation) has full manual capability. There are a limited number of special use cameras (-506) that do not have full manual capability. Full manual capability is discussed in the Operations section.

A photocathode receives the image focused by the camera lens and converts the visual image into an electron image, which is then



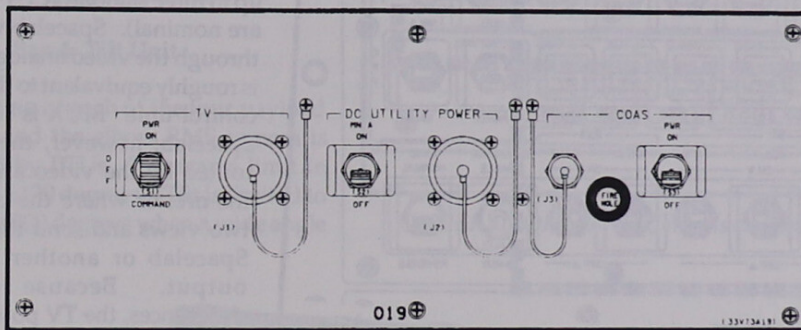
ALC and GAMMA Push Buttons on Panel A7U

focused on the silicon target. When an electron beam scans the rear of the target, variations in the instantaneous current experienced by the target are fed as "raw video" to a video processor, which provides amplification, sync insertion, and wave shaping. An automatic gain control (AGC) circuit adjusts the video amplifier gain in an attempt to maintain a constant peak signal level.

The camera also incorporates automatic light control (ALC) circuitry that controls the silicon intensified target high voltage supply, further optimizing target voltage response. Crewmember inputs using the ALC push buttons on panel A7U (or on the rear of the camera) can shift the camera's dynamic range from neutral (NORM push button), toward the black

CCTV cameras operate on 28 V dc (MN A, MN B, or MN C) but require both a power "ON" command and +28 V power input for powerup. Cabin camera power is located adjacent to the CCTV power connectors on panels O19 and MO58F. Payload bay/RMS cameras are powered from the CAMERA POWER switches on panel A7U. All cameras, except the two RMS cameras, may be operated simultaneously. Selecting the wrist (end effector) camera powers off the elbow camera and vice versa.

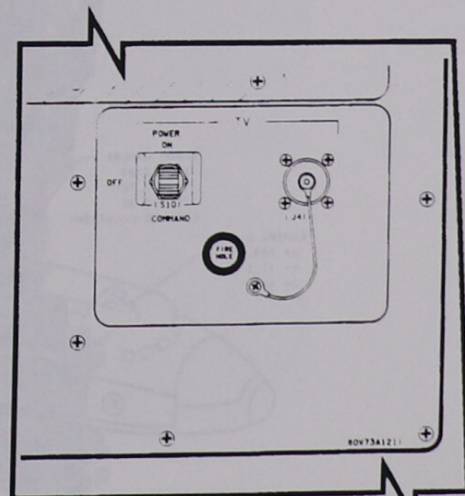
Currently five to seven CCTV cameras are flown: one in the crew cabin, four in the payload bay corners, and two on the RMS. Up to three additional cameras can be mounted (no pan-tilt unit) along



Cabin Camera Power Connectors/Controls on Panel O19

spectrum (AVG push button), or toward the white spectrum (PEAK push button). ALC also controls the lens iris in automatic operation for scene brightness.

There are also several automatic corrective circuits within the camera. One of these, gamma, can be manipulated if required. Crewmember command inputs using the GAMMA push buttons on panel A7U (or on the rear of the camera) enable optimization of gray-scale response in the upper and lower brightness regions of a given scene. By selecting the BLACK STRCH or WHITE STRCH push buttons on panel A7U, the crew is able to stretch (improve) the camera's response in one region, which results in compression (loss) of detail in the other region. The NORM position (nominal) selects a neutral environment. Either of the two STRCH push buttons can also be used to disable ALC for manual operations (see Operations).



Cabin Camera Power Connectors/Controls on Panel MO58F

2. SYSTEMS  
2.3 Closed Circuit Television

the orbiter's keel to aid in payload deployment and reberthing, although one alone has proven sufficient. Keel camera video is accessed via the VIDEO INPUT PL (payload) push buttons on panel A7U. Keel cameras are powered from a standard switch panel.

All CCTV cameras are identical (excluding thermal cover and upper surface radiator). On STS 41B, the EVA crew retrieved a faulty payload bay camera (including the lens and pan-tilt unit). They exchanged it with a functioning cabin camera and, on a subsequent EVA, reinstalled the assembly.

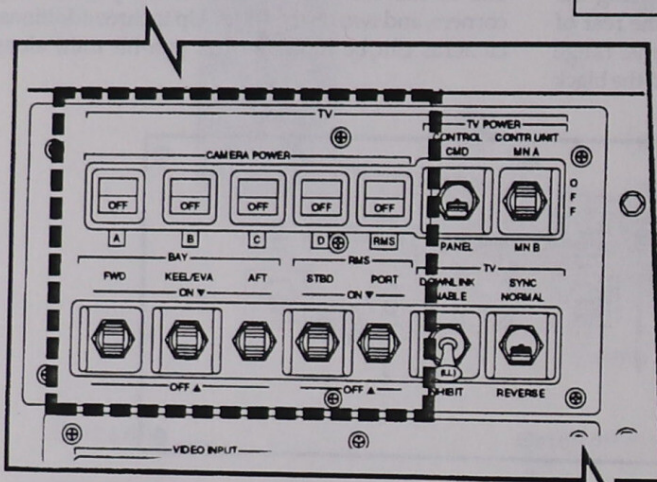
Payload bay/RMS cameras use two internal 13 watt foil heaters to keep the cameras above 0° C (32° F) when the cameras are not in operation. Power to the heaters comes from MN A, MN B, or MN C circuit breakers on panel R15.

**CAUTION**

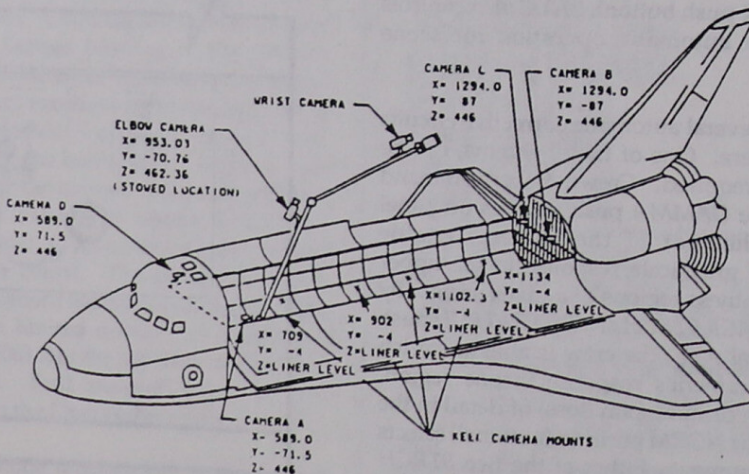
Never leave a payload bay camera in a manual mode (either semi- or full) while in direct sunlight or any bright light. Damage to the camera will result.

**Spacelab**

The Spacelab module has provisions for up to three standard CCTV cameras (two are nominal). Spacelab video is routed through the video analog switch, which is roughly equivalent to the orbiter video control unit. MUX is not available in Spacelab; however, the video can be routed by the video analog switch to the orbiter where the crew can MUX two views and send them back to the Spacelab or another orbiter video output. Because of hardware differences, the TV power cables used in the module are not interchangeable with their orbiter counterparts.



CAMERA POWER Switches and Talkbacks on Panel A7U



Payload Bay CCTV Camera Location

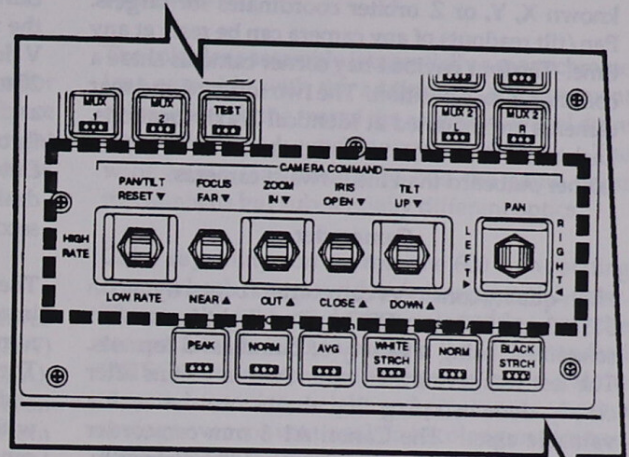
### EMU TV

The EMU TV is a solid state miniature color camera mounted in a housing that can be attached to the EMU helmet. The camera provides real-time scenes of the approximate perspective of the EVA crewmember. A dual lens assembly (normal and closeup) is available to the crewmember via a switch on the helmet. The camera operates on eight lithium batteries that give it about 6 hours of operation. The camera transmits its image to the orbiter S-band FM antennas, which route the image to the EMU TV receiver mounted in the middeck. This component processes the signal for compatibility with the orbiter CCTV system and feeds it to the VCU via a CCTV system and feeds it to the VCU via a TV video cable connected to the middeck TV power connector (panel MO58F).

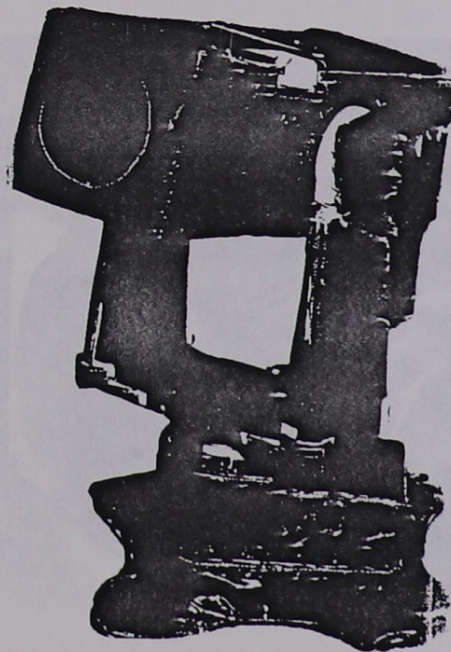
### Pan & Tilt Unit

Remote pointing of each of the four payload bay cameras and the elbow RMS camera is accomplished by PTUs. The travel limit in pan and tilt is  $\pm 170$  degrees. (Tilt is limited to a maximum of 300 degrees when a wide angle

lens assembly is installed). The pan and tilt movements are initiated with the PAN and TILT switches on panel A7U. A camera may be panned and tilted at the same time. The rate of pan/tilt is controlled by the PAN/TILT switch, which provides HIGH RATE (12 degrees/sec) or LOW RATE (1.2 degrees/sec) operation. Drive force is provided by two identical stepper motors (pan and tilt) connected



CAMERA COMMAND Controls on Panel A7U



Pan/Tilt Unit with Camera and Thermal Blankets

through an 18:1 reduction gear head and a friction clutch to the pan/tilt mechanism. The PTUs are thermally protected by a blanket and dual heaters. The PTU is also thermally coupled to the camera.

The crew can point the cameras with considerable accuracy by using the alphanumeric pan/tilt readouts available on the CCTV monitors and known X, Y, or Z orbiter coordinates for targets. Pan/tilt readouts of any camera can be reset at any time. The four payload bay corner cameras share a common Z axis position. The two forward and rear cameras are mounted at identical X axis locations. Each of the aft cameras is mounted about 17 inches farther outboard than the forward cameras.

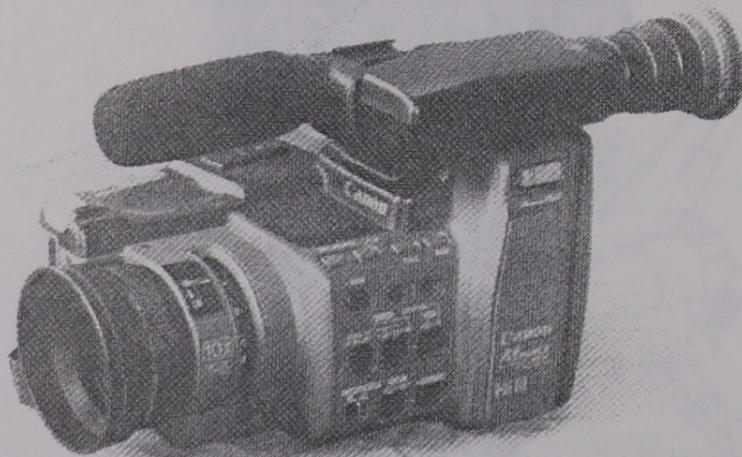
#### Camcorder

High-quality consumer camcorders began flying on STS-30 in 1989 as a DTO. Five flight tests were scheduled, using a variety of brands and formats. The test was terminated after three missions after clearly demonstrating that the camcorder was a valuable asset. The Canon A1 8 mm camcorder was selected for operational use in 1990. Presently, the Mark II version is being flown. As camcorders

evolve and mature, new models will be evaluated for flight. In 1991, a decision was made to delete one CCTV camera from the nominal flight stowage and replace it with the 8 mm camcorder (augmented with a wide angle conversion lens).

The A1 Mark II is a 3.3 lb Hi-Band National Television Standards Committee (NTSC) color 8 mm camcorder operating on a 6 V dc battery or through the video interface unit-C (VIU-C) from orbiter 28 V dc power (MNC). Recording time on a battery is 20 to 40 minutes (depending on the use of autofocus and power zoom). The camera has automatic through-the-lens focus, exposure, and color balance. Date and/or time can be recorded in the image, if desired, and shutter speeds up to 1/10,000 of a second can be selected (1/60 sec nominal).

The 8 to 80 mm f/1.4 macro zoom lens projects the image onto a 1/2 inch CCD chip. The camera's minimum light level for a usable image is 4 lux. The 8 mm cassette (slightly larger than a standard audio cassette) offers 2 hours of recorded video with stereo sound. The camera, or recorder video, can be downlinked through the VIU-C like a CCTV camera. Audio downlink is not yet available.



*Canon A1 Mark II Hi-Band 8 mm Camcorder*

Standard air-to-ground is normally used for audio with camcorder operations, or audio is dubbed over recorded video using orbiter audio. With a 0.5 diopter wide angle conversion lens, the camcorder provides a field-of-view very near that of the wide-angle lens cabin camera it has replaced. Since the camera is not integral to the CCTV system, only the crew can operate the camcorder.

#### New Cameras

General Electric has designed a new three chip color camera and a black and white model for the Space Shuttle. Some development problems and tight budgets have slowed the introduction of the new cameras originally slated for flight in 1992.

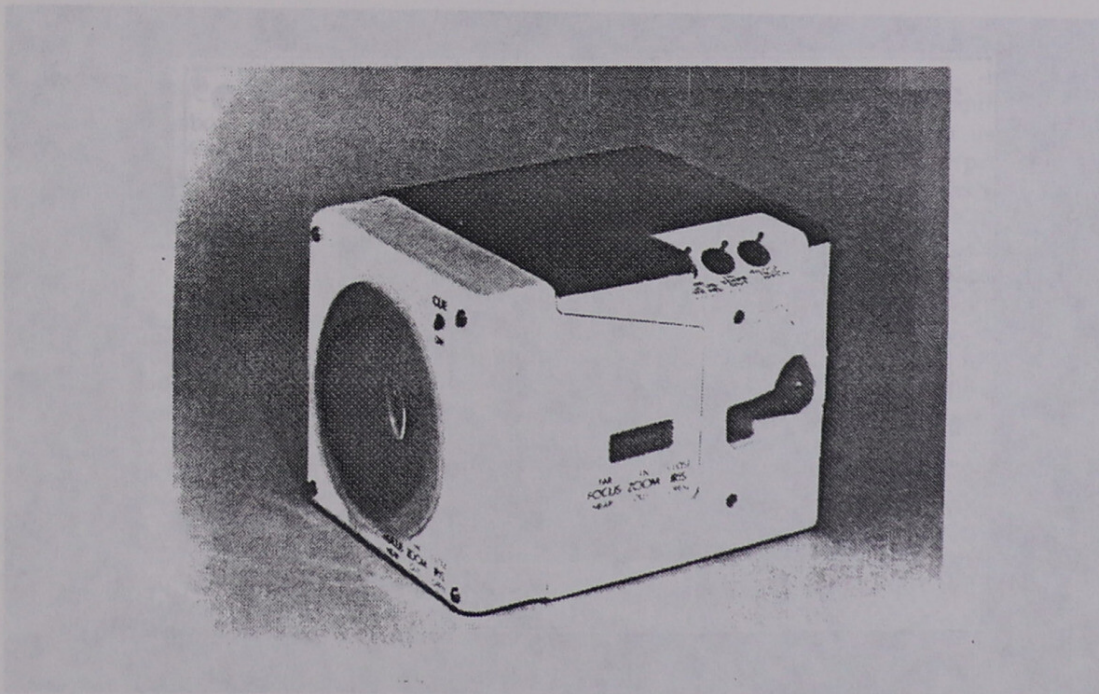
#### Lenses

The orbiter CCTV camera can be fitted with three possible lens assemblies: (1) monochrome (B&W) lens assembly (MLA), (2) color lens assembly (CLA), (3) wide angle color lens assembly (WLA). Each lens has remote zoom, focus, and iris control from the A7U panel and on the lens itself. The color and wide-angle lens assemblies also incorporate a small

red cue light on the front of the lens housing that illuminates when that camera's video is selected for downlink. Lens selection for a particular mission is determined 9 months to 1 year prior to flight, but can be changed if mission training points out such a need. (Changes to the forward cameras after major payloads are installed in the payload bay will likely require "mission success" rationale before approval.)

The color lens assembly is essentially a monochrome lens assembly with the addition of a six segment color wheel on the rear of the assembly, wheel drive mechanism, and synchronization circuitry. The wide-angle lens assembly has the same color mechanisms but substantially different optics.

Color capability comes from the 600 rpm rotating color wheel that provides field-sequential color. This method of producing color video lost the competition in 1953 to become the U. S. standard (NTSC) but was selected for use in Apollo and the Shuttle due to size, weight, and power consumption savings over conventional three color gun cameras. Drawbacks to the system are the noise of the rotating



*CCTV Lens (Color/Monochrome Lens Assembly Model)*



Lens	Focal length (zoom)	Zoom ratio	Focus distance	F-stop (iris)
Monochrome	18mm to 108mm	6:1	2.5 ft to ∞	f1.6 to f16
Color	18mm to 108mm	6:1	2.5 ft to ∞	f1.6 to f16
Wide Angle	8.2mm to 25mm	3:1	2 ft to ∞	f3.5 to f22

Zoom	Focus	FOV (horizontal)	
		MLA & CLA	WLA
Out	Far	40.9°	83.3°
In	Far	6.6°	29.5°

*CCTV Lens Data*

wheel, degraded target motion rendition, reduction in low light capability, and the requirement for ground processing to produce a color image.

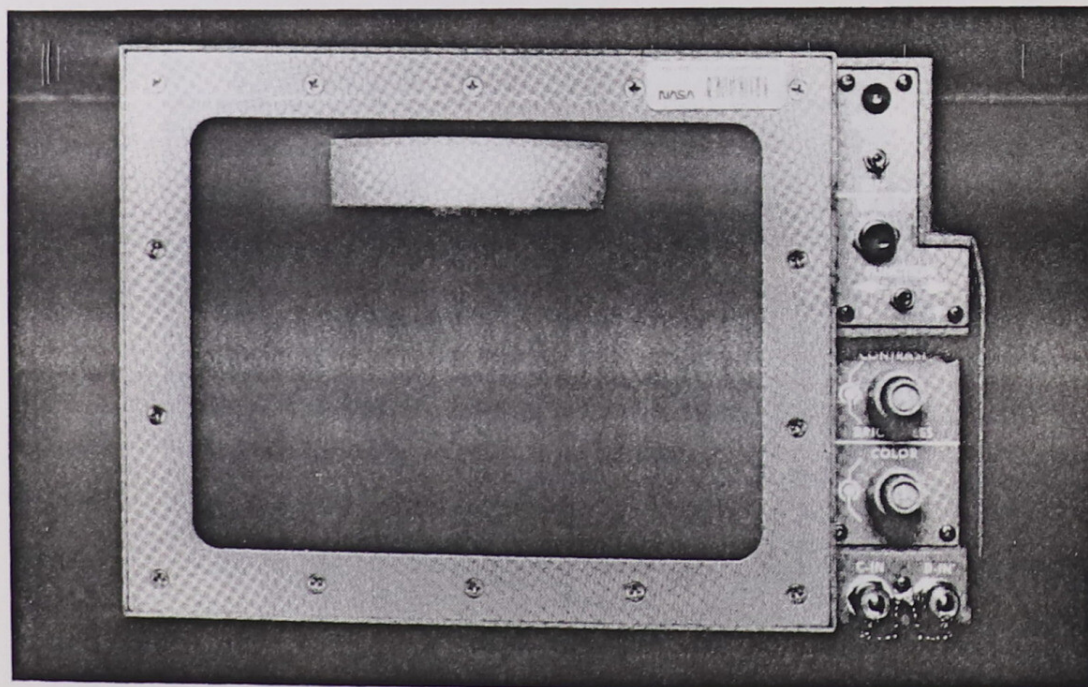
The lens zoom and focus controls require about 8 seconds to drive from one extreme to the other. (As with any zoom lens, the operator should zoom in on the subject before attempting to adjust the focus.) Continued activation of the zoom or focus after a limit is reached will not harm the mechanism. (A clicking sound is not unusual.)

## Monitors

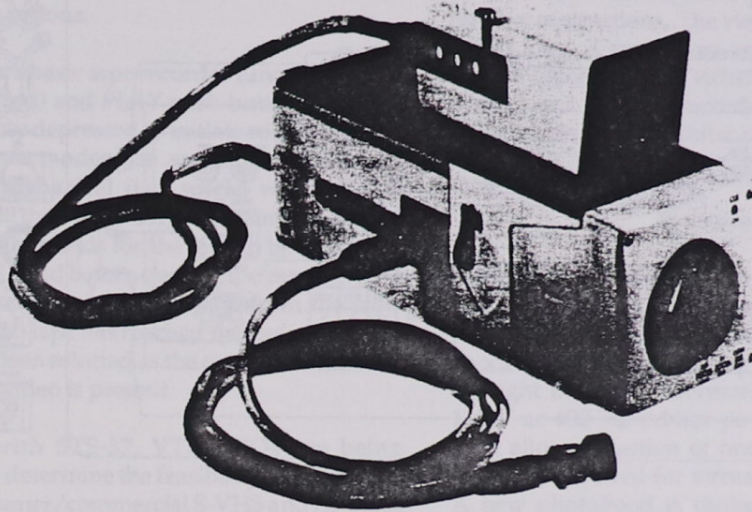
Beginning with STS-44, new color monitors have been added to the CCTV system for all subsequent flights (with the exception of STS 42). Information about the old B&W monitors may be found in the July 1988 CCTV Workbook or the Shuttle Flight Operations Manual Vol 4D (out of print). The orbiter also has a small B&W viewfinder monitor to aid the crew when the camera is used on the middeck.

### Color Monitors

Two color 10-inch diagonal monitors are mounted on the right side of the aft flight deck panel. They allow the crew to verify video scene requirements, picture quality, payload and RMS operations, rendezvous operations, and VTR playback. The monitors (#1-top, #2-bottom) can accommodate FSC, NTSC, or monochrome video inputs. The only crew action normally required is to turn the monitors on and ensure the controls (*BRIGHTNESS*, *CONTRAST*, *COLOR*, *TINT*) are in their detents. With all the controls in their detents, both monitors will have the identical response to the same input.



*CCTV Color Monitor*



*CCTV Viewfinder Monitor Mounted on Camera*

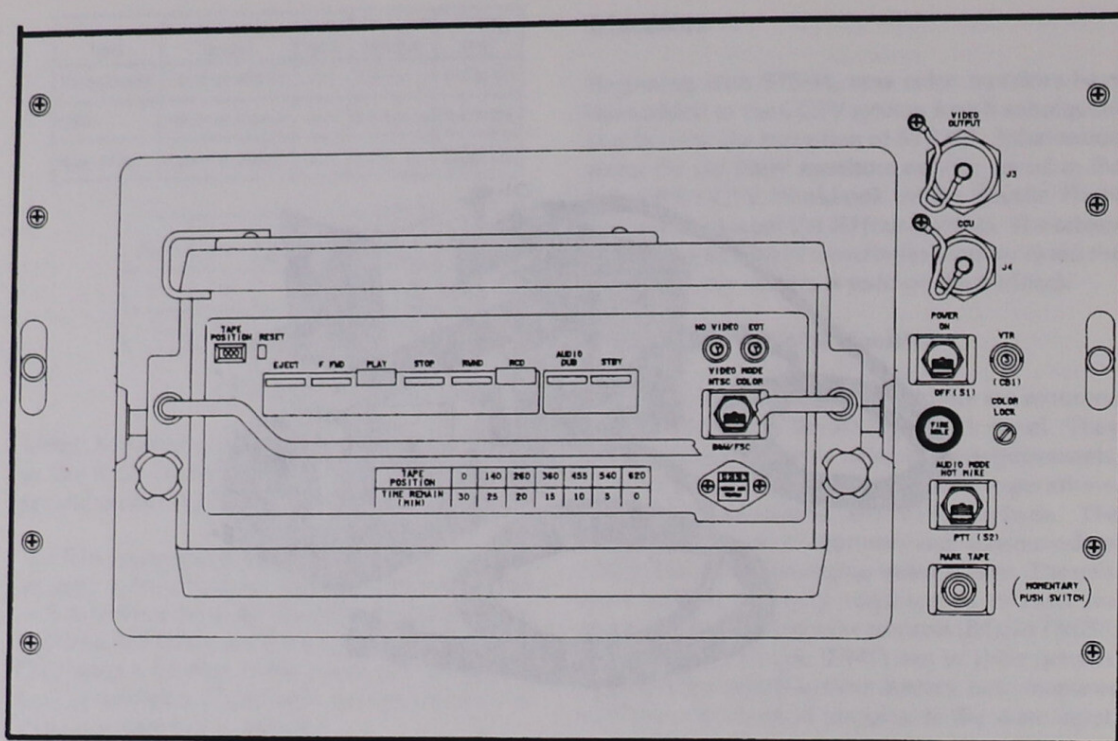
Each monitor has a menu of functions (e.g., alphanumeric camera data, internal or external sync, crosshair, FSC/NTSC/MONO) that will be displayed for about 10 seconds when the monitor is powered on. A push button redisplay the menu, as required, and a toggle switch enables selections within the menu. Two BNC connectors provide additional (balanced) video inputs to each of the monitors.

#### **Viewfinder Monitor**

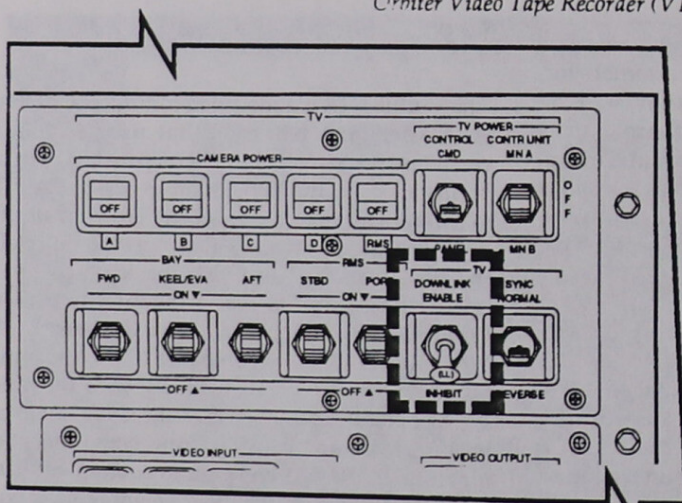
The viewfinder monitor is a 3.8 inch diagonal B & W miniature portable TV monitor that can be connected via a power cable to the cabin CCTV camera. The monitor can be mounted on the top or side of the camera facing forward or aft. It may also be used up to 9 feet (cable length) away from the camera. The monitor has brightness and contrast controls along with a *PEAK* switch that alters the high frequency response of the video amplifier.

#### **Video Tape Recorder (VTR)**

The Shuttle VTR is a modified commercial 3/4 inch (U-Matic) tape recorder that uses 30-minute cassettes. It is usually located on panel R11 but can be installed on the left station as well. The VTR (also known as the interim or IVTR) provides the capability to record video from any of the selectable input sources and can play back video to the onboard monitors and/or downlink to Mission Control. Downlink is enabled or inhibited by the *TV DOWNLINK* switch on panel A7U. Audio may also be recorded simultaneously with the video signal, or it can be dubbed onto the tape. Audio can be inserted into the VTR crew communication umbilical (CCU) via crew audio equipment (hand held microphone or very lightweight headset with a headset interface unit), or it may be fed from a vehicle CCU through the audio distribution system/video tape recorder (ADS/VTR) cable.



Orbiter Video Tape Recorder (VTR)



TV DOWNLINK Switch on Panel A7U

Up to four VTRs have been flown when required. When more than one VTR is flown, a variant of the standard VTR (OAST VTR) supplements the nominal unit. Also, when multiple VTRs are flown or when the VTR is located on the left station, A7U panel VTR functions will be altered.

The VTR can only be operated by the crew. Since the VTR was not originally a part of the CCTV system, its signal is not synchronized by the VCU. Consequently, any time the VTR is played into the CCTV system, the VCU will incorrectly interpret noise in the video line reserved for camera temperature as an actual camera overtemp with a corresponding C&W alert. VTR operation will also cause ALC and GAMMA push button lights on panel A7U to flash on and off. The camera overtemp C&W alert can be inhibited during VTR operations with a data processing entry listed on the VTR cue card. Inhibiting the overtemp detection system requires

periodic checks on each operating camera to ensure that they are within limits.

The VTR has no active cooling, though there is some conductive cooling. The crew has no way of monitoring the VTR's temperature, nor is there an

overtemp warning. After 4 hours continuous use, the VTR may reach its maximum allowable internal temperature of 120° F. If the VTR reaches 120° F, it will take approximately 4 hours to cool down to ambient cabin temperature. The VTR has been used for periods of 6 continuous hours with no heat-related malfunctions.

The VTR offers basic tape recorder functions. Both the *RCD* (record) and *PLAY* push buttons must be simultaneously depressed to initiate recording, and no fast search modes are available. The eject function is mechanical (i.e., works without VTR power). While the VTR is *ON*, crewmembers should allow up to 10 seconds for the tape to be unwound from the VTR head before ejecting the cassette. The VTR incorporates two lights that inform the crew when the video tape has reached the end, and when the VTR has been selected as the output destination, but no input video is present.

Beginning with STS-37, VTR DTOs are being conducted to determine the feasibility of using high quality, consumer/commercial S-VHS and Hi-Band 8 mm VTRs.

### Accessories

CCTV system accessories include the airborne digitizing unit (ADU), power cables, photo flood, multiuse mounts, arms, clamps, baseplate adapter, and light shades.

#### ADU

The ADU is a mission-specific video digitizer/encryptor used on DOD missions or whenever a secure television image is required. The unit essentially takes a snapshot of an incoming video signal, converts it from analog to digital, and stores it in a memory buffer. The output of the buffer can be encrypted before being downlinked via Ku-band (high/low) or S-band (FM/PM). The encrypted signal is routed to Mission Control, where it is processed in a secure facility and routed to designated video monitors. The Ku-band high data rate (which is not yet available) completes about ten frames per second. The Ku-band low and S-band FM modes require 2.5 seconds per frame. The S-band PM mode requires about 3 minutes per frame. The unit is mounted on panel R11 adjacent to the VTR.

### Power Cables

The cabin CCTV camera uses a 20 ft power cable that permits use of the camera on either cabin deck without switching power sources. A 10 ft cable can be manifested that is more practical for a limited number of situations. The viewfinder monitor cable is 9 ft long. Camcorders and DTO VTRs require specific cables to route video to and from the video control unit. The camcorder also requires a TV power cable if using orbiter power or routing video into the CCTV system.

### Photoflood

Whenever in-cabin video is done, light augmentation is recommended. The Shuttle photoflood (though not a true flood light) is an anodized aluminum housing containing two 14 watt daylight balanced fluorescent tubes operating on 115 V ac 400 Hz orbiter power. A switch on the light allows selection of one or both tubes. Both tubes are required for virtually all in-cabin scenes. A new photoflood is projected to fly on STS-48. The battery operated 35 watt light will operate for about 10 minutes on one Canon camcorder 6 V battery.

### Multiuse Mounts/Arms/Clamps and Baseplate Adapter

See *Photographic Equipment* subsection of Section 2.5.

### Light Shades

Cloth light shades are provided to prevent aft and left or right station lights from degrading video taken on the aft flight deck. Rigid light shades are also stowed for the aft and overhead windows. Forward windows have built-in accordion-type cloth shades that are highly recommended for most forward flight deck scenes.

### Closeup Lens

Also included in the orbiter CCTV accessories is a closeup lens set with three ganged closeup lenses for the wide-angle lens assembly. The three lenses (+1, +2, and +3 diopters) may be used individually or as a set (+6 diopters) for closeup work.

## Operations

After basic CCTV operations have been learned and practiced during crew training, operating the CCTV system utilizing the TV and VTR cue cards is quite straightforward. This section includes amplifying information along with the cue cards and checklist procedures. Camcorder operations are addressed in the Photo/TV Checklist. ADU operations are represented by the cue card only. Small but important differences exist between the Shuttle CCTV system and the various simulators and trainers. The cue card procedures will work for both the trainers and the flight vehicles.

### Monitors

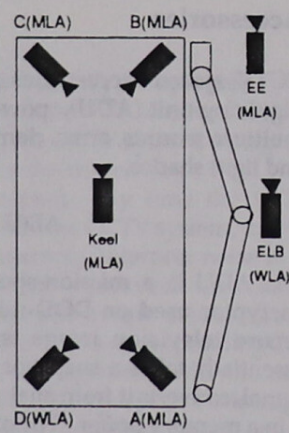
The CCTV color monitors require a short warmup time before the menu appears for about 10 seconds. Pressing the *SELECT* push button will redisplay

the menu for an additional 10 seconds. Normally, no changes are required since the monitor functions default to nominal ones each time the monitor is powered up. If a change is desired in a particular function, while the menu is displayed, the crewmember toggles to the desired function with the *FUNCTION* switch and chooses items within that function with the *SELECT* push button.

### Power Control

The *TV POWER CONTROL* switch on panel A7U must be in *PANEL* for the *TV POWER CONTR UNIT* switch to respond to the selection of *MN A* or *MN B*. After the power source is selected, the *TV POWER CONTROL* switch should normally be placed in *CMD* to allow Mission Control to control the cameras as coordinated with the crew or directed in the Photo/TV Checklist. CCTV cameras may now be powered.

TV	
<b>ACTIVATION</b>	TV DNLC - INH (DOD); ENA (NASA) MON 1(2) PWR - ON TV PWR - PNL, MNA, CMD TV CAMR PWR - ON Sel Test Pattern and adjust monitor(s)
<b>OPERATION</b>	MON 1(2) - Sel Camr Auto mode ALC - NORM; GAMMA - NORM
Semi Manual Mode	IRIS - OP/CL (√Two ALC Its-on)
Full Manual Mode (n/a -506 Camr)	IRIS - OP/CL GAMMA - WHITE STRCH/BLACK STRCH
Manual Modes off	Any ALC pb - push
<b>CAUTION</b> Do not leave Camrs unattended in Manual mode. Direct sunlight may damage Camr	
Split Screen	MON 1(2) - MUX 1(2) MUX 1L(2L) - Sel Camr; ALC - NORM; GAMMA - NORM MUX 1R(2R) - Sel Camr; ALC - NORM; GAMMA - NORM
<b>CAUTION</b> Dnlk not secure	
TV DNLC	Coordinate MCC Coverage Config A/G Audio (if reqd) On MCC go: DNLC - Sel Camr, MUX, or VTR
<b>DEACTIVATION</b>	Cabin CAMR IRIS - CL (8 sec) TV CAMR PWR - OFF TV PWR - PNL, OFF, CMD MON PWR (two) - OFF



All Camrs -508 unless otherwise designated

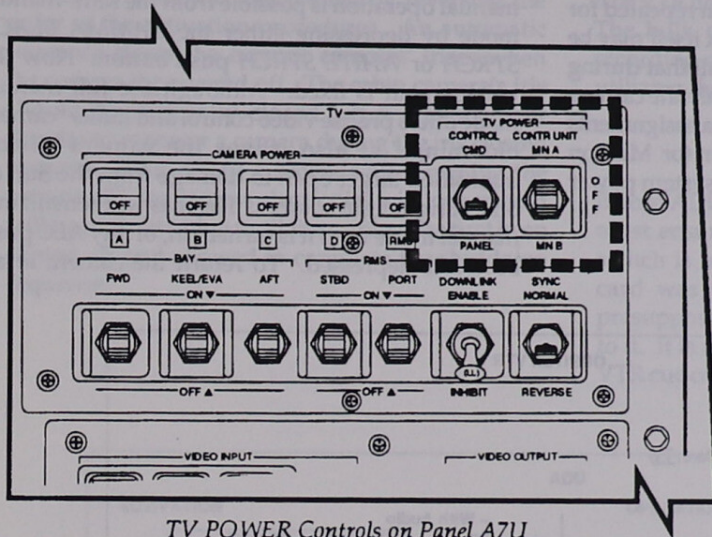
FWD  
↓

TV Cue Card from Photo/TV Checklist

When a payload bay/RMS camera is powered on, the iris is completely closed. It remains closed until any ALC push button is activated (NORM is nominal) or until the iris is manually opened (off-nominal method). After the iris is opened with the

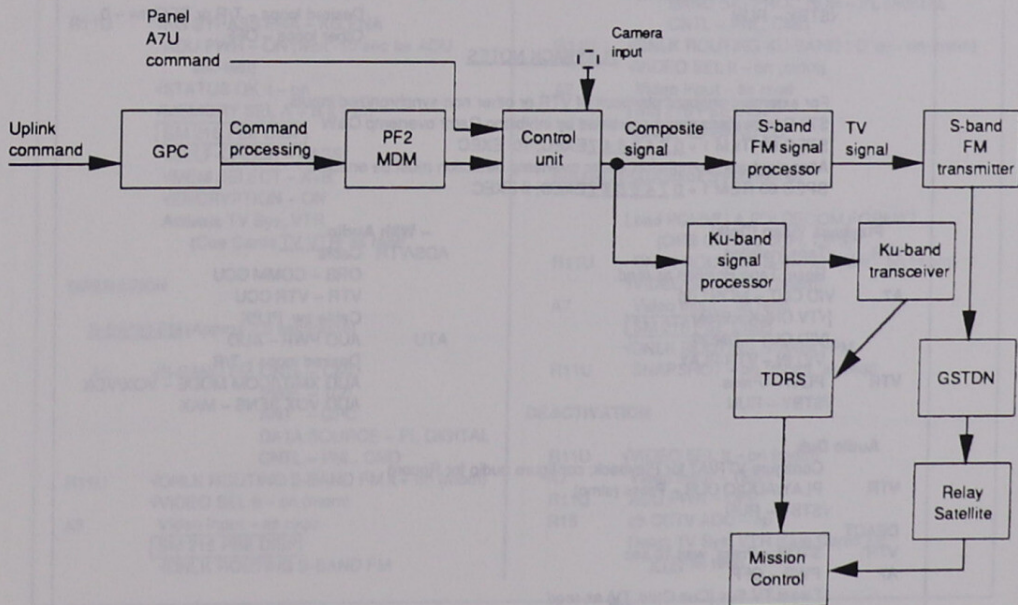
ALC NORM push button, the iris, ALC, and AGC circuits will automatically adjust the light entering the lens. To send video to the monitors (or any other output) the output source must be selected first and then the input.

PTU



TV POWER Controls on Panel A7U

If PTU information is required, camera data are selected on the monitors, and the cameras are calibrated. The calibration consists of pointing a camera at a target (usually another camera) along the X or Y axis and activating the PAN/TILT RESET switch (momentary) on panel A7U. The camera's PTU numbers go to 0, creating a known reference point that is valid until the camera is turned off. Periodic recalibration is required to maintain accuracy.



CCTV System Downlink Routing

### Split Screen

Split screen (MUX) is achieved by assigning a monitor to MUX 1 or 2, then selecting the output, *MUX 1* or *MUX 2 L* or *R*, and the video input desired on that side of the screen (e.g., camera A, flight deck camera, etc.). The process is then repeated for the other half of the screen. The MUX itself may be sent to the VTR or downlinked. Recall that during a MUX, if camera data are selected, only the camera ID will be displayed. The MUX camera assignments will not change until a crewmember (or Mission Control) changes them, or the CCTV system power is secured.

### Camera Modes

The semi-manual mode is entered when the iris is manually closed or opened. Depth of field may be altered, but ALC and AGC will readjust the picture to what it was in automatic (up to their limits). Full manual operation is possible from the semi-manual mode by depressing either the *GAMMA BLACK STRCH* or *WHITE STRCH* push button. Now the voltage gain is fixed. Although the full manual mode offers precise video control and limits "camera blooming," it also leaves the camera silicon intensified target open to damage from the Sun or other bright light sources. The lens will remain in a manual mode until it is turned off, or any *ALC* push button is depressed. To return the camera to an

**ORBITER VTR**

**ACTIVATION**

R1   √PL CAB – MNA(B)  
VTR   PWR – ON  
A7    Activate TV Sys (Cue Card, TV)

**OPERATION**

<p><b>Record Video</b></p> <p>VTR   √Tape installed           Tape Counter – Reset, as reqd A7    VID OUT – VTR RCD           VID IN – as reqd VTR   √NO VIDEO It – off           PLAY/RCD – Press (simo)           √STBY – RUN</p>	<p><b>– With Audio</b></p> <p>VTR    AUD MODE – HOT MIKE ADS/VTR Cable           ORB – COMM CCU           VTR – VTR CCU           Cable sw – RCD ATU    AUD PWR – AUD           Desired loops – T/R or REC, tw – 0           Other loops – OFF</p>
---	--

**PLAYBACK NOTES**

For extended onboard playback of VTR or other non-synchronized inputs, S76 Comm alerts may be avoided by inhibiting Camr overtemp C&W  
SPEC 60 ITEM 1 + 0 7 4 0 8 4 7 EXEC, 10 EXEC  
After playback, completion, Camr overtemp detection must be enabled,  
SPEC 60 ITEM 1 + 0 7 4 0 8 4 7 EXEC, 9 EXEC

<p><b>Playback Video [Dnlk]</b></p> <p>VTR   √Tape installed           Reset Tape Position as reqd A7    VID OUT – MON1 (2)           [√TV DNK – ENA]           [VID OUT – DNK]           VID IN – VTR PLAY VTR    PLAY – Press           √STBY – RUN</p>	<p><b>– With Audio</b></p> <p>ADS/VTR Cable           ORB – COMM CCU           VTR – VTR CCU           Cable sw PLBK ATU    AUD PWR – AUD           Desired loops – T/R           AUD XMIT/ICOM MODE – VOX/VOX           AUD VOX SENS – MAX</p>
---	---

**Audio Dub**

VTR    Configure VTR/A7 for Playback; configure audio for Record  
          PLAY/AUDIO DUB – Press (simo)  
          √STBY – RUN

DEACT

VTR    STOP – Press, wait 10 sec  
A7    PWR – OFF  
          Deact TV Sys (Cue Card, TV) as reqd

*ORBITER VTR Cue Card from Photo/TV Checklist*

automatic mode, the crewmember actuates any *ALC* push button. Nominal automatic mode is returned by actuation of the *ALC NORM* push button.

### Deactivation

The CCTV system is deactivated by reversing the order of the activation procedures. An automatic sequence closes the exterior cameras' irises when the camera is powered off. The cabin camera's iris should be manually closed. If a crewmember decides to repower a camera during the iris closing process (within about 4 seconds after turning the camera off), the camera electronics will lock up and will not permit video until the camera has first been turned off and allowed to complete the shutdown sequence.

### VTR

Use of the ORBITER VTR cue card also assumes familiarity with the equipment and its interface with the CCTV system. Although the recorder functions must be selected on the VTR, video assignments to it or VTR downlinks are accomplished at panel A7U. The bulk of the cue card procedures deal with recording and downlinking audio from the VTR utilizing the ADS/VTR cable.

### ADU

Before ADU operations are to be initiated, the crew must ensure that the panel A7U *TV DOWNLINK* switch is in the *INHIBIT* position. The ADU cue card was written for the unit's first flight and presupposes that the crew has had limited exposure to it. It is necessary to use the TV, and perhaps the VTR cue card, in conjunction with ADU operations.

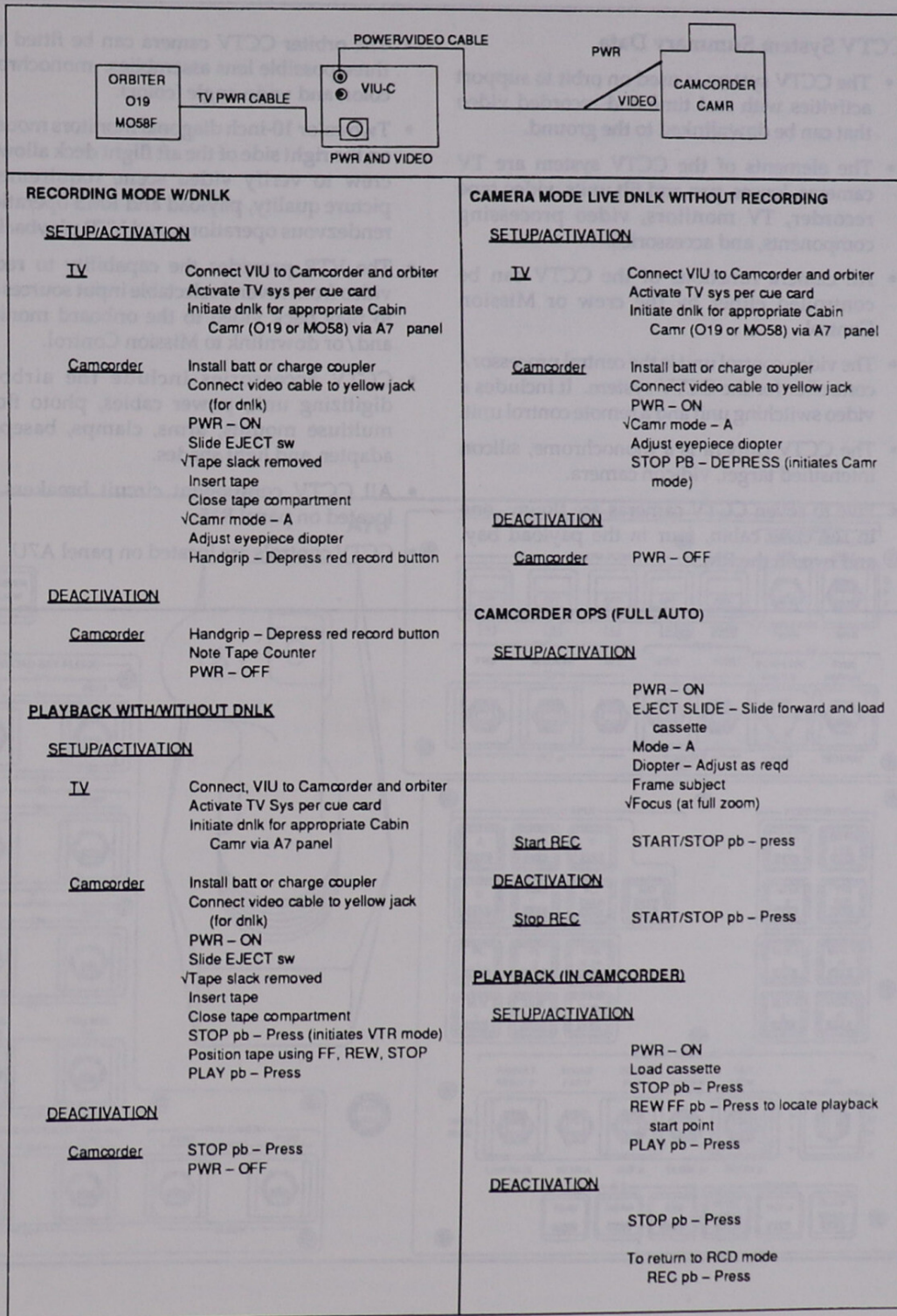
ACTIVATION		ADU	
<div style="border: 1px solid black; padding: 5px; width: fit-content; margin: 0 auto;"> <p><b>CAUTION</b> Ensure A7 DNK sw - INH for secure ops</p> </div>			
R15	cb CCTV ADU - cl	<b>OPERATION (Cont)</b>	
R11U	√KG BYPASS ENA - KG ENA ADU PWR - ON (wait -10 sec for ADU self-test) √STATUS OK lt - on √MEMORY SEL A + B lt - on <span style="border: 1px solid black; padding: 2px;">SM 215 PSE DISP</span> √SELF-CHECK - PASS √MEM SELECT - A+B √ENCRYPTION - ON Activate TV Sys, VTR (Cue Cards <u>TV</u> , <u>VTR</u> as reqd)	<b>KU-BAND LO</b> (Approx 2.5 sec/frame)	
<b>OPERATION</b>		Perform KU-BD DEPLOY & ACTIVATION (ORB OPS)	
<b>S-BAND FM</b> (Approx 2.5 sec/frame)		A1	√KU CNTL - CMD BAND SIG PROC HDR - PL DIGITAL CNTL - PNL, CMD
A1	√S-BAND FM CNTL - CMD PWR - 1(2) ANT - GPC DATA SOURCE - PL DIGITAL CNTL - PNL, CMD	R11U	√DNK ROUTING KU-BAND LO lt - on (mom) √VIDEO SEL lt - on (mom)
R11U	√DNK ROUTING S-BAND FM lt - on (mom) √VIDEO SEL lt - on (mom)	A7	Video Input - as reqd <span style="border: 1px solid black; padding: 2px;">SM 215 PSE DISP</span> √DNK KU-BAND LO
A7	Video Input - as reqd <span style="border: 1px solid black; padding: 2px;">SM 215 PSE DISP</span> √DNK ROUTING S-BAND FM	<b>S-BAND PM</b> (Approx 3 min/frame)	
		Load PCMMU & PDI DECOM FORMAT (ORB OPS FS or PL OPS)	
		R11U	√DNK ROUTING S-BAND PM lt - on (mom) √VIDEO SEL lt - on (mom)
		A7	Video Input - as reqd <span style="border: 1px solid black; padding: 2px;">SM 215 PSE DISP</span> √DNK ROUTING S-BAND PM
		R11U	SNAPSHOT - on (mom), as reqd
		<b>DEACTIVATION</b>	
		R11U	√VIDEO SEL lt - on (mom)
		A7	Video Input - TEST
		R11U	ADU PWR - OFF
		R15	cb CCTV ADU - op Deact TV Sys, VTR (Cue Cards <u>TV</u> , <u>VTR</u> as reqd)

ORBITER ADU Cue Card from Photo/TV Checklist



### Camcorder

Camcorder operations require no CCTV interfaces unless the crew powers the camera from the VIU-C or feeds the video into the CCTV system for playback. Powering the camcorder with the VIU-C requires a TV power cable and the camcorder adapter cable. If the crew intends to route the camcorder video to the CCTV system, the RCA connector from the adapter cable must be inserted into the VIDEO OUT jack on the camcorder. Several minutes prior to initiating a camcorder downlink, the crew should inform Mission Control so that INCO and other technicians can condition the reception devices for the asynchronous NTSC signal. Otherwise, false overtemps will result, and GMT data will be inserted into the video. This appears as two horizontal lines pulsing across the image. Additionally, since the NTSC color signal does not require conversion, the "lip sync" delay factor must be changed.



**RECORDING MODE W/DNLK**

SETUP/ACTIVATION

**TV** Connect VIU to Camcorder and orbiter  
Activate TV sys per cue card  
Initiate dnlk for appropriate Cabin  
Camr (O19 or MO58) via A7 panel

**Camcorder** Install batt or charge coupler  
Connect video cable to yellow jack  
(for dnlk)  
PWR - ON  
Slide EJECT sw  
√Tape slack removed  
Insert tape  
Close tape compartment  
√Camr mode - A  
Adjust eyepiece diopter  
Handgrip - Depress red record button

DEACTIVATION

**Camcorder** Handgrip - Depress red record button  
Note Tape Counter  
PWR - OFF

**PLAYBACK WITH/WITHOUT DNLK**

SETUP/ACTIVATION

**TV** Connect, VIU to Camcorder and orbiter  
Activate TV Sys per cue card  
Initiate dnlk for appropriate Cabin  
Camr via A7 panel

**Camcorder** Install batt or charge coupler  
Connect video cable to yellow jack  
(for dnlk)  
PWR - ON  
Slide EJECT sw  
√Tape slack removed  
Insert tape  
Close tape compartment  
STOP pb - Press (initiates VTR mode)  
Position tape using FF, REW, STOP  
PLAY pb - Press

DEACTIVATION

**Camcorder** STOP pb - Press  
PWR - OFF

**CAMERA MODE LIVE DNLK WITHOUT RECORDING**

SETUP/ACTIVATION

**TV** Connect VIU to Camcorder and orbiter  
Activate TV sys per cue card  
Initiate dnlk for appropriate Cabin  
Camr (O19 or MO58) via A7 panel

**Camcorder** Install batt or charge coupler  
Connect video cable to yellow jack  
PWR - ON  
√Camr mode - A  
Adjust eyepiece diopter  
STOP PB - DEPRESS (initiates Camr mode)

DEACTIVATION

**Camcorder** PWR - OFF

**CAMCORDER OPS (FULL AUTO)**

SETUP/ACTIVATION

PWR - ON  
EJECT SLIDE - Slide forward and load  
cassette  
Mode - A  
Diopter - Adjust as reqd  
Frame subject  
√Focus (at full zoom)

**Start REC** START/STOP pb - press

DEACTIVATION

**Stop REC** START/STOP pb - Press

**PLAYBACK (IN CAMCORDER)**

SETUP/ACTIVATION

PWR - ON  
Load cassette  
STOP pb - Press  
REW FF pb - Press to locate playback  
start point  
PLAY pb - Press

DEACTIVATION

STOP pb - Press

To return to RCD mode  
REC pb - Press

Camcorder Procedures from Photo/TV Checklist

**CCTV System Summary Data**

- The CCTV system is used on orbit to support activities with real time and recorded video that can be downlinked to the ground.
- The elements of the CCTV system are TV cameras, lenses, pan and tilt units, video tape recorder, TV monitors, video processing components, and accessories.
- All camera functions of the CCTV can be controlled either by the crew or Mission Control.
- The video control unit is the central processor/controller for the CCTV system. It includes a video switching unit and a remote control unit.
- The CCTV camera is a monochrome, silicon intensified target, vidicon camera.
- Five to seven CCTV cameras are flown: one in the crew cabin, four in the payload bay, and two on the RMS.
- The orbiter CCTV camera can be fitted with three possible lens assemblies: monochrome, color, and wide-angle (color).
- Two color 10-inch diagonal monitors mounted on the right side of the aft flight deck allow the crew to verify video scene requirements, picture quality, payload and RMS operations, rendezvous operations, and VTR playback.
- The VTR provides the capability to record video from several selectable input sources and to play back video to the onboard monitors and/or downlink to Mission Control.
- CCTV accessories include the airborne digitizing unit, power cables, photo flood, multiuse mounts, arms, clamps, baseplate adapter, and light shades.
- All CCTV component circuit breakers are located on panel R15.
- CCTV controls are located on panel A7U.

2.4 COMMUNICATIONS

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Description ..... 2-4-1

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5-Band Frequency Modulation ..... 2-4-10

Auto-Dial System ..... 2-4-12

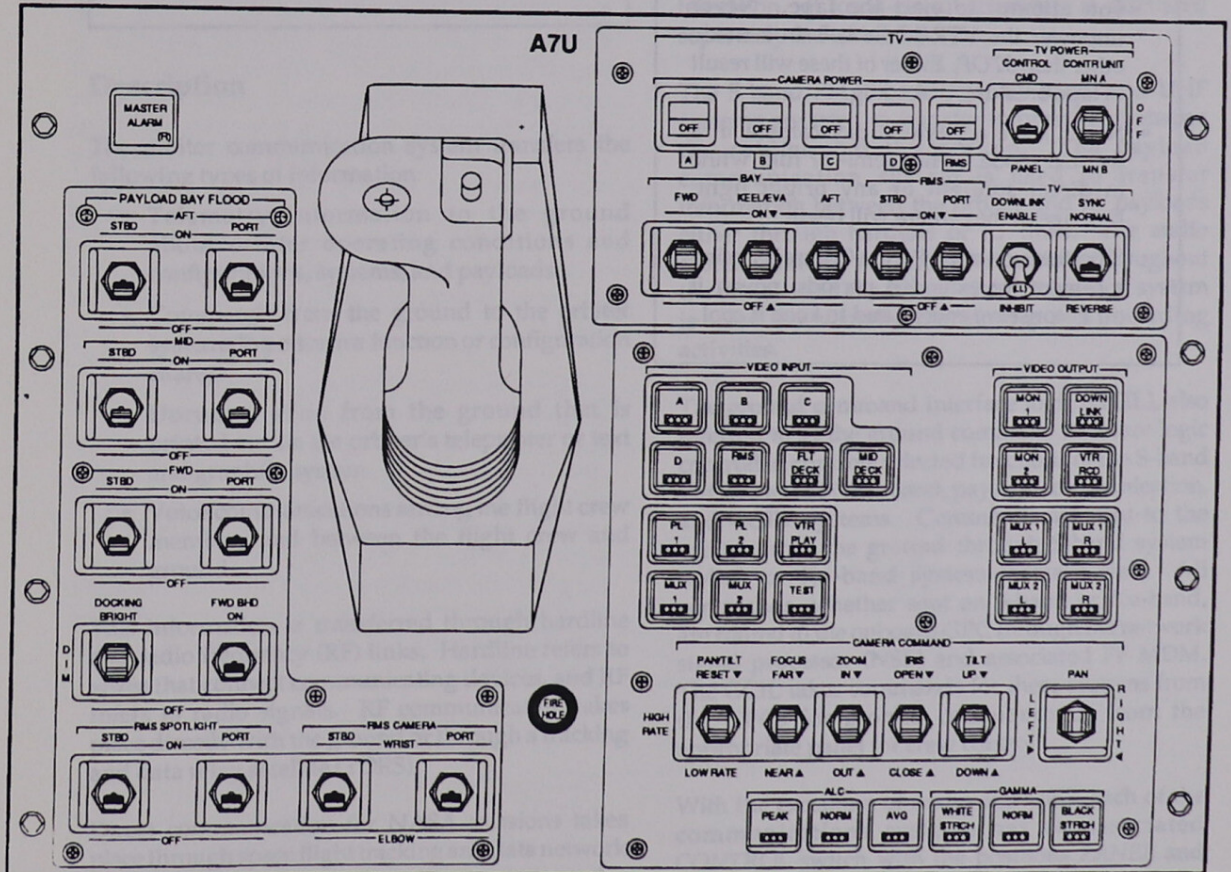
Payload Communication System ..... 2-4-20

High Frequency System ..... 2-4-25

Audio Display System ..... 2-4-25

Intercom System ..... 2-4-3

Test and Control System ..... 2-4-4



Panel A7U

### ***CCTV System Rules of Thumb***

- When the VCU is powered on, the crew must wait 10 seconds before any CCTV commands can be accepted. This time is used to initialize the VCU.
- Always wait at least 4 seconds after powering off a camera before powering it back on. This gives the iris enough time to fully close.
- Always wait at least 4 seconds after switching from the RMS wrist camera to the RMS elbow camera before switching back to wrist, and vice versa. This gives the iris enough time to fully close.
- When ejecting VTR tapes, always wait at least 10 seconds after selecting *STOP* before you attempt to eject the tape. Never unpower the VTR while it is in a mode other than *STOP*. Either of these will result in tape breaking or fouling.
- Never leave a payload bay camera in a manual mode (either semi- or full) while in direct sunlight or any bright light. Damage to the camera will result.
- If neither you nor Mission Control is using a camera for extended periods, power it off to conserve energy and to keep it cool.

## 2.4 COMMUNICATIONS

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### Description

The orbiter communication system transfers the following types of information:

- Telemetry information to the ground about orbiter operating conditions and configurations, systems, and payloads
- Commands from the ground to the orbiter systems to perform a function or configuration change
- Documentation from the ground that is printed out on the orbiter's teleprinter or text and graphics system
- Voice communications among the flight crew members and between the flight crew and ground.

This information is transferred through hardline and radio frequency (RF) links. Hardline refers to wires that connect communicating devices, and RF refers to radio signals. RF communication takes place directly with the ground or through a tracking and data relay satellite (TDRS).

Direct communication for NASA missions takes place through space flight tracking and data network (STDN) ground stations. For military missions, Air Force Satellite Control Facility (AFSCF) remote tracking station sites, also known as space-ground

link system (SGLS) ground stations, are used. Direct signals from the ground to the orbiter are referred to as uplinks, and signals from the orbiter to the ground are called downlinks.

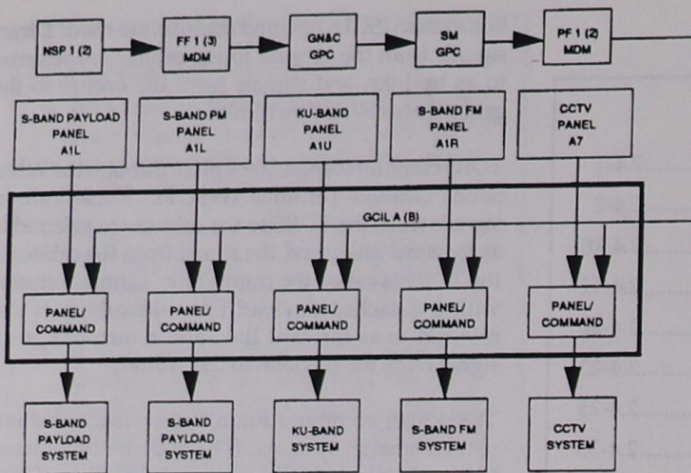
TDRS communication takes place through the White Sands Ground Terminal (WSGT). These indirect signals from the TDRS to the orbiter are referred to as forward links, and the signal from the orbiter to the TDRS is called the return link. Communication with a detached payload from the orbiter is also referred to as forward link, and return link is the signal from the payload to the orbiter.

The orbiter communication system is divided into several smaller systems: S-band phase modulation (PM), S-band frequency modulation (FM), Ku-band, ultrahigh frequency (UHF), payload communications, audio, and closed-circuit television. (Closed-circuit television is discussed separately in Section 2.3.)

The S-band FM, S-band PM, Ku-band, and UHF systems are used to transfer information between the orbiter and the ground. The payload communication system is used to transfer information between the orbiter and its payloads either through hardline or RF links. The audio systems transfer voice communications throughout the orbiter, and the closed-circuit television system is used for visually monitoring and recording activities.

The ground command interface logic (GCIL), also referred to as the ground command interface logic controller, controls selected functions of the S-band PM, S-band FM, Ku-band, payload communication, and CCTV systems. Commands are sent to the orbiter from the ground through S-band system uplink or Ku-band system forward link. All commands, whether sent on S-band or Ku-band, are routed to the onboard GPC through the network signal processor (NSP) and associated FF MDM. The GCIL takes commands for these systems from the GPCs for ground commands or from the appropriate panel for crew control.

With the exception of audio and UHF, each of the communications systems has an associated *CONTROL* switch with the positions *PANEL* and *CMD*. When the switch is set to *PANEL*, the system can be accessed by the crew using panel switches.



Ground Command Interface Logic

When the switch is set to *CMD*, control is by ground command via GCIL. The locations and operations of these switches are provided in the individual communications systems discussions that follow.

**NOTE**

Because of the large number of distinct elements of the Communications system, a separate Operations subsection is not included. Rather, this information is provided within the separate element discussions.

**S-Band Phase Modulation**

The S-band PM system provides two-way communication between the orbiter and the ground, either directly or through a relay satellite. It provides communication channels for five functions:

- Command channel: used to send commands from ground to orbiter.
- Voice channel(s): used for one-way and two-way voice communications between ground and orbiter. One of the two voice channels can be used for teleprinter signals from ground to orbiter.
- Telemetry channel: carries real-time orbiter and payload operational telemetry data to ground.

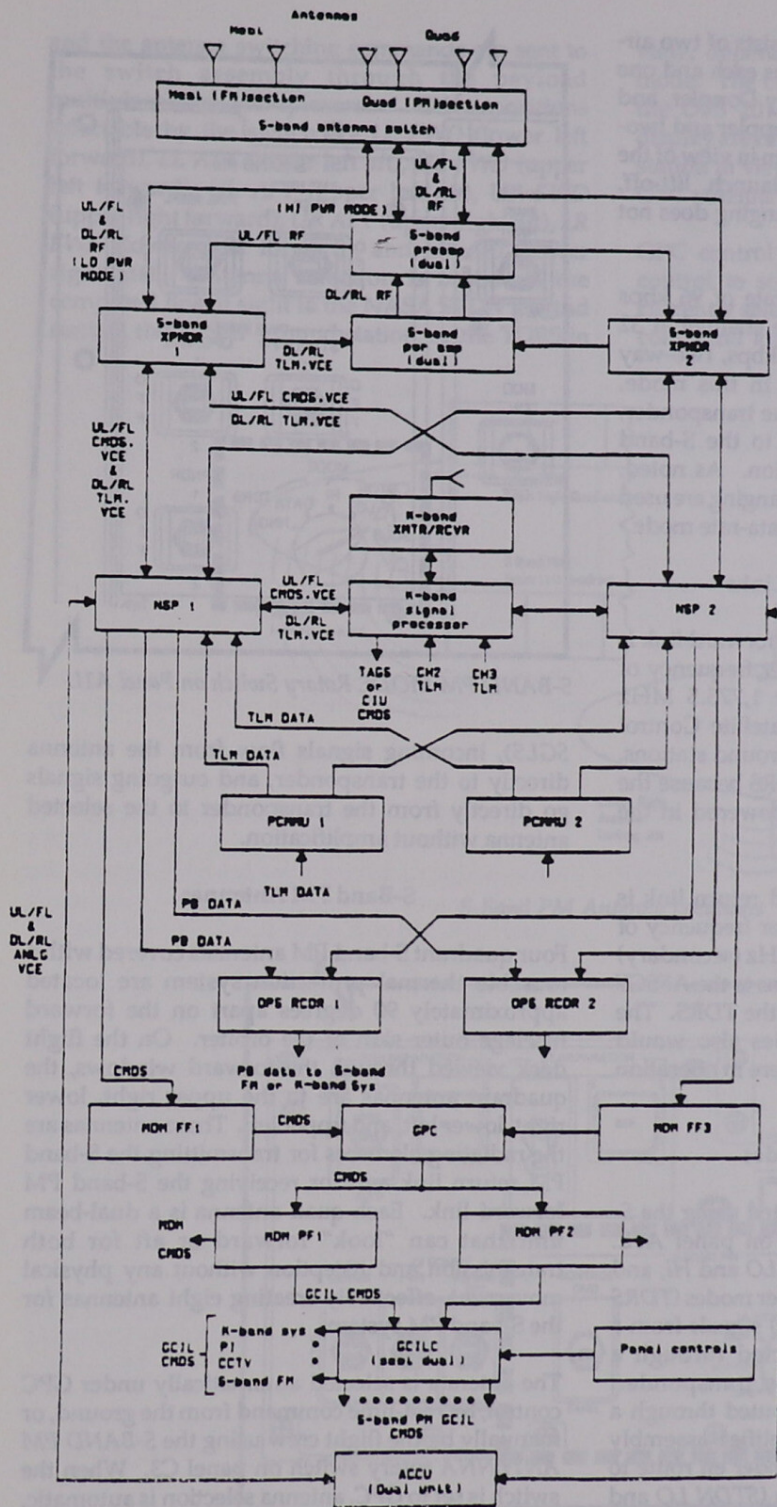
- Turnaround tone ranging channel: used to determine slant range from a known point to the orbiter. Tones are transmitted from the ground to the orbiter where they are "turned around" and transmitted back to ground from the orbiter on a coherent RF carrier. Slant range can be computed from net total two-way phase delay of the major tone for the "round trip."
- Two-way Doppler tracking: used to aid in tracking the orbiter. An RF carrier, of precisely known frequency, is transmitted to the orbiter.

A characteristic of RF signals in the S-band range is that "line-of-sight" must exist between transmitting and receiving antennas to permit communications. With the availability of the east and west TDRS, potential total S-band PM support time using direct and relay links will be as much as 80 percent of mission time. (For some missions, vehicle attitude constraints imposed by experiment requirements may cause the loss of portions of that potential support time because the required orbiter attitudes may at times be incompatible with orbiter S-band PM quad antenna patterns.)

A fully operational TDRS system provides east and west satellites that are both supported by the WSGT facility. The east and west satellites are approximately 130 degrees apart in geosynchronous orbits. In the S-band mode, the TDRS single access antenna is gimballed but does not automatically track the orbiter. It is sequentially commanded by the ground to follow the orbiter position. There is a set of zones of exclusion where the orbiter, operating at normal altitudes, will not be in line-of-sight with either satellite.

**S-Band Forward Link**

The S-band forward link operates through the STDN or TDRS. It is phase modulated on a center carrier frequency of either 2,106.4 MHz (primary) or 2,041.9 MHz (secondary) for NASA. The two frequencies would prevent interference if two users were in



S-Band PM System Interfaces and Data Flow

operation at the same time and place, since one user could select the high frequency, and the other could select the low frequency.

The forward link originates from Mission Control through the NASA STDN ground stations used for launch, lift-off, ascent, or landing, or through the WSGT via the TDRS system to the orbiter. The high data rate is 72 kilobits per second, consisting of two air-to-ground voice channels at 32 kbps each and one command channel at 8 kbps, two-way Doppler, and two-way tone ranging. The low data rate is 32 kbps, consisting of one air-to-ground voice channel at 24 kbps and one command channel of 8 kbps, two-way Doppler, and two-way ranging. The two-way ranging does not operate through the TDRS.

### S-Band Return Link

The S-band return link operates through the STDN or TDRS. It is phase modulated on a center carrier frequency of 2,287.5 MHz (primary) or 2,217.5 MHz (secondary) for NASA. The two frequencies prevent interference if two users are in operation at the same time and place.

The S-band PM return link can originate from one of two S-band PM transponders aboard the orbiter, each of which can use one frequency, but not both at the same time. The link transmits the data through the NASA STDN ground stations used for launch, lift-off, ascent, or landing, or through the TDRS and TDRS system via the WSGT to Mission Control.



The high data rate of 192 kbps consists of two air-to-ground voice channels at 32 kbps each and one telemetry link of 128 kbps, two-way Doppler, and two-way ranging. The two-way Doppler and two-way ranging are operative only when in view of the NASA STDN ground stations at launch, lift-off, ascent, or landing. The two-way ranging does not operate with the TDRS.

The S-band return link low data rate of 96 kbps consists of one air-to-ground voice channel at 32 kbps and one telemetry link at 64 kbps, two-way Doppler, and two-way ranging. In this mode, incoming signals flow directly to the transponder, and outgoing signals go directly to the S-band antenna switch without amplification. As noted, the two-way Doppler and two-way ranging are used in the same manner as in the high-data-rate mode.

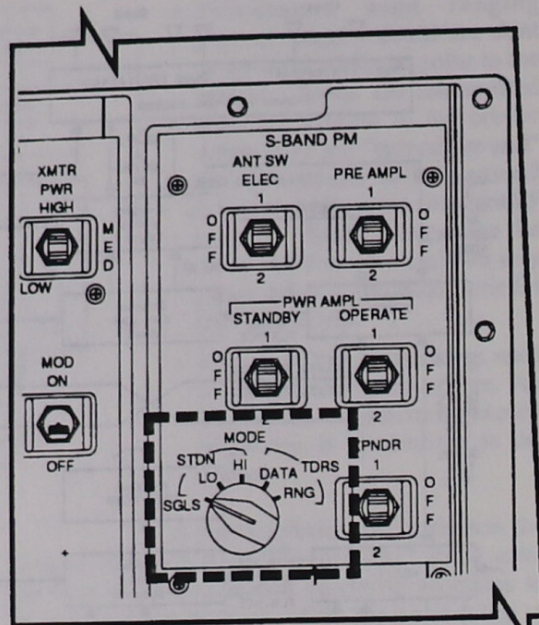
### Department of Defense Links

The Department of Defense S-band forward link is phase modulated on a center carrier frequency of either 1,831.8 MHz (primary) or 1,775.5 MHz (secondary) from the Air Force Satellite Control Facility (AFSCF) through its own ground stations. It does not operate through the TDRS because the S-band power amplifiers are not powered in the AFSCF mode.

The Department of Defense S-band return link is phase modulated on a center carrier frequency of 2,287.5 MHz (primary) or 2,217.5 MHz (secondary) through the Air Force ground stations to the AFSCF and also does not operate through the TDRS. The two S-band return link frequencies also would prevent interference if two users were in operation at the same time.

### S-Band PM Power Modes

S-band PM power modes are selected using the S-BAND PM MODE rotary switch on panel A1L. Selectable modes are SGLS, STDN LO and HI, and TDRS DATA and RNG. In high power modes (TDRS and STDN HI) incoming (received) signals from a quad-selected antenna are directed through a preamplifier before reaching the transponder. Outgoing (transmit) signals are routed through a power amplifier and the preamplifier assembly diplexer after leaving the transponder en route to an antenna. In low power modes (STDN LO and



S-BAND PM MODE Rotary Switch on Panel A1L

SGLS), incoming signals flow from the antenna directly to the transponder, and outgoing signals go directly from the transponder to the selected antenna without amplification.

### S-Band PM Antennas

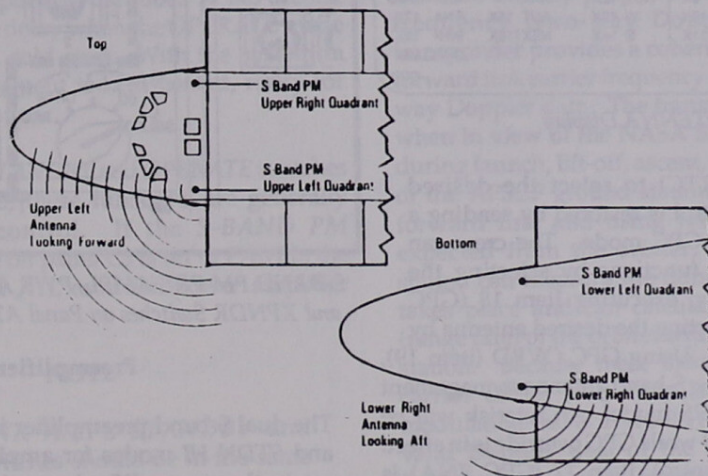
Four quadrant S-band PM antennas covered with a reusable thermal protection system are located approximately 90 degrees apart on the forward fuselage outer skin of the orbiter. On the flight deck viewed through the forward windows, the quadrant antennas are to the upper right, lower right, lower left, and upper left. These antennas are the radiating elements for transmitting the S-band PM return link and for receiving the S-band PM forward link. Each quad antenna is a dual-beam unit that can "look" forward or aft for both transmission and reception without any physical movement, effectively creating eight antennas for the S-band PM system.

The antenna is selected automatically under GPC control, by real-time command from the ground, or manually by the flight crew using the S-BAND PM ANTENNA rotary switch on panel C3. When the switch is set to GPC, antenna selection is automatic,

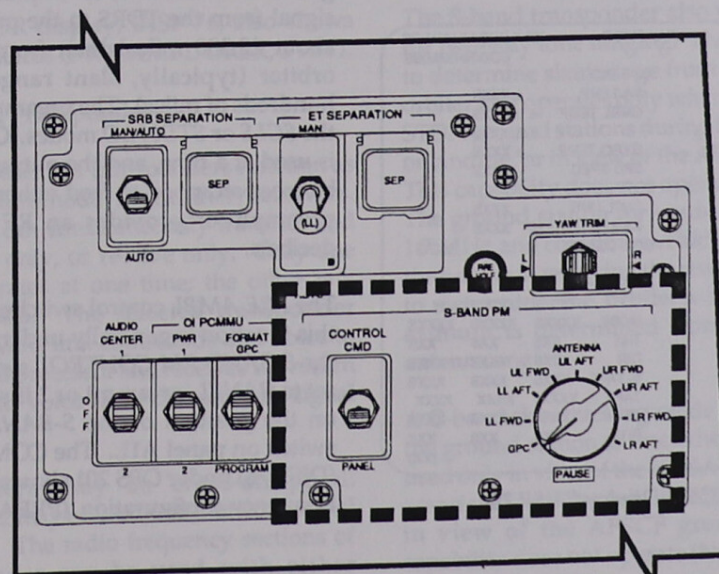
and the antenna switching commands are sent to the switch assembly through the payload multiplexers/demultiplexers. Other positions selectable by the switch are LL FWD (lower left forward), LL AFT (lower left aft), UL FWD (upper left forward), UL AFT (upper left aft), UR FWD (upper right forward), UR AFT (upper right aft), LR FWD (lower right forward), and LR AFT (lower right aft). Antenna selection is based on the computed line of sight to the NASA STDN ground station, the AFSCF ground station, or the TDRS in

view, depending on the orbiter communication mode. The current antenna selection is shown on the OPS 201 ANTENNA display. Also on the display are related items such as the S-band ground station in view, TDRS in line of sight, and whether GPC antenna selection is enabled or inhibited.

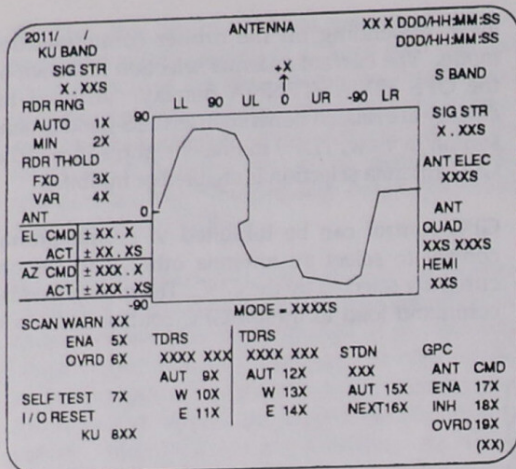
GPC control can be inhibited to permit ground control to select an antenna other than the one currently selected by the GPC. The ground sends a command load to inhibit GPC control and a real-



S-Band PM Antenna Locations

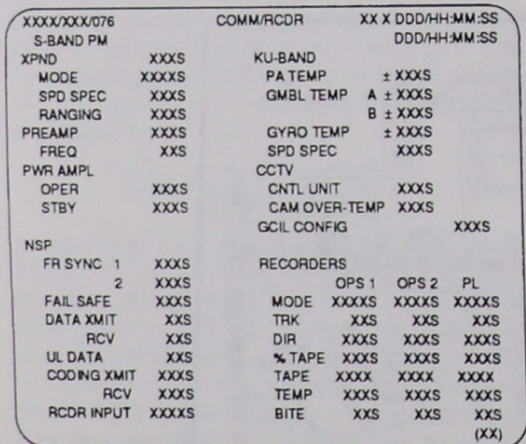


S-BAND PM System Switches on Panel C3

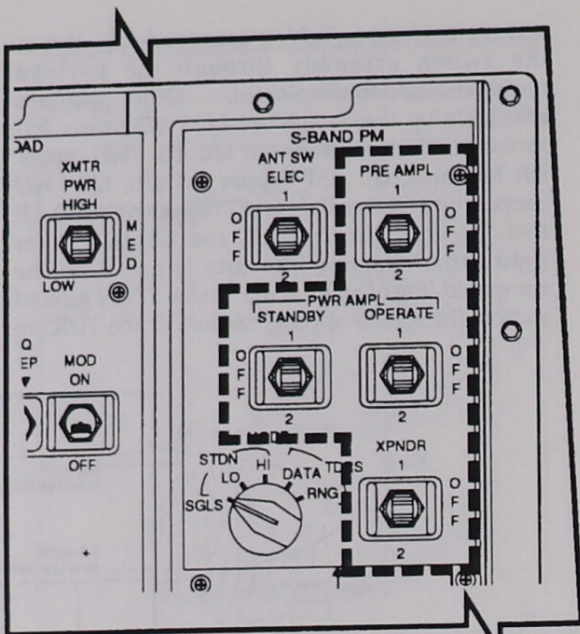


ANTENNA Display

time command (RTC) to select the desired antenna. GPC control is restored by sending a load to enable the GPC mode. The crew can perform the same functions by selecting the ANTENNA display, executing Item 18 (GPC INH), and then selecting the desired antenna by RTC via keyboard. Using GPC OVRD (item 19), the crew can force the S-band antenna management software to the TDRS mode. An asterisk will be displayed by item 19 while GPC override is in effect. To restore GPC control, item 17 (GPC ENA) is executed.



COMM/RCDR Display (DISP 76)



S-BAND PM PRE AMPL, PWR AMPL,  
and XPNDR Switches on Panel A1L

### Preamplifiers

The dual S-band preamplifier is used in the TDRS and STDN HI modes for amplification. In TDRS mode, the preamplifier is required full-time for the forward link radio frequency because of the much greater distance and, consequently, lower strength signal from the TDRS to the orbiter (minimum of about 22,300 miles) than from the STDN to the orbiter (typically, slant ranges are in the low hundreds of miles). The preamplifier is not used in the SGLS or STDN LO modes. One of the two units is used at a time, and the output of either unit can be cross-strapped to feed either transponder. The preamplifier provides an RF gain of about 25 decibels.

The PRE AMPL control switches are on panel A1L; this function is generally under ground control. If the S-BAND PM CONTROL switch on panel C3 is set to PANEL, preamp 1 or 2 is selected, depending on the position of the S-BAND PM PRE AMPL switch on panel A1L. The COMM/RCDR display (DISP 76) under OPS 201 shows preamp status and frequency configuration (PREAMP and FREQ).

### Power Amplifiers

The S-band power amplifiers provide selectable amplification of transponder RF output for *STDN HI* and *TDRS* operational modes. The nominal power gain is about 17 decibels. There are two power amplifiers; one is used at a time, and the input of either can be interconnected with the output of either transponder.

The power amplifiers use a traveling wave tube, which has a filament that must be warmed up before high voltage is applied to the tube. A 140-second timer provides the delay when the *OPERATE* mode is selected from a cold start. With the system in *STANDBY*, the filament is kept heated, ready for "instant on" operation.

The *PWR AMPL STANDBY* and *OPERATE* switches are on panel A1L; these functions are generally under ground control. If the *S-BAND PM CONTROL* switch on panel C3 is set to *PANEL*, the switches on panel A1L establish power amplifier configuration.

#### NOTE

Both the *PWR AMPL STANDBY* and *OPERATE* switches should be in the same position to avoid a reset of the 140-second timer when the standby system is selected.

The *COMM/RCDR* display, *DISP 76*, also shows power amplifier status (*PWR AMPL OPER, STBY*).

### Transponders

Two identical S-band PM transponders function as multipurpose, multimode transmitter/receivers. The transponder can simultaneously transmit and receive, transmit only, or receive only. Only one transponder operates at one time; the other is a redundant backup. The selected transponder transfers the forward link commands and voice to the network signal processor and receives the return link telemetry and voice from the network signal processor.

The transponders may be cross-strapped. Transponder 1 or 2 may be used with network signal processor 1 or 2. The radio frequency sections of either transponder can be used with either preamplifier and power amplifier 1 or 2.

The selected transponders also provide a coherent turnaround of the PM forward link and PM return two-way Doppler and two-way tone ranging signals. The two-way Doppler and two-way ranging signals are operative when the orbiter is in view of the NASA *STDN* ground stations at launch, lift-off, ascent, or landing, or when it is in view of the *AFSCF* ground stations. The two-way Doppler operates through the *TDRS*, but the two-way ranging does not.

Two-way Doppler is used by ground stations to track the orbiter. The S-band PM forward and return links are directly proportional to the forward link frequency (two-way Doppler). The S-band transponder provides a coherent turnaround of the forward link carrier frequency necessary for the two-way Doppler data. The transponder operates only when in view of the NASA *STDN* ground stations during launch, lift-off, ascent, or landing, or in view of the *AFSCF* ground stations. By measuring the forward link and using return link frequencies expected from the orbiter, the ground tracking station can measure the double Doppler shift that takes place and can calculate the radial velocity (range rate) of the orbiter with respect to the ground station. Because these links are PM, the S-band carrier center frequency is not affected by the modulating wave. It would be impossible to obtain valid Doppler data of the S-band carrier center frequency if it were affected by the modulating technique.

The S-band transponder also provides a subcarrier for two-way tone ranging. The transponder is used to determine slant range from a known point to the orbiter and operates only when in view of the NASA *STDN* ground stations during launch, lift-off, ascent, or landing, or in view of the *AFSCF* ground stations. This capability does not operate through the *TDRS*. The ground station forward-links ranging tones at 1.7 MHz and computes vehicle slant range from the time delay in receiving the return link 1.7-MHz tones to determine the orbiter's range. The orbiter's azimuth is determined from the ground station antenna angles.

A C-band skin-tracking mode also is provided from the ground station to track the orbiter and, again, is used only in view of the NASA *STDN* ground station associated with launch, lift-off, ascent or landing, or in view of the *AFSCF* ground stations. This capability does not operate through the *TDRS*.

The *S-BAND PM XPNDR* switch is located on panel A1L; this function is generally handled by ground command via the GCIL. If the *S-BAND PM CONTROL* switch on panel C3 is set to *PANEL*, the *XPNDR* selection is made from panel A1L.

The *COMM/RCDR* display, *DISP 76* in *OPS 201*, gives transponder status (*XPND* and *MODE*).

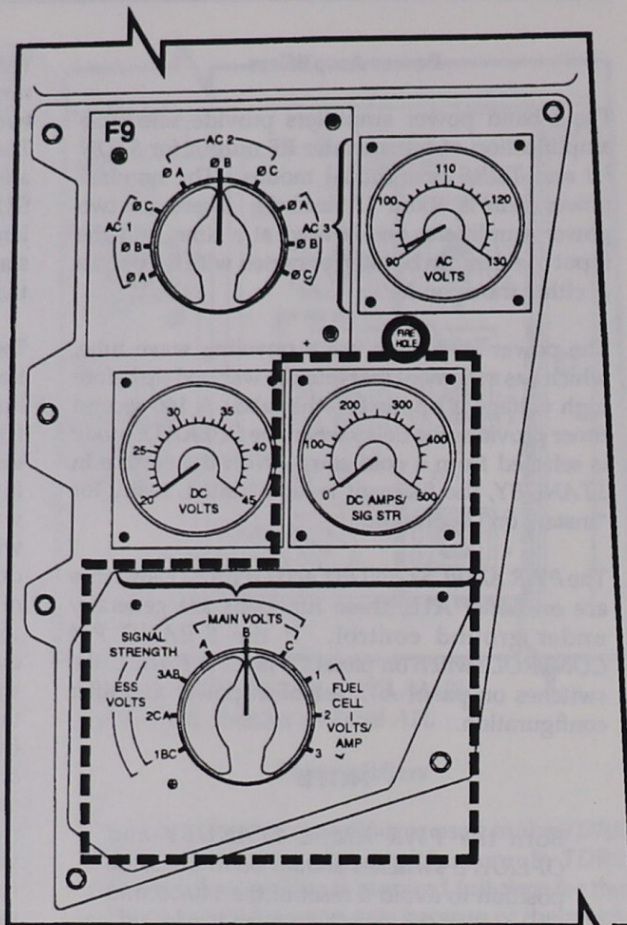
Received *S-band PM* RF signal strength is shown on the *DC AMPS/SIG STR* meter on panel F9 when the rotary switch below the meter is set to *SIGNAL STRENGTH*, and on the *SIGNAL STRENGTH* indicator on panel A1U when the switch to the left of the indicator is set to *S-BAND PM*. Signal strength is also shown on the *OPS 201 ANTENNA DISPLAY (SIG STR)*; however, during launch and landing, the display is not available.

**NOTE**

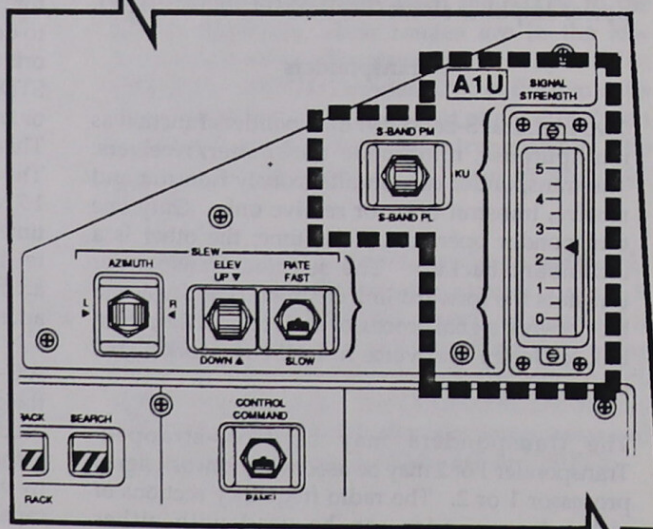
The panels F9 and A1U signal strength indications come from the transponder receiver, whereas *OPS 201 ANTENNA* display signal strength comes from *OI MDM 3* data.

**Network Signal Processors**

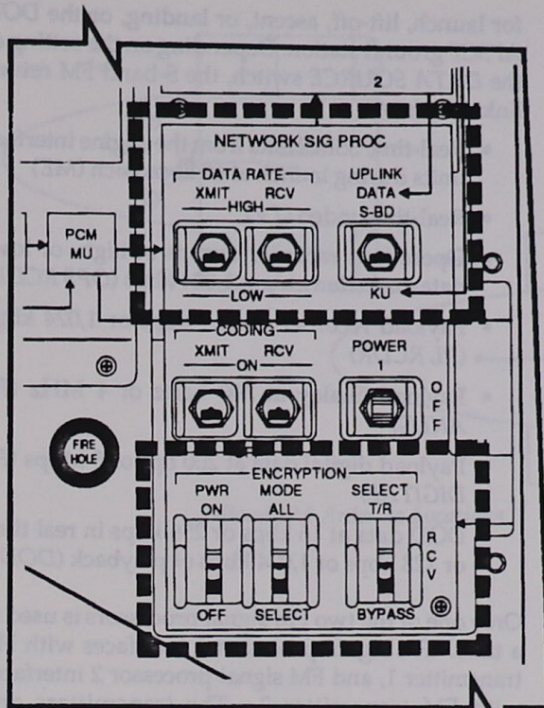
The two onboard network signal processors (NSPs) receive commands (forward link) and transmit telemetry data (return link) to the selected *S-band* transponder. Only one signal processor operates at a time; the other provides a redundant backup. The selected processor receives one or two analog voice channels from the onboard audio central control unit, depending on whether one (in the low-data-rate mode) or both (in the high-data-rate mode) of the air-to-ground channels are being used. Both voice channels are downlinked only if the NSP is high data rate on both forward and return links. It converts them to digital voice signals, time-division-multiplexes them with the telemetry from the pulse code modulation master unit,



*DC AMPS/SIG STR Meter and Rotary Switch on Panel F9*



*SIGNAL STRENGTH Indicator and Switch on Panel A1U*



NETWORK SIG PROC and ENCRYPTION Switches on Panel A1L

and sends the composite signal to the S-band PM transponder for transmission on the return link. On the forward S-band PM link, the NSP does just the reverse. It receives the composite signal from the S-band transponder and outputs it as either one or two analog voice signals to the audio central control unit. The composite forward link also has ground commands that the NSP decodes and sends through the FF MDMs (nominally NSP 1 to FF 1 and NSP 2 to FF 3) to the onboard computers, which route the commands to the intended onboard systems. The NSP data

routing/processing modes are controlled by the NETWORK SIG PROC switches on panel A1L.

**NOTE**

The NSP can also route return link (telemetry and voice) and receive forward link (commands and voice) via the Ku-band system.

**Communications Security**

Communications security (COMSEC) equipment provides the capability for encryption/decryption of operational data aboard the orbiter. The COMSEC equipment works with the NSPs to provide selectable transmit, receive, and record combinations under NSP mode control.

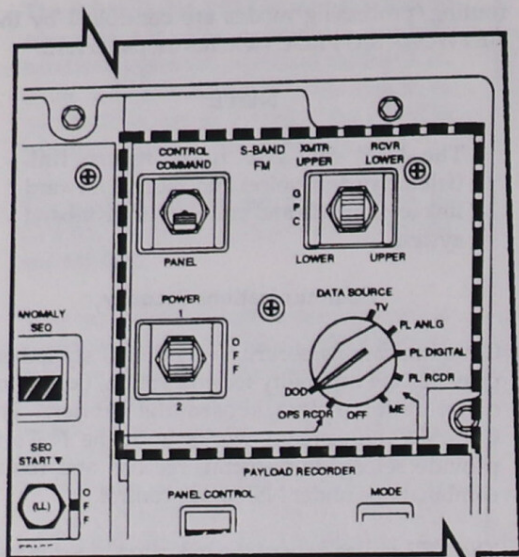
The NSP routes data of the indicated type through the COMSEC encryptor or decryptor as appropriate if "ENC" and gets the data back from the COMSEC line-replaceable unit encrypted/decrypted; if "CLR", the indicated data are handled directly by the NSP, and the COMSEC is bypassed.

The three ENCRYPTION switches on panel A1L provide power and routing control for encrypted data through the NSP.

*NSP/COMSEC Link Functions*

NSP ENCRYPTION Switch MODES		Link function
ALL (DOD)		Recorded Data Encrypted * Transmitted Data Encrypted Received Data Encrypted
SELECT (NASA)	T/R	Recorded Data Clear (unencrypted) ** Transmitted Data Encrypted Received Data Encrypted
	RCV	Recorded Data Clear (unencrypted) ** Transmitted Data Clear (unencrypted) Received Data Encrypted
	BYPASS	Recorded Data Clear (unencrypted) ** Transmitted Data Clear (unencrypted) Received Data Clear (unencrypted)

\* Data rate determined by NSP downlink DATA RATE switch.  
\*\* HDR only.



S-BAND FM Switches on Panel A1R

## S-Band Frequency Modulation

The S-band FM system cannot receive information; it is used to downlink data from up to seven different sources, one at a time, directly to the ground when there is a line of sight between the orbiter and STDN or Air Force ground stations. The S-band FM return link can originate from two S-band transmitters aboard the orbiter. Both transmitters are tuned to 2,250 MHz. The S-band FM return link can be transmitted simultaneously with the S-band PM return link to the STDN ground station or Mission Control or to the Air Force ground station. The S-band FM return link does not operate through the TDRS system.

Controls for the S-band FM system are on panel A1R. Control of status and configuration of electronic elements of the system can be either by panel switches or GCIL, depending on whether the *CONTROL* switch is set to *COMMAND* or *PANEL*. Set to *PANEL*, the switch allows rotary switch selection of the *DATA SOURCE*.

The FM signal processor is commanded to select one of seven sources for output to the S-band FM transmitter, which transmits it to the S-band FM return link through the STDN ground station used

for launch, lift-off, ascent, or landing, or the DOD AFSCF ground station. Depending on the setting of the *DATA SOURCE* switch, the S-band FM return link transfers:

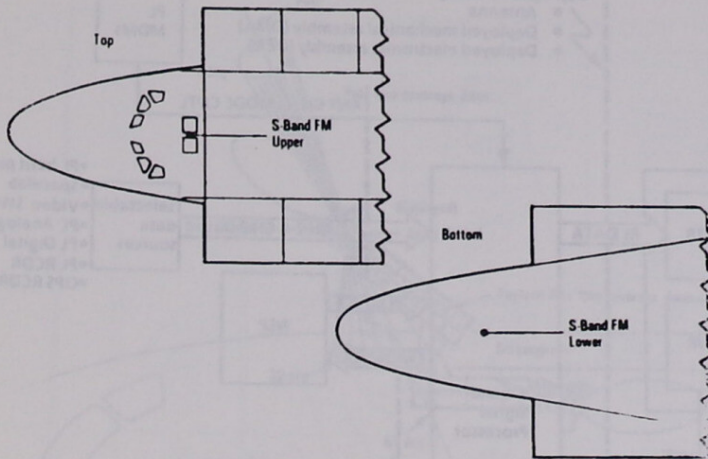
- Real-time SSME data from the engine interface units during launch at 60 kbps each (*ME*)
- Real-time video (*TV*)
- Operations recorder dumps of high- or low-data-rate telemetry at 1,024 kbps (*OPS RCDR*)
- Payload recorder at 25.5 kbps or 1,024 kbps (*PL RCDR*)
- Payload analog at 300 hertz or 4 MHz (*PL ANLG*)
- Payload digital data at 200 bps or 5 Mbps (*PL DIGITAL*)
- DOD data at 16 kbps or 256 kbps in real time or 128 kbps or 1,024 kbps of playback (*DOD*).

Only one of the two FM signal processors is used at a time. FM signal processor 1 interfaces with FM transmitter 1, and FM signal processor 2 interfaces with FM transmitter 2. The transmitters and processors cannot be cross-strapped.

## S-Band FM Antennas

Two hemispherical S-band FM antennas covered with a reusable thermal protection system are located on the forward fuselage outer skin of the orbiter approximately 180 degrees apart. On the flight deck, the hemispherical antennas are above the head (upper) and below the feet (lower) and radiate the S-band FM return link.

The S-band antenna switch assembly provides the signal switching among the two S-band FM transmitters and either of the two hemispherical antennas. The proper antenna is selected automatically by onboard or real-time command from the ground, computer control, or manual flight crew selection using the *S-BAND FM XMTR UPPER*, *RCVR LOWER* switch on panel A1R. In the *GPC* mode, the onboard SM computer selects the proper hemispherical antenna to be used whenever an S-band FM transmitter is active. The antenna selection is based on the computed line of sight to the NASA STDN ground station used for launch, lift-off, ascent, or landing, or the AFSCF ground stations.

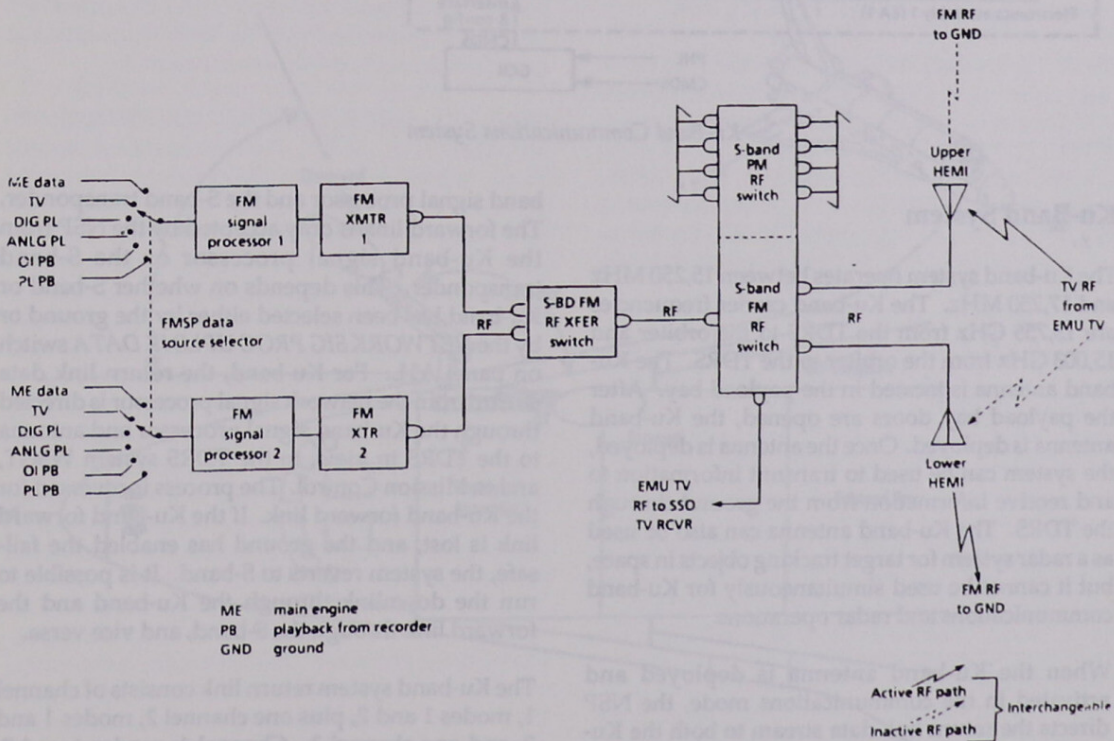


S-Band FM Antenna Locations

The basic difference between the quadrant and hemispherical antennas is that the hemispherical antennas have a larger beamwidth, whereas the quadrant antennas have a higher antenna gain. The hemispherical antennas are so named because there are two of them, one on the top of the orbiter and one on the bottom.

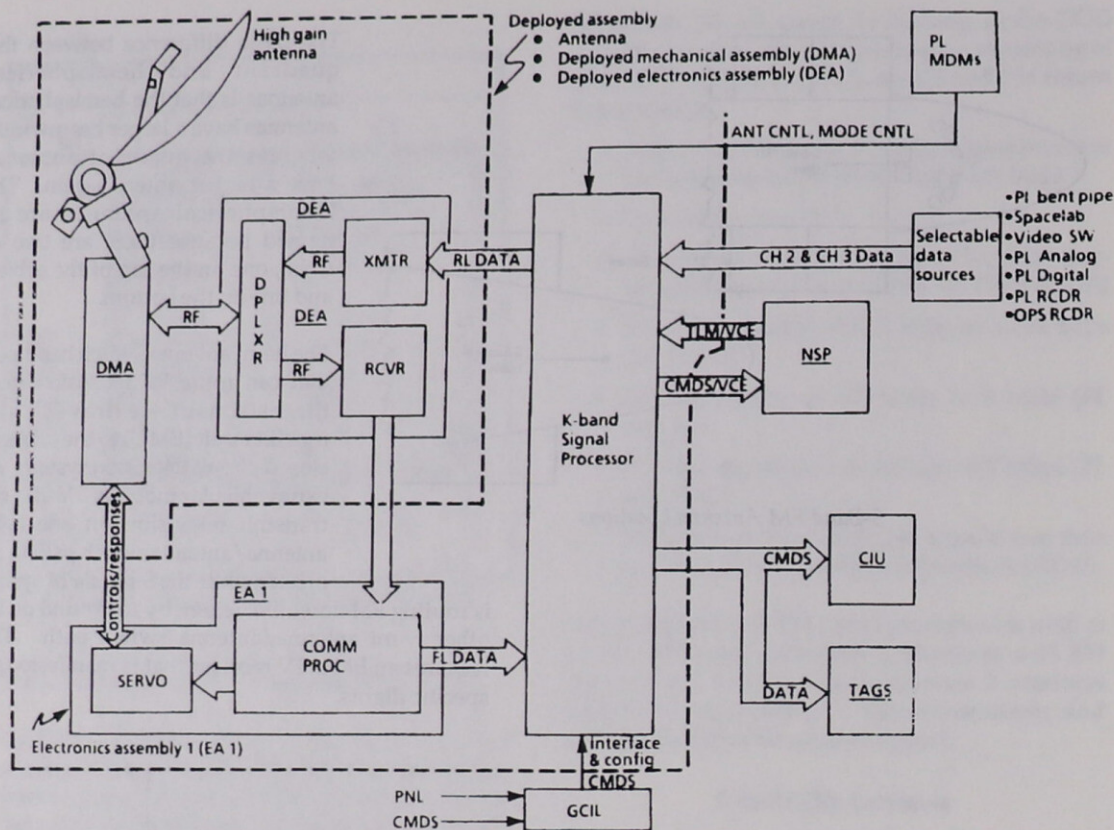
The hemi antenna switch has a port that can route RF television from the astronaut's extravehicular mobility unit (EMU) to the orbiter's closed-circuit television system. An extravehicular mobility TV unit can transmit television on one hemi antenna/antenna switch path to the orbiter while the S-band FM system

is routing FM downlink telemetry to ground on the other hemi antenna/antenna switch path. This requires an EMU TV receiver that is manifested for specific flights.



S-Band FM System Block Diagram





Ku-Band Communications System

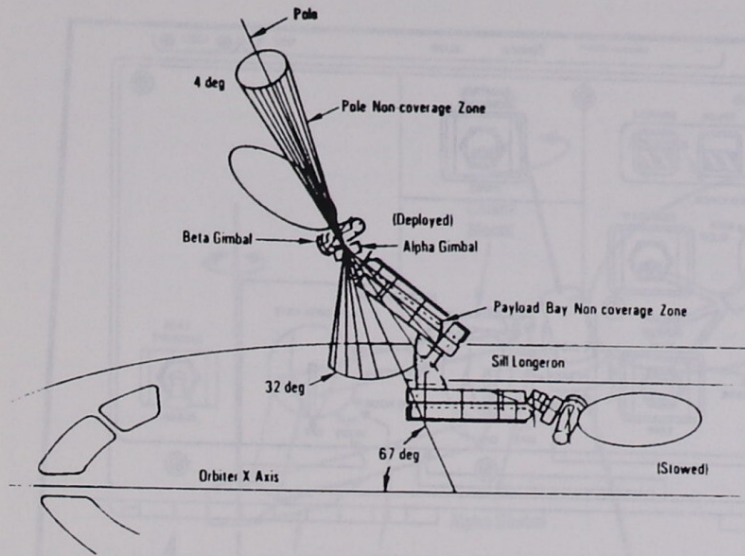
### Ku-Band System

The Ku-band system operates between 15,250 MHz and 17,250 MHz. The Ku-band carrier frequencies are 13,755 GHz from the TDRS to the orbiter and 15,003 GHz from the orbiter to the TDRS. The Ku-band antenna is located in the payload bay. After the payload bay doors are opened, the Ku-band antenna is deployed. Once the antenna is deployed, the system can be used to transmit information to and receive information from the ground through the TDRS. The Ku-band antenna can also be used as a radar system for target tracking objects in space, but it cannot be used simultaneously for Ku-band communications and radar operations.

When the Ku-band antenna is deployed and activated in the communications mode, the NSP directs the return link data stream to both the Ku-

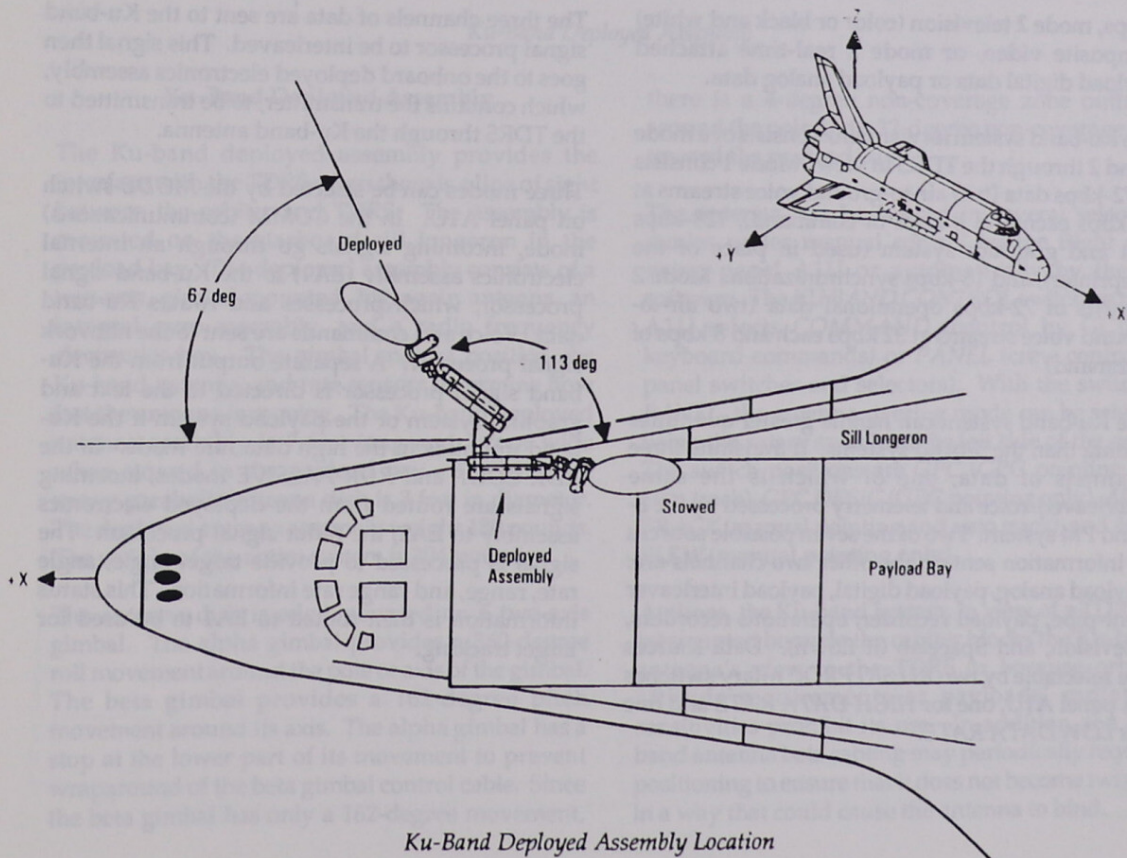
band signal processor and the S-band transponder. The forward link is only accepted by the NSP from the Ku-band signal processor or the S-band transponder. This depends on whether S-band or Ku-band has been selected either by the ground or by the *NETWORK SIG PROC UPLINK DATA* switch on panel A1L. For Ku-band, the return link data stream from the network signal processor is directed through the Ku-band signal processor and antenna to the TDRS in view, to the TDRS system WSGT, and to Mission Control. The process is reversed for the Ku-band forward link. If the Ku-band forward link is lost, and the ground has enabled the fail-safe, the system reverts to S-band. It is possible to run the downlink through the Ku-band and the forward link through the S-band, and vice versa.

The Ku-band system return link consists of channel 1, modes 1 and 2, plus one channel 2, modes 1 and 2, and one channel 3. Channel 1, modes 1 and 2,

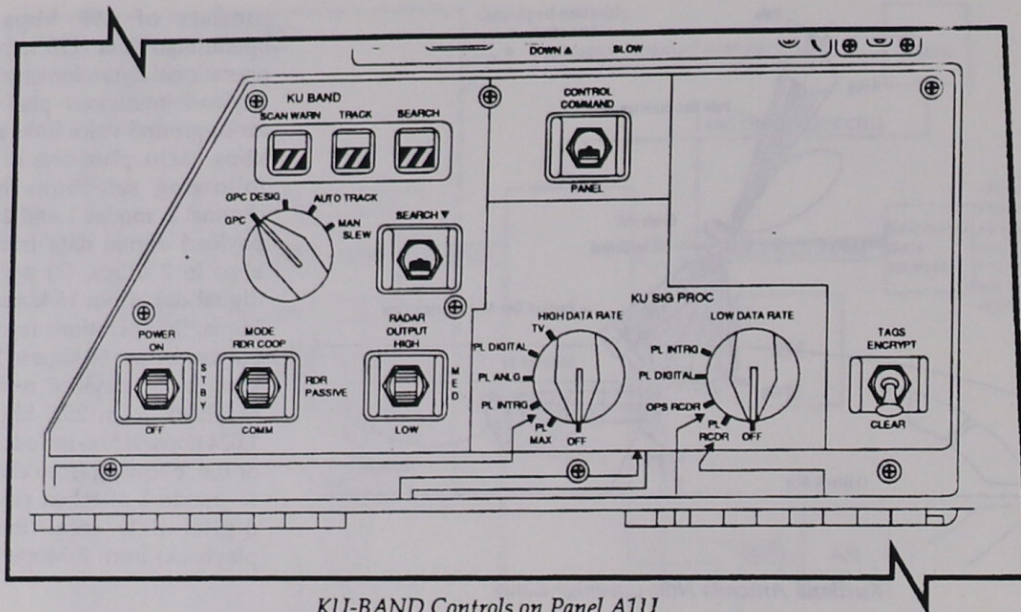


*Ku-Band Antenna Non-Coverage Zones*

consists of 192 kbps of operational data (128 kbps of operational data telemetry and payload interleaver plus two air-to-ground voice links at 32 kbps each) plus one of the following selections from channel 2, modes 1 and 2: (1) payload digital data from 16 kbps to 2 Mbps, (2) payload digital data from 16 kbps to 2 Mbps, (3) operations recorder playback from 60 kbps to 1,024 kbps, or (4) payload recorder playback from 25.5 kbps to 1,024 kbps. It also includes one of the following from channel 3: mode 1 attached payload digital data (real-time or playback) from 2 Mbps to 50



*Ku-Band Deployed Assembly Location*



KU-BAND Controls on Panel A1U

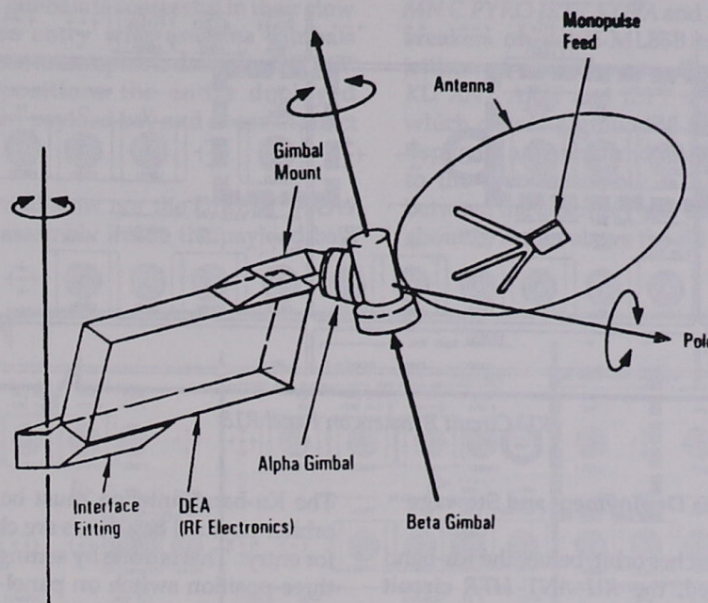
Mbps, mode 2 television (color or black and white) composite video, or mode 2 real-time attached payload digital data or payload analog data.

The Ku-band system forward link consists of a mode 1 and 2 through the TDRS in view. Mode 1 consists of 72-kbps data (two air-to-ground voice streams at 32 kbps each and 8 kbps of command), 128-kbps text and graphics system (used in place of the teleprinter), and 16-kbps synchronization. Mode 2 consists of 72-kbps operational data (two air-to-ground voice streams at 32 kbps each and 8 kbps of command).

The Ku-band system can handle greater quantities of data than the S-band systems. It transmits three channels of data, one of which is the same interleaved voice and telemetry processed by the S-band PM system. Two of the seven possible sources of information sent on the other two channels are: payload analog, payload digital, payload interleaver bent-pipe, payload recorder, operations recorders, television, and Spacelab (if flown). Data sources are selectable by two *KU SIG PROC* rotary switches on panel A1U, one for *HIGH DATA RATE* and one for *LOW DATA RATE*.

The three channels of data are sent to the Ku-band signal processor to be interleaved. This signal then goes to the onboard deployed electronics assembly, which contains the transmitter, to be transmitted to the TDRS through the Ku-band antenna.

Three modes can be selected by the *MODE* switch on panel A1U. In the *COMM* (communications) mode, incoming signals go through an internal electronics assembly (EA1) to the Ku-band signal processor, which processes and routes Ku-band data. Voice and commands are sent to the network signal processor. A separate output from the Ku-band signal processor is directed to the text and graphics system or the payload system if the Ku-band uplink is in the high data rate mode. In the *RDR COOP* and *RDR PASSIVE* modes, incoming signals are routed from the deployed electronics assembly to EA2, the radar signal processor. The signal is processed to provide target angle, angle rate, range, and range rate information. This status information is then routed to EA1 to be used for target tracking.



*Ku-Band Deployed Assembly*

### Ku-Band Deployed Assembly

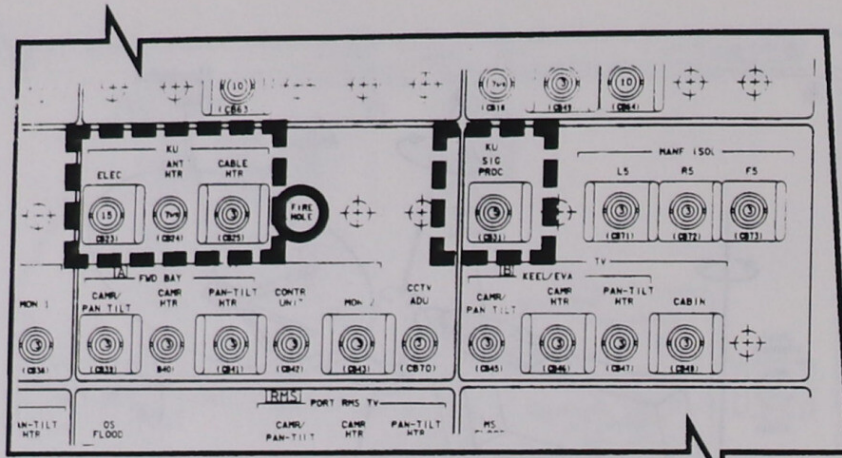
The Ku-band deployed assembly provides the interface with the TDRS when there is a line of sight between the orbiter and TDRS. The assembly is mounted on the starboard sill longeron in the payload bay. The deployed assembly consists of a two-axis, gimbal-mounted, high-gain antenna, an integral gyro assembly, and a radio frequency electronics box. The gimbal motors position the Ku-band antenna, and rate sensors determine how fast the antenna is moving. The Ku-band deployed antenna assembly is 7 feet long and 1 foot wide when stowed in the payload bay. The graphite epoxy parabolic antenna dish is 3 feet in diameter. The deployed antenna assembly weighs 180 pounds. The weight of the entire system is 304 pounds.

The antenna dish is edge-mounted on a two-axis gimbal. The alpha gimbal provides a 360-degree roll movement around the pole or axis of the gimbal. The beta gimbal provides a 162-degree pitch movement around its axis. The alpha gimbal has a stop at the lower part of its movement to prevent wraparound of the beta gimbal control cable. Since the beta gimbal has only a 162-degree movement,

there is a 4-degree non-coverage zone outboard around the pole and a 32-degree non-coverage zone toward the payload bay.

The antenna can be steered in several selectable modes under manual control by the flight crew using panel A1U or automatically by the SM software. The *KU BAND CONTROL* switch on panel A1U selects *COMMAND* (control by GCIL or keyboard commands) or *PANEL* (crew control by panel switches and selectors). With the switch in *PANEL*, the antenna steering mode can be selected using the rotary switch on the left side of the panel. The switch positions are *GPC* (GPC pointing and auto track), *GPC DESIG* (GPC pointing only), *AUTO TRACK* (manual pointing and auto track), and *MAN SLEW* (manual pointing only).

At times, the Ku-band system, in view of a TDRS, is interrupted because the orbiter blocks the Ku-band antenna's view to the TDRS or because orbiter attitude requirements or payloads' radiation sensitivities prohibit its use. In addition, the Ku-band antenna beta cabling may periodically require positioning to ensure that it does not become twisted in a way that could cause the antenna to bind.



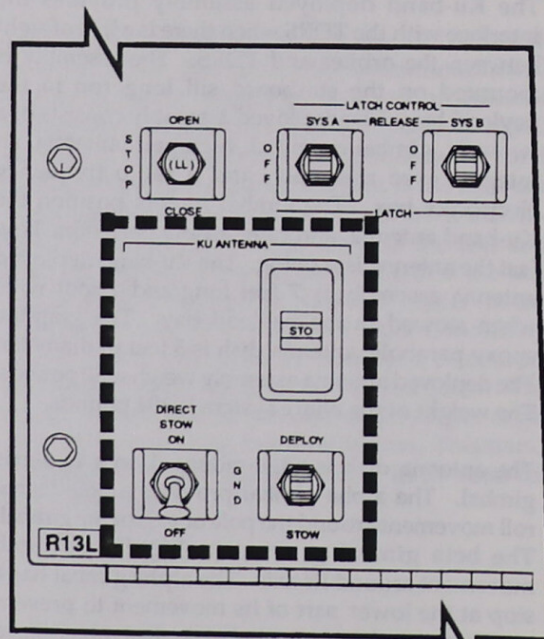
KU Circuit Breakers on Panel R15

### Ku-Band Antenna Deployment and Stowage

When the Shuttle reaches orbit, before the Ku-band antenna is deployed, the *KU ANT HTR* circuit breaker on panel R15 is closed to energize thermostatically controlled heaters for the deployed electronics assembly, gimbals, and antenna assembly. During Ku-band activation, the *KU ELEC* and *KU SIG PROC* circuit breakers on panel R15 are closed. (There is also a *CABLE HTR* circuit breaker on panel R15. The Ku-band system was originally designed to have a cable heater, but it was never installed. Therefore, this circuit breaker is always left open.) These circuit breakers provide electrical power to the Ku-band electronic elements, electronics assemblies 1 and 2, the signal processor assembly, and Ku-band portions of panels A1U and A2. Actual deployment involves the *KU ANTENNA* controls and associated talkback on panel R13L. The antenna is locked in the stowed position to clear the adjacent payload bay doors and radiators when they are closed or moving.

Twenty-three seconds are normally required to deploy or stow the assembly. In the deployed position, the assembly forms a 67-degree angle with the orbiter X axis. Activating the Ku electronics and taking the *KU BAND POWER* switch on panel A1U to *ON* frees the antenna gimbals by removing the gimbal locking pins. The beginning of stow operations contains approximately 30 seconds of gimbal lock sequencing before assembly stow begins.

The Ku-band antenna must be stowed before the orbiter payload bay doors are closed in preparation for entry. This is done by setting the *KU ANTENNA* three-position switch on panel R13L to the *STOW* position. If the assembly does not respond to normal stow operations, the *KU ANTENNA DIRECT STOW* switch on panel R13L is used. Setting this switch to *ON* bypasses the normal stow control sequences and causes the assembly to be driven inside the

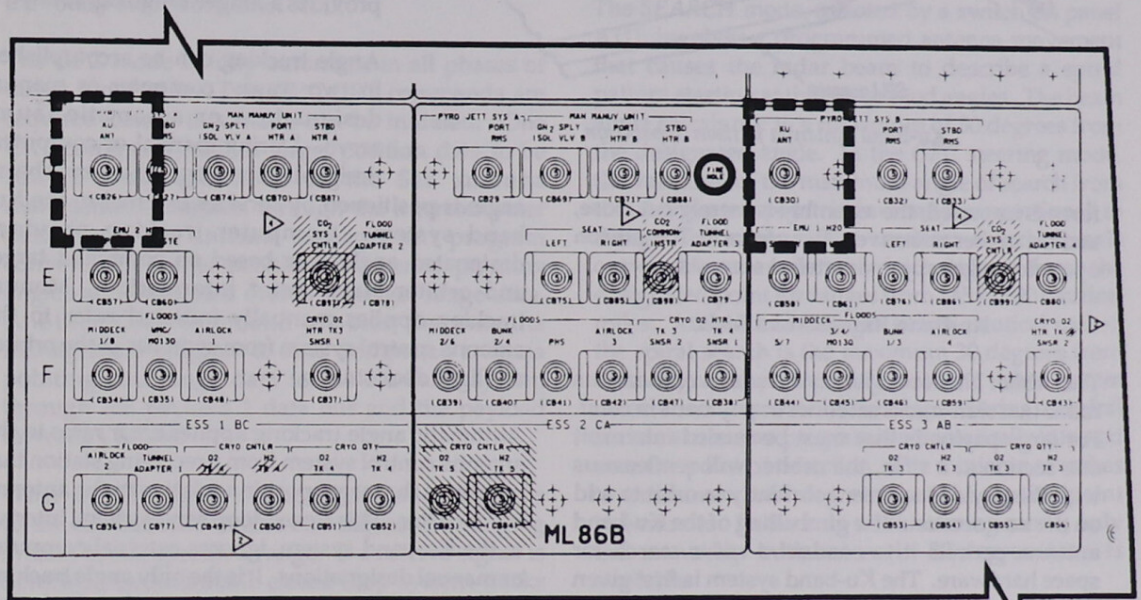


KU ANTENNA Switches and Talkback on Panel R13L

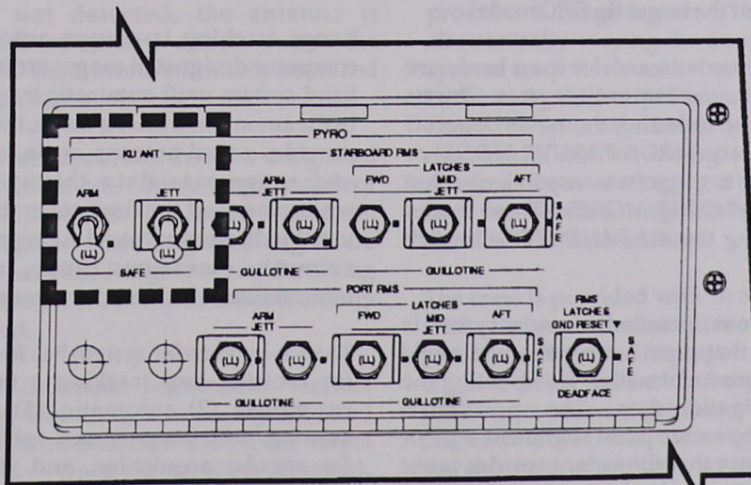
payload bay. The *KU ANTENNA DIRECT STOW* switch procedure is only used if locking of the alpha and beta antenna gimbals is successful in their stow position, because entry with antenna gimbals unlocked may cause unacceptable damage. *DIRECT STOW* merely positions the entire deployed assembly inside the payload bay and does not affect gimbal locking.

If neither the normal stow nor the *DIRECT STOW* can position the assembly inside the payload bay,

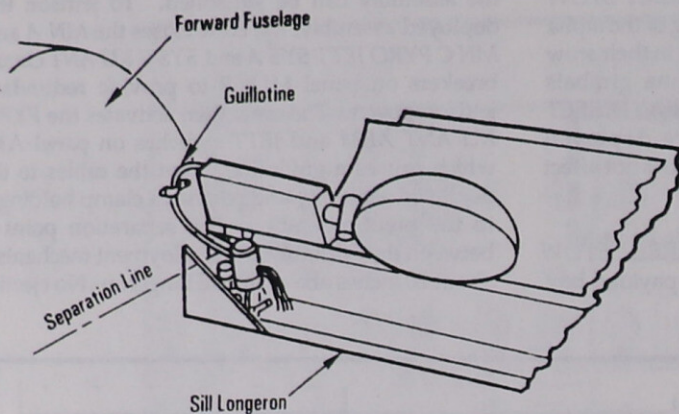
the assembly can be jettisoned. To jettison the deployed assembly, the crew closes the *MN A* and *MN C PYRO JETT SYS A* and *SYS B KU ANT* circuit breakers on panel ML86B to provide redundant jettison power. The crew then activates the *PYRO KU ANT ARM* and *JETT* switches on panel A14, which causes a guillotine to cut the cables to the deployed assembly and releases a clamp holding it to the pivot assembly. The separation point is between the assembly and deployment mechanism about 20 inches above the sill longeron. No ejective



PYRO JETT KU Circuit Breakers on Panel ML86B



KU ANT Switches on Panel A14



*Ku-Band Antenna Jettison Separation*

force is imparted; the assembly is merely cut loose, and the orbiter maneuvers away from it. The jettison operation takes approximately 4 seconds.

#### **Ku-Band Rendezvous Radar**

The orbiter Ku-band system includes a rendezvous radar that skin-tracks satellites or payloads in orbit. For large payloads that must be carried into orbit one section at a time, the orbiter will rendezvous with the payload segment currently in orbit to add on the next section. The gimbaling of the Ku-band antenna permits it to conduct a radar search for space hardware. The Ku-band system is first given the general location of the hardware by the orbiter computer; then the antenna makes a spiral scan of the area to pinpoint the target (in GPC mode).

Radar may also be used to search for space hardware using a wide spiral scan of up to 60 degrees. Objects may be detected by reflecting the radar beam off the surface of the target (*RDR PASSIVE MODE*) or by using the radar to trigger a transponder beacon on the target (*RDR COOP MODE*). These modes are selectable using the *KU BAND MODE* switch on panel A1U.

During a rendezvous operation, the radar system is used as a sensor that provides target angle, angle rate, and range rate information for updating the rendezvous navigation data. The operation is similar to using the crew optical alignment sight or star trackers, except that the radar provides range data in addition to angle data. Angle tracking

maintains appropriate antenna pointing to keep the target within the antenna beam. Range tracking is accomplished by electronically measuring the time between a transmitted pulse and a return pulse from the target. The return pulse may be reflected from a passive (skin-tracked) target or cooperative target transmitter that is triggered by the radar-initiated pulse. The latter provides a longer range capability.

Angle tracking can be accomplished in two ways: computer or manual designations or automatic (auto) servo. During manual or computer-designated tracking, the antenna beam

angle is positioned by services external to the Ku-band system. Computer tracking provides designated angle data based on combined target and orbiter state vector information. Manual tracking applies manually initiated rates to the antenna control system from switches at the orbiter aft flight deck station.

Automatic angle tracking applies error rates to the antenna control system from a receiving station that measures the target position relative to the antenna beam center. This closed-loop servosystem, internal to the Ku-band system, ignores external computer or manual designations. It is the only angle tracking mode that provides angle data for updating navigation data.

Range tracking is always automatic, although computer-designated ranges are applied to the Ku-band system until automatic tracking is achieved. In the automatic tracking mode, the Ku-band system provides actual antenna angle, angle rate, range, and range rate data through an MDM for rendezvous and proximity operations. Data routed to the indicators on panel A2 represent hard-wired azimuth, elevation, range, and range rate information, which is not processed by the GPCs.

The Ku-band radar system has four steering modes for locating and tracking a target: (1) crew-controlled, (2) automatic, (3) manual antenna steering, with programmed spiral search routines for angular acquisition, and (4) range tracking (previously mentioned). In addition, there are two antenna stabilization modes.

Before any radar mode is used, the orbiter is normally maneuvered to an attitude with the minus Z axis pointing at the GPC-calculated target location. In all modes, therefore, the radar antenna is normally maneuvered around the minus Z axis.

The Ku-band system provides for antenna steering modes, each with a different combination of capabilities for acquiring and tracking a target: *GPC*, *GPC DESIG*, *AUTO TRACK*, and *MAN SLEW*. All are mutually exclusive and crew selectable using the rotary switch on panel A1U.

The *GPC* mode is fully automatic in all phases of target acquisition. Two GPC CRT commands are required before this mode can be initiated. One CRT command enables target position data to be routed from the GNC to the SM antenna management program through the intercomputer data bus. The antenna management program converts the target position to antenna pointing angles and estimated orbiter-to-target range data. Another CRT command enables the antenna management program to send designated antenna pointing and range data to the Ku-band system through the payload 1 data bus and the payload forward 1 MDM.

When the *GPC* mode is selected, the antenna points to the commanded angles and adjusts the ranging system to the specified range. If a receive signal is detected, the automatic closed-loop system tracks the target in angles and range and provides data for the SM and GNC computers and panel displays. If the target is not detected, the antenna is automatically commanded to search around the designated point. The antenna is inertially stabilized during the search operation.

The *GPC DESIG* mode provides the same designated pointing as the *GPC* mode without angle search or angle-tracking capabilities. No closed-loop angle tracking is provided. The designated angles are updated every 2 seconds. Range search and tracking are automatic. The antenna may be either inertially or body stabilized.

The *AUTO TRACK* mode begins with manual antenna control, including a manually initiated search and inertial stabilization during the target acquisition phase. Once the target is detected,

automatic angle and range tracking is initiated and manual control is inhibited until auto tracking is broken.

The *MAN SLEW* mode allows manual control of antenna movement with maximum automatic range search. Once the target is detected, an automatic range track is initiated, but angles are still under manual control. No angle search is available in this mode.

The *SEARCH* mode, selected by a switch on panel A1U, involves a programmed antenna movement that causes the radar beam to describe a spiral pattern starting at the designated angles. The beam angle spirals out to a maximum of 30 degrees from the designated angle. In the *GPC* steering mode, the variation of the maximum angle of search from the designated point is inversely proportional to designated range. The smallest search spirals outward to a maximum of 6.2 degrees from the designated point for ranges from 145 to 300 nautical miles. At minimum ranges (0 to 8 nautical miles), the spiral search is the maximum 30 degrees from the designated point. If the antenna drive system detects but overshoots the target during a spiral search, a miniscan program is automatically initiated near the point of detection. The miniscan searches to a maximum of 9 degrees from the starting point in 1 minute. In the auto track steering mode, only the manually initiated main 30-degree scan is available.

In addition to angle search, the Ku-band system provides a range search. The process includes electronically varying the timing within the range system until it coincides with the time interval between the transmitted and received radar pulses. Once the intervals coincide, radar tracking is established, and the range data output represents the range between the target and the orbiter. The crew can read the range and range rate values as panel and CRT parameters.

The crew is provided with two controls associated with range. Transmitter power output is automatically varied in proportion to range when a target is being tracked to keep the return signal relatively constant, regardless of range. If, however, the track is lost, and the range system begins to search, the transmitter may transmit maximum



power during the search. The crew can limit the maximum transmitter power by using an aft station panel control. The other control is a CRT command that limits the range search in GPC steering mode to 2,400 feet.

The Ku-band system has body and inertial antenna stabilization modes. When the body is stabilized, the antenna beam remains in a fixed relationship to the orbiter X, Y, and Z axes during orbiter attitude changes. When the system is inertially stabilized, the antenna beam remains aligned to a point in inertial space, regardless of the orbiter attitude changes. Both of these modes are effective only when the radar angle-tracking system is not tracking a target. In the target angle-tracking mode, the system aligns the antenna beam to the target, and antenna movement is independent of orbiter attitude changes.

Each antenna steering mode, except the designate mode, has a specific stabilization mode. The designate mode selects either body or inertial stabilization on the basis of a real-time GPC command (not available to the crew). Since the designate mode provides range tracking only, inertial stabilization is effective during target tracking.

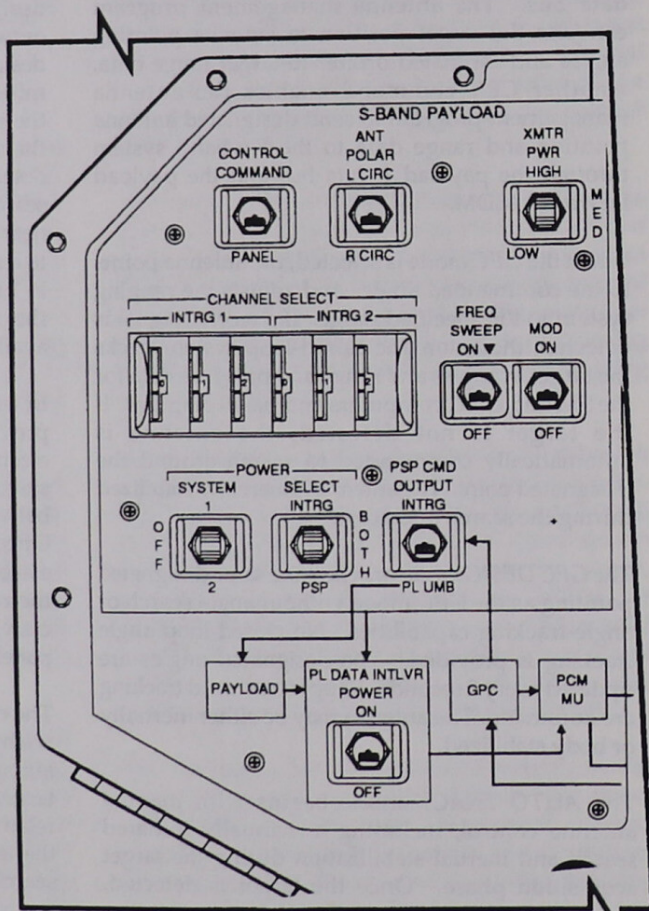
### Payload Communication System

The payload communication system is used to transfer information between the orbiter and its payload or payloads. It supports hardline and radio frequency communications with a variety of payloads. The system is used to activate, check out, and deactivate attached and detached payloads.

Communication with an attached payload takes place through the payload patch panel at the crew compartment flight deck aft station, which is connected to external equipment with internal systems. From this panel, the attached payload telemetry can take different paths. All command and telemetry signals that meet the payload communication system specifications can be processed on board. Incompatible signals can be sent to the

ground through Ku-band. This method of transmission, referred to as bent-pipe telemetry, means that no onboard signal processing occurs before the telemetry is sent to the Ku-band system. Payload telemetry can go directly to the S-band FM or Ku-band systems for transmission to the ground, payload analog, or payload digital, to the payload recorder for later transmission, or to the payload data interleaver to be interleaved with other payload data. The system also processes commands and provides payload telemetry to the pulse code modulation master unit (PCMMU), where the data can be accessed for display on various payload-related controls and displays.

The S-band payload antenna is located on the top of the outer skin of the orbiter's forward fuselage, just aft of the upper hemispherical antenna. The payload antenna is covered with reusable thermal



S-BAND PAYLOAD Switches on Panel A1L

protection system. This antenna is used as the radiating element for S-band transmission and reception to and from the orbiter to detached payloads through the forward and return links.

Communication problems involving antenna position relative to payload position are not evident while the payload is within a half mile of the orbiter. However, to maintain good communication with the orbiter from distances of several miles, the payload must be within an 80-degree beamwidth (with reference to the minus Z axis) of the orbiter's payload interrogator antenna. The boundary of the 80-degree beamwidth is the 3-decibel point (or half-power point), which must be considered during communication with deployed payloads. This constraint is normally satisfied by the payload deployment and retrieval process.

The basic elements in the payload communication system are the payload interrogator, payload signal processor, communication interface unit, payload data interleaver, pulse code modulation master unit, and payload recorder. These elements are in the forward avionics bay. Commands to the payload communication system are routed through payload MDMs 1 and 2, although these MDMs are also used for orbiter commanding. Status and control of payload communication systems can also be accessed by the PCMMU/PL COMM display (SPEC 62).

XXXX/062/	PCMMU/PL COMM	XX X	DD/HH:MM:SS
SM COM BUFF XXX			DD/HH:MM:SS
PCMMU			
8 BITE WORD XXXX			
FMT			
SEL FXD 1XS			
PGM 2XS			
PGM ID 64 XXX			
128 XXX			
3 SEL ID XXX			
LOAD 4 XXXX			
I/O RESET			
PCM 5XX			
PSP	PL INTRG		
I/O RESET	1 CHANNEL XXXX		
PSP1 6XX	2 CHANNEL XXXX		
PSP2 7XX	PHASE LOCK XXXX		
SYNC BIT XXXX	ERR ±XXX		
FRAME XXXX	XMIT PWR XX.XXS		
LOAD XXXX XXXX	PL SIG STR X.XXS	18 TFL GPC SEL X	
			(XX)

PCMMU/PL COMM Display (SPEC 62)

### Payload Interrogator

Detached payloads communicate with the orbiter on an RF signal through the payload antenna by the payload interrogator. The payload interrogator is a transmitter/receiver/transponder unit that provides full duplex RF communications between the orbiter and a detached payload. It transmits commands to and receives telemetry from NASA- or DOD-compatible payloads through the payload antenna. Payload interrogator controls are located on panel A1L.

The main carrier frequency of the detached payload telemetry is demodulated by the payload interrogator. The telemetry is routed directly to the Ku-band system for transmission to the ground (bent-pipe telemetry) and to the payload signal processor. The payload signal processor demodulates the telemetry from the subcarrier and sends it to the payload data interleaver to be interleaved with other payload data. Hardline payload commands are routed through the payload signal processor and then output through the payload patch panel directly to an attached payload. Detached RF commands are routed through the payload signal processor and then through the payload interrogator for transmission to the payload through the payload antenna.

The payload interrogator receiver automatically sweeps to acquire and track an unmodulated or modulated RF signal. Payload interrogator telemetry is available through the operational instrumentation MDM to verify signal strength and frequency lock.

When the payload outputs a data rate that is not compatible with the payload signal processor or communication interface unit, payload telemetry is sent to the payload signal processor for processing before being routed to the payload data interleaver.

### Payload Signal Processor

The payload signal processor is the RF and hardline command interface between the ground or flight crew and the payload. It is also a detached payload telemetry interface to the payload data interleaver. The payload signal processor is controlled by the PSP CMD OUTPUT switch on panel A1L.

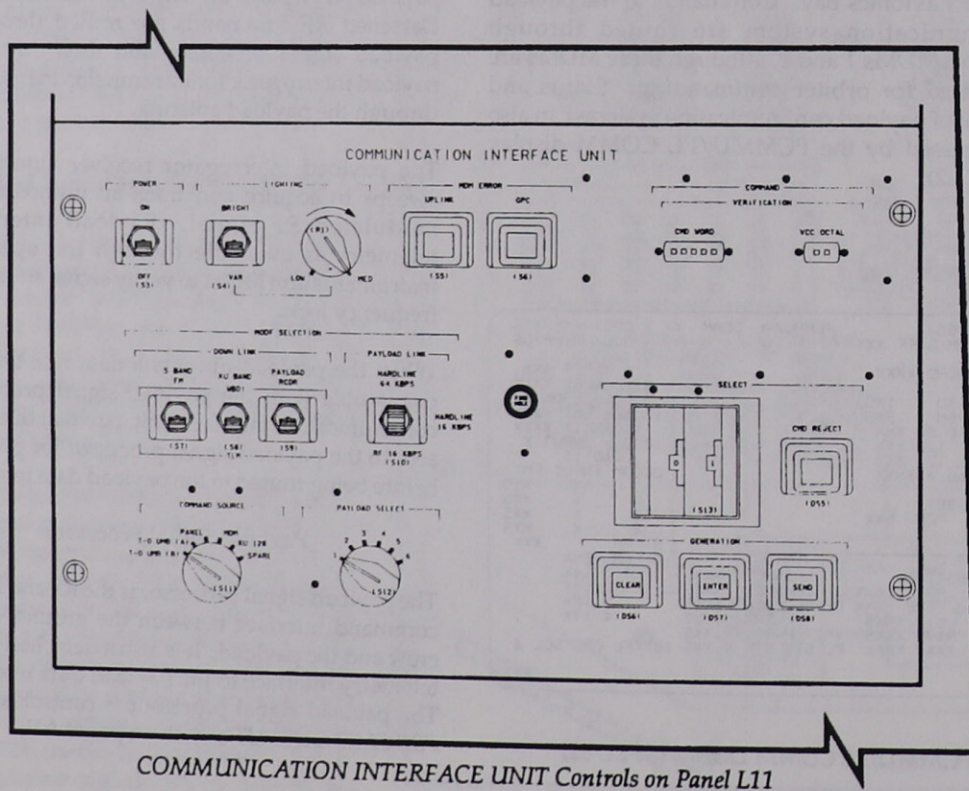
### Communication Interface Unit

The communication interface unit sometimes replaces the payload signal processor. The payload signal processor may be retained to act as a backup. The communication interface unit is commonly used with the Inertial Upper Stage, although it may be used with other payloads compatible with SGLS. The communication interface unit interfaces indirectly with the payload data interleaver through the patch panel because the communication interface unit is treated as an attached payload accessed through a patch panel input of the payload data interleaver. The payload signal processor is hard-wired directly to the payload data interleaver. This provides a command and telemetry path between the orbiter guidance, navigation, and control, GPC, and an SGLS-compatible payload or between the flight crew and an SGLS-compatible payload. The communication interface unit passes commands and telemetry to either attached or detached payloads. COMMUNICATION INTERFACE UNIT controls are on panel L11.

### Payload Data Interleaver

In the NASA mission configuration, the payload patch panel interfaces attached payloads to the payload data interleaver (PDI). Attached payloads are wired to specific input channels of the PDI via the payload patch panel during prelaunch activities. When the PDI is reconfigured by the flight crew, programming procedures include assigning inputs in the payload data interleaver to one of four decommutators.

The PDI allows the payload communication system to interface with the rest of the orbiter communication system and computers. It receives up to six different inputs from attached or detached payloads and one ground support equipment input. For missions using the payload signal processor, a maximum of five attached payloads can be accommodated on inputs 1 through 5. Input 6 is reserved for detached payload telemetry using the RF link through the payload signal processor. For missions using the communication interface unit,



COMMUNICATION INTERFACE UNIT Controls on Panel L11

all data, attached or detached, are routed through input 5. The PDI has four decommutators that can process up to four payload data streams. The PDI ships the payload telemetry to the PCMMU, where it can be accessed by the SM GPC for display, and combined with orbiter telemetry for transmission to the ground. The *PL DATA INTLVR POWER* switch is on panel A1L.

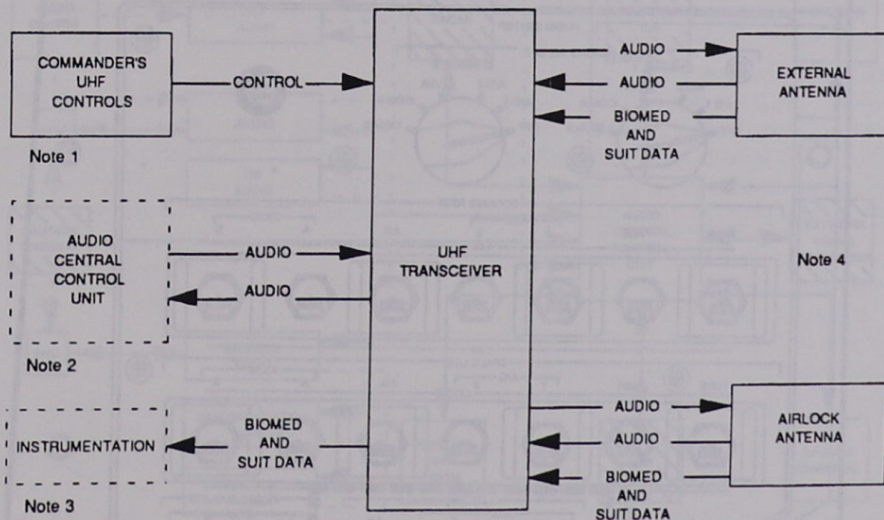
### Ultrahigh Frequency System

The UHF system is used as a backup for the S-band PM and Ku-band voice communications, primarily during EVA. For communications with the STDN or SGLS ground stations, the UHF system operates in a simplex mode, which means that the orbiter flight crew can transmit or receive, but cannot do both simultaneously. The UHF system may also be used for air traffic control and two-way voice with chase aircraft during landing operations.

The UHF transceiver takes the voice signal from the audio central control unit and routes it through the external UHF antenna on the bottom of the

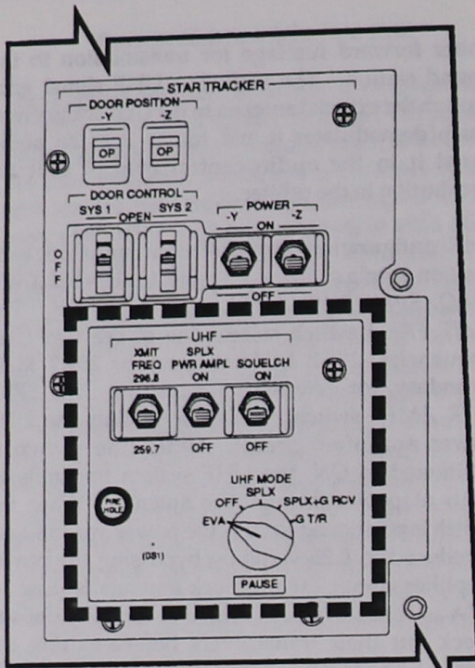
orbiter forward fuselage for transmission to the ground station. The incoming UHF signal goes through the external antenna to the UHF transceiver, which demodulates it and routes it as an audio signal to the audio central control unit for distribution in the orbiter.

UHF configuration is controlled through three two-position toggle switches on panel O6 labeled *XMIT FREQ*, *SPLX PWR AMPL*, and *SQUELCH*. The *XMIT FREQ* switch selects one of the two UHF frequencies, 296.8 MHz primary or 259.7 MHz secondary, for external transmission. The *SPLX PWR AMPL* switch enables or inhibits the UHF power amplifier circuit. When the switch is positioned to *ON*, the UHF system transmits 10 watts of power through the antenna. When the switch is positioned to *OFF*, the power transmission is reduced to 0.25 watts by bypassing the power amplifier circuit. (An airlock antenna is used by EVA astronauts in extravehicular mobility units to check out their transceivers before exiting the airlock.) The *SQUELCH* switch permits *ON* or *OFF* selection of UHF squelch.



- Note 1 — Selects UHF mode, XMT FREQ, power, and squelch
- Note 2 — May be either A/G-1, A/G-2, or A/A
- Note 3 — Biomed/suit data received from EVA backpacks and routed to the orbiter instrumentation system
- Note 4 — External antenna is for communication with locations external to orbiter  
— Airlock antenna is for communication with EMUs in airlock

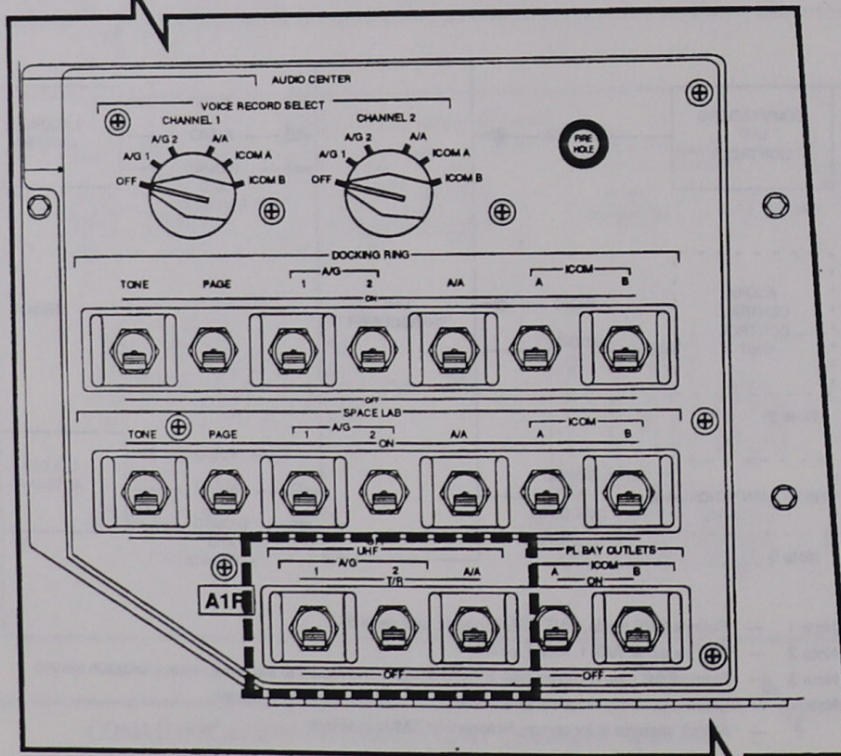
*UHF Subsystem Functional Block Diagram*



UHF System Controls on Panel O6

A five-position *UHF MODE* rotary switch on panel O6 activates power to the UHF transceiver and selects any of the following modes of UHF transmission. When the rotary switch is positioned to *EVA*, *EVA* transmissions are made on one frequency selected by the *XMIT FREQ* switch, and the message is received on two other frequencies. The *OFF* position removes all electrical power. When the rotary switch is positioned to *SPLX*, transmission and reception are both on the frequency selected by the *XMIT FREQ* switch. Positioned to *SPLX + G RCV*, transmission and reception are the same as in simplex except that reception of the UHF guard (emergency) frequency (243.0 MHz) also is possible. In the *G T/R* position, transmission and reception are both on the UHF guard (emergency) frequency.

Three two-position *UHF* toggle switches located on the bottom of the *AUDIO CENTER* portion of panel A1R control routing of audio from the audio central control unit to the UHF transceiver. The switches are labeled *T/R* for transmit/receive, *OFF* for



UHF Controls on Panel A1R

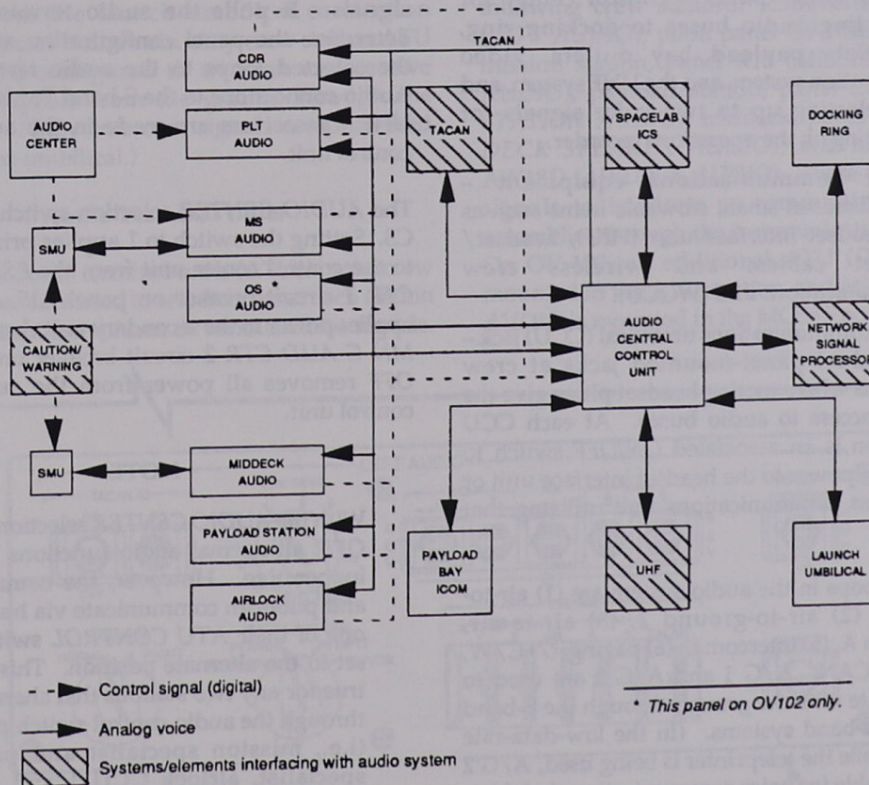
blocking UHF audio to or from the UHF transceiver, A/G for the air-to-ground channels, and A/A for the air-to-air channel.

For normal EVA operations, the orbiter transmits 296.8 MHz and receives 259.7 MHz and 279.0 MHz. The EVA astronauts are transmitting voice and biomedical/suit data on their respective frequencies. The astronaut configured for mode A transmits on 259.7 MHz. The astronaut configured for mode B transmits on 279.0 MHz. Each of the two EVA astronauts receives the other on the respective transmitted frequencies. Every 2 minutes, biomedical data are replaced with suit telemetry data for 15 seconds. EVA conversations are routed to Mission Control via the S-band PM or Ku-band system on A/G 1 or A/G 2, depending on the configuration of the UHF A/G 1 and A/G 2 switches on panel A1R. As a backup procedure only when the orbiter is over a UHF ground station, the EVA astronauts, orbiter, and ground can switch to the 259.7-MHz UHF, simplex.

The UHF system may be used after entry during the approach and landing phase of the mission. UHF air-to-ground voice communications may take place between the orbiter, the landing site control tower, and chase planes (if used).

### Audio Distribution System

The audio distribution system gathers audio signals from multiple sources and routes them throughout the orbiter. It provides the means by which crew members communicate with each other and with external locations, such as Mission Control, through the S-band PM, Ku-band, and UHF systems. It also interfaces with the caution and warning system for reception of C/W (tone) signals and with the three tactical air navigation (TACAN) sets for monitoring the TACAN audio identification codes. The network signal processor supplies S-band and Ku-band signals to the audio system for transmission and/or reception at various flight crew stations in the spacecraft. The audio distribution system routes



Audio Loops and System Interface

audio signals to an on-board Spacelab module, docking ring, operations recorder, payload bay stations, and the video distribution system under control of switches on panel A1R.

The major elements of the audio distribution system include:

1. Audio central control unit (ACCU) – acts as central “switchboard” to gather and route audio signals throughout the orbiter; internally redundant line-replaceable unit.
2. Audio terminal unit (ATU) – control panels at crew stations that permit crewmembers to select audio talk/listen buses and to control external/internal communication keying modes and listen volume levels.
3. Speaker/microphone unit (SMU) – two wall-mounted, two-way units with associated controls for adjustment of microphone sensitivity, speaker volume, and microphone keying.
4. Audio center panel – control center for extending audio buses to docking ring, Spacelab, payload bay outlets, video distribution system, and the UHF system, and for selecting up to two voice signals for recording on the operations recorder.
5. Loose communications equipment – miscellaneous small, stowable items such as the headset interface unit (HIU), headset/helmet cables, and wireless crew communications unit (WCCU).
6. Crew communications umbilical (CCU) jack – individual panel-mounted jacks at crew stations where mating headset plugs give the crew access to audio buses. At each CCU location is an associated ON/OFF switch to control power to the headset interface unit or wireless communications unit utilizing that jack.

The eight loops in the audio system are (1) air-to-ground 1, (2) air-to-ground 2, (3) air-to-air, (4) intercom A, (5) intercom B, (6) paging, (7) C/W, and (8) TACAN. A/G 1 and A/G 2 are used to communicate with the ground through the S-band PM and Ku-band systems. (In the low-data-rate mode or while the teleprinter is being used, A/G 2 is not available for voice communications.) A/A is

used, by convention, to communicate with the ground and with EVA astronauts through the UHF system. Intercoms A and B are used to communicate from station to station within the orbiter and Spacelab. The paging loop allows one crewmember to send voice transmissions to all active stations. The C/W loop sounds different tones for different malfunctions or emergencies. The TACAN loop, accessible only at the commander's and pilot's stations, is used to identify TACAN ground stations for navigation.

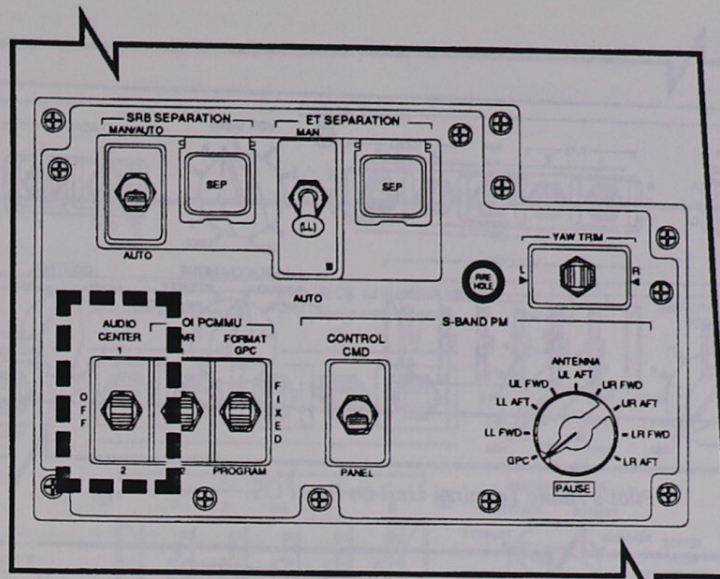
#### Audio Central Control Unit

The audio central control unit, the heart of the audio system, is located in the crew compartment middeck forward avionics bay. (There are two redundant audio central control units, but only one is used at any given time.) The unit identifies, switches, and distributes signals among the various audio distribution system components. Both digital and audio signals are received and processed by the audio central control unit, but it transmits only audio signals. It polls the audio terminal units to determine the panel configuration and connects the selected loops to the audio terminal units. Audio connections to the S-band PM Ku-band and UHF transceivers are made in the audio central control unit.

The *AUDIO CENTER* selection switch is on panel C3. Setting the switch to 1 applies primary power to the control center unit from the *ESS 2CA AUD CTR 1* circuit breaker on panel R15. Selecting 2 applies power to the secondary unit electronics from *MN C AUD CTR 2* circuit breaker on panel R15. *OFF* removes all power from the audio central control unit.

#### NOTE

With the *AUDIO CENTER* selection switch *OFF*, all normal audio functions will be inoperative. However, the commander and pilot can communicate via headset if one of their ATU *CONTROL* switches is set to the alternate position. This is also true for any two stations that share ATUs through the audio control switch position (i.e., mission specialist and payload specialist, airlock CCU 1 and 2, and middeck speaker/microphone unit).



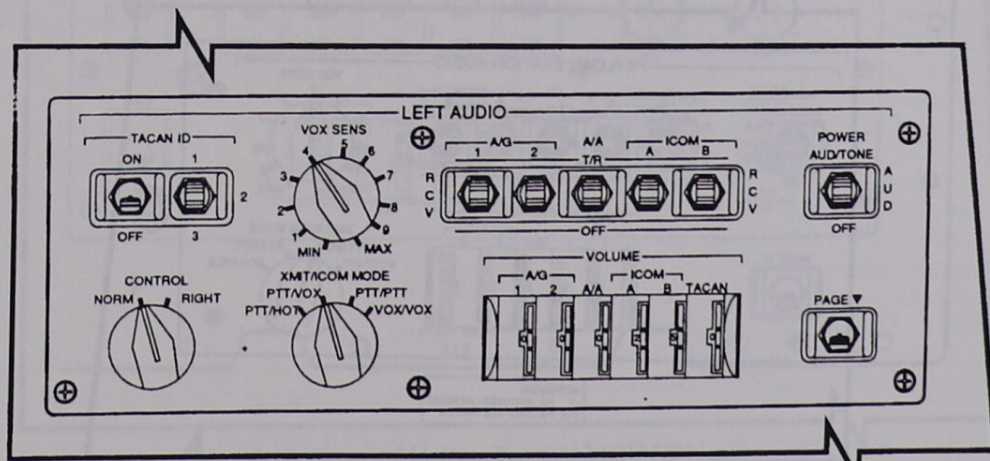
AUDIO CENTER Selection Switch on Panel C3

The audio central control unit circuitry activates signals from the launch umbilical connection intercom A and B channels. Any crew station ATU can then be configured to transmit and receive intercom signals from the ground through the umbilical. (Only intercom signals are processed through the umbilical.)

#### Audio Terminal Units

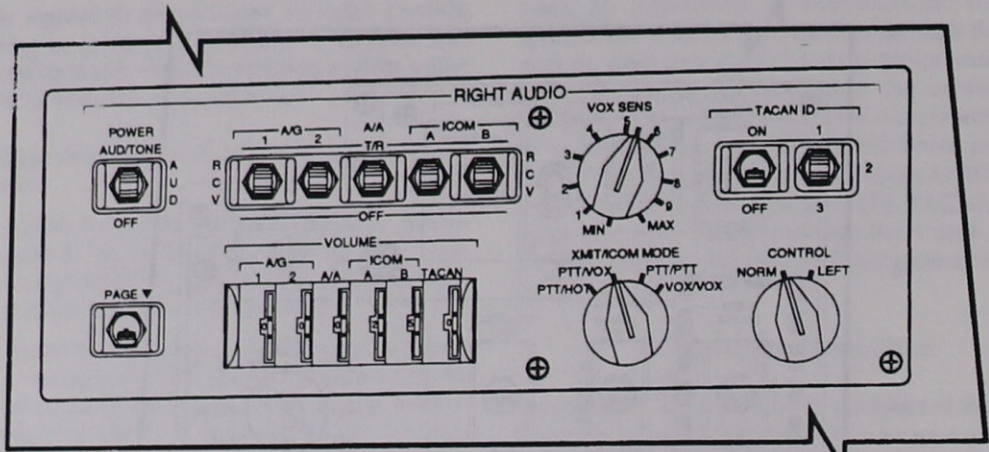
Up to eight audio terminal units (ATUs) in the crew compartment are used to select access at each station and to control the volume of various audio signals.

Audio terminal unit panels are located at the following crew stations: commander, panel O5 (LEFT AUDIO); pilot, panel O9 (RIGHT AUDIO); mission station, panel R10 (MISSION STATION AUDIO); payload station, panel L9 (PAYLOAD STATION AUDIO); middeck, panel M042F (MID DECK SPEAKER AUDIO); and airlock, panel AW18D (AIRLOCK AUDIO). These panels control signals to headsets or communication carrier assemblies through the communications umbilical. On OV-102, an additional ATU (OS AUDIO) is mounted in the A13 position, and MID DECK CCU AUDIO is mounted in the M058F position.

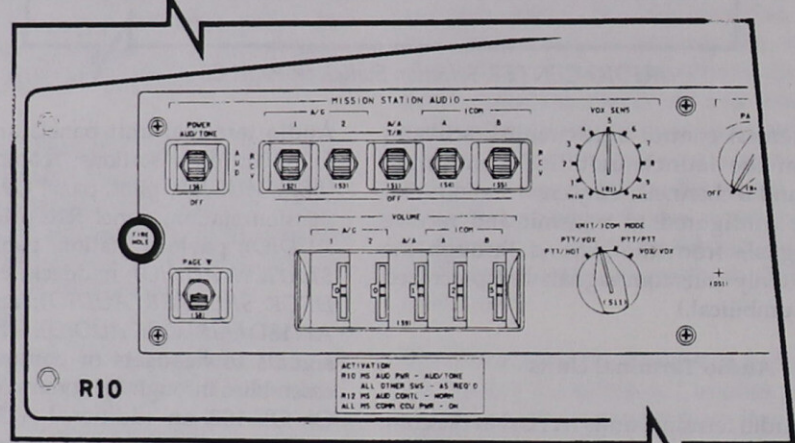


Commander's Audio Terminal Unit on Panel O5

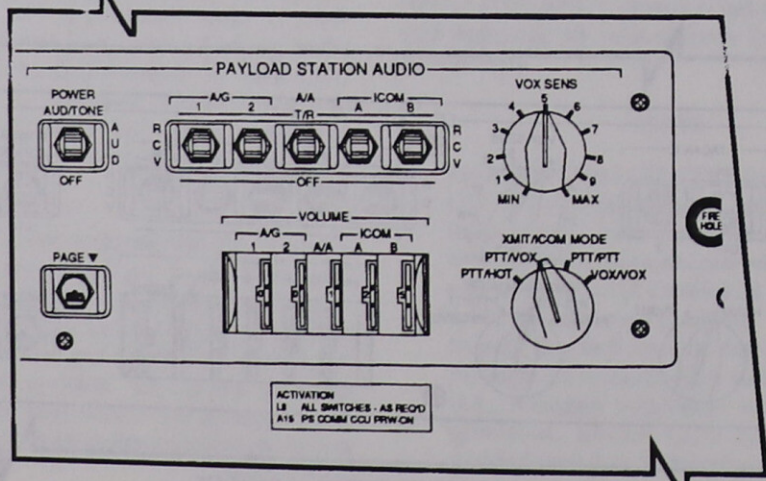




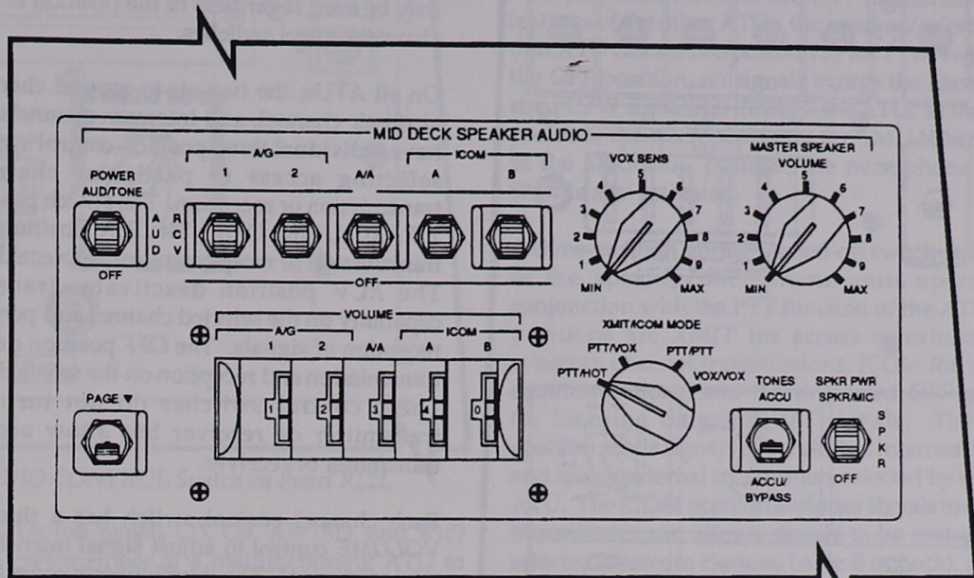
Pilot's Audio Terminal Unit on Panel O9



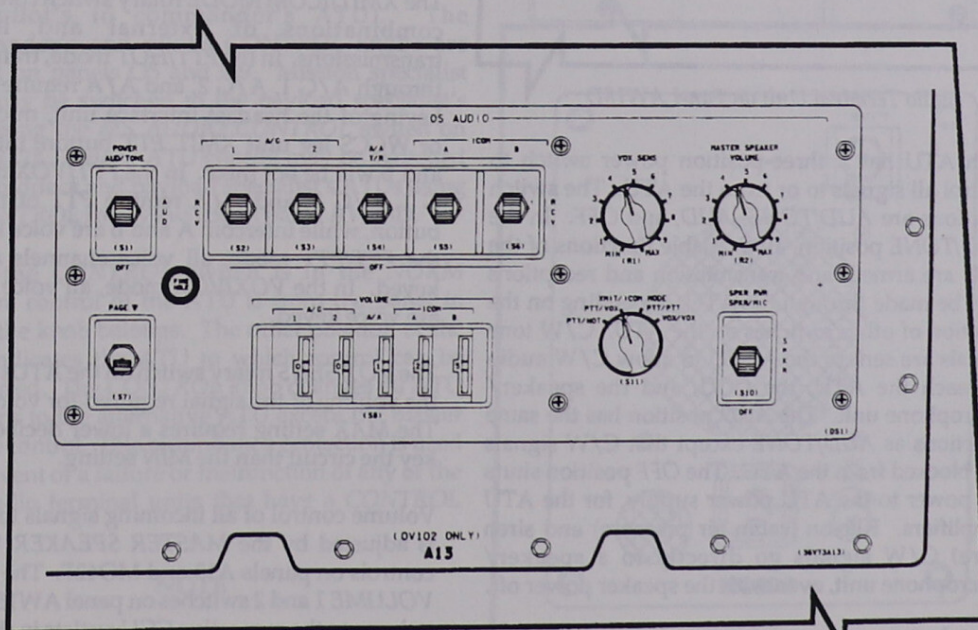
Audio Terminal Unit on Panel R10



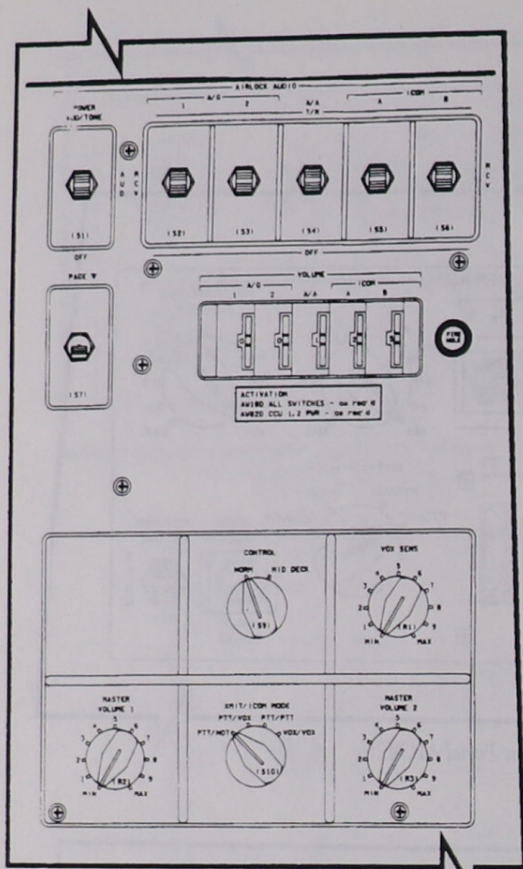
Audio Terminal Unit on Panel L9



Audio Terminal Unit on Panel MO42F



Audio Terminal Unit on Panel A13 (OV 102)



Audio Terminal Unit on Panel AW18D

Each ATU has a three-position power switch to control all signals to or from the ATU. The switch positions are *AUD/TONE*, *AUD*, and *OFF*. In the *AUD/TONE* position, all available functions of the ATU are armed, and transmission and receptions may be made through the ATU, depending on the position of other switches on the ATU. C/W tone signals are sent to the ACCU to allow C/W audio to reach the ATU, the CCU, and the speaker/microphone unit. The *AUD* position has the same functions as *AUD/TONE* except that C/W signals are blocked from the ATU. The *OFF* position shuts off power to the ATU power supply, for the ATU amplifiers. Klaxon (cabin air pressure) and siren (fire) C/W signals go directly to a speaker/microphone unit, even with the speaker power off.

Each ATU has a two-position, spring-loaded-off *PAGE* switch that must be held in the *PAGE* position

to activate the circuit. When activated, the circuit enables the ATU to transmit to all other ATUs, the EVA transceiver, and the attached payload circuit (e.g., Spacelab). Any number of stations may use the paging circuit simultaneously, and the circuit may be used regardless of the position of the other channel control switches.

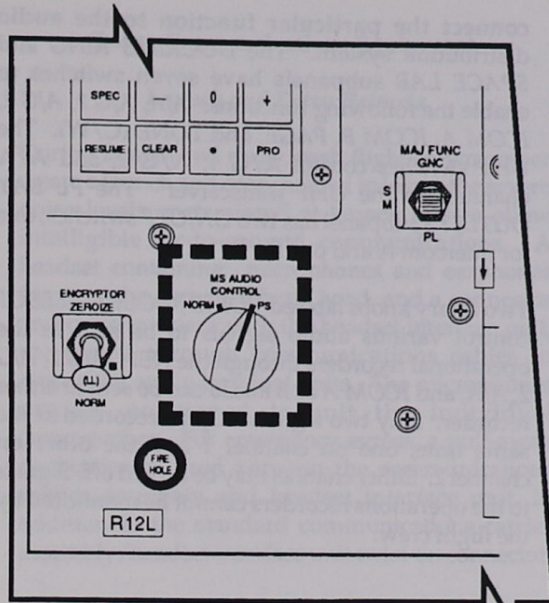
On all ATUs, the two air-to-ground channels, the air-to-air channel, and intercom channels A and B have individual three-position control switches for selecting access to particular channels for transmission or reception. The switch positions are *T/R*, *RCV*, and *OFF*. The *T/R* position permits transmission or reception over the selected channel. The *RCV* position deactivates transmission capability on the selected channel and permits only reception of signals. The *OFF* position deactivates transmission and reception on the selected channel. These control switches do not turn on any transmitter or receiver but allow access to a transmitter or receiver.

Each channel control switch has a thumbwheel *VOLUME* control to adjust signal intensity on the related channel. The thumbwheels cover a range of approximately 27 decibels in 3-decibel increments.

The *XMIT/ICOM MODE* rotary switch controls four combinations of external and intercom transmissions. In the *PTT/HOT* mode, transmission through A/G 1, A/G 2, and A/A requires manual keying of the headset interface unit, microphone, or WCCS leg unit *XMIT PTT* button; intercom A and B will be hot mike. In the *PTT/VOX* mode, A/G 1, A/G 2, and A/A require PTT of the *XMIT* button, while intercom A and B are voice keyed. In the *PTT/PTT* mode, all voice channels are voice keyed. In the *VOX/VOX* mode, all voice channels are voice keyed.

The *VOX SENS* rotary switch on the ATUs regulates the volume of the signal required for voice keying. The *MAX* setting requires a lower decibel level to key the circuit than the *MIN* setting.

Volume control of all incoming signals to speakers is adjusted by the *MASTER SPEAKER VOLUME* controls on panels A13 and MO42F. The *MASTER VOLUME 1* and 2 switches on panel AW18D control volume to the respective CCU outlets in the airlock.



MS AUDIO CONTROL Switch on Panel R12L

Four ATUs (on panels O5, O9, AW18D, and R10) allow a crewmember at a malfunctioning ATU to switch the CCU jack to an alternate ATU. The left may be switched to the right (commander's to pilot's ATU), or right ATU control may be switched to the left (pilot's to commander's ATU). The commander's and pilot's CONTROL knobs are located on panels O5 and O9. Mission specialist ATU may be switched to the payload specialist's ATU using the MS AUDIO CONTROL switch on panel R12L. Airlock ATU control may be switched to the middeck and payload specialist's ATUs using the CONTROL rotary switch on panel AW18D.

When the CONTROL switch is in the NORM position, control of the ATU is from the panel to which the knob belongs. The other position of the knob indicates the ATU to which control can be transferred. The CONTROL knob changes all ATU functions to the alternative ATU except the master volume control. This redundancy protection is used in the event of a failure or malfunction of any of the four audio terminal units that have a CONTROL knob.

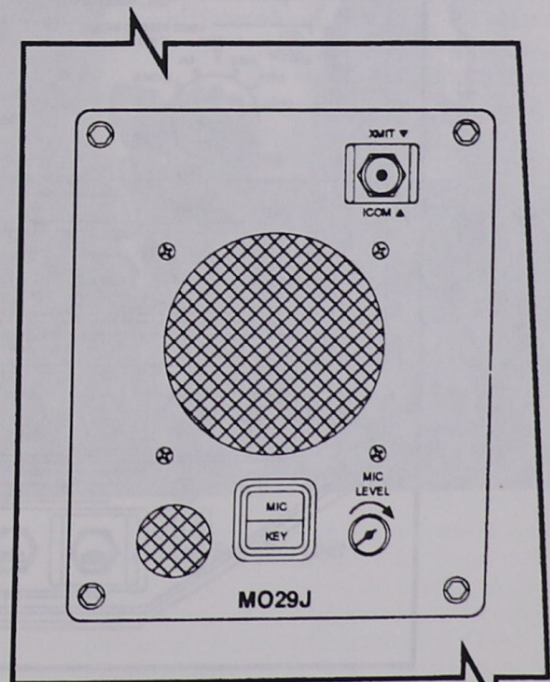
**NOTE**

If an ATU loses power, switching to the other CONTROL position will restore listen capability but not talk capability.

**Speaker/Microphone Units**

A speaker/microphone unit (SMU) is located on panels A2 and MO29J. They are controlled by the ATU on panels A13 and MO42F. In addition to the features of the other ATUs, the speaker/microphone unit ATU has a three-position SPKR PWR switch. In the OFF position, no signals except the klaxon and siren C/W signals go through the ATU. In the SPKR position, the microphone on the SMU is activated. In the SPKR/MIC position, the microphone on the SMU is also activated.

A three-position, spring-loaded-off switch on the face of the speaker/microphone units operates in conjunction with the PTT function of the ATU. The positions are XMIT for access to external and intercom channel transmissions, ICOM for internal communications, and the unlabeled OFF position for blocking outgoing PTT signals. The XMIT position sends signals over selected intercom circuits and to any external transmitters selected by the SMU ATU. The ICOM position excludes signals to external transmitters and allows signals to be sent over the selected intercom channel (A or B or both). Keying the ICOM or XMIT switch mutes the speaker, except C/W emergency signals.



Speaker/Microphone Unit on Panel MO29J

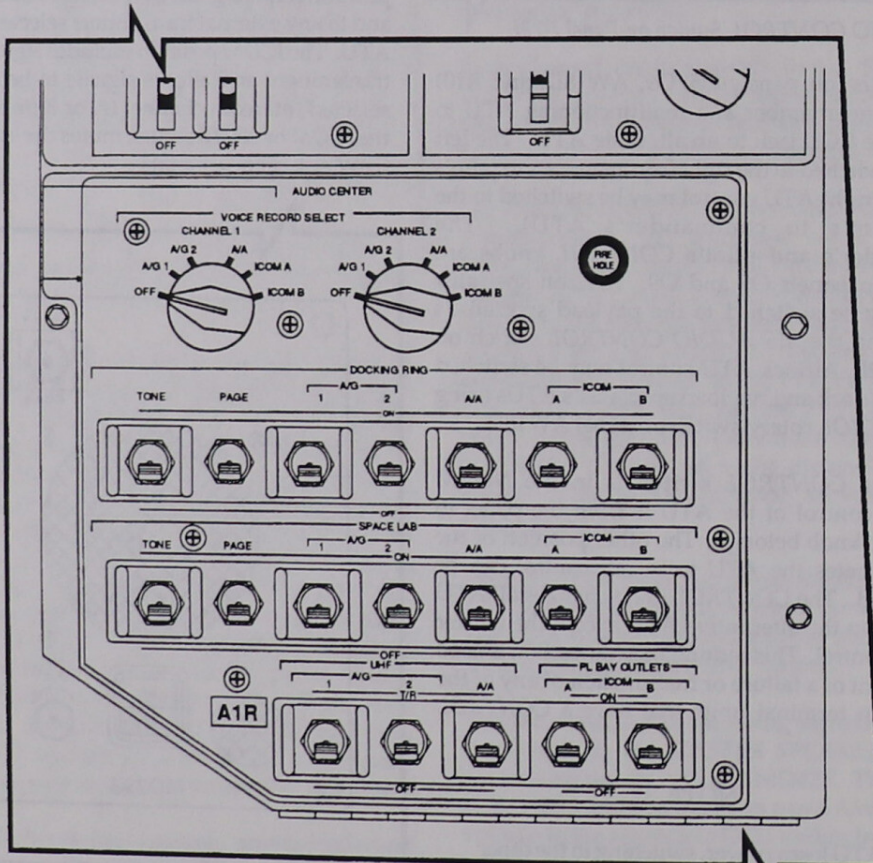
The *MIC KEY* light on the SMU panel is a two-position, adjustable-intensity light that operates in conjunction with SMU microphones. The intensity of the top half of the light is adjustable by the *MIC LEVEL* knob; the brighter the light, the louder the signal. The bottom half of the light (*KEY*) is illuminated when a PTT function is selected, and the circuit is keyed.

### Audio Center Panel

The *AUDIO CENTER* controls on panel A1R have three functions: UHF control, voice interface capability with external vehicles and the payload bay, and operations recorder selection. All switches on the panel send digital impulses to the audio central control unit, enabling the selected functions to communicate with Spacelab and the payload bay. Sets of toggle switches labeled *DOCKING RING*, *SPACE LAB*, and *PL BAY OUTLETS* electrically

connect the particular function to the audio distribution system. The *DOCKING RING* and *SPACE LAB* subpanels have seven switches to enable the following functions: *A/A*, *A/G 1*, *A/G 2*, *ICOM A*, *ICOM B*, *PAGE*, and *TONE (C/W)*. The UHF switches control *A/G 1*, *A/G 2*, and *A/A* channels to the UHF transceiver. The *PL BAY OUTLETS* subpanel has two *ON/OFF* switches, one for intercom A and one for B.

Two rotary knobs labeled *VOICE RECORD SELECT* control various audio signals to be sent to the operational recorders through the NSP. *A/G 1*, *A/G 2*, *A/A*, and *ICOM A* or *B* audio can be sent to either recorder. Any two signals may be recorded at the same time, one on channel 1 and the other on channel 2. Either channel may be turned off. Signals to the operations recorders cannot be monitored by the flight crew.



AUDIO CENTER Controls on Panel A1R

## Loose Communications Equipment

### *Launch and Entry Helmets*

During launch and entry, each flight crewmember wears a launch and entry helmet to lessen the severe noise levels encountered at launch and to allow intelligible air-to-ground communications. A headset containing microphones and earphones fits over the crewmember's head, and a connector and cable interface with the headset interface unit, connected through communications cables to respective audio terminal units. The microphones can be positioned to suit the individual crewmember. For emergency egress, a pull-away connection is used between the communications carrier assembly and headset interface unit, in addition to the standard communications carrier assembly/headset interface unit twist-on connector.

The helmets have redundant noise-canceling microphones and electrically isolated earphones. When air is inhaled, the demand breathing regulator shuts off the microphones to avoid transmitting breathing sounds.

#### NOTE

An improper face seal will cause enough oxygen flow to cut off microphones.

### *Headset Interface Unit*

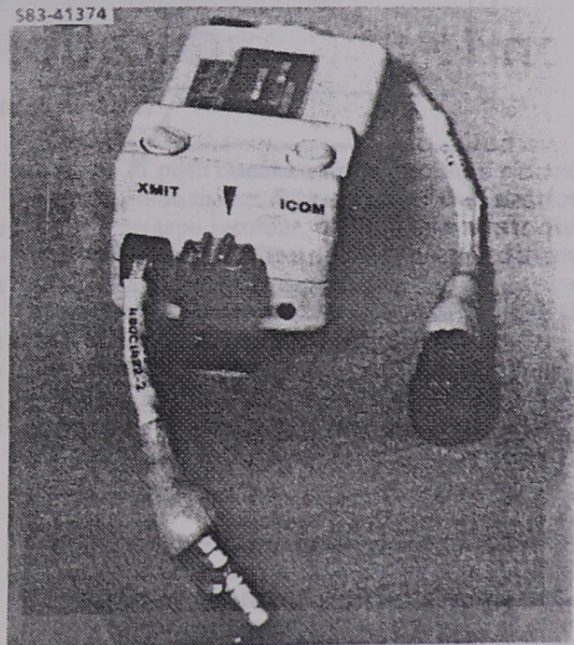
The headset interface unit has separate push-to-talk (PTT) buttons for transmit and intercom modes and a volume control that determines the level of sound heard through the earphone (microphone sound level is determined by automatic gain control circuitry within the audio terminal unit). (Push-to-talk means that a push button must be depressed to allow a crewmember to talk through the system.) The *XMIT* push button allows access to intercom and external circuits, while the *ICOM* push button is for intercom only. The volume control knob acts in series with the volume controls on the associated

audio terminal unit. In addition, the commander and pilot have PTT switches on their rotational hand controllers for the transmit mode.

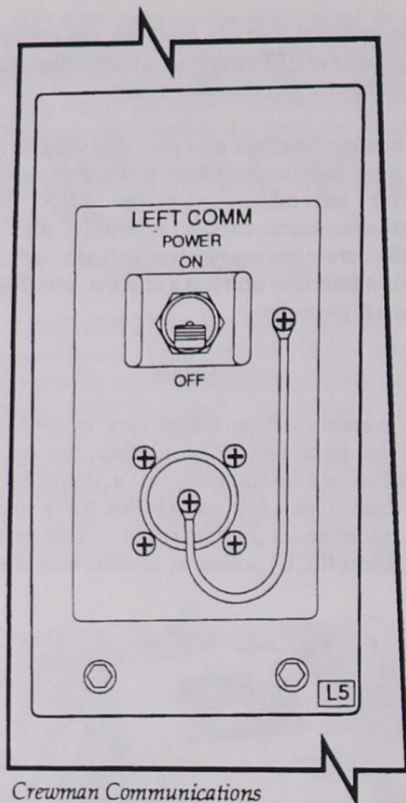
The headset interface unit provides volume control and push-to-talk capabilities to the communications carrier assembly used for EVA, to the communications carrier assembly, and to the wireless crew communication unit as a backup. The headset interface unit has a clip that attaches to the crew's flight suits.

### *Cables*

The communication cables vary in configuration depending on seat location. Each seat has two 4-foot communication cables or a 14-foot length, as required. One 4-foot cable is flown as a spare. The cables connect to crewman communications umbilical (CCU) outlets at various locations in the



*Headset Interface Unit*



Crewman Communications  
Umbilical on Panel L5

crew compartment. Each CCU has a specific audio terminal unit that controls communication loop configurations. The CCU associated with the ATU on panel O5 is located on panel L5 (*LEFT COMM*); for O9 on R6 (*RIGHT COMM*); for R10 on A11 (*MS COMM*), for L9 on A15 (*PS COMM*), and for MO42F on MO39M (*MID DECK COMM*); two others for the airlock ATU are located on panel AW82D (*CCU 1* and *CCU 2*).

Each CCU outlet has a power switch that controls the associated microphone power. Leaving CCU power off confines an individual to a listen-only mode, independent of audio terminal unit configuration.

#### Multiple Headset Adapter

A multiple headset adapter may be plugged into the CCU outlets. The three CCU outlets on the adapter allow up to three crewmembers to share

one CCU outlet. When any one person connected to a multiple headset adapter keys (in PTT mode) or activates the voice-operated transmitter, all three individuals' microphones will be keyed, and individuals sharing the multiple headset adapter will hear each other talking only on side tone.

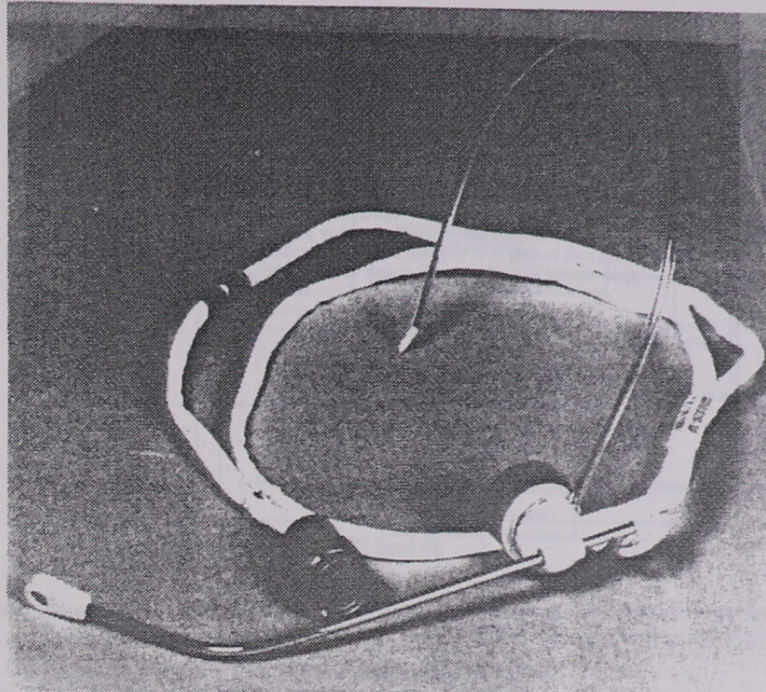
#### Wireless Communications Units

On orbit, the crew may use wireless communication units in place of headsets or communication cables. A wireless unit consists of one wall unit (audio interface unit) and two leg units (crew remote units) worn by crewmembers during orbital operations. The wall unit connects to a CCU outlet and remains attached to the crew compartment wall. Each wall unit transmits on a unique pair of UHF frequencies. Leg units may be configured to work with any wall unit. Each wall unit is identified by a letter enclosed in a box. Each unit is stowed with its cabling attached. The wall unit has a 23-inch cable to interface with the CCU outlet, and the leg unit has a 22-inch cable attached to a lightweight headset.

#### NOTE

A loud squeal may occur during voice transmissions if two leg units are set to use the same frequency.

When the wireless unit is unstowed, part of the assembly necessary is to insert and tighten the flexible antenna in the bottom of each wall and leg unit. The wall unit receives power from the CCU outlet. The *MASTER VOL CONTROL* is set to full volume. All other switches are set as required; typically, the individual communication loops are used. The leg unit is stowed with battery pack installed and is attached to the crewmember's leg with a wraparound elastic strap. The rotary *ON/OFF/VOLUME* knob (unlabeled) is turned clockwise past the *ON/OFF* detent, and the volume is set as desired. Batteries are changed by depressing the battery pack latch push button lever (unlabeled) and sliding the battery pack off the unit. Expected use from one battery is 3 days (with the unit turned off during sleep periods). Sliding the new battery pack into the unit causes both the electrical connector and mechanical connector to latch.



*Very Lightweight Headset*

#### *Very Lightweight Headset*

The very lightweight headset is the interface between the leg unit and crewmember. A single-strand wire headband holds the earphone against the ear and supports a thin boom holding a noise-canceling microphone near the mouth. A cable and connector are attached to the crewmember's leg unit. The lightweight headset cable and connector also can interface with the headset interface unit.

#### *Handheld Microphone*

The handheld microphone is a noise-canceling microphone that connects directly to any CCU outlet. The microphone is used primarily with the SMUs located at panels A2 and MO29J. To avoid feedback when using the speakers, one ATU and its corresponding CCU outlet on the aft flight deck and one ATU and associated CCU on the middeck are equipped with a speaker muting capability. On OV103, OV104, and subsequent vehicles, muting is controlled through ATUs at panels R10 and MO42F. On OV102, the muting ATUs are located at panels A13 and MO42F.

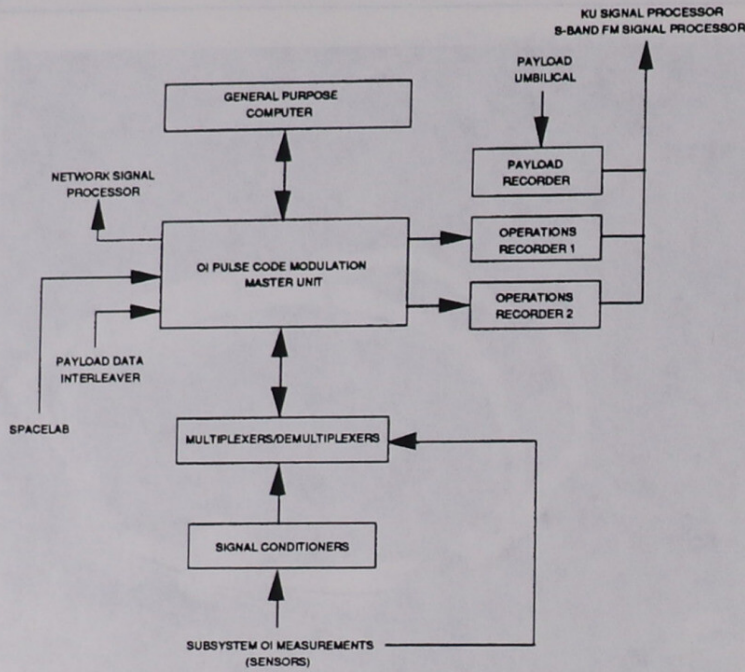
Two PTT push buttons are provided for XMIT and ICOM audio modes. When used to record audio on the videotape recorder, either can be used. The push buttons should face the operator to ensure that the noise-canceling feature of the microphone remains functional. The handheld microphone is equipped with a 7-foot cable that can connect at any CCU or to other cables. The microphone/SMU configuration is used as an alternative on-orbit communication configuration.

#### **Instrumentation**

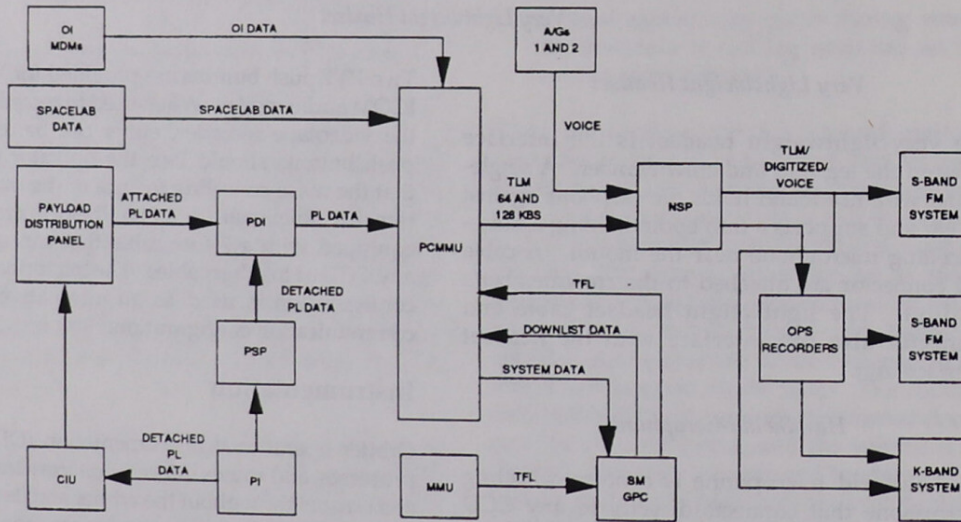
Orbiter operational instrumentation (OI) collects, processes, and routes information from transducers and sensors throughout the orbiter and its payloads. More than 3,000 data parameters are monitored.

The instrumentation system consists of transducers, signal conditioners, MDMs, two pulse code modulation master units, two operational recorders, one payload recorder, master timing equipment, and onboard checkout equipment.





*Simplified Instrumentation Data Flow*



- |                                    |   |
|------------------------------------|---|
| A/G — Air-to-Ground                | PCMMU — Pulse Code Modulation Master Unit |
| CIU — Communication Interface Unit | PDI — Payload Data Interleaver            |
| GPC — General Purpose Computer     | PI — Payload Interrogator                 |
| MDM — Multiplexer/Demultiplexer    | PL — Payload                              |
| MMU — Mass Memory Unit             | PSP — Payload Signal Processor            |
| NSP — Network Signal Processor     | SM — Systems Management                   |
| OI — Operational Instrumentation   | TFL — Telemetry Format Load               |
| OPS — Operations                   | TLM — Telemetry                           |

*Operational Instrumentation System Overview*

Area	Characteristics
Signal Conditioning	<ul style="list-style-type: none"> <li>• 13 DSCs conditioning approximately 1,200 channels</li> <li>• Six WBSC to MDM</li> <li>• Approximately 45 high-level transducers</li> <li>• Distributes data to PCM data system, panel displays, C/W, flight-critical MDMs</li> </ul>
PCM Data System	<ul style="list-style-type: none"> <li>• Acquires data through seven OI MDMs, approximately 2,800 measurements</li> <li>• Receives and provides data to five computers</li> <li>• Accepts payload data through PDI or payload data bus (Spacelab)</li> <li>• Provides output data in 64- and 128-kbps formats</li> <li>• Provides synchronization to PDI and NSP</li> <li>• Provides data to NSP and T-O umbilical</li> </ul>
Payload Data Recorders	<ul style="list-style-type: none"> <li>• Receives data directly from payload or PLSP</li> <li>• Provides data to GPCs and PCM</li> <li>• Stores three channels of engine data at 60-kbps rate</li> <li>• Stores interleaved voice and data at 96, 128 or 192 kbps rates</li> <li>• Stores payload data</li> </ul>
Master Timing	<ul style="list-style-type: none"> <li>• Provides for playback of recorded data during and after mission</li> <li>• Provides time reference to computers, OI PCM, display panel and payload</li> <li>• Provides synchronization to instrumentation and other subsystems</li> </ul>

### OI System

The OI system senses, acquires, conditions, digitizes, formats, and distributes data for display, telemetry, recording, and checkout. It provides for pulse code modulation recording, voice recording, and master timing for onboard systems.

Instrumentation equipment, except sensors and selected dedicated signal conditioners, is located in the forward and aft avionics bays. Sensors and dedicated signal conditioners are located throughout the orbiter in areas selected on the basis of accessibility, minimum harness requirements, and functional requirements. Abbreviations used to designate the locations of equipment are as follows: OA refers to operational aft, OF to operational forward, OL to operational left, OR to operational right, and OM to operational mid.

#### Dedicated Signal Conditioners

Dedicated signal conditioners convert digital and analog data signals received from the various sensors to a usable form. Some raw sensor data may need to be conditioned for compatibility with a multiplexing system. Signal conditioning provides the multiplexer with compatible inputs. The signal conditioners provide input from transducer signals such as frequency, voltage, current, pressure, temperature (variable resistance and thermocouple), displacement (potentiometer), 28- or 5-volt-dc discrete output signals, analog and digital level changes, polarity changes, or an ac signal change to

a dc signal. The conditioners send these converted signals to the appropriate MDMs, displays, and the C/W system.

#### Multiplexer/Demultiplexers (MDMs)

MDMs can operate in two ways. As multiplexers, they take data from several sources, convert the data to serial digital signals (a digitized representation of the applied voltage), and interleave the data into a single data stream. As demultiplexers, the MDMs take interleaved serial digital information, separate and convert it to analog, discrete, or serial digital, and send each separate signal to its appropriate destination. The payload MDMs generally act as demultiplexers. They take interleaved commands from the orbiter GPCs, separate them, and send each command to its appropriate destination, such as payload ground command interface logic.

The OI MDMs generally act only as multiplexers. Upon request from the pulse code modulation master unit (PCMMU), the MDMs send these interleaved streams to the PCMMU through the OI data buses. When the MDM is addressed by the PCMMU, the MDM selects, digitizes, and sends the requested data to the PCMMU in serial digital form. The PCMMU/OI MDM interface is based on demand and response; that is, the OI MDMs do not send data to the PCMMU until the PCMMU makes the request.

### Pulse Code Modulation Master Unit (PCMMU)

The PCMMU receives data requested from the OI MDMs, downlist data from the GPCs under control of flight software, and payload telemetry from the payload data interleaver and Spacelab computers. It then interleaves the data, formats data according to programmed instructions stored within the PCMMU (the telemetry format load, or TFL), and sends the interleaved data to the network signal processor to be combined with the analog air-to-ground voice data from the audio central control unit for transmission through the S-band PM downlink or Ku-band system return link. Telemetry from the PCMMU is also sent through the network signal processor to the operational recorders for storage and subsequent downlink on the S-band FM or Ku-band system. OI and payload data collected by the PCMMU are sent to the GPCs for display and monitoring purposes upon request. All data received by the PCMMU are stored in memory and periodically updated.

The PCMMU has two formatter memories: programmable read only and random access. The read-only memory is programmed only before launch; the random-access memory is reprogrammed several times during flight. The PCMMU uses the format memories to load data from the computers and OI MDMs into PCM telemetry data streams.

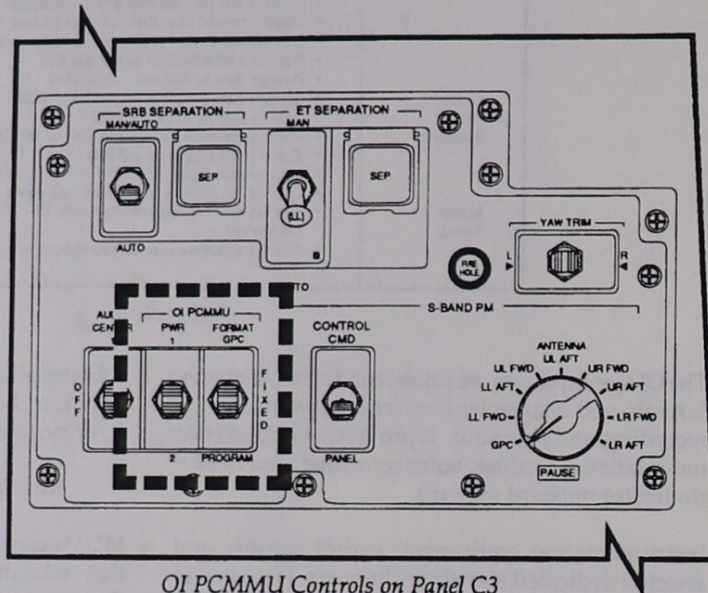
#### NOTE

When the PCMMU is powered off (as when switching to the alternate unit), the telemetry format load changes to the fixed format loaded in read only memory.

One of the two redundant PCMMUs and network signal processors operates at a time. The one used is controlled by the crew through the flight deck display and control panel. The primary port of each MDM operates with PCMMU 1 and the secondary port operates with PCMMU 2.

The PCMMUs receive a synchronization clock signal from the master timing unit. If this signal is not present, the PCMMU provides its own timing and continues to send synchronization signals to the payload data interleaver and network signal processor.

The OI PCMMU controls are located on panel C3.



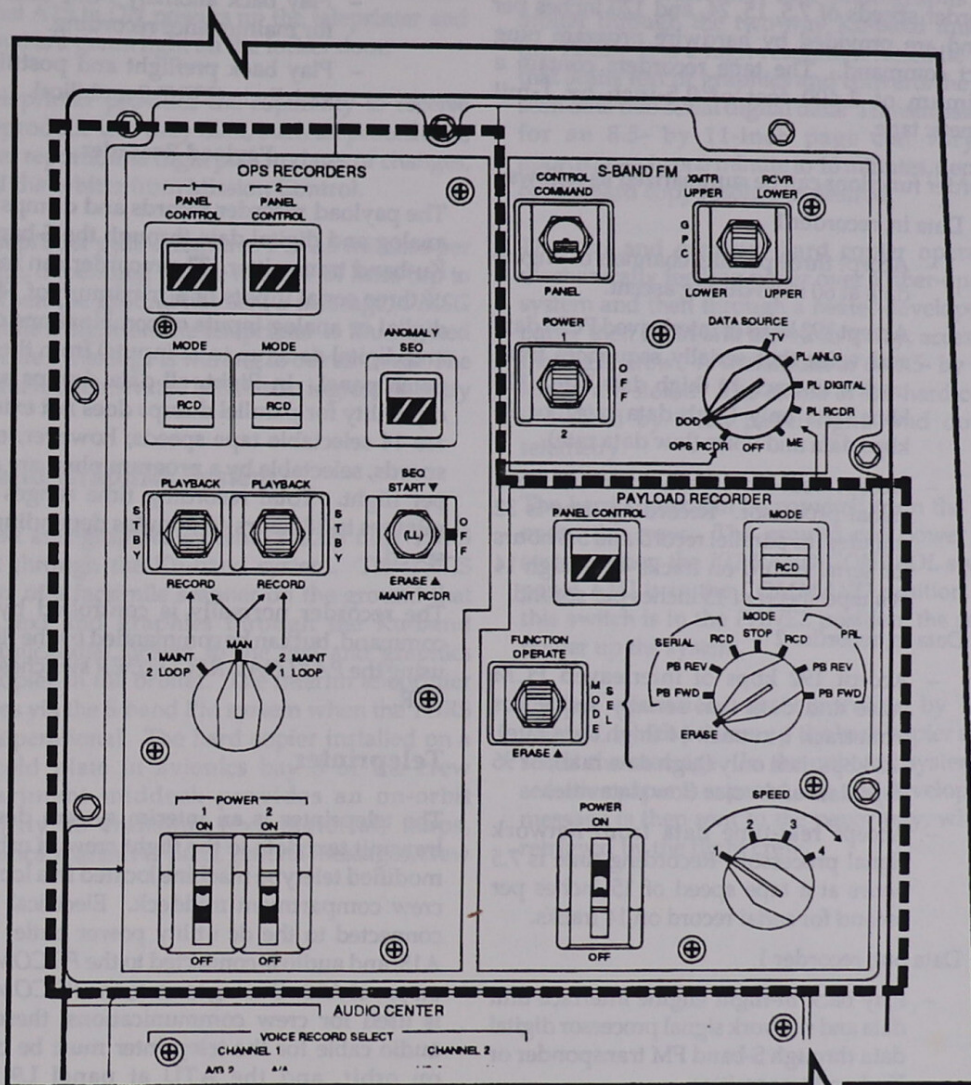
OI PCMMU Controls on Panel C3

### Master Timing Unit

The master timing unit is a stable crystal-controlled timing source. It provides synchronization for instrumentation, payloads, and other systems. The master timing unit is described in more detail in Section 2.6.

### Operations Recorders

Two recorders are used for serial recording and dumping of digital voice and pulse code modulation (PCM) data from the OI systems. The recorders normally are controlled by ground command, but they can be commanded by the flight crew through the flight deck display and control panel keyboard or through the OPS RECORDERS switches on panel A1R or commanded via uplink. The input to the recorders is from the network signal processor, in the form of either 128-kbps PCM data or a 192-kbps



Recorder Controls on Panel A1R

composite signal that includes the 128-kbps PCM data and two 32-kbps voice channels. In addition, during ascent, operations recorder 1 receives three channels of main engine data at 60 kbps.

The operations recorders can be commanded to dump recorded data from one recorder while continuing to record real-time data on the other. The dump data are sent to the FM signal processor

for transmission to the ground station through the S-band FM transmitter on the S-band FM return link or to the Ku-band signal processor. When the ground has verified that the received data are valid, the operations recorders can use that track on the tape to record new data. If ground is controlling recorders, the crew cannot, unless ground sets a "crew reset" command or its equivalent from SPEC 1.

Recorder speeds of 7.5, 15, 24, and 120 inches per second are provided by hardwire program plug direct command. The tape recorders contain a minimum of 2,400 feet of 0.5-inch by 1-mil magnetic tape.

Recorder functions can be summarized as follows:

- Data in, recorder 1
  - Accept three parallel channels of engine data at 60 kbps during ascent.
  - Accept 192 kbps of interleaved PCM data and voice that serially sequences from track 4 to track 14 (high data rate), 128 kbps data only (high data rate), or 96 kbps data and voice (low data rate).
  - Accept real-time data from network signal processor. Recording time is 32 minutes for parallel record and 5.8 hours for serial record on tracks 4 through 14 at a tape speed of 15 inches per second.
- Data in, recorder 2
  - Accept 192 kbps of interleaved PCM voice and data that serially sequences from track 1 to track 14 (high data rate), 128 kbps data only (high data rate), or 96 kbps data and voice (low data rate).
  - Accept real-time data from network signal processor. Recording time is 7.5 hours at a tape speed of 15 inches per second for serial record on 14 tracks.
- Data out, recorder 1
  - Play back in-flight engine interface unit data and network signal processor digital data through S-band FM transponder or Ku-band transmitter.
  - Play back in-flight anomaly PCM data for maintenance recording.
  - Play back data serially to ground support equipment to T-0 ground support equipment umbilical.
- Data out, recorder 2
  - Play back digital data through S-band FM transponder or Ku-band transmitter in flight.

- Play back anomaly PCM data in flight for maintenance recording.
- Play back preflight and postflight data serially to GSE T-0 umbilical.

#### Payload Recorder

The payload recorder records and dumps payload analog and digital data through the S-band FM or Ku-band transmitter. The recorder can record one of three serial inputs or a maximum of 14 parallel digital or analog inputs or combinations of analog and digital data (up to 14 inputs) from the payload patch panel. In flight, all data dumps are serial; capability for parallel dumps does not exist. There are 14 selectable tape speeds; however, only four speeds, selectable by a program plug, are available per flight. Total recording time ranges from 56 minutes to 18 hours 40 minutes depending on tape speed.

The recorder normally is controlled by ground command, but can be commanded by the flight crew using the *PAYLOAD RECORDER* switches on panel A1R.

#### Teleprinter

The teleprinter is an interim system designed to transmit text data to the flight crew in orbit. It is a modified teletype machine located in a locker in the crew compartment middeck. Electrical power is connected to the dc utility power outlet on panel A15, and audio is connected to the *PS COMM* outlet on panel A15. During launch, the *PS COMM* outlet is used for crew communications; therefore, the audio cable for the teleprinter must be connected on orbit, and the ATU at panel L9 must be reconfigured on orbit for teleprinter support. The panel L9 *PAYLOAD STATION AUDIO POWER* switch is positioned to *AUD*, *A/G 1* is positioned to *OFF*, *A/G 2* is positioned to *T/R*, the *VOLUME* thumbwheel is positioned to *9*, *A/A* is positioned to *OFF*, the two *ICOM* switches are positioned to *OFF*, and the *XMIT/ICOM MODE* rotary switch is positioned to *PTT/PTT*. The *POWER* switch on the teleprinter locker door is in the *ON* position at

launch. Turning the *DC UTILITY POWER* switch on panel A15 to *ON* powers up the teleprinter and illuminates a green light on the locker door.

The teleprinter provides the capability to receive and reproduce text-only data, such as procedures, weather reports, and flight plan updates or changes, aboard the orbiter from Mission Control.

The teleprinter uplink requires 1 to 2.5 minutes per message, depending on the number of lines (up to 66). When the ground has sent a message, a *MSG RCV* yellow light on the teleprinter is illuminated to indicate a message is waiting to be removed. The teleprinter is deactivated before seat ingress on entry day.

### Text and Graphics System

The text and graphics system (TAGS) uses TDRS uplink through the Ku-band system. The TAGS consists of a facsimile scanner on the ground that sends text and graphics through the Ku-band communications system to the text and graphics hard copier in the orbiter. The interim teleprinter operates via the S-band PM system when the TDRS is not operational. The hard copier installed on a dual cold plate in avionics bay 3 of the crew compartment middeck provides an on-orbit capability to transmit text material, maps, schematics, maneuver pads, general messages, crew

procedures, trajectory, and photographs to the orbiter through the two-way Ku-band link using the TDRS. It is a high-resolution facsimile system that scans text or graphics and converts the analog scan data into serial digital data. Transmission time for an 8.5- by 11-inch page can vary from approximately one minute to 16 minutes, depending on the hard copy resolution desired.

The text and graphics hard copier operates by mechanically feeding paper over a fiber-optic CRT system and then through a heater-developer. The paper then is cut and stored in a tray, accessible to the flight crew. A maximum of 60 8.5- by 11-inch sheets are stored. The status of the hard copier is indicated by front panel lights and downlink telemetry.

The hard copier can be powered from the ground or by the crew. The ground can power up the system when the *KU-BAND CONTROL* switch on panel A1U is in the *COMMAND* position. When this switch is in the *PANEL* position, the crew can power up the system.

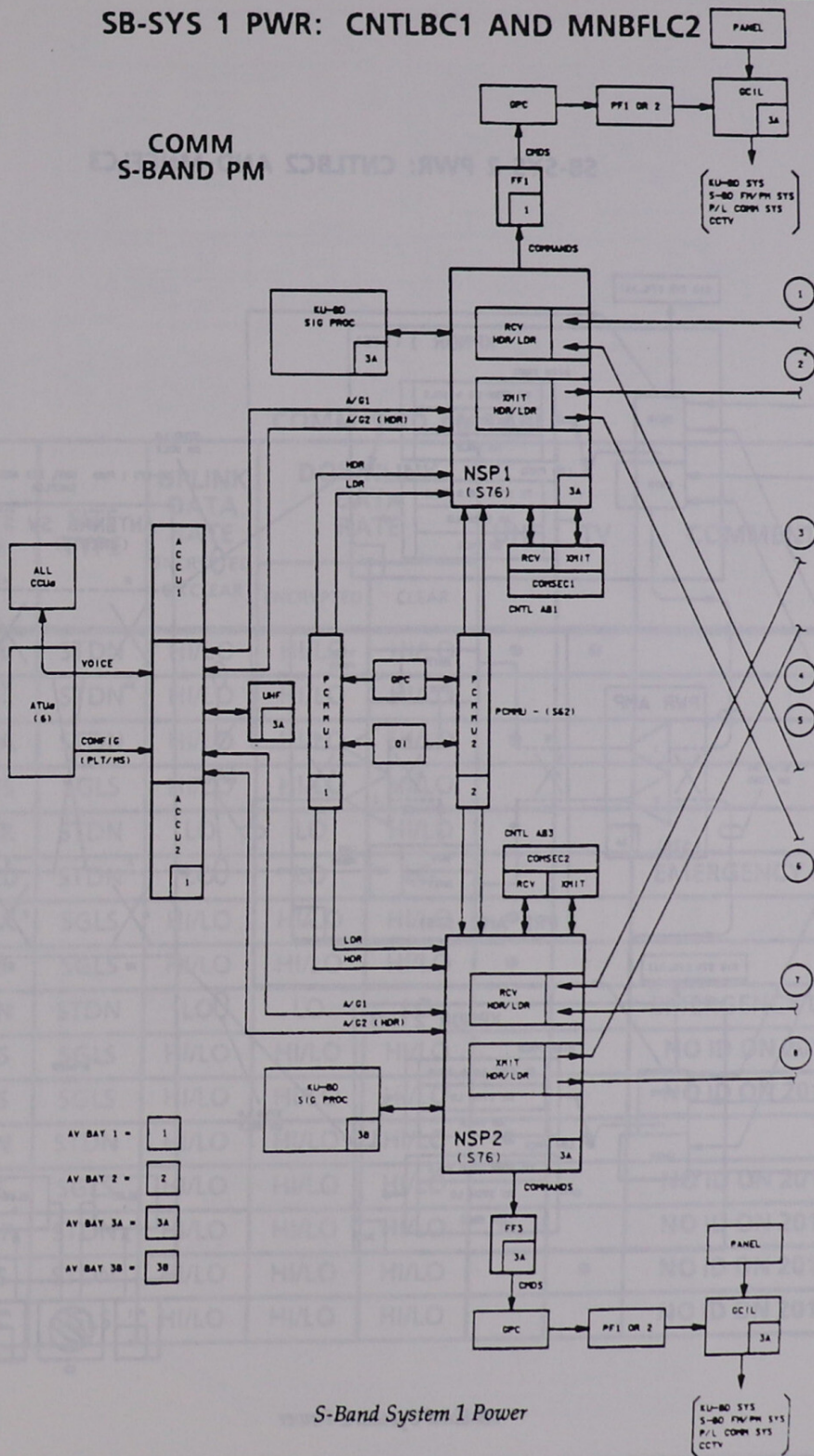
Uplink operations are controlled by Mission Control, which powers up the hard copier and then sends the message. In the onboard system, light-sensitive paper is exposed, cut, and developed. The message is then sent to the paper tray, where it is retrieved by the flight crew.

### Communications System Summary

- The orbiter communications system transfers information between the orbiter and the ground, either through hardline or radio frequency links.
- The system is divided into several smaller systems: S-band phase modulation, S-band frequency modulation, Ku-band, UHF, payload communications, audio, and CCTV.
- The S-band PM system provides two-way communication between the orbiter and the ground, through either an STDN/SGLS ground station or a relay satellite. It provides channels for five functions: command, voice, telemetry, turnaround tone ranging, and two-way Doppler tracking.
- Four quadrant S-band antennas provide a selection of eight directions.
- The S-band FM system cannot receive information. It is used to downlink data directly to the ground from seven different sources: SSME interface units, the video switching unit, the operations recorder, the payload recorder, payload analog, or payload digital.
- There are two hemispherical S-band FM antennas.
- The Ku-band system provides for on-orbit communication between the orbiter and the ground. It can also be used as a radar system for tracking objects in space.
- The Ku-band antenna is deployed when the payload bay doors are opened, and stowed when they are closed. The antenna is steerable.
- TV data can be downlinked over Ku-band and S-band FM only.
- The payload communication system is used to transfer information between the orbiter and its payloads.
- The UHF system is used as a backup for the S-band PM and Ku-band voice communications. UHF is used as the primary communications link with EVA astronauts.
- The audio distribution system gathers audio signals from multiple sources and routes them throughout the orbiter. It may be used as a means by which crewmembers communicate with each other.
- The major elements of the audio distribution system are: the ACCU, ATU, SMU, audio center, CCU, and loose communications equipment.
- Orbiter operational instrumentation (OI) collects, routes, and processes information from transducers and sensors throughout the orbiter and its payloads.
- The OI system consists of transducers, signal conditioners, two pulse code modulation master units, encoding equipment, two operations recorders, one payload recorder, master timing unit, and onboard checking equipment.
- Additional communication equipment includes a teleprinter and a text and graphics system.
- Major communications equipment and control panels are A1R, A1U, A1L, R13L, O5, O6, O9, R10, L9, and R11. Others are found on panels A13, A14, A15, L5, F9, C3, R12L, R15, MO29J, MO42F, and AW18D.
- Specific communications system CRTs are OPS 201 ANTENNA, COMM/RCDR (DISP 76), and PC MMU/PL COMM (SPEC 62).

SB-SYS 1 PWR: CNTLBC1 AND MNBFLC2

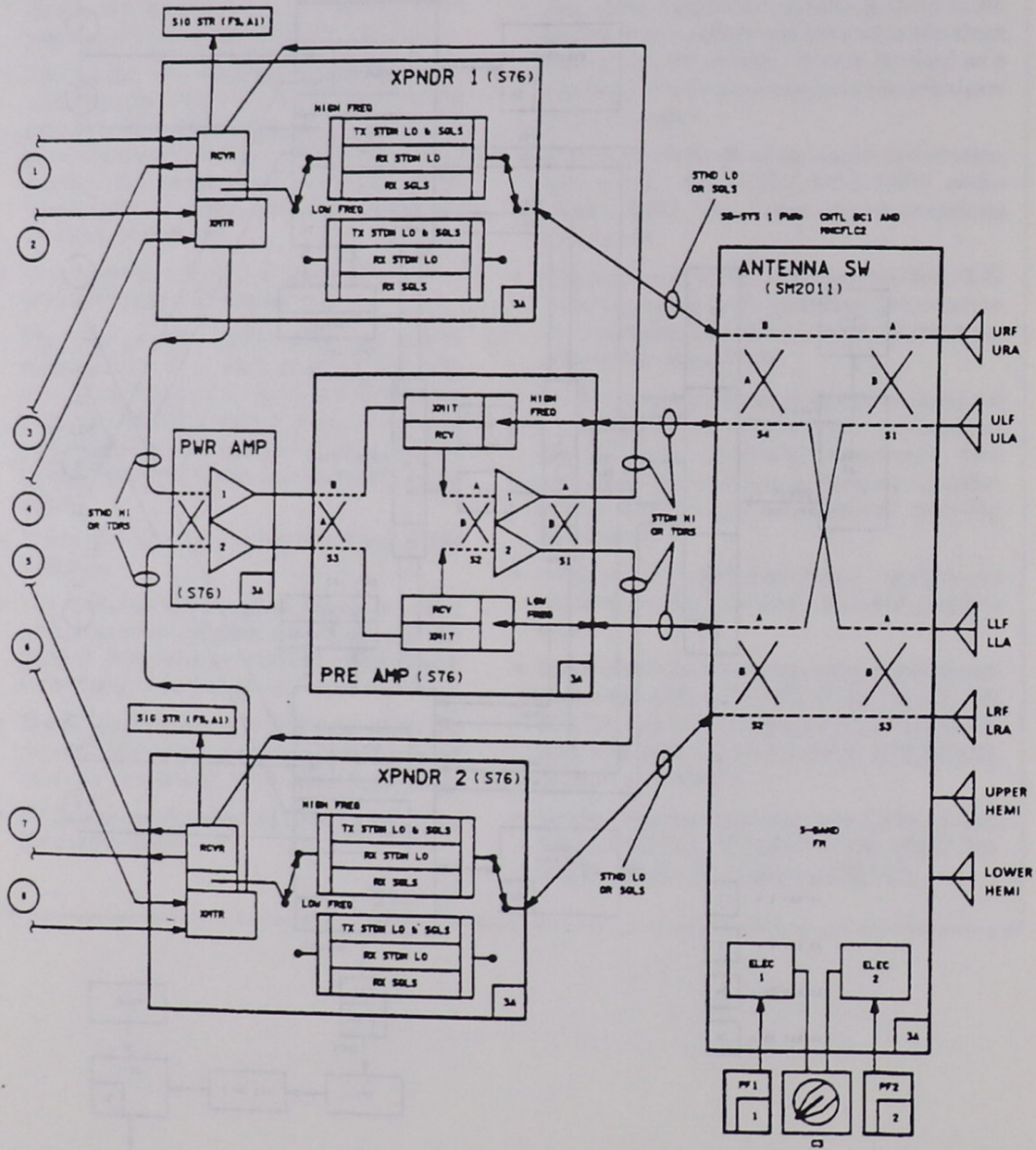
COMM  
S-BAND PM



S-Band System 1 Power



SB-SYS 2 PWR: CNTLBC2 AND MNCFLC3

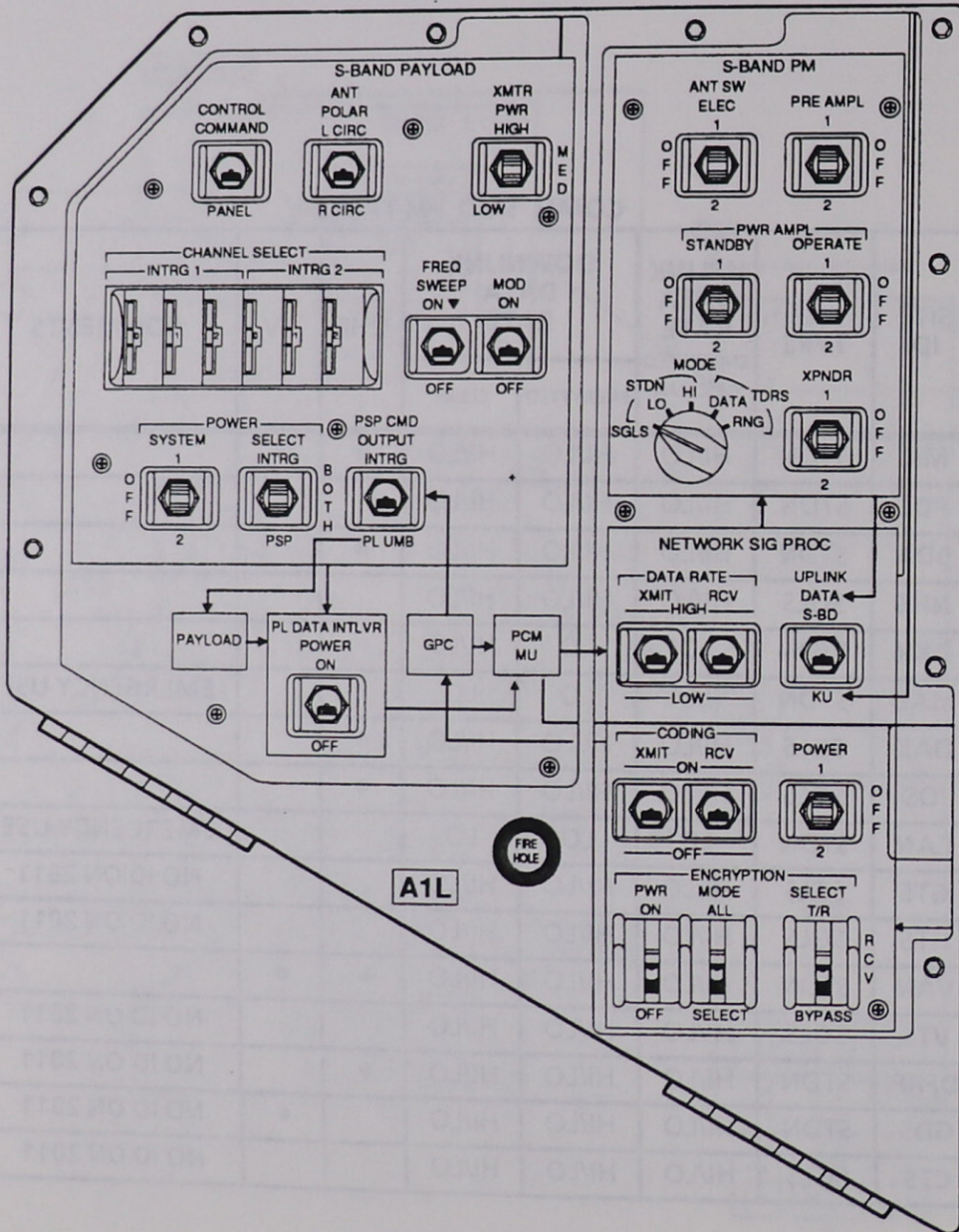


S-Band System 2 Power

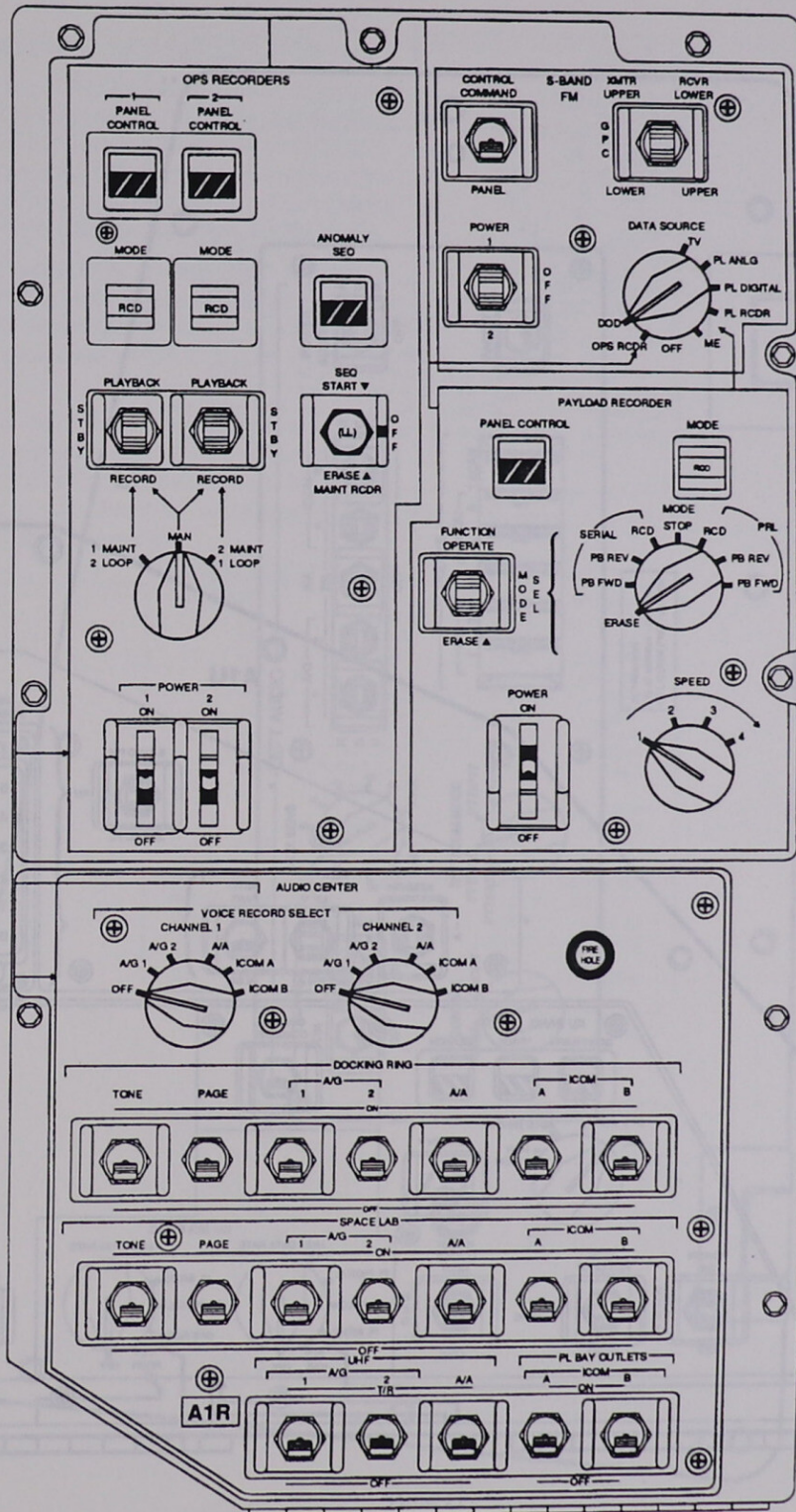
COMM S-BD PM TABLE

SITE ID	SITE TYPE	UPLINK DATA RATE ENCRYPTED OR CLEAR	DOWNLINK DATA RATE		UHF	TV	COMMENTS
			ENCRYPTED	CLEAR			
MIL	STDN	HI/LO	HI/LO	HI/LO	•	•	
PDL	STDN	HI/LO	HI/LO	HI/LO			
BDA	STDN	HI/LO	HI/LO	HI/LO	•		
NHS	SGLS	HI/LO	HI/LO	HI/LO			
DKR	STDN	LO	LO	HI/LO	•		
MAD	STDN	LO	LO	LO			EMERGENCY USE
OAK	SGLS	HI/LO	HI/LO	HI/LO	•		
IOS	SGLS	HI/LO	HI/LO	HI/LO	•		
CAN	STDN	LO	LO	LO			EMERGENCY USE
GTS	SGLS	HI/LO	HI/LO	HI/LO			NO ID ON 2011
HTS	SGLS	HI/LO	HI/LO	HI/LO			NO ID ON 2011
VAN	STDN	HI/LO	HI/LO	HI/LO	•	•	
VTS	SGLS	HI/LO	HI/LO	HI/LO			NO ID ON 2011
DFRF	STDN	HI/LO	HI/LO	HI/LO	•		NO ID ON 2011
GDS	STDN	HI/LO	HI/LO	HI/LO		•	NO ID ON 2011
CTS	SGLS	HI/LO	HI/LO	HI/LO			NO ID ON 2011

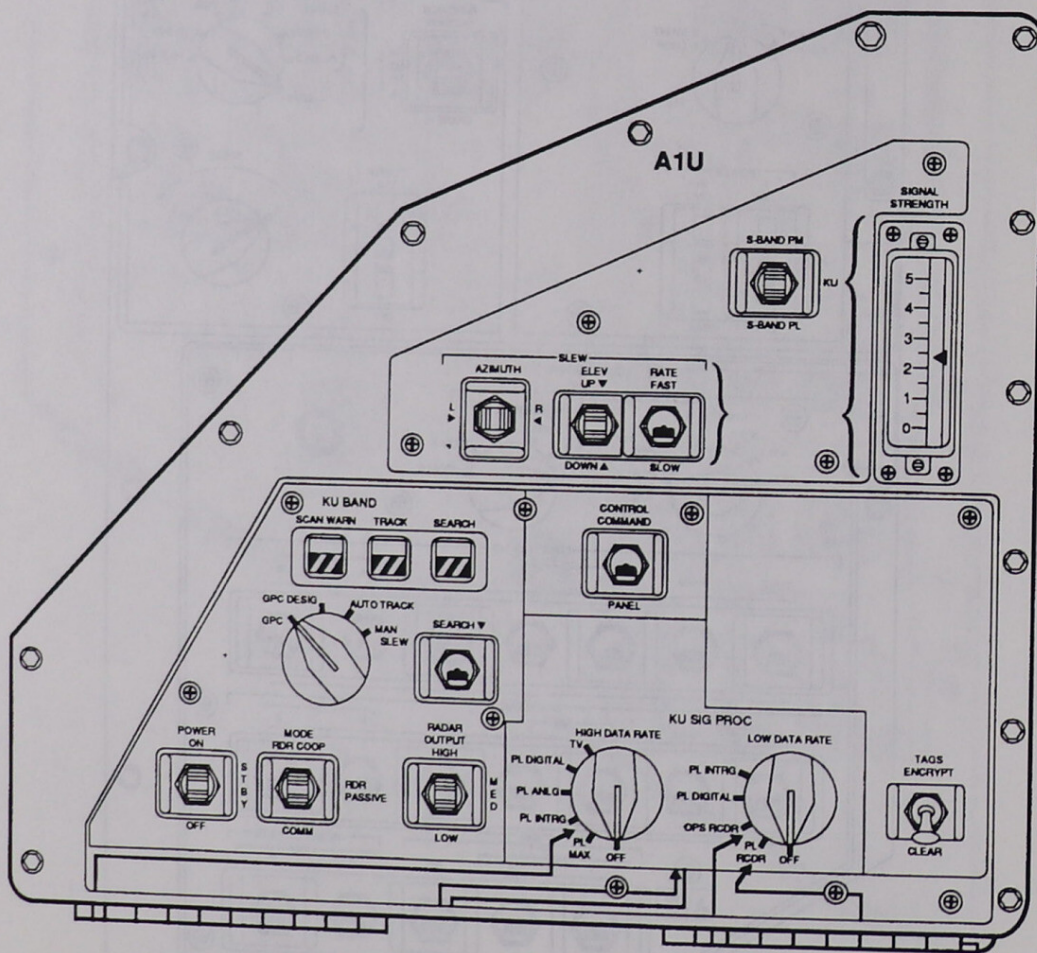
S-Band PM Table

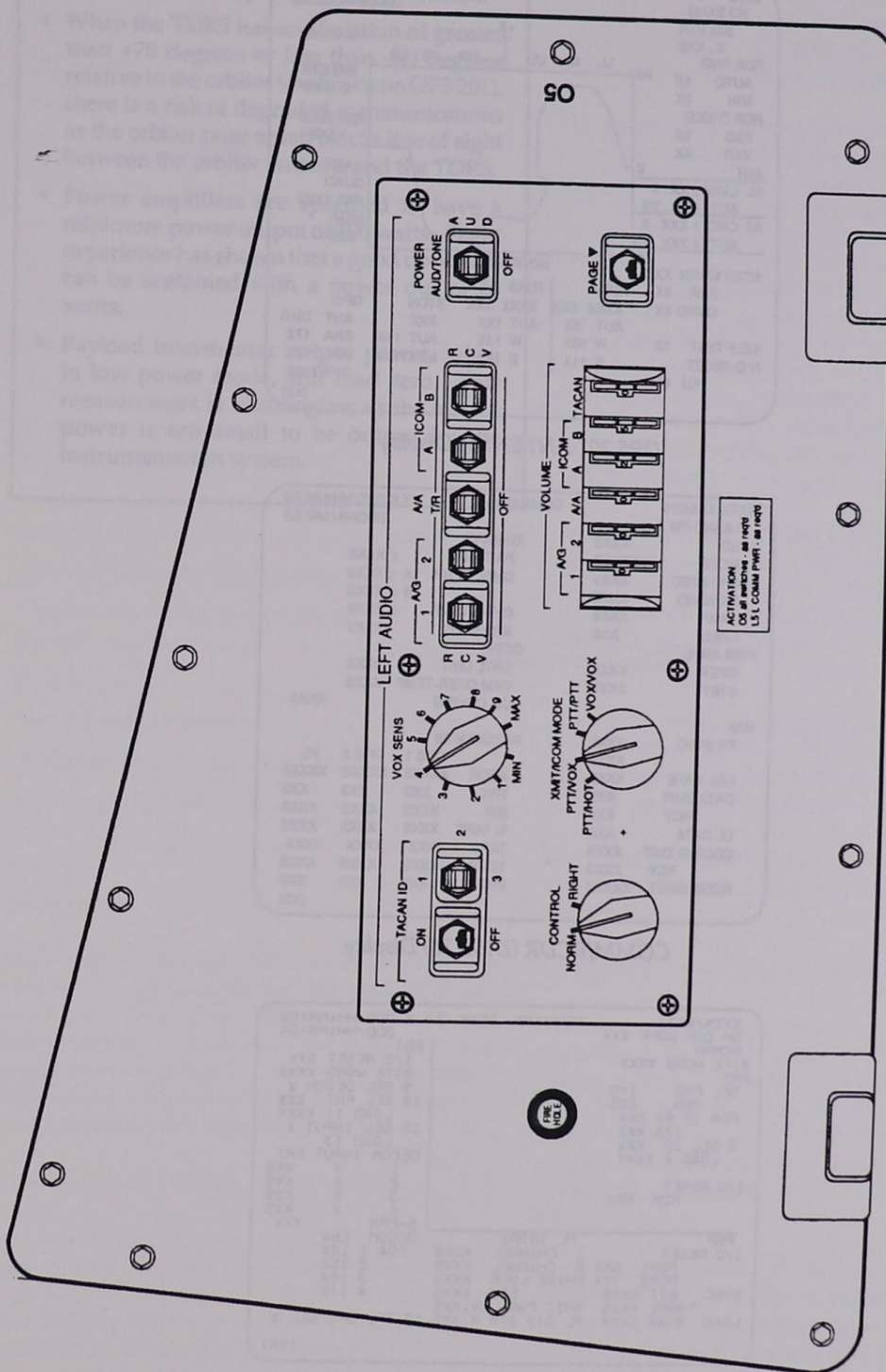


Panel A1L

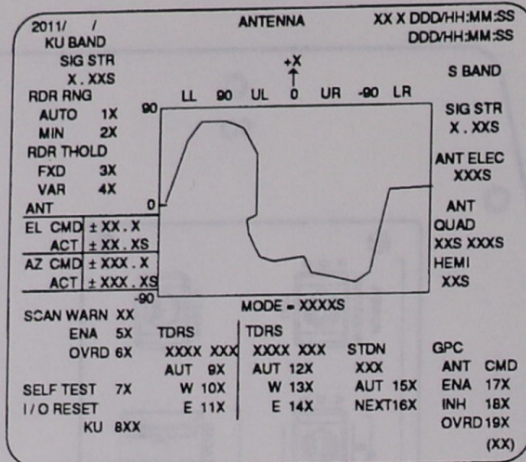


Panel A1R

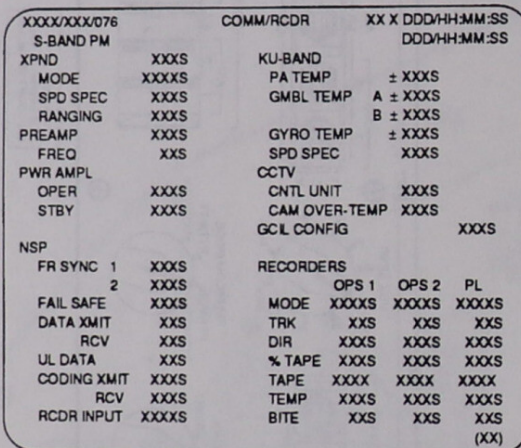




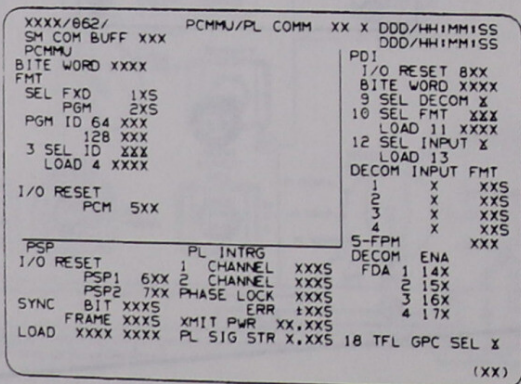
Panel O5



OPS 201 ANTENNA Display



COMM/RCDR (DISP 76) Display



PCMMU/PL COMM Display (SPEC 62)

**Communications System Rules of Thumb**

- When the TDRS has an elevation of greater than +70 degrees or less than -60 degrees relative to the orbiter (as shown on OPS 201), there is a risk of degraded communications as the orbiter nose or tail blocks line of sight between the orbiter antenna and the TDRS.
- Power amplifiers are specified to have a minimum power output of 100 watts. Flight experience has shown that a good downlink can be sustained with a power out of 65 watts.
- Payload interrogator output power, when in low power mode, will read zero. This measurement is meaningless as the output power is too small to be output by the instrumentation system.

Swallow Counter Medical System ..... 2-10

Operational Instrumentation System ..... 2-11

Crew ..... 2-12

Survival Equipment ..... 2-14

Air Quality System ..... 2-15

Air Sampling System ..... 2-16

**Description**

Several types of equipment and systems that the crew uses are not covered in other sections of this manual, since they are not necessarily part of any of the larger systems. These items and systems, which focus on crew efficiency and comfort, are discussed in this section. Where appropriate, operations are described within each separate subject area.

**Crew Clothing/Worn Equipment**

The crew clothing/worn equipment consists of items that provide for the personal needs of all crewmembers. Prior to each flight, crewmembers select clothing and worn equipment from a list of required and optional flight equipment.

During launch and entry, crewmembers wear the launch/entry suit (LES), which consists of a helmet, communications cap, pressure garment, gloves, boots, and anti-exposure, anti-gravity suit.

The parachute harness is worn over the LES during launch and entry. The harness provides attachment points for the personal parachute assembly (PPA) and carries the life preserver unit, rescue container, emergency oxygen supply, and survival water. The PPA has automatic and manual parachute deployment capabilities for the pilot, drogue, and main canopy chutes, and carries the UHF-33 radio beacon and life raft. Survival equipment is carried in the pocket packs. The survival equipment consists of a signal mirror, strobe light, pen/gun flare kit, day/night flares, PBC radio beacon, chem lights, motion sickness pills, and survival rations. The PPA is covered in more detail in Section 2.10.

On orbit, optional clothing and equipment include underwear, urine collection device, sunglasses, communications headset, canteen bag, flashlight, Swiss army knife, keyboard, pens and pencils, storage bags, watches, and food and drink containers.

Crew clothing and equipment used during on-orbit activities include flight suits, canteens, jackets, shirts, slacks, shorts, soft slippers, underwear, shoes, underwear, pocket downies, and pocket food.

Crew clothing is designed for use by 90 percent of the male and female population, the 5th to 95th percentiles.

**Personal Hygiene Provisions**

Personal hygiene and grooming provisions are furnished for both male and female flight crewmembers. Ample water for washing comes from a personal hygiene unit (PHU) attached to the galley auxiliary port. Other personal hygiene provisions are stored in ratcheted lockers and/or the ratchet storage bag at launch and are removed for use on orbit.

A personal hygiene kit is furnished for each crewmember for brushing teeth, hair care, shaving, nail care, etc. A kit is also furnished with undergarments for women, hygiene and grooming.



## 2.5 CREW SYSTEMS

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### Description

Several types of equipment and systems that the crew uses are not covered in other sections of this manual, since they are not necessarily part of any of the larger systems. These items and systems, which focus on crew efficiency and comfort, are discussed in this section. Where appropriate, operations are described within each separate subject area.

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The parachute harness is worn over the LES during launch and entry. The harness provides attach points for the personal parachute assembly (PPA) and carries the life preserver unit, rescue carabiner, emergency oxygen supply, and survival water. The PPA has automatic and manual parachute deployment capabilities for the pilot, drogue, and main canopy chutes, and carries the URT-33 radio beacon and life raft. Survival equipment is carried in leg pocket packs. The survival equipment consists of a signal mirror, strobe light, pen gun flare kit, day/night flare, PRC radio beacon, chem lights, motion sickness pills, and survival mittens. The PPA is covered in more detail in Section 2.10.

On orbit, optional clothing and equipment include underwear, urine collection devices, eyeglasses, communications headset, emesis bag, flashlight, Swiss army knife, kneeboard, pens and pencils, stowage bags, watches, and food and drink containers.

Crew clothing and equipment used during on-orbit activities include flight suits, trousers, jackets, shirts, sleep shorts, soft slippers, underwear, scissors/lanyard, pocket dosimeter, and pocket food.

Crew clothing is designed for use by 90 percent of the male and female population, the 5th to 95th percentile.

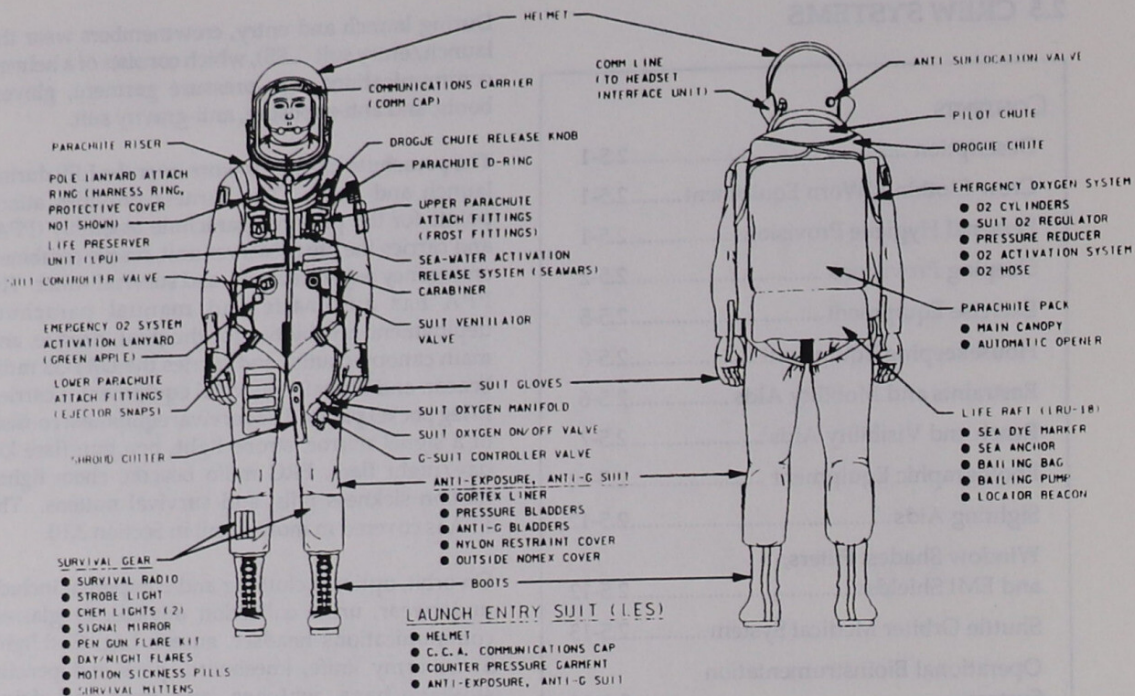
### Personal Hygiene Provisions

Personal hygiene and grooming provisions are furnished for both male and female flight crewmembers. Ambient water for washing comes from a personal hygiene hose (PHH) attached to the galley auxiliary port. Other personal hygiene provisions are stowed in middeck lockers and/or the airlock stowage bag at launch and are removed for use on orbit.

A personal hygiene kit is furnished for each crewmember for brushing teeth, hair care, shaving, nail care, etc. A kit is also furnished with articles essential to women's hygiene and grooming.

## 2. SYSTEMS

### 2.5 Crew Systems



*The Launch/Entry Suit*

Two washcloths and one towel per crewmember per day are provided. In addition, wet wipes, dry wipes, tissues, and wash 'n' dri wipes are provided for personal hygiene and are located in the waste management compartment. The wash 'n' dri wipes are located in Volume G (spares) and in the galley. Additional wet/dry wipes are located in the hygiene locker. Rubber grommets in the waste management compartment allow crewmembers to restrain their towels and washcloths.

If the WMS becomes nonfunctional, contingency equipment is located in Volume G. This equipment consists of wash 'n' dri wipes, urine collection devices, urinal assemblies, and Apollo fecal bags.

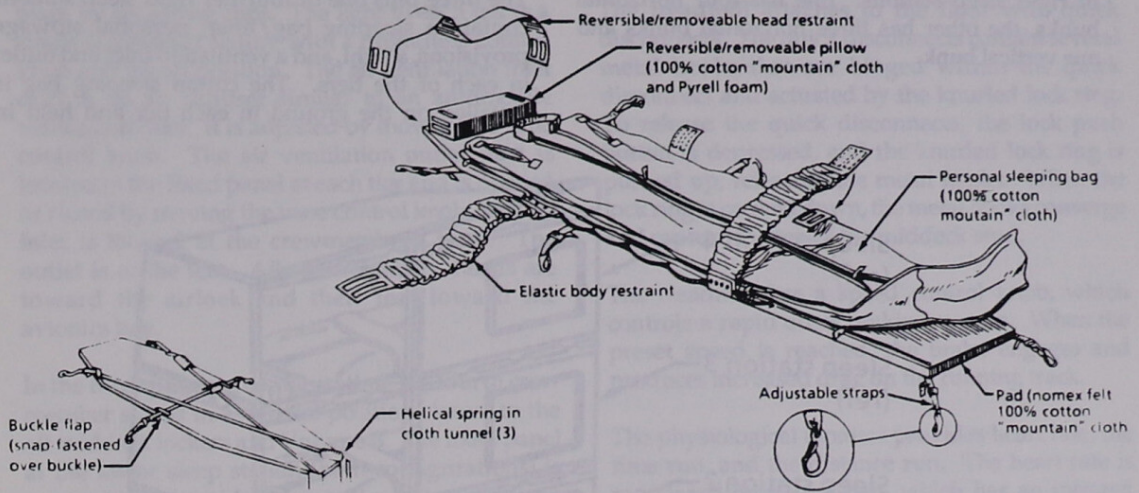
### Sleeping Provisions

During a one-shift operations mission, all crewmembers sleep simultaneously. At least one crewmember wears a communication headset to ensure reception of ground calls and orbiter caution and warning alarms.

A 24-hour period is normally divided into an 8-hour sleep period and a 16-hour wake period for each crewmember. Three hours are allocated for pre/post sleep activities in which crewmembers perform housekeeping, orbiter cleaning, sleep and wake preparation, personal hygiene, and food preparation and eating activities.

Sleeping provisions for flight crewmembers consist of sleeping bags and liners, or rigid sleep stations with one sleeping bag and two liners per bunk. Sleeping bags are installed on the starboard middeck wall and relocated for use on orbit. Some sleeping bags can remain on the starboard wall, and some can be attached via pip pins to the middeck lockers. Others can be relocated to the airlock, Spacelab, or flight deck (crew preference). A sleeping bag is furnished for each crewmember and contains a support pad with adjustable restraining straps and a reversible/removable pillow and head restraint.

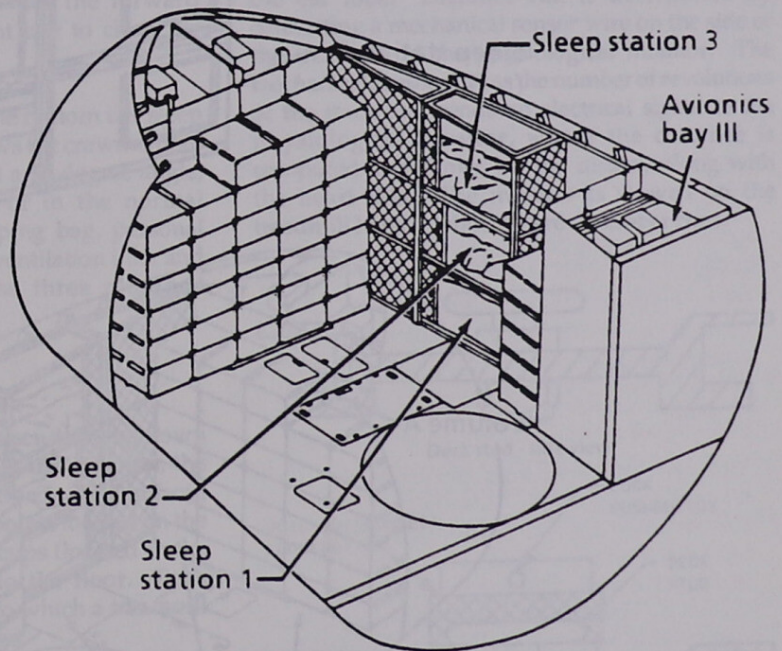
Six adjustable straps permit the sleeping bag to be adjusted to its proper configuration. Three helical springs above the adjustable straps on one side of



*Operational Sleeping Bag*

the bag relieve loads exerted by the crewmember on the crew compartment structure. Six pip pins allow the bag to be attached to the middeck locker face in either a horizontal or vertical configuration. Two elastic adjustable straps restrain the upper and lower parts of the body in the bag. Velcro strips on the ends of both sides of the head restraint attach it to the pillow. A double zipper arrangement permits the sleeping bag to be opened and closed from the bottom to the top of the bag. One zipper on each side of the sleeping bag allows the bag to be attached to a support pad for better rigidity.

A sleep kit is provided for each crewmember and is stowed in the crewmember's clothing locker during launch and entry. Each kit contains eye covers and ear plugs for use as required during the sleep period.



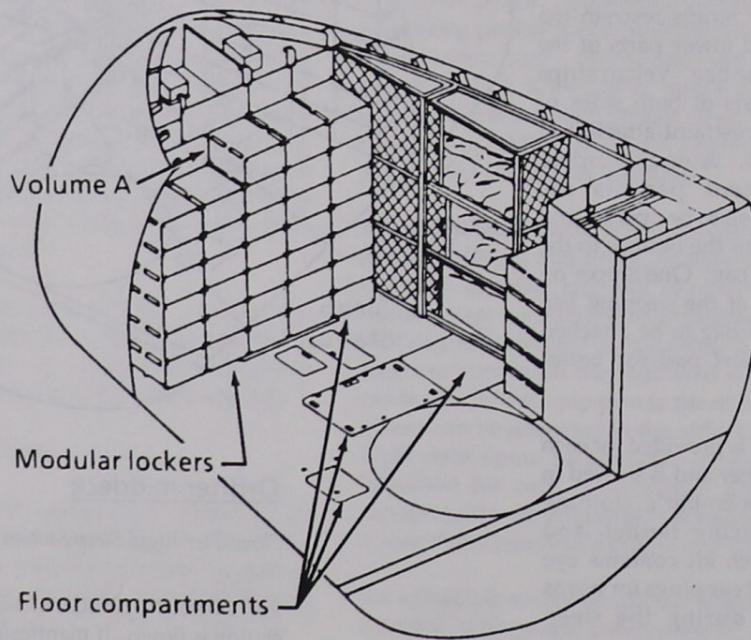
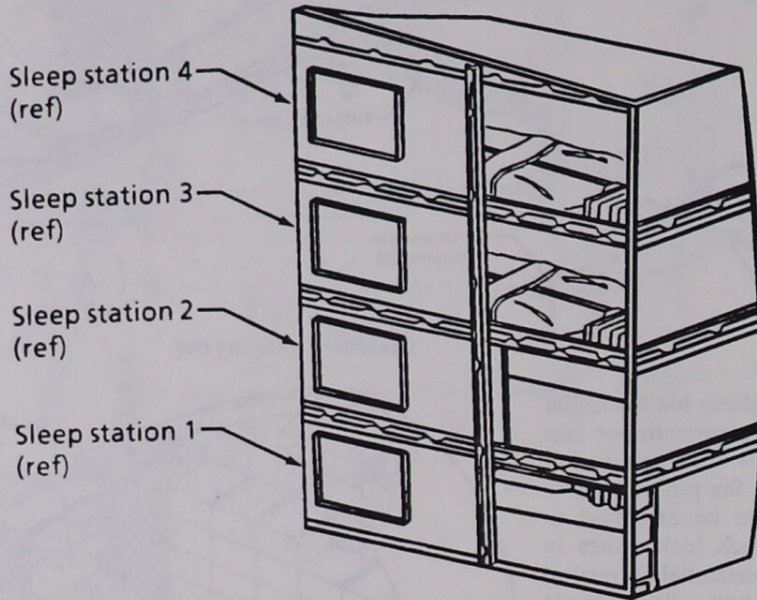
**Orbiter middeck**

*Three-Tier Rigid Sleep Station*

For 24-hour operations missions, the rigid sleep station is flown. If manifested, it is installed on the starboard side of the middeck. There are two types

of rigid sleep stations: one has four horizontal bunks, the other has three horizontal bunks and one vertical bunk.

The three plus one or four-tier rigid sleep stations contain a sleeping bag/liner, personal storage provisions, a light, and a ventilation inlet and outlet in each of the tiers. The cotton sleeping bag is installed on the ground in each tier and held in



*Four-Tier Rigid Sleep Station*

place by six spring clips. The light in each tier is a single fluorescent fixture with a brightness control knob and an off position. The air ventilation inlet duct is an air diffuser similar to an automobile ventilation duct. It is adjusted by moving the vane control knob. The air ventilation outlet duct is located in the fixed panel at each tier and is opened or closed by moving the vane control knob. The air inlet is located at the crewmember's head. The outlet is at the feet. All crewmembers' heads are toward the airlock and their feet toward the avionics bay.

In the three plus one configuration, the fourth crew member sleeps in a vertical position closest to the aft middeck lockers and Volume B. The fixed panel at the lower sleep station (both configurations) is removable to provide access to the cabin debris trap door for cleaning the cabin filter, to gain access to floor locker MD76C, and to enter the forward portion of the lower equipment bay to clean the avionics bay fan filter.

In the four-tier configuration, the bottom tier sleep restraint hookup provision allows the crewmember to position himself or herself at a 15-degree angle, which provides more room, or in the normal horizontal position. The sleeping bag, personal stowage provisions, light, and ventilation inlet and outlet are the same as in the three plus one configuration.

### Exercise Equipment

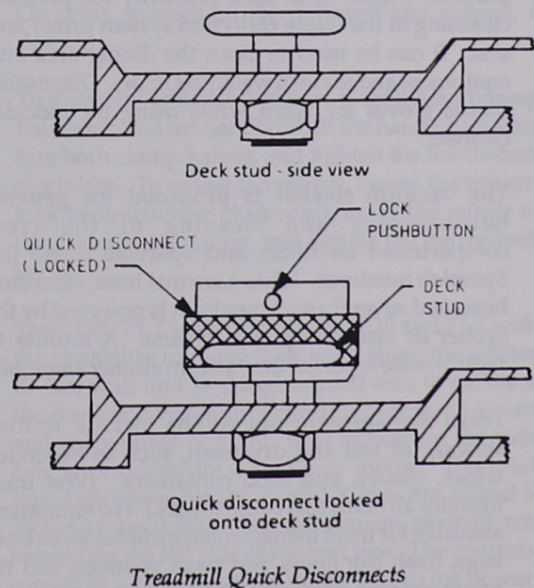
The only exercise equipment presently being flown is a treadmill. In the on-orbit in-use position, the treadmill is attached to the middeck floor in front of the airlock using two attach points located on the LiOH door and two treadmill cups (located in the IFM locker), which screw into the floor. Each treadmill cup provides a stud to which a treadmill quick disconnect can be mounted.

The treadmill is used with a restraint system to allow a crewmember to run or jog in orbit. The treadmill kit is stowed on top of the treadmill and contains the waist belt, two shoulder straps, four extender hooks, and a physiological monitor. The treadmill kit is restrained by four force cords that are used to restrain the body during exercise.

The treadmill attaches to the floor with quick disconnects. The quick disconnects contain several metal hooks that are hinged within the quick disconnect and actuated by the knurled lock ring. To release the quick disconnects, the lock push button is depressed, and the knurled lock ring is pushed up, releasing the metal hooks. When the lock ring is pushed down, the metal hooks converge and capture the top of the middeck stud.

The treadmill has a speed control knob, which controls a rapid onset braking system. When the preset speed is reached, the brake engages and produces increased drag on the running track.

The physiological monitor provides heart rate, the time run, and the distance run. The heart rate is monitored by an ear clip, which has an infrared sensor that detects increased blood flow (pulses) in the ear lobe. Distance run is determined by connecting a mechanical sensor wire on the side of the treadmill to the physiological monitor. The mechanical sensor detects the number of revolutions of the track and sends an electrical signal to the physiological monitor, where the distance is computed and shown on the display along with the heart rate. The monitor is stowed on the treadmill handle while the crewmember runs.



## Housekeeping Equipment

In addition to time scheduled for sleep periods and meals, each crewmember has housekeeping tasks that require from 5 to 15 minutes of time at intervals throughout the day. These include cleaning of the waste management compartment, the dining area and equipment, floors and walls (as required), and the cabin air filters; trash collection and disposal; and changeout of the crew compartment carbon dioxide (lithium hydroxide) absorber canisters. (Changeout of the canisters is discussed in Section 2.9.)

The materials and equipment available for cleaning operations are biocidal cleanser, disposable gloves, general-purpose wipes, and a vacuum cleaner. The vacuum is stowed in a middeck locker, and the remaining hardware is stowed primarily in the waste management compartment. Additional wipes are located in the hygiene locker, and an additional pair of gloves is located in each personal hygiene kit.

The biocidal cleanser is a lotion-type detergent formulation in a container approximately 2 inches in diameter and 6 inches long with a built-in dispenser. The cleanser is squirted on the surface to be cleaned and wiped off with dry, general-purpose wipes. It is used primarily for periodic cleansing of the waste collection system urinal and seat. It can be used to clean the dining area and equipment and to clean walls and floors. Disposable plastic gloves are worn while using the biocidal cleanser.

The vacuum cleaner is provided for general housekeeping and cleaning of the crew compartment air filters and Spacelab filters (on Spacelab missions). It has a normal hose, extension hose, and several attachments. It is powered by the orbiter dc electrical power system. A muffler to reduce noise is part of the vacuum cleaner assembly.

Trash management operations include routine stowage of wet and dry trash, such as expended wipes, tissues, and food containers. (Wet trash includes all items that could offgas.) The equipment available for trash management includes three trash bags, trash bag liners, wet trash volumes, and the waste collection system (WCS) coffee canister.

Three trash bags for dry trash are located in the crew compartment: one on the back of the waste management compartment (WMC) door, one below the text and graphics system, and one on the port flight deck. Each bag contains one installed disposable trash bag liner and seven spare liners (located outside the installed liner but inside the trash bag). When the liner becomes full, it is removed and stowed in a jettison stowage bag. A new liner is then installed.

The WMC wet trash compartment has a volume of 1.85 cubic feet and is vented overboard for odor control. Trash from the WMC is inserted into the circular opening and is contained by a fabric bag. Tissues, as well as used WCS coffee canister bags, are disposed of in this wet trash compartment. The coffee canister, which is about the same size and shape as an off-the-shelf can of coffee, is installed near the WMC during post insertion. Trash bags are inserted in the canister and are filled with wipes used for fecal collection. A used trash bag is disposed of in the WMC wet trash, and a new one is retrieved from the stowage volume on the WMC wall and installed in the canister.

An 8-cubic-foot wet trash stowage compartment is available under the middeck floor (Volume F). This compartment is vented overboard (3 lb/day) for odor control. Any item that can create an odor is considered to be wet trash and is disposed of there.

## Restraints and Mobility Aids

Restraints and mobility aids are provided in the orbiter to enable the flight crew to perform all tasks safely and efficiently during ingress (1-g, orbiter vertical), egress (1-g, orbiter horizontal), and orbital flight (orbiter orientation arbitrary).

Mobility aids are located in the crew compartment for movement of the flight crewmembers during ingress, egress, and orbital flight. These devices consist of permanent and soft handholds, a platform in the middeck, and an interdeck access ladder.

Restraints consist of foot loop restraints, seat restraints, the airlock foot restraint platform, stowage bags, Velcro, tape, snaps, cable restraints, clips, bungees, and tethers.

Foot loop restraints are cloth loops attached to the crew compartment decks by adhesive to provide stability in zero g. Before launch, the foot loop restraints are installed by the VITT personnel on the floor areas of the aft flight deck work stations, middeck, and near the waste management system and galley (if installed). Spares are stowed in the modular lockers. To install a foot restraint, the protective backing on the underside of the restraint is removed, and the restraint is placed in its desired location. The foot loop restraints are easily used by placing a foot in the loop.

Seat restraints are similar to foot loop restraints. They can be installed prelaunch, and spares are manifested in the same locker as the foot restraints. One adhesive patch is placed on one side of the seat, and the other patch is placed on the opposite side. A restraint strap is placed over the seat back and attached to each patch via clips.

The temporary stowage bag is used to restrain, stow, or transport loose equipment temporarily. One is snapped to the crew station prelaunch, and another is manifested in the stowage bag locker. Eight inflight stowage bags are manifested: one per crewmember plus spares. These brown mesh bags are used to stow suits, boots, and chutes on orbit. A brown mesh middeck retention net, attached to the forward middeck lockers and the starboard wall (no sleep station), is used to restrain the inflight stowage bags, as well as other hardware. The airlock stowage net, also made of brown mesh net, can restrain this equipment in the airlock if the sleep station is manifested, or if the crew determines they wish to stow this hardware in the airlock. The flight deck stowage bags provide restraint for flight deck items when those items are not immediately returned to locker stowage compartments. These bags are manifested in the stowage bag locker and are installed on orbit on the back of the CDR and PLT seats (one per seat). The jettison stowage bags are used for restraining dry trash or early return items. (See Section 2.22 for further details on all stowage bags.)

Velcro, tape, snaps, cable restraints, clips, bungees, and tethers are all manifested in the IFM locker and can be utilized for a variety of purposes.

The flight data file (FDF) is a flight reference data file that is readily available to crewmembers aboard the orbiter. Seats 2 through 5 have a white Nomex FDF bag attached to the right-hand side of the seat. This soft fabric container has one large compartment and a small pocket. The container is easily removed from the bracket by pulling the release handle and removing the Velcro strap on the seat leg structure. There are also four permanent FDF containers (two for the CDR and two for the PLT) located on the flight deck. (See Section 2.22 for further details.) Seats 6 and 7 (if manifested) will use a helmet stowage bag for any FDF or personal articles.

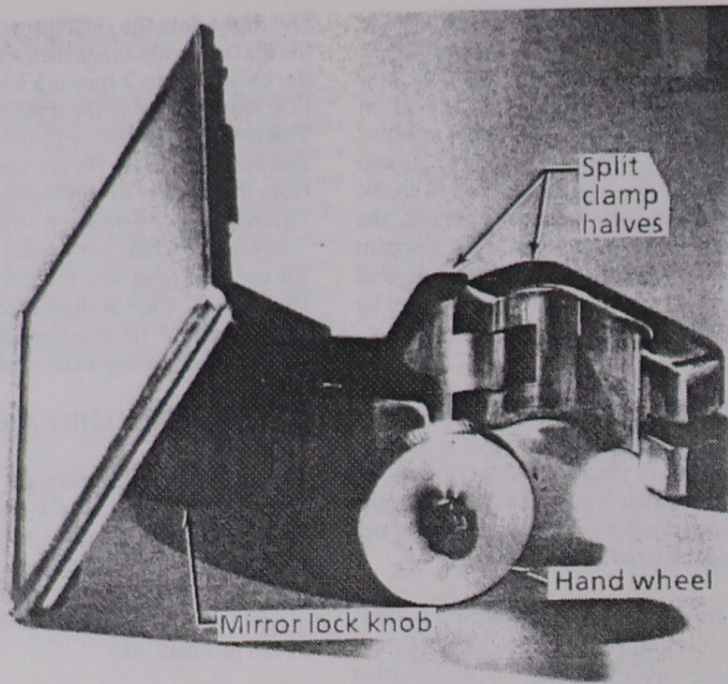
### Reach and Visibility Aids

Reach and visibility aids are hardware items that assist the flight crew in monitoring and manipulating displays and controls throughout various phases of flight. These aids consist of CDR/PLT adjustable mirrors, CDR/PLT two axis (Z and X) seat adjustment, wicket tabs, and an auxiliary reach mechanism.

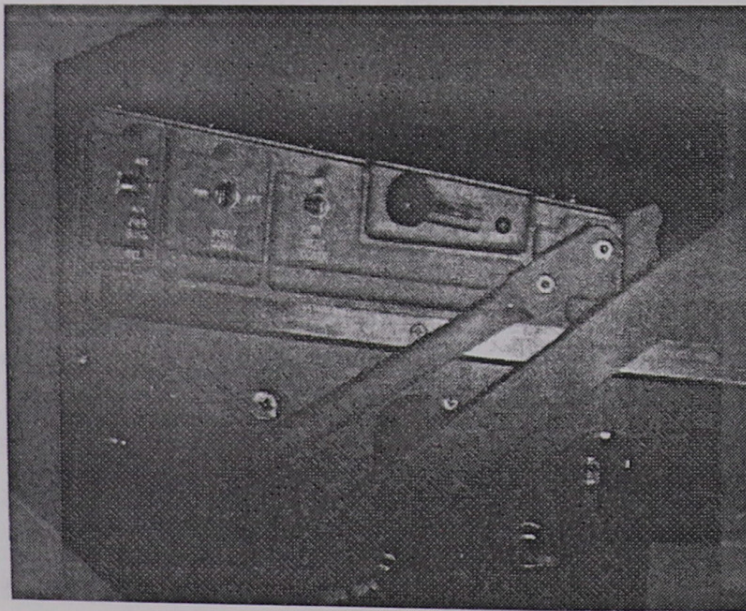
The adjustable mirrors are installed at launch on handholds located between windows 2 and 3 for the CDR and windows 4 and 5 for the PLT. During ascent and entry, the CDR and PLT use the adjustable mirrors to facilitate seeing controls that are in the obscured areas of their vision envelope. On orbit, mirrors can be removed and stowed, if desired.

To install the adjustable mirror, place the split clamp halves around the handhold, fit the handwheel stem into both clamp halves, and tighten the handwheel clockwise. To adjust the mirror, loosen the mirror-lock knob (counter-clockwise), move the mirror to the desired orientation, and tighten the mirror-lock knob.

The CDR/PLT seats provide the CDR and PLT with the capability to move their seats along the orbiter Z- (vertical) and X- (longitudinal) axes to facilitate the reach and visibility of controls during the ascent and entry phase of flight. Seat movement for each axis is provided by a single ac motor. The total travel distances for the Z- and X-axes are 10 and 5 inches respectively. Seat adjustment controls are located on the left side of the seat pan. The controls consist of a three-position toggle switch for power



*Adjustable Mirror*



*Seat Power and Controls*



bus selection and one spring-loaded, three-position toggle switch each for control of horizontal and vertical seat movement.

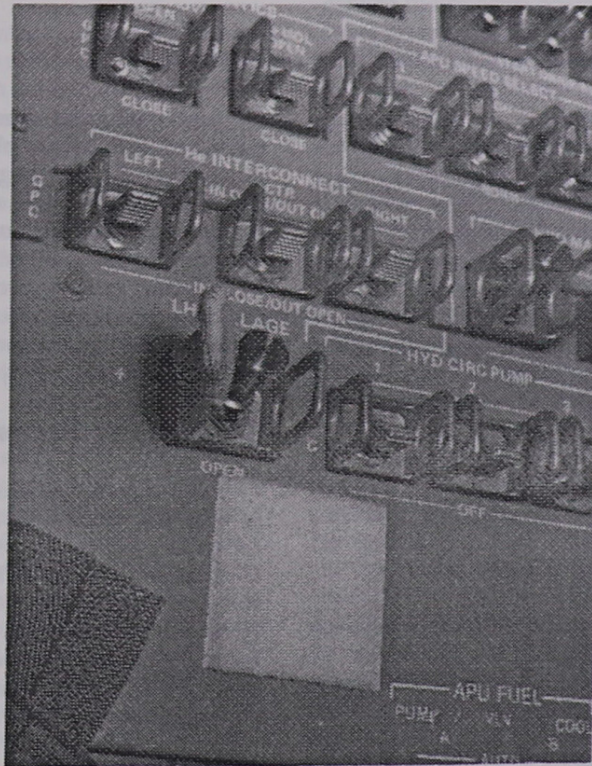
To operate the CDR/PLT seat, the crewmember must first assign ac power to his or her seat motors by moving the *POWER BUSS SEL* switch to AC2 (up) or AC3 (down). To move the seat along the horizontal axis, crewmembers must actuate the *HORIZ CONTR* toggle switch FWD to move the seat forward and AFT to move the seat aft. Similarly, to move the seat along the vertical axis, the crewmember must actuate the *VERT CONTR* toggle switch UP to move the seat upward and DN to move the seat downward.

If the seat motors fail to work, and seat adjustment is needed, manual adjustment capability is provided. However, manual seat adjustment can take place only on orbit and is accomplished with a

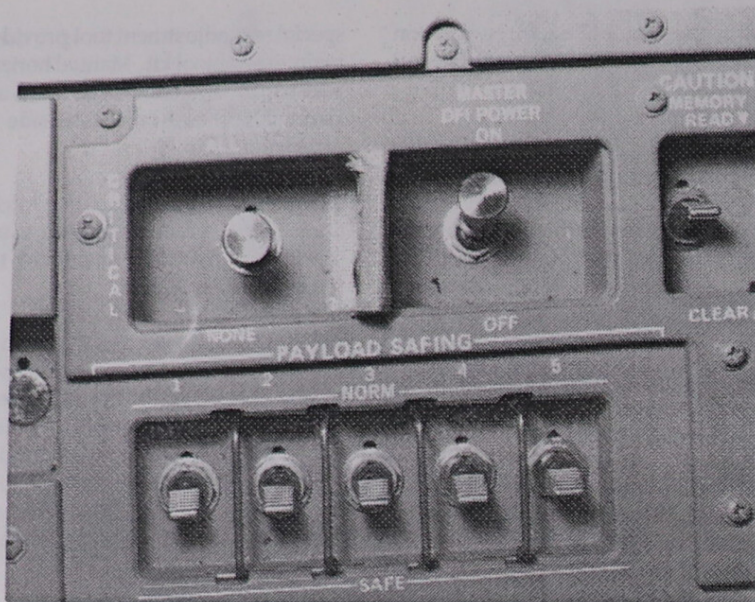
special seat adjustment tool provided in the in-flight maintenance tool kit. Manual horizontal and vertical seat adjustment control locations are under the seat pan cushion and on the aft side of the fixed seat structure.

The seat adjustment tool is a ratchet-driven, 3/16-inch Allen wrench inserted into the vertical or horizontal manual adjustment to move the seat along the Z- or X-axis.

Wicket tabs are devices that help the crewmember activate controls when his or her vision is degraded. The tabs provide the crewmember with tactile cues to the location of controls to be activated as well as a memory aid to their function, sequence of activation, and other pertinent information. Wicket tabs are found on controls that are difficult to see on panels O8, C3, and R2 during the ascent and entry flight phases.



Wicket Tabs on Panel R2



*Wicket Tabs on Panel C3*

The auxiliary reach mechanism, sometimes known as the "swizzle stick," is a short adjustable bar with multipurpose end effectors that are used to actuate controls that are out of the reach of seated crewmembers. The reach aid is used to push in and pull out circuit breakers, move toggle switches, and turn rotary knobs. It is stowed on the inboard side of the PLT seat. It may be used during any phase of flight, but is not recommended for use during ascent because of the attenuation and switch-cuing difficulties resulting from acceleration forces.

Operation of the reach aid consists of extending it and actuating controls with the end effector. To extend the reach aid, the crewmember depresses the spring-loaded extension tab and pulls the end effector out to the desired length.

The reach and visibility envelope of each crewmember is limited by the LES. Tactile cues are restricted by the LES pressure glove. Visibility is reduced because of the helmet and neck ring, and reach is restricted by the bulk of the LES and the parachute and harness. Crewmembers should

practice techniques that enable them to adjust their reach and visibility envelope. The helmet can be swiveled on the neck ring. The neck ring tie down may be adjusted to help open up downward field of view. Mirrors, the auxiliary reach mechanism (swizzle stick), and other crewmembers can aid in locating and actuating controls. Seat headrest pads and helmet pads may be used to adjust the position of the head in the seat and in the helmet. The CDR and PLT seats may be adjusted as necessary.

### **Photographic Equipment**

Two still camera systems and one motion picture camera are used on orbit to document crew activities, meet payload requirements, and record Earth observations. Additional cameras can be stowed as required. Nikon 35 mm and Hasselblad 70 mm single lens reflex (SLR) cameras are flown for still photography. An Arriflex 16 mm camera is used for motion picture photography. When stowage and weight provisions allow, the crew may request an Aero Linhof 4X5 aerial photography camera.

Additional camera systems may be flown for specific experiments or as part of an ongoing NASA evaluation of new cameras and technology. Camera systems being evaluated are the Nikon F4 35 mm autofocus and Rolleiflex 70 mm SLR systems. Periodically, the IMAX Corporation manifests its 70 mm motion picture camera aboard the Shuttle as a commercial payload. Recently, a JSC-developed 35 mm still video camera was successfully used on orbit. It stores photographs on a hard disk that can be downlinked.

Two different Nikon 35 mm cameras are typically flown on the orbiter. One is essentially a Nikon F3 model with factory modifications that qualify it for use on EVAs. The camera permits automatic or manual exposure with an LCD exposure readout in the viewfinder. It uses standard 35 mm 36-exposure rolls of film. Both negative (print) and positive (slide) films of various speeds are flown to allow flexibility in changing photographic situations. The standard film is Kodak 64 ISO (ASA) Professional positive film.

The standard complement of interchangeable lenses includes a 28 mm f/2, 35 mm f/1.4, and 35 - 70 mm f/3.5 zoom. The crew can select other lenses ranging from 15 mm super wide angle to a 600 mm telephoto if stowage and weight limitations allow.

The camera motor drive operates on eight AA batteries and provides automatic film advance, if desired, or continuous film advance at up to 3.5 frames per second. The camera system also includes a flash that integrates with camera electronics for automatic through-the-lens, off-the-film plane exposure. The flash operates on four AA batteries.

In 1991, NASA began flying the Nikon autofocus F4 model SLR camera in addition to one F3. The F4 provides state-of-the-art metering for automatic ambient light and flash exposure and exposures as brief as 1/8000 of a second. The camera incorporates a "full information" LCD viewfinder display. Interchangeable autofocus lenses of various focal lengths, including 28 mm f/2.8 and 35 - 70 mm f/2.8 zoom, are available. Manual focus lenses can be used on the F4 (in the manual focus mode) with the camera indicating when proper focus is achieved. The camera motor drive advances the film after each exposure or permits continuous exposure at 3.4 or 5.7 frames per second. It operates on six AA

batteries. The F4 flash is a state-of-the-art unit operating on four AA batteries. The 35 mm cameras are used primarily for in-cabin crew activities, experiments, and EVA (F3 model only). They may also be used for payload deployments and Earth observations.

Two 70 mm SLR medium format (2.25 in square) cameras are usually flown on each Shuttle mission. The cameras are Hasselblad 500 EL/Ss (EL/Xs with minor modifications). Only manual exposure is available with the 70 mm cameras. Two Minolta handheld reflected light (spot) meters are manifested to provide exposure information as required. Interchangeable magazines provide approximately 95 exposures on Kodak 64 ISO Professional 70 mm perforated positive film. Occasionally, color infrared film is used for Earth observations. Each magazine has a detachable data recording device that prints flight-specific data on the edge of the film. Interchangeable lenses, including 50 mm f/4, 100 mm f/3.5, and 250 mm f/5.6, are part of the standard complement. The camera motor drive operates on five AA batteries. It permits single frame automatic film advance or a continuous rate of about one frame per second. The 70 mm cameras are used exclusively for photography of payload bay activities, Earth observations, and occasionally for ET separation. An automatic exposure Rolleiflex 70 mm camera has been used successfully on several missions to augment the Hasselblad cameras.

Motion picture filming is accomplished with an Arriflex professional 16 mm through-the-lens viewing rotary shutter camera with integral light meter. The crystal-controlled camera motor transports film at 24 frames per second. The nominal shutter speed is 1/48 second. The camera utilizes an interchangeable 10 - 100 mm f/2 zoom or 5.9 mm f/1.8 wide angle lens. Both lenses permit manual exposure. The zoom lens aperture can be controlled by inputs from the camera light meter for automatic exposure as well. Interchangeable magazines are reloaded in flight with 400 ft rolls of 100 or 500 ISO Kodak tungsten light balanced color negative film. A full magazine will provide about 11 minutes of filming. Color correction filters must be used whenever sunlight is the main subject light. The camera is normally powered by a NASA developed 15 V dc battery containing 40 AA batteries. The camera may also be powered from

the orbiter, via an adapter cable and the inflight maintenance (IFM) "breakout box." A rarely flown accessory provides variable frame rates for the Arriflex and bar code time data on the film. A photoflood light is available and is used during interior filming. The Arriflex is used primarily to document in-cabin and payload bay activities.

The Aero Linhof is a manual exposure 4X5 camera that is manifested approximately every other mission if stowage space and weight constraints allow. The camera produces large (4 in by 5 in) images on Kodak 64 ISO thin base positive film. Each removable magazine contains approximately 285 exposures. The camera uses a 90 mm f/5.6 wide angle and a 250 mm f/5.6 lens. Camera power is supplied by orbiter 28 V dc. An attachable viewfinder can be used to estimate the field-of-view (FOV) of the lens in use. The Linhof camera is used primarily for Earth observations photography.

Most of the photography and cinematography conducted in the orbiter are handheld. With the exception of flash photography, however, many of the images and scenes crew capture on film can be improved through the use of the multiuse mounts, clamps, arms, or baseplate adapters. The multiuse mounts attach to 22 dovetail "quick shot" devices located on the flight deck, the middeck, and the airlock. The baseplate adapters (crew installed) provide quick shoes in windows 9 and 10. The multiuse clamp is used on switchguards or other structures to provide a multiuse mount at locations without a quick shoe. The multiuse arm is a modified commercial device that attaches to a camera and a multiuse mount/clamp. The arm permits universal pointing of the camera until the center "elbow" knob is tightened. When the knob is secure, the camera is held rigidly at the selected orientation (zero g). Multiuse equipment is also used to mount the CCTV camera, camcorder, and photo flood.

### Sighting Aids

Sighting aids include all items used to aid the flight crew within and outside the crew compartment. The sighting aids include the crew optical alignment sight (COAS), binoculars, adjustable mirrors, and spotlights. (The COAS is discussed in detail in Section 2.13.)

The 8-by-30 binoculars are noted for close focal distance at high magnification and have a built-in measuring scale. The 14-by-40 gyrostabilized binoculars contain a gyrostabilized system that enhances target acquisition and retention. When the crewmember is subjected to ambient vibrations or hand tremor while using the gyrostabilized binoculars, the target image remains clear and stable. The gyrostabilized binoculars are electrically powered by six alkaline-type AA batteries and will operate continuously up to 3 hours on one battery pack. A spare battery pack is located in panel A16.

The spotlight is a high-intensity, hand-held flashlight powered by a battery pack consisting of five 1.2-volt one-half D size nickel-cadmium batteries. The spotlight produces a 20,000-candlepower output with a continuous running time of 1.5 hours. The lamp is a 6-volt tungsten filament and cannot be replaced in flight.

### Window Shades, Filters, and EMI Shields

Window shades and filters are provided for installation on the orbiter windows to minimize crewmember exposure to sunglare during ascent, entry, and orbital flight phases. An electromagnetic interference (EMI) shield is installed in the orbiter overhead window (W8) for launch and entry to protect orbiter overhead electronics from lightning and electromagnetic interference. During a postlanding egress, W8 is blown open with pyrotechnic devices. Another EMI shield is manifested in the window shade bag if needed. An EMI filter is installed in W7 for launch and entry.

The window shades, filters, and shields are stowed in a compartmented bag attached to a mounting pallet on the port side of the forward middeck.

To install the W1 through W6 window shades, the crewmember unrolls the shade (white surface outboard) over the window and mates the Velcro with the Velcro on the window frame. Removal of the shades is accomplished by just the reverse. Demate the Velcro, and roll the shade up as compactly as possible (blue surface visible). Insert into window shade holders and close the holders by mating Velcro together.

EMI shields are installed by placing the shield (partitioned side outboard) against the W7 and W8 window edges and closing the four latches to retain the shield in place.

Aft window shades and filters are installed simply by placing the correct shade or filter in the appropriate window (reflective side outboard) and securing it to the mating Velcro on the window ledges.

To remove a window shade, filter, or EMI shield from the window shade stowage container, the crewmember must unfasten the securing straps and pull the Velcro-restrained closure panel away from the desired stowage pouch.

Interdeck light shades are provided to minimize light leakage between the flight deck and middeck during in-cabin photography. The light shade is attached with Velcro to the flight deck floor around the interdeck access. Adjustable louvers are provided to regulate the amount of light between the flight deck and the middeck.

The side hatch viewport is the only optical-quality window on OV 103, 104, and 105. Unlike the 10 windows on the flight deck, the side hatch viewport does not provide protection from solar ultraviolet (UV) rays, which can cause serious injury in as little as 10 seconds. Therefore, a removable UV filter must be placed on the side hatch viewport for on-orbit operations. The filter is held against the viewport by Velcro and is normally installed post insertion and removed during deorbit preparations.

### Shuttle Orbiter Medical System

The Shuttle orbiter medical system (SOMS) is required to provide medical care in flight for minor illnesses and injuries. It also provides support for stabilizing severely injured or ill crewmembers until they are returned to Earth.

The SOMS is provided in two separate packages: the medications and bandages kit (MBK) and the emergency medical kit (EMK). The MBK is blue with blue Velcro and a blue strap. The EMK is also blue with red Velcro and a red strap.

The medical kits are stowed in a middeck modular locker. If the kits are required on orbit, they are unstowed and installed on the locker doors with Velcro. The kits have a patch of Velcro on the bottom to match the Velcro on the outside of the doors.

Each kit contains pallets and a pocket inside the back. Pockets containing medications and equipment are mounted on each side of the pallets. The MBK pallet designators are E, F, and G. The E pallet contains pills, capsules, and suppositories. The F pallet contains bandage materials for covering or immobilizing body parts. The G pallet contains medications to be administered by topical application.

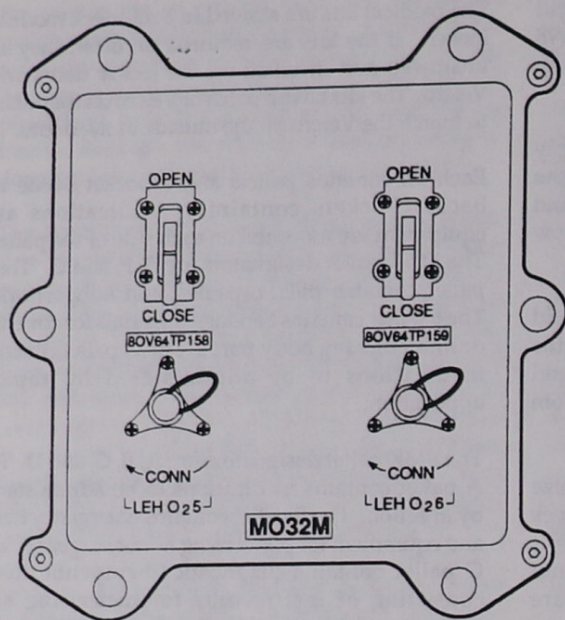
The EMK pallet designators are A, B, C, and D. The A pallet contains medications to be administered by injection. The B pallet contains emergency items and equipment for performing minor surgeries. The C pallet contains diagnostic/therapeutic items consisting of instruments for measuring and inspecting the body. The D pallet contains dental items, injectables, and intravenous fluid/administration sets.

Detailed descriptions of medications can be found in the Medical Equipment Workbook, MED EQ 2102.

The onboard medical checklist and medical checklist flight supplement specify the location of medications/equipment in the two medical kits by an alphanumeric code. The first character is the alphanumeric code of the pallet (A through G). The second character is the side of the pallet (1 or 2). The third and fourth characters are the number of the specific pocket on the pallet. The pallets are appropriately marked.

The medical accessory kit supplements the SOMS kit by providing additional storage capability for crew-specific and/or mission-specific medications, such as toxin antidotes, additional I.V. fluid, etc.

The SOMS also includes a resuscitator and patient/rescuer restraints. The resuscitator consists of a mask with a retaining cap, a manually activated/demand regulated oxygen supply valve, a 6-foot hose, and a quick disconnect fitting. The resuscitator assembly is stored in a middeck locker with the EMK and MBK.



Panel MO32M

The resuscitator is emergency hardware to be utilized, along with the patient/rescuer restraints, in the case of a crewmember becoming ill as called out for in JSC-17327, Medical Checklist - All Flights.

The resuscitator provides the capability to deliver 100 percent oxygen, control ventilation, and perform CPR for extended periods of time.

The resuscitator valve can supply 100 percent supplemental oxygen in two ways: (1) at 40 LPM positive pressure for unconscious patients, and (2) on demand flow for conscious patients.

The resuscitator, upon unstowage, can be connected to the orbiter oxygen supply on the middeck connections on panels MO32M and MO69M and the flight deck connection on panel C6. Oxygen flow can be checked by depressing the O<sub>2</sub> trigger arm. Following verification of O<sub>2</sub> flow, a crewmember will position and tighten the resuscitator mask over the crewmember's face using the head cap and elastic straps.

The patient/rescuer restraints consist of two belts with two pip pins each for the patient and one belt with two pip pins for the rescuer. They are designed to interface into the holes in the middeck locker latches.

The patient/rescuer restraint system is emergency hardware to be utilized in the case of a crewmember becoming ill. The restraints are stored in a middeck locker with the EMK and MBK.

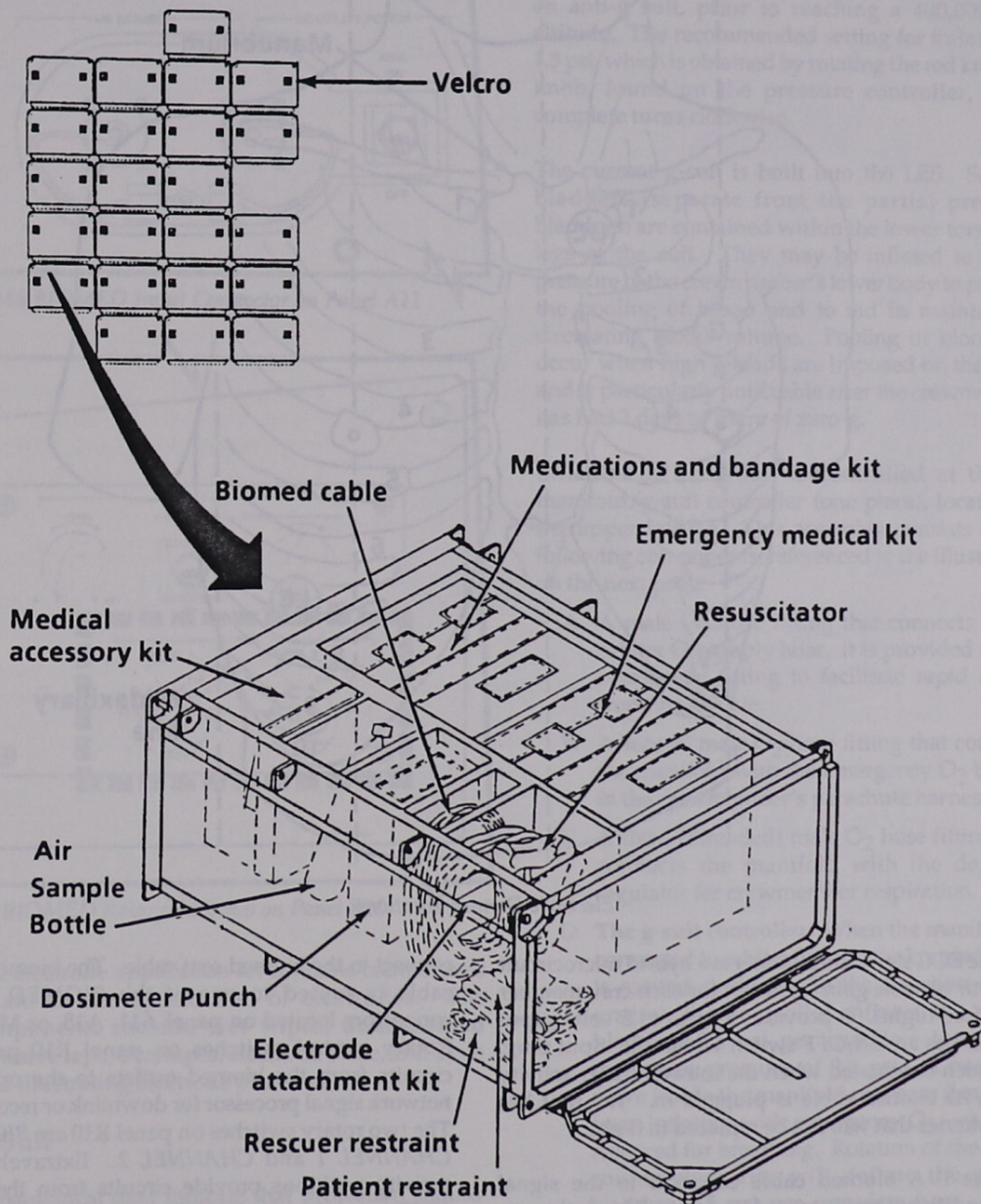
The patient restraints will restrain the patient in the mid-calf area and the chest area. The restraints can be easily tightened to fit the patient. The rescuer restraint will wrap around the rescuer's waist and will have two extensions from the waist belt with pip pins on the end to fasten into the locker latches. This will allow the rescuer and patient to remain stationary.

The diagnostic equipment on board and information from the flight crew will allow diagnosis and treatment of injuries and illnesses through consultation with flight surgeons in Mission Control.

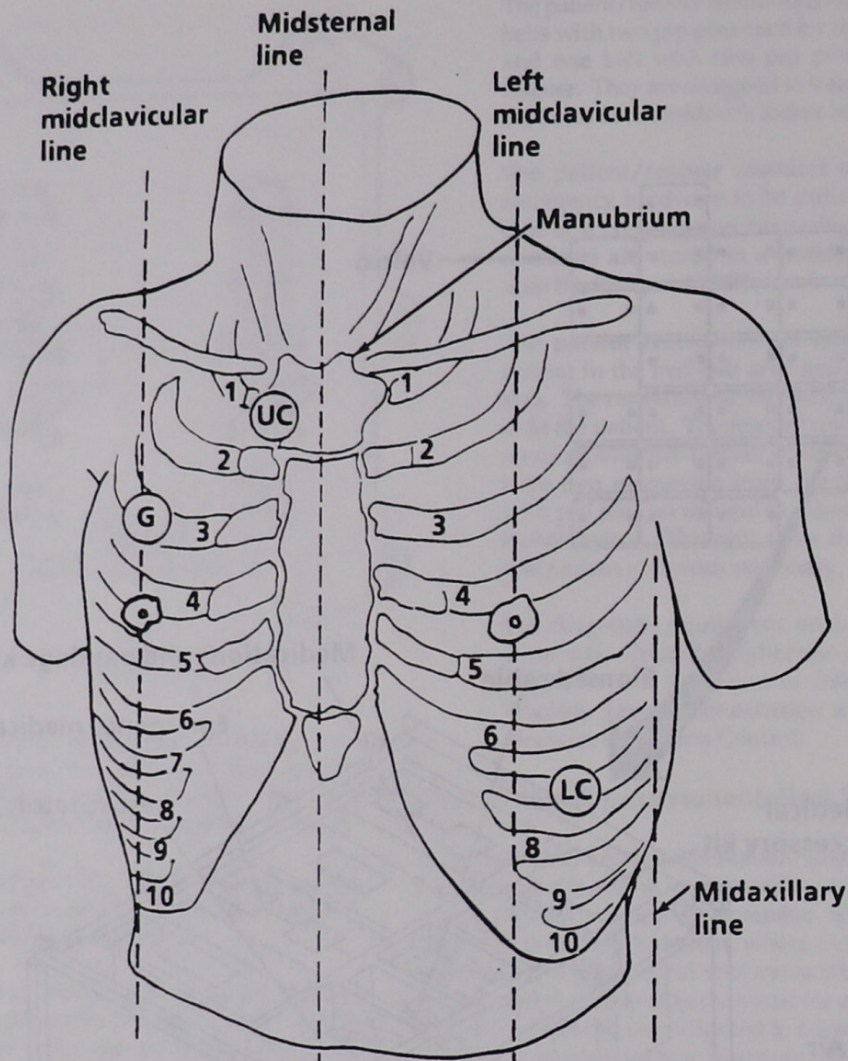
## Operational Bioinstrumentation System

The operational bioinstrumentation system (OBS) provides an amplified electrocardiograph (ECG) analog signal from any crewmember aboard the orbiter to the avionics system, where the signal is converted to digital signal and transmitted to the ground in real time or stored on tape for dump at a later time. On-orbit use is limited to crewmembers in EVA or to contingency situations (only at the request of the flight surgeon).

The OBS electrodes are attached to the skin with electrode paste to establish electrical contact. The electrode is composed of a plastic housing containing a non-polarizable pressed pellet. The housing is attached to the skin with double-sided adhesive tape, and the pellet contacts the skin. There are three electrodes on the harness, marked LC (lower chest), UC (upper chest), and G (ground).



*Modular Locker Equipment and Locations*



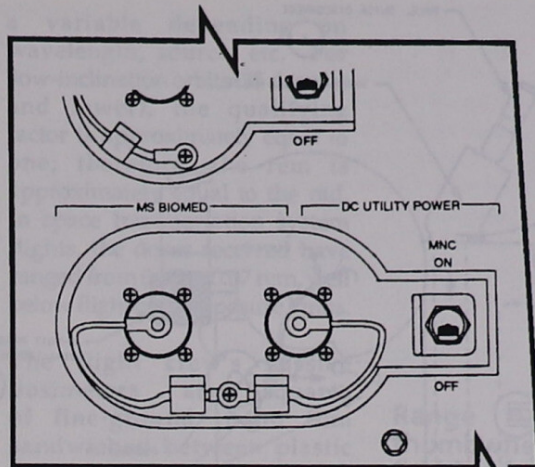
Electrode Donned Locations

The ECG signal conditioner is a hybrid microcircuit with variable gain (adjusted for each crewmember before flight). It provides a zero- to 5-volt output and has an *ON/OFF* switch within the input plug, which is actuated when the intravehicular activity (IVA) biomed cable is plugged in. The unit has batteries that will not be replaced in flight.

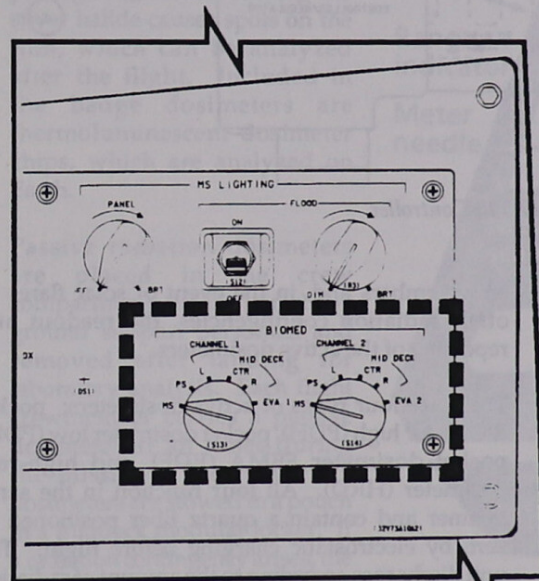
The IVA biomed cable connects to the signal conditioner and is routed under the IVA clothing to

connect to the biomed seat cable. The biomed seat cable is routed to one of the *BIOMED* input connectors located on panel A11, A15, or M062M. Rotary control switches on panel R10 provide circuits from the biomed outlets to the orbiter's network signal processor for downlink or recording. The two rotary switches on panel R10 are *BIOMED CHANNEL 1* and *CHANNEL 2*. Extravehicular activity positions provide circuits from the EVA UHF transceiver.





MS BIOMED Input Connector on Panel A11



BIOMED Rotary Switches on Panel R10

The electrode application kit contains components to aid in the application of electrodes. The components include wet wipes, double-sided adhesive tape, overtapes, electrode paste, and a cue card illustrating electrode placement.

### G-Suit

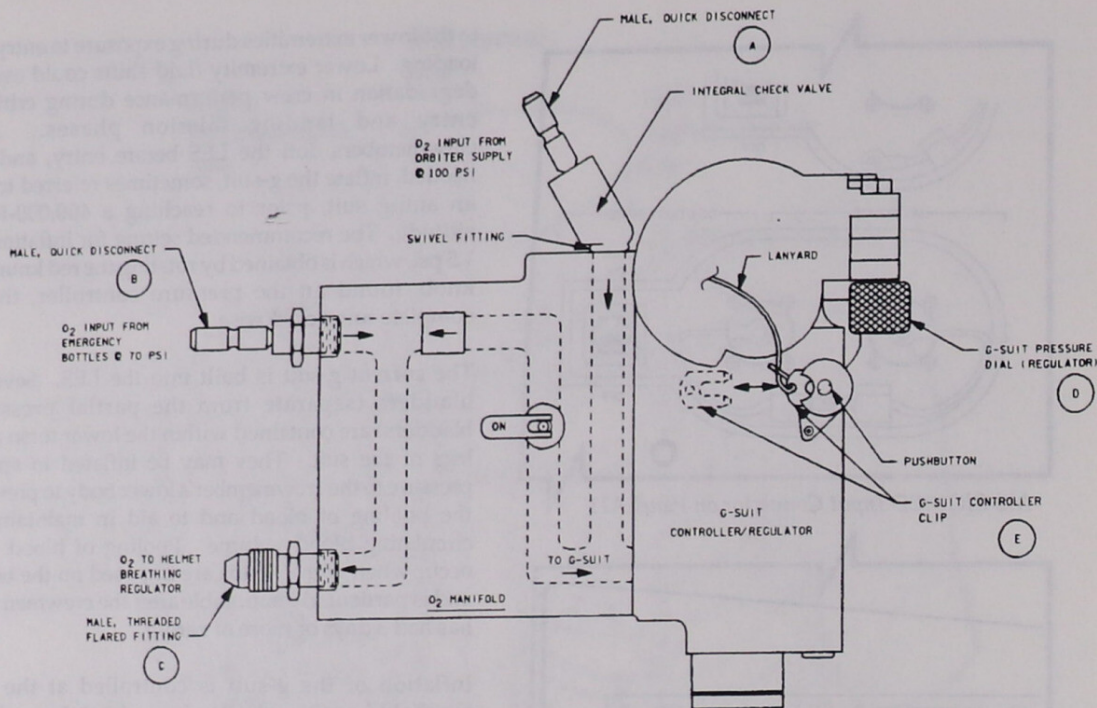
Physiological data indicate that protection should be provided for orbiter crewmembers on flights exceeding 12 hours duration to prevent fluid shifts

to the lower extremities during exposure to entry g-loading. Lower extremity fluid shifts could cause degradation in crew performance during critical entry and landing mission phases. All crewmembers don the LES before entry, and, if needed, inflate the g-suit, sometimes referred to as an anti-g suit, prior to reaching a 400,000-foot altitude. The recommended setting for inflation is 1.5 psi, which is obtained by rotating the red knurled knob, found on the pressure controller, three complete turns clockwise.

The current g-suit is built into the LES. Several bladders (separate from the partial pressure bladders) are contained within the lower torso and legs of the suit. They may be inflated to apply pressure to the crewmember's lower body to prevent the pooling of blood and to aid in maintaining circulating blood volume. Pooling of blood can occur when high g-loads are imposed on the body and is particularly noticeable after the crewmember has had 3 days or more of zero-g.

Inflation of the g-suit is controlled at the O<sub>2</sub> manifold/g-suit controller (one piece), located on the upper left leg. This assembly consists of the following components, referenced to the illustration on the next page:

- A. A male O<sub>2</sub> hose fitting that connects to the orbiter O<sub>2</sub> supply hose. It is provided with a breakaway fitting to facilitate rapid egress from the vehicle.
- B. A second male O<sub>2</sub> hose fitting that connects the manifold with the emergency O<sub>2</sub> bottles in the crewmember's parachute harness.
- C. A third (threaded) male O<sub>2</sub> hose fitting that connects the manifold with the demand regulator for crewmember respiration.
- D. The g-suit controller. When the manifold is connected to orbiter O<sub>2</sub>, and the knurled knob is rotated clockwise (in the direction of the arrow), the controller inflates the g-suit bladders 0.5 psi per complete turn, to a maximum pressure of 2.5 psi. A one-way valve inside the manifold prevents the g-suit from inflating with emergency O<sub>2</sub>, which is reserved for breathing. Rotation of the knob counterclockwise will deflate the g-suit bladders 0.5 psi per complete turn. Each complete revolution of the knob is indicated by a slight detent.



O<sub>2</sub> Manifold/G-Suit Controller

E. The g-suit controller clip. When pulled free, the clip will trap the current volume of O<sub>2</sub> inside the g-suit bladders and prevent any deflation, even when the O<sub>2</sub> manifold is disconnected from orbiter O<sub>2</sub>. Reinstallation of the clip will allow a normal deflation of the g-suit bladders.

An internal pressure relief valve vents g-suit pressure in excess of 32 psi into the partial pressure bladders, where it will either be held or vented out of the suit, depending on cabin pressure.

### Radiation Equipment

The harmful biological effects of radiation must be minimized through mission planning based on calculated predictions and monitoring of dosage exposures. Preflight requirements include a projection of mission radiation dosage, an assessment of the probability of solar flares during the mission, and a radiation exposure history of flight crewmembers. In-flight requirements include the carrying of passive dosimeters by the flight

crewmembers and, in the event of solar flares or other radiation contingencies, the readout and reporting of the active dosimeters.

There are four types of active dosimeters: pocket dosimeter high (PDH), pocket dosimeter low (PDL), pocket dosimeter FEMA (PDF), and high-rate dosimeter (HRD). All four function in the same manner and contain a quartz fiber positioned to zero by electrostatic charging before flight. The unit discharges according to the amount of radiation received; as the unit discharges, the quartz moves. The position of the fiber along a scale is noted visually. The PDH unit's range is zero to 100 rads. The PDF and PDL units' ranges are zero to 200 millirads, and the HRD unit's range is zero to 600 rads.

The rad is a unit based on the amount of energy absorbed and is defined as any type of radiation that is deposited in the absorbing media. Radiation absorbed by humans is expressed in roentgen equivalent in man, or rems. The rem is determined by multiplying rads times a qualifying factor that is

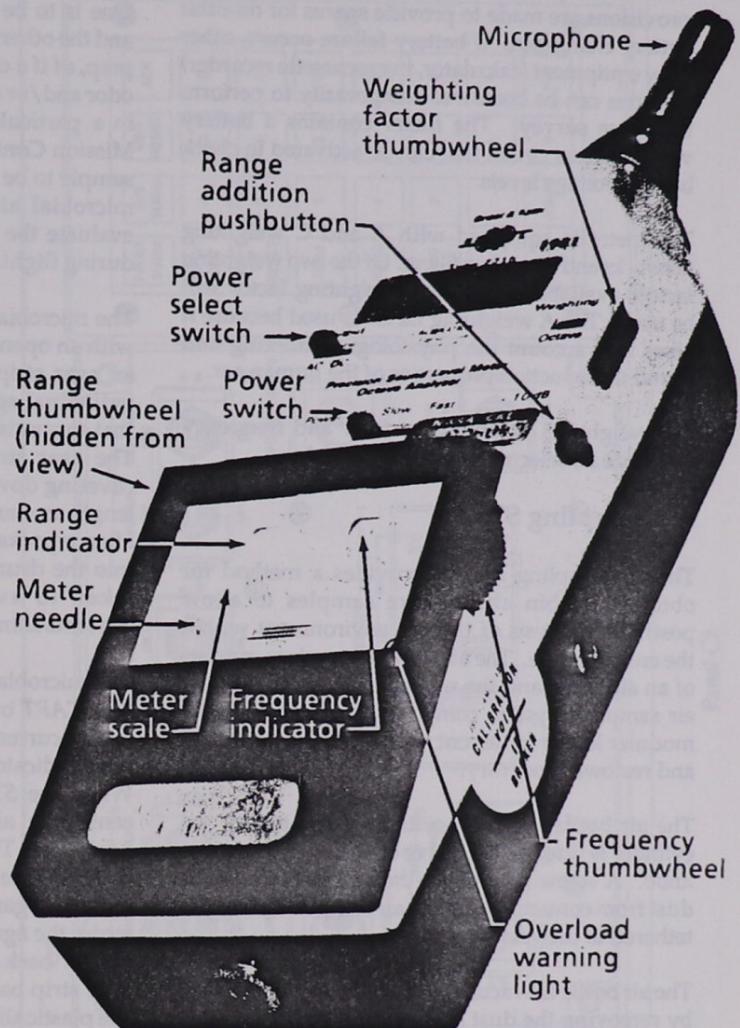
a variable depending on wavelength, source, etc. For low-inclination orbits (35 degrees and lower), the qualifying factor is approximately equal to one; therefore, the rem is approximately equal to the rad. In space transportation system flights, the doses received have ranged from 0.05 to 0.07 rem, well below flight crew exposure limits.

The flight crew's passive dosimeters are squares of fine-ground photo film sandwiched between plastic separators in a light-proof package. Radiation striking the silver halide causes spots on the film, which can be analyzed after the flight. Included in the badge dosimeters are thermoluminescent dosimeter chips, which are analyzed on Earth.

Passive radiation dosimeters are placed in the crew compartment before launch by ground support personnel and removed after landing for laboratory analysis. Each flight crewmember carries a passive dosimeter at all times during the mission. The remaining dosimeters are stowed in a pouch in a middeck modular locker. If a radiation contingency arises, the PDL, PDH, HRD and PDF active dosimeters will be unstowed, read, and recorded for downlink to the ground.

### Acoustics Provisions

The acoustics provisions include a sound level meter and earplugs. The sound level meter is provided when an on-orbit cabin acoustical noise level survey is required. The major reason for conducting noise level surveys is excessive noise level on orbit. If noise levels exceed those required for medical safety, precautions will be taken.



Sound Level Meter

Depending on the requirements for each flight, the crew is required to take specific meter readings at certain specified vehicle and equipment locations. The data obtained by the crew will be logged and/or voice recorded.

The sound level meter is equipped with a condenser microphone that gives it a frequency range of 20 Hz to 20 kHz and an overall dynamic range of 26 to 140 dB (A-weighted). The meter provides direct sound level and frequency readings via a meter-type display.

The meter is powered by four 1.5-volt batteries. No provisions are made to provide spares for on-orbit battery changeout. If battery failure occurs, other crew equipment (calculator, microcassette recorder) batteries can be borrowed temporarily to perform the noise survey. The meter contains a battery voltage status circuit that can be activated to check battery voltage levels.

The meter is equipped with A and C weighting networks and 10-octave filters. Of the two weighting factors available, only the A weighting factor will be used. The A weighting factor is used because it takes into account the physiological filtering and sound transduction properties of the human ear.

The weighting factor/octave filter and frequency range are all selected by the crewmember.

### Air Sampling System

The air sampling system provides a method for obtaining cabin atmosphere samples to allow postflight analysis of the gas environment within the crew module. The air sampling system consists of an air bottle and the microbial air sampler. The air sampling system components are stowed in a modular locker for ascent, unstowed for sampling, and restowed for entry.

The air bottle is a steel cylinder. The end of the cylinder is fitted with a valve operated by the valve knob. A screw cap covers the air inlet to prevent dust from contaminating the air sample. This cap is tethered to the valve.

The air bottle is evacuated preflight and is operated by removing the dust cap, turning the valve knob counterclockwise until full open, and then turning it clockwise until full close. The time it takes to open and close the valve is sufficient to fill the cylinder with cabin gas. When the valve is opened, a hissing sound may not always be heard because of cabin noise or valve variations.

Two air sample bottles are nominally manifested. One is to be utilized for fire/smoke in the cabin, and the other is used for air sampling during deorbit prep, or if a crewmember notices either an unusual odor and/or excessive sneezing and/or watery eyes in a particular area of the cabin. If this occurs, Mission Control should be notified for a microbial sample to be taken of that location post flight. The microbial air sampler can be used on orbit to evaluate the microbial buildup in the crew cabin during flight. It is manifested on a per flight basis.

The microbial air sampler consists of a metal tube with an open end drum that has a slot for inserting an agar strip. The agar strip is composed of 34 individual agar wells and is a nutritional medium that supports the growth of many microorganisms. The agar strip is opened by pulling the plastic covering down no more than one third of the total length as marked. This is to prevent contamination after repackaging. Upon inserting the agar strip into the drum (agar facing inward), care must be taken to avoid touching (and consequently contaminating) the agar wells.

The microbial air sampler power is turned on and the *START* button depressed. The *POWER* switch allows current to flow from the four D-cell batteries to an indicator light that verifies batteries are good. When the *START* push button is depressed, the centrifugal air fan within the drum will operate for 2 minutes. The microorganisms are drawn into the drum by the centrifugal air fan and are deposited onto the agar surface. After the centrifugal air fan stops, the agar strip is removed from the drum and placed back into its original package. After the agar strip back is placed into the original package, the plastic slide seal is slid up over the area that was pulled down for removing the agar strip. The mission elapsed time is then recorded on the outside of the agar strip package. The total number of strips flown is mission specific, and sample time will be scheduled out in the crew activity plan.

## 2.6 DATA PROCESSING SYSTEM (DPS)

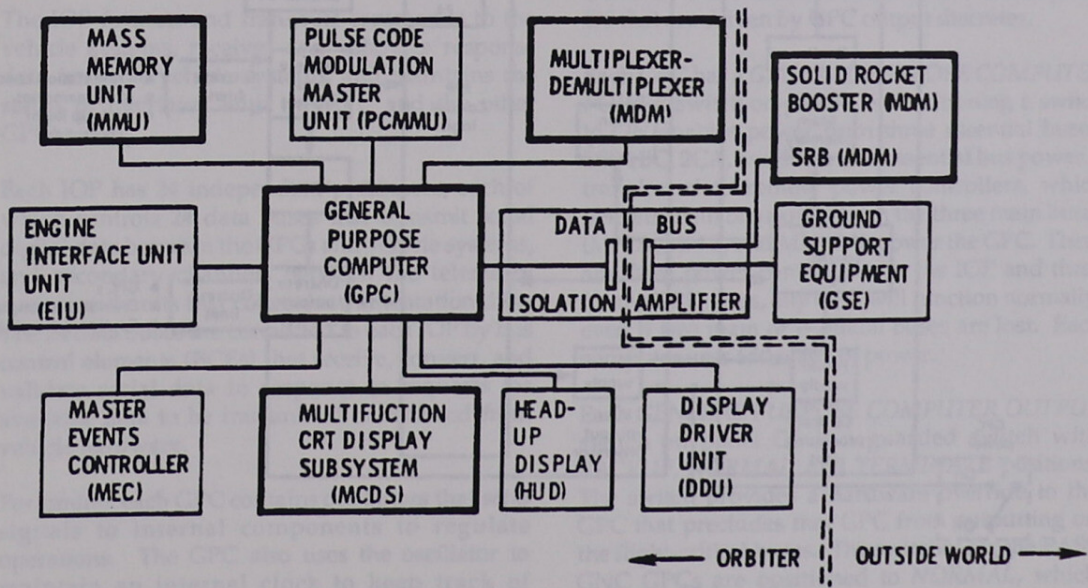
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- Support the guidance, navigation, and control of the vehicle, including calculations of trajectories, SSME burn data, and vehicle attitude control data.
- Monitor and control vehicle subsystems, such as the electrical power system and the environmental control and life support system.
- Process vehicle data for the flight crew and for transmission to the ground, and allow ground control of some vehicle systems via transmitted commands.
- Check data transmission errors and crew control input errors; support annunciation of vehicle system failures and out-of-tolerance system conditions.
- Support payloads with flight crew/software interface for activation, deployment, deactivation, and retrieval.
- Process rendezvous, tracking, and data transmissions between payloads and the ground.

### Description

The DPS, consisting of various hardware components and self-contained software, provides the entire Space Shuttle vehicle with computerized monitoring and control. DPS functions are:

The DPS hardware consists of five general-purpose computers (GPCs), two mass memory units (MMUs) for large-volume bulk storage, and a network of serial digital data buses to accommodate the data traffic between the GPCs and vehicle systems. The



Data Processing System Interfacing Hardware

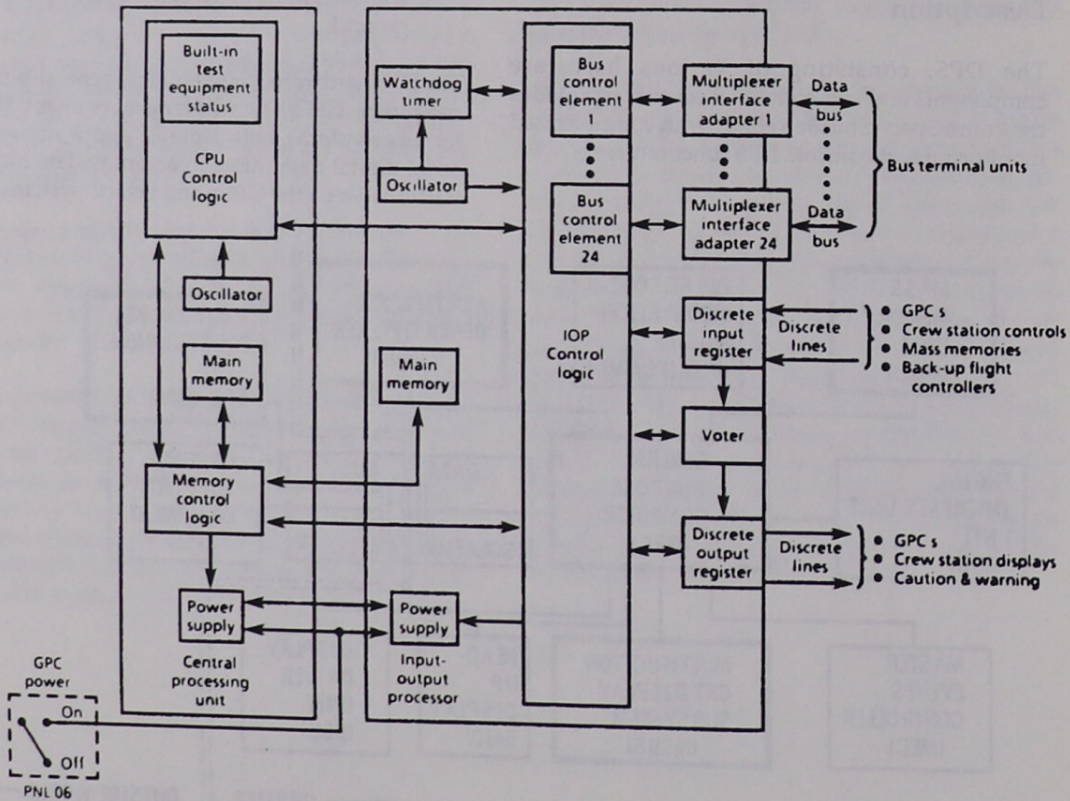
DPS also includes 19 orbiter and four SRB multiplexers/demultiplexers (MDMs) to convert and format data from the various vehicle systems, three SSME interface units to command the SSMEs, four multifunction CRT display systems used by the flight crew to monitor and control the vehicle and payload systems, two data bus isolation amplifiers to interface with the ground support equipment/launch processing system and the SRBs, two master events controllers, and a master timing unit.

DPS software accommodates almost every aspect of Space Shuttle operations, including orbiter checkout, prelaunch and final countdown for launch, turnaround activities, control and monitoring during launch, ascent, on-orbit activities, entry, and landing, and aborts or other contingency mission phases. A multicomputer mode is used for the critical phases of the mission, such as launch, ascent, orbit, entry, landing, and aborts.

### General Purpose Computers (GPCs)

The orbiter has five identical IBM AP-101S GPCs. The GPCs receive and transmit data to and from interfacing hardware via the data bus network. GPCs also contain the software that provides the main on-board data processing capability. Four of the systems run identical software. The fifth system runs different software, programmed by a different company, designed to take control of the vehicle if an error in the primary software or other multiple failures cause a loss of vehicle control. The software on the four primary GPCs is referred to as PASS (primary avionics system software); on the backup it is referred to as BFS (backup flight system).

GPCs 1 and 4 are located in forward middeck avionics bay 1, GPCs 2 and 5 are located in forward middeck avionics bay 2, and GPC 3 is located in aft middeck avionics bay 3. The GPCs receive forced-



General Purpose Computer Functional Block Diagram

air cooling from an avionics bay fan. (There are two fans in each avionics bay, but only one is powered at a time.)

**CAUTION**

If both fans in an avionics bay fail, the computers will overheat and cannot be relied on to operate properly for more than 60 minutes for an operating GPC.

Each GPC consists of a central processing unit (CPU) and an input/output processor (IOP) stored in one avionics box. The boxes are 19.55 inches long, 7.62 inches high, and 10.2 inches wide; they weigh 64 pounds. Each CPU and IOP contains a memory area for storing software and data. These memory areas are collectively referred to as the GPC's main memory. The main memory of each GPC is volatile (the software is not retained when power is interrupted), but a battery pack preserves software contents when the GPC is powered off. The memory capacity of the GPCs is about 256 k whole words.

The CPU controls access to GPC main memory for data storage and software execution and executes instructions to control vehicle systems and manipulate data.

The IOP formats and transmits commands to the vehicle systems, receives and validates response data from the vehicle systems, and maintains the status of interfaces with the CPU and the other GPCs.

Each IOP has 24 independent processors, each of which controls 24 data buses that transmit serial digital data between the GPCs and vehicle systems, and secondary channels between the telemetry system and units that collect instrumentation data. The 24 data buses are connected to each IOP by bus control elements (BCEs) that receive, convert, and validate serial data in response to requests for available data to be transmitted or received from vehicle hardware.

For timing, each GPC contains oscillators that send signals to internal components to regulate operations. The GPC also uses the oscillator to maintain an internal clock to keep track of

Greenwich mean time and mission elapsed time as a backup to the timing signal from the master timing unit.

Since the BFS does not operate in synchronization with other GPCs that can check its proper functioning, each GPC contains a watchdog timer. The watchdog timer is a decrementing clock register in the IOP that is reset about once every second by a signal from the CPU. If the timer ever counts down to zero, then an IOP/CPU interface problem exists and is annunciated by a self-fail indication from that GPC.

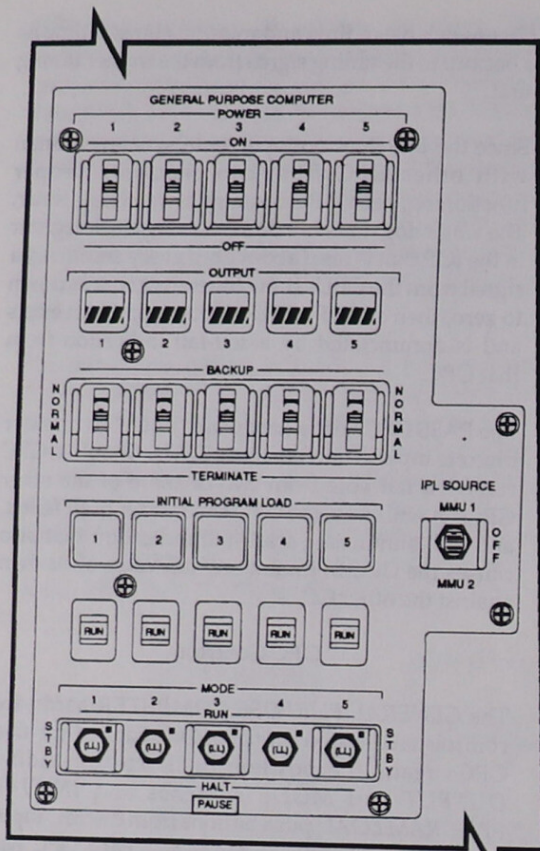
The PASS GPCs use a hardware "voter" to monitor discrete inputs from the other GPCs. Should a GPC receive a fail vote from two or more of the other GPCs, it will cause the GPC to consider itself failed, and will annunciate a self-fail indication that also causes the GPC to inhibit any fail votes of its own against the other GPCs.

**GPC Controls**

The *GENERAL PURPOSE COMPUTER* hardware controls are located on panel O6. Each of the five GPCs reads the position of its corresponding *OUTPUT* and *MODE* switches and *INITIAL PROGRAM LOAD* push buttons from discrete input lines that go directly to the GPC. Each GPC has *OUTPUT* and *MODE* talkback indicators on panel O6 that are driven by GPC output discrettes.

Each GPC has a *GENERAL PURPOSE COMPUTER POWER* switch on panel O6. Positioning a switch to *ON* enables power from three essential buses, ESS 1BC, 2CA, and 3AB. The essential bus power is transferred to remote power controllers, which permits main bus power from the three main buses (MN A, MN B, and MN C) to power the GPC. There are three power controllers for the IOP and three for the CPU; thus, any GPC will function normally, even if two main or essential buses are lost. Each computer uses 650 watts of power.

Each *GENERAL PURPOSE COMPUTER OUTPUT* switch on panel O6 is a guarded switch with *BACKUP*, *NORMAL*, and *TERMINATE* positions. The switch provides a hardware override to the GPC that precludes that GPC from outputting on the flight-critical buses. The switches for the PASS GNC GPCs are positioned to *NORMAL*, which



GENERAL PURPOSE COMPUTER  
Hardware Controls on Panel O6

permits them to output. The backup flight system switch (GENERAL PURPOSE COMPUTER 5) is positioned to BACKUP, which precludes it from outputting until it is engaged. The switch for a GPC designated on-orbit to be a systems management computer is positioned to TERMINATE, since the GPC is not to command anything on the flight-critical buses.

The talkback indicator above each OUTPUT switch on panel O6 indicates gray if that GPC output is enabled and barberpole if it is not.

Each GPC receives RUN, STBY, or HALT discrete inputs from its MODE switch on panel O6, which determines whether that GPC can process software. The MODE switch is lever-locked in the RUN position. The HALT position initiates a hardware-

controlled state in which no software can be executed. A GPC that fails to synchronize with others is either powered OFF or moded to HALT as soon as possible to prevent the failed computer from outputting erroneous commands. The talkback indicator above the MODE switch for that GPC indicates barberpole when that computer is in HALT.

In STBY, a GPC is also in a state in which no PASS software can be executed, but it is in a software-controlled state. The STBY mode allows an orderly startup or shutdown of processing. It is necessary, as a matter of procedure, for a GPC that is shifting from RUN to HALT to be temporarily (more than 3 seconds) in the STBY mode before going to HALT, since the STBY mode allows for an orderly software cleanup and allows a GPC to be correctly initialized without an initial program load. If a GPC is moded from RUN to HALT without pausing in STBY, it may not perform its functions correctly upon being remoded to RUN. There is no STBY indication on the talkback indicator above the MODE switch.

The RUN position permits a GPC to support its normal processing of all active software and assigned vehicle operations. Whenever a computer is moded from STBY or HALT to RUN, it initializes itself to a state in which only system software is processed (called OPS 0). If a GPC is in another operational sequence (OPS) before being moded out of RUN, and the initial program has not been loaded since, that software still resides in main memory; however, it will not begin processing until that OPS is restarted by flight crew keyboard entry. The MODE talkback indicator always reads RUN when that GPC switch is in RUN, and no failures exist.

Placing the backup flight system GPC in STBY does not stop BFS software processing or preclude BFS engagement; it only prevents the BFS from commanding the payload buses used by BFS systems management software.

The GPC/BUS STATUS display (DISP 6) indicates the current mode of each PASS GPC in the common set. The display does not differentiate between STBY and HALT; only RUN or HALT is displayed (GPC MODE).



XXXX/XXX/006		GPC/BUS STATUS					XX X DDD/HH:MM.SS DDD/HH:MM.SS	
GPC		1S	2S	3S	4S	5S		
MODE	OPS	XXXX	XXXX	XXXX	XXXX	XXXX		
		XX	XX	XX	XX	XX		
STRING	1	FF	XS	XS	XS	XS	XS	XS
		FA	XS	XS	XS	XS	XS	XS
	2	FF	XS	XS	XS	XS	XS	XS
		FA	XS	XS	XS	XS	XS	XS
	3	FF	XS	XS	XS	XS	XS	XS
		FA	XS	XS	XS	XS	XS	XS
	4	FF	XS	XS	XS	XS	XS	XS
		FA	XS	XS	XS	XS	XS	XS
	PL	1	XS	XS	XS	XS	XS	XS
		2	XS	XS	XS	XS	XS	XS
	LAUNCH	1	XS	XS	XS	XS	XS	XS
		2	XS	XS	XS	XS	XS	XS
	CRT	1	XS	XS	XS	XS	XS	XS
		2	XS	XS	XS	XS	XS	XS
		3	XS	XS	XS	XS	XS	XS
		4	XS	XS	XS	XS	XS	XS

(XX)

GPC/BUS STATUS Display (DISP 6)

The INITIAL PROGRAM LOAD push button for a GPC on panel O6 activates the initial program load command discrete input when depressed. When the input is received, that GPC initiates an initial program load (IPL) from the MMU specified by the IPL SOURCE switch on panel O6. The talkback indicator above the MODE switch for that GPC indicates IPL.

During non-critical periods in orbit, only one or two GPCs are used for GNC tasks, and another is used for systems management and payload operations.

A GPC on-orbit can also be "freeze-dried"; that is, it can be loaded with the software for a particular memory configuration and then moded to HALT. Before an OPS transition to the loaded memory configuration, the freeze-dried GPC can be moded back to RUN and the appropriate OPS requested.

#### NOTE

Because all BFS software is loaded into the BFS GPC at the same time, the BFS GPC is sometimes referred to as being freeze-dried on-orbit when it is placed in HALT. The BFS GPC can be moded to RUN prior to entry and will begin processing entry software following the OPS 3 request without having to access a mass memory unit.

## GPC Modes of Operation

GPC modes of operation are redundant set, common set, and simplex. Redundant set operations refer to the mode in which two or more GPCs are concurrently receiving the same inputs, executing the same GNC software, and producing the same outputs. This mode uses a maximum amount of intercomputer communications, and the GPCs must maintain a high level of synchronization (called redundant set synchronization).

During redundant set operations, each GPC outputs only certain portions of its total software output to its interfacing hardware. Therefore, although each GPC "thinks" it is performing all its operations, only the GPC responsible for supporting a specific group of hardware will be able to actually transmit its data and commands. The redundant set GPCs compare all calculations to ensure that individual outputs are the same.

Common set operations occur when two or more GPCs communicate with one another while they are performing their individual tasks. They do not have to be performing the same major function (although they can be), but they do maintain common set synchronization. Any GPC operating as a member of the redundant set is also a member of the common set.

A simplex GPC is in RUN but not a member of the redundant set, such as the BFS GPC. Systems management and payload major functions are always processed in a simplex GPC.

GPCs running together in the same GNC OPS are part of a redundant set performing identical tasks from the same inputs and producing identical outputs. Therefore, any data bus assigned to a commanding GNC GPC (except the instrumentation buses because each GPC has only one dedicated bus connected to it) is heard by all members of the redundant set. These transmissions include all CRT inputs and mass memory transactions, as well as flight-critical data. If one or more GPCs in the redundant set fail, the remaining computers can continue operating in GNC. Each GPC performs about 325,000 operations per second during critical phases.

Each computer in a redundant set operates in synchronized steps and cross-checks results of processing about 440 times per second. Synchronization refers to the software scheme used to ensure simultaneous intercomputer communications of necessary GPC status information among the PASS computers. If a GPC operating in a redundant set fails to meet two redundant synchronization points in a row, the remaining computers will vote it out of the redundant set. If a GPC has a problem with its multiplexer interface adapter receiver during two successive reads of response data and does not receive any data while the other members of the redundant set do receive the data, they in turn will vote the GPC out of the set. A failed GPC is either powered OFF or moded to HALT as soon as possible by the crew.

**GPC Failure Indications**

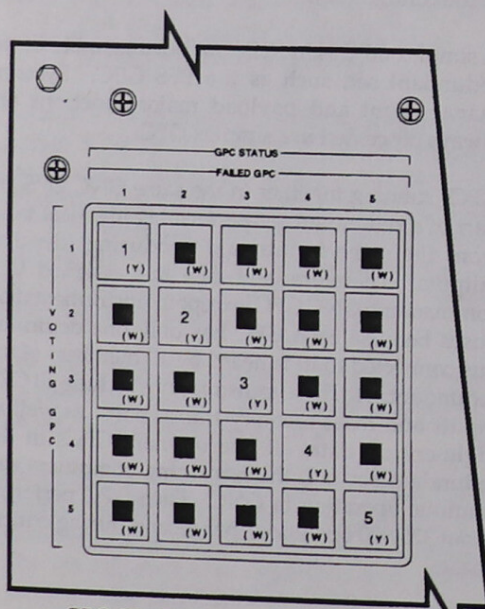
GPC failure votes are annunciated in a number of ways. Each GPC has discrete output lines for fail votes against each of the other GPCs that go to the other GPCs and the GPC status matrix. A GPC FAIL detection will cause a class 2 GPC FAULT message with illumination of the MASTER ALARM.

Error indications may be displayed on DISP 18 GNC SYS SUMM 1 and DISP 6 GPC/BUS STATUS displays.

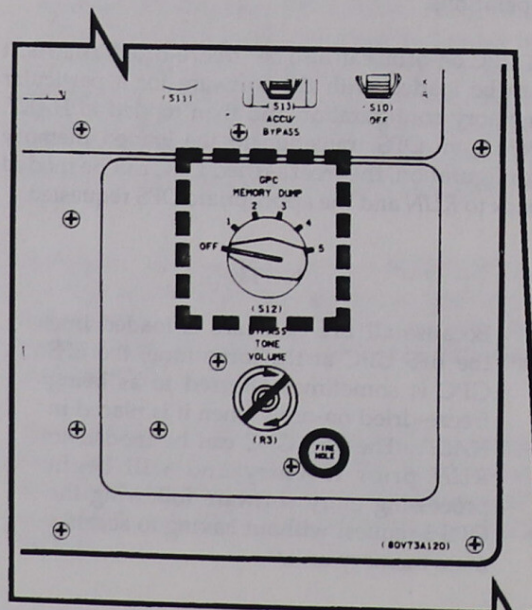
XXXX/XXX018			GNC SYS SUMM 1			XX X DDD/HH:MM:SS DDD/HH:MM:SS					
RCS	JET	ISOL	SURF	POS	MOM	DPS	1	2	3	4	5
MANF	FAIL	VLV				GPC	S	S	S	S	S
F1	XXX	XXS	L OB	XXX	XS XXS	MDM	FF	S	S	S	S
2	XXX	XXS	IB	XXX	XS XXS	FA	S	S	S	S	S
3	XXX	XXS	R IB	XXX	XS XXS						
4	XXX	XXS	OB	XXX	XS XXS						
5	XXX	XXS	AIL	XXX	X						
L1	XXX	XXS	RUD	XXX	X	FCS	CH	1	2	3	4
2	XXX	XXS	SPD BRK	XXX	X			S	S	S	S
3	XXX	XXS	BDY FLP	XXX	X						
4	XXX	XXS		XXXXXX							
5	XXX	XXS				NAV	1	2	3	4	
R1	XXX	XXS				IMU	S	S	S		
2	XXX	XXS	CNTRL	1	2	3	ACC	S	S	S	S
3	XXX	XXS	RHC	L	S	S	SGA	S	S	S	S
4	XXX	XXS		R	S	S	TAC	S	S	S	
5	XXX	XXS		A	S	S	MLS	S	S	S	
			THC	L	S	S	ADTA	S	S	S	S
				A	S	S					
			SBTC	L	S	S					
				R	S	S					

DPS Parameters on GNC SYS SUMM 1 Display (DISP 18)

The GPC STATUS matrix on panel O1 is a 5-by-5 matrix of lights. Each light corresponds to a GPC's fail vote against another GPC or itself. For example, if GPC 2 sends out a failure vote against GPC 3, the second white light in the third column is illuminated. The off-diagonal votes are votes against other GPCs. The yellow diagonal lights from upper left to lower right are self-failure votes. Whenever a GPC receives



GPC STATUS Matrix on Panel O1  
(W=white; Y=yellow)



GPC MEMORY DUMP Switch on Panel MO42F

two or more failure votes from other GPCs, it illuminates its own yellow light and resets any failure votes that it made against other GPCs (any white lights in its row are extinguished). Any time a yellow matrix light is illuminated, the GPC caution and warning light on panel F7 is illuminated, in addition to *MASTER ALARM* illumination, and a GPC fault message is displayed on the CRT.

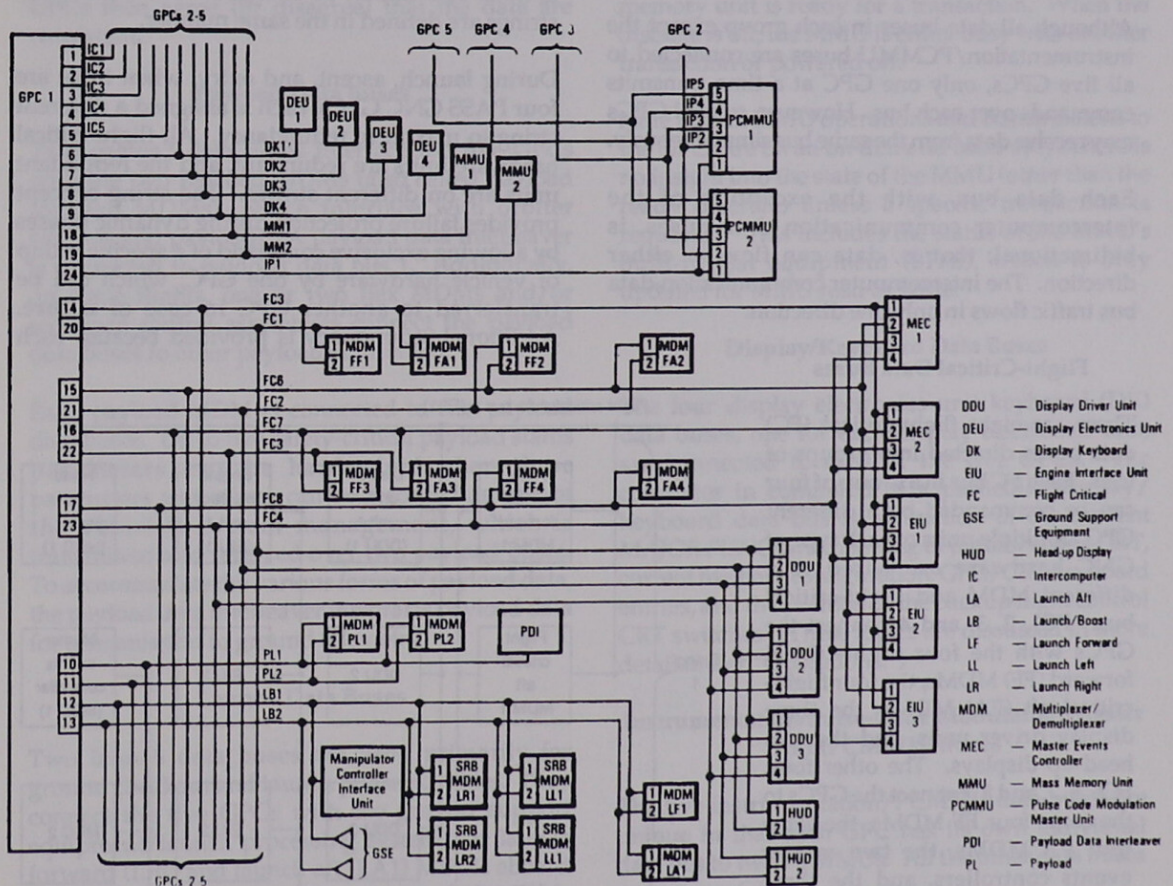
A failed GPC can be hardware-initiated, stand-alone-memory-dumped by powering *ON*, switching the computer to *TERMINATE* and *HALT*, and then selecting the number of the failed GPC on the *GPC MEMORY DUMP* rotary switch on panel M042F.

Then the GPC is moded to *STBY* to start the dump, which takes 3 to 7 minutes.

### Data Bus Network

The data bus network supports the transfer of serial digital commands between the GPCs and vehicle systems. The network is divided into seven groups that perform specific functions:

1. Flight-critical (FC) data buses that tie the GPCs to the flight-critical multiplexer/demultiplexers (MDMs), display driver units, head-up displays, engine interface units, and master events controllers



Data Bus Network

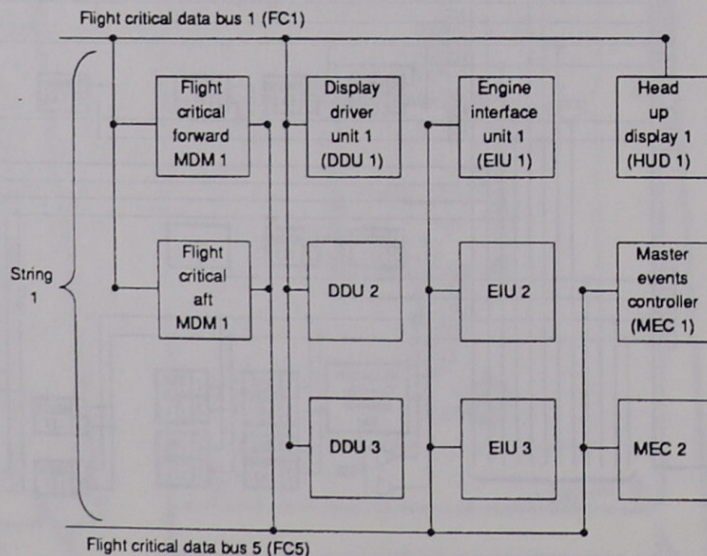
2. Payload data buses that tie the GPCs to the payload MDMs and the payload data interleaver (PDI), as well as the flex MDMs and sequence control assemblies
3. Launch data buses that tie the GPCs to ground support equipment, launch forward, launch aft, and SRB MDMs, and the manipulator controller interface unit used by the remote manipulator system
4. Mass memory data buses for GPC/MMU transactions
5. Display/keyboard data buses for GPC/display electronics unit transactions
6. Instrumentation/pulse code modulation master unit (PCMMU) data buses
7. Intercomputer communication data buses.

Although all data buses in each group except the instrumentation/PCMMU buses are connected to all five GPCs, only one GPC at a time transmits commands over each bus. However, several GPCs may receive data from the same bus simultaneously.

Each data bus, with the exception of the intercomputer communication data buses, is bidirectional; that is, data can flow in either direction. The intercomputer communication data bus traffic flows in only one direction.

#### Flight-Critical Data Buses

There are eight flight-critical (FC) data buses directed into groups of four. Each FC bus in a group of four can be commanded by a different GPC. Multiple units of each type of GNC hardware are wired to a different MDM and flight-critical bus. FC1, 2, 3, and 4 connect the GPCs with the four flight-critical forward (FF) MDMs, the four flight-critical aft (FA) MDMs, the three display driver units, and the two head-up displays. The other four, FC5, 6, 7, and 8, connect the GPCs to the same four FF MDMs, the same four FA MDMs, the two master events controllers, and the three main engine interface units.



Components of String One

This distribution of hardware is referred to as a string. A string is composed of two FC data buses: one from the first group (FC1, 2, 3, or 4) and one from the second group (FC5, 6, 7, or 8). Vehicle hardware is segmented into these groups to facilitate GPC command of these components for redundancy, to allow for nominal mission operations in the event of a loss of one string caused by a GPC or MDM failure, and to allow for safe return to Earth in the event of the loss of a second string.

String 1 consists of FC data buses 1 and 5, MDMs FF1 and FA1 and their hard-wired hardware, controls, and displays, the three engine interface units, the two master events controllers, the three display driver units, head-up display 1, and their associated displays. This distribution of hardware is fixed and cannot be changed. The other three strings are defined in the same manner.

During launch, ascent, and entry, when there are four PASS GNC GPCs, each is assigned a different string to maximize redundancy. All flight-critical hardware units are redundant, and the redundant units are on different strings. The string concept provides failure protection during dynamic phases by allowing exclusive command of a specific group of vehicle hardware by one GPC, which can be transferred to another GPC in case of failure. Additional redundancy is provided because each

flight-critical forward and aft MDM is connected to the GPCs by two flight critical data buses; thus, all or part of one string can be lost, and all functions will still be retained through the other strings.

With four PASS GNC GPCs in a redundant set, each GPC is responsible for issuing commands over the string assigned to it; that is, it is the commander of that string. The other GNC GPCs will monitor or listen to this string. When the string's commanding GPC sends a request for data to the hardware on the string, all the other GNC GPCs will hear and receive the same data coming back on the string. This transaction (one commanding GPC and multiple listening GPCs) is occurring in parallel with the other three strings. Therefore, all GNC GPCs will get a copy of all of the data from all four strings. Once all the data are received from the string, the GPCs then agree (or disagree) that the data are consistent.

#### Payload Data Buses

Two payload data buses interface the five GPCs with the two payload MDMs (also called payload forward MDMs), which interface with orbiter systems and payloads. A payload data interleaver is connected to payload data bus 1. Additionally, on some flights, one or two flex MDMs and/or sequence control assemblies connect the payload data buses to other payload equipment.

Each payload MDM is connected to two payload data buses. Up to five safety-critical payload status parameters may be hard-wired; then these parameters and others can be recorded as part of the vehicle's system management, which is transmitted and received over two payload buses. To accommodate the various forms of payload data, the payload data interleaver integrates payload data for transmission to ground telemetry.

#### Launch Data Buses

Two launch data buses are used primarily for ground checkout and launch phase activities. They connect the five GPCs with the ground support equipment/launch processing system, the launch forward (LF1) and launch aft (LA1) MDMs aboard the orbiter, and the two left and right SRB MDMs (LL1, LL2, LR1, and LR2). Launch data bus 1 is

used on orbit for interface with the remote manipulator system controller by the systems management GPC.

#### Mass Memory Data Buses

Each of two MMUs interfaces with its data bus via a multiplexer interface adapter, which functions just like the ones in the GPCs. Each data bus is connected to all five GPCs. The serial digital commands and data from the GPCs and the data read from the mass memory unit are sent on the data bus. Each MMU is connected to only one mass memory data bus.

In addition, each MMU has a separate discrete line called the "ready discrete" that goes to each of the GPCs. If the discrete is on, it tells the GPC the mass memory unit is ready for a transaction. When the discrete is off, the MMU is either busy with another transaction or powered off.

Note that all MMU operations and transmissions to the GPCs are on an on-demand basis only. There is no insight into the state of the MMU (other than the ready discrete) unless a specific transaction is requested. This includes the status of the MMU's built-in test equipment (BITE), which is only updated for MMU read or write.

#### Display/Keyboard Data Buses

The four display electronics unit keyboard (DK) data buses, one for each display electronics unit, are connected to each of the five GPCs. The computer in command of a particular display/keyboard data bus is a function of the current *MAJOR FUNC* switch setting of the associated CRT, current memory configuration, GPC/CRT keyboard entries, and the position of the backup flight control CRT switches. (These topics are discussed in more detail under "Operations.")

#### Instrumentation/Pulse-Code Modulation Master Unit (PCMMU) Buses

The five instrumentation/PCMMU data buses are unique in that each GPC has its own individual data bus to two PCMMUs. All the other data buses go to every GPC.

Flight controllers monitor the status of the vehicle's onboard systems through data transmissions from the vehicle to the ground. These transmissions, called downlink, include GPC-collected data, payload data, instrumentation data, and onboard voice. The GPC-collected data, called downlist, includes a set of parameters chosen before flight for each mission phase.

The system software in each GPC assimilates the specified GNC, systems management, payload, or DPS data according to the permission-defined format for inclusion in the downlist. Each GPC is physically capable of transmitting its downlist to the current active PCMMU over its dedicated instrumentation/PCMMU data bus. Only one PCMMU is powered at a time. It interleaves the downlist data from the different GPCs with the instrumentation and payload data according to the telemetry format load programmed in the PCMMU. The resulting composite data set, called the operational downlink, is transmitted to one of two network signal processors (NSPs). Only one NSP is powered at a time. In the NSP, the operational downlink is combined with onboard recorded voice for transmission to the ground. The S-band and Ku-band communications systems transmit the data either to the space flight tracking and data network remote site ground stations or through the Tracking and Data Relay Satellite (TDRS) system to Mission Control.

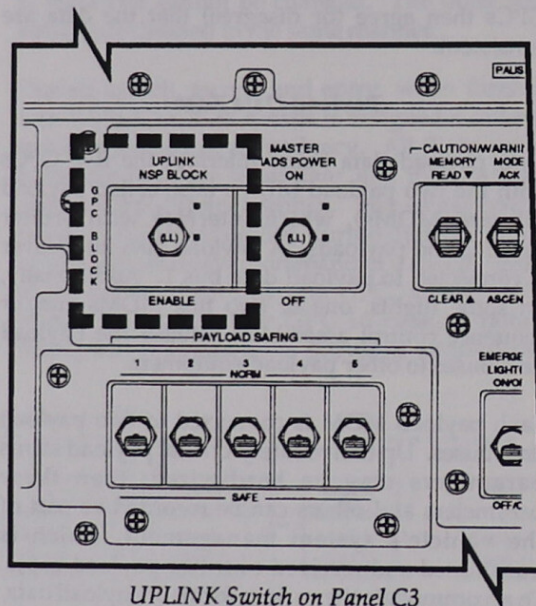
Uplink is the method by which ground commands originating in Mission Control are formatted, generated, and transmitted to the orbiter for validation, processing, and eventual execution by onboard software. This capability allows ground systems to control data processing, change modes in orbiter hardware, and store or change software in GPC memory and mass memory.

From Mission Control consoles, flight controllers issue commands and request uplink. The command requests are formatted into a command load for transmission to the orbiter either by the STDN sites or by the TDRS system. The S-band or Ku-band transponder receivers aboard the orbiter send the commands to the active NSP. The NSP validates the commands until they are requested by the GPCs through a flight-critical MDM. The GPCs also validate the commands before executing them.

Those GPCs not listening directly to the flight-critical data buses receive uplink commands over the intercomputer communication data buses.

The PCMMU also contains a programmable read-only memory for accessing subsystem data, a random-access memory in which to store data, and a memory in which GPC data are stored for incorporation into the downlink.

To prevent the uplink of spurious commands from somewhere other than Mission Control, the flight crew can control when the GPCs accept uplink commands, and when uplink is blocked. The GPC BLOCK position of the UPLINK switch on panel C3 inhibits uplink commands during ascent and entry when the orbiter is not over a ground station or in TDRS coverage.



### Intercomputer Communication Data Buses

There are five intercomputer communication (IC) data buses. The following information is exchanged over these buses for proper DPS operation: input/output errors, fault messages, GPC status matrix data, display electronics unit major function switch settings, GPC/CRT keyboard entries, resident GPC memory configuration, memory configuration table,

operational sequences, master timing unit, internal GPC time, system-level display information, uplink data, and state vectors.

All GPCs processing PASS exchange status information over the IC data buses. During launch, ascent, and entry, GPCs 1, 2, 3, and 4 are usually assigned to perform GNC tasks, operating as a redundant set, with GPC 5 as the backup flight system. One of the PASS GPCs acts as a commander of a given IC data bus in the flight control scheme and initiates all data bus transactions.

The four PASS GPCs are loaded with the same software. Interconnecting the four IC buses to the four PASS GPCs allows each GPC access to the status of data received or transmitted by the other GPCs so that identical results among the four PASS GPCs can be verified. Each IC bus is assigned to one of the four PASS GPCs in the command mode, and the remaining GPCs operate in the listen mode for the bus. Each GPC can receive data with the other three GPCs, pass data to the others, request data from the others, and perform any other tasks required to operate the redundant set.

### Multiplexers/Demultiplexers (MDMs)

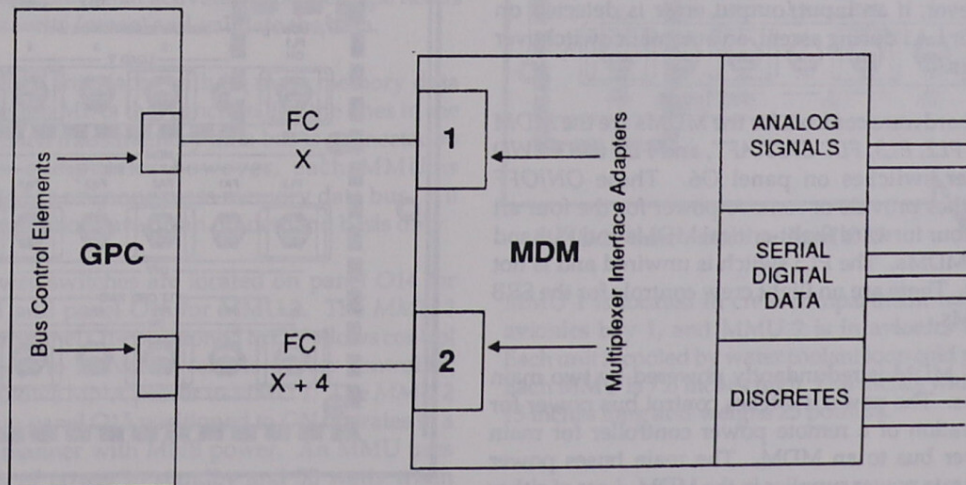
The MDMs convert and format (demultiplex) serial digital GPC commands into separate parallel discrete, digital, and analog commands for various vehicle hardware systems. The MDMs also convert

and format (multiplex) the discrete, digital, and analog data from vehicle systems into serial digital data for transmission to the GPCs. Each MDM has two redundant multiplexer interface adapters (MIAs) connected to two data buses. The MDM's other functional interface is its connection to the appropriate vehicle system hardware by hard-wired lines.

There are 23 MDMs aboard the orbiter; 16 are part of the DPS, connected directly to the GPCs and named and numbered according to their location in the vehicle and hardware interface. The remaining seven MDMs are part of the vehicle instrumentation system and send vehicle instrumentation data to the PCMMUs. (They are termed operational instrumentation (OI) MDMs.)

The DPS MDMs consist of flight-critical forward (FF) MDMs 1 through 4, flight-critical aft (FA) MDMs 1 through 4, payload (PL) MDMs 1 and 2, SRB launch left (LL) MDMs 1 and 2, launch right (LR) MDMs 1 and 2, and GSE/LPS launch forward (LF) 1 and launch aft (LA) 1. One or two flex MDMs (FMDMs) may also be connected to the PL data buses, depending on the payload needs for a particular flight.

Of the seven operational instrumentation MDMs, four are located forward (OF1, OF2, OF3, and OF4), and three are located aft (OA1, OA2, and OA3).



GPC/MDM Interfaces

The system software in each redundant set of GPCs activates a GNC executive program and issues commands to the bus and MDM to provide a set of input data. Each MDM receives the command from the GPC assigned to it, acquires the requested data from the GNC hardware wired to it, and sends the data to the GPCs.

Each FC data bus is connected to a flight forward and flight aft MDM. Each MDM has two MIAs, or ports, and each port has a channel through which the GPCs can communicate with an MDM; however, the FC data buses can interface with only one MIA port at a time. Port moding is the software method used to control the MIA port that is used in an MDM. Initially, these MDMs operate with port 1; if a failure occurs in port 1, the flight crew can select port 2. Since port moding involves a pair of buses, both MDMs must be ported at the same time. The control of all other units connected to the affected data buses is unaffected by port moding.

Payload data bus 1 is normally connected to the primary MIA port of payload MDM 1, and payload data bus 2 is connected to the primary port of payload MDM 2. Payload data bus 1 can be connected to the secondary MIA port of payload MDM 2, and payload data bus 2 can be connected to the secondary port of payload MDM 1 by flight crew selection.

The two launch data buses are also connected to dual launch MDM multiplexer interface adapter ports. The flight crew cannot switch these ports; however, if an input/output error is detected on LF1 or LA1 during ascent, an automatic switchover occurs.

The hardware controls for the MDMs are the MDM PL1, PL2, PL3, FLT CRIT AFT, and FLT CRIT FWD power switches on panel O6. These ON/OFF switches provide or remove power for the four aft and four forward flight-critical MDMs and PL1 and PL2 MDMs. The PL3 switch is unwired and is not used. There are no flight crew controls for the SRB MDMs.

Each MDM is redundantly powered by two main buses. The power switches control bus power for activation of a remote power controller for main power bus to an MDM. The main buses power separate power supplies in the MDM. Loss of either

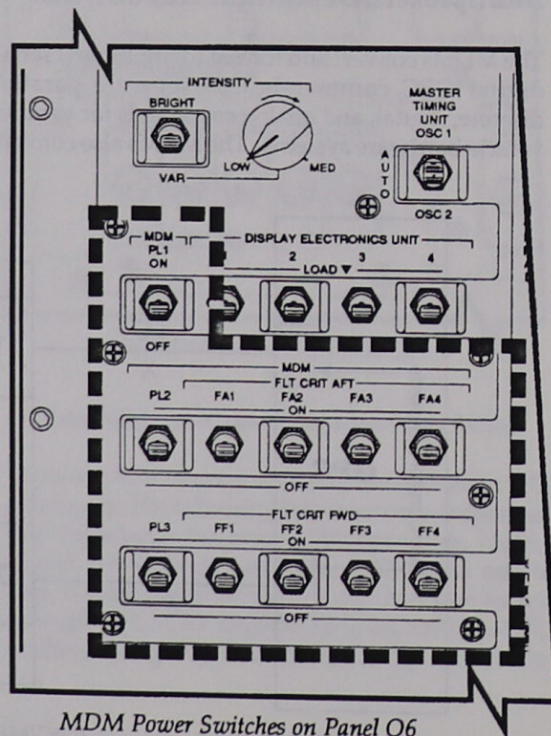
the main bus or MDM power supply does not cause a loss of function because each power supply powers both channels in the MDM. Turning power to an MDM off resets all the commands to subsystems.

The SRB MDMs receive power through SRB buses A and B; they are tied to the orbiter main buses and controlled by the master events controller circuitry. The launch forward and aft MDMs receive their power through the preflight test buses.

The FF, PL, and LF MDMs are located in the forward avionics bays and are cooled by water coolant loop cold plates. LA and FA MDMs are in the aft avionics bays and are cooled by Freon coolant loop cold plates. MDMs LL1, LL2, LR1, and LR2 are located in the SRBs and are cooled by passive cold plates.

Modules and cards in an MDM depend on the hardware components accessed by that type of MDM. A flight-critical forward and aft MDM are not interchangeable. However, one flight-critical MDM may be interchanged with another or one payload MDM with another.

Each MDM is 13 by 11 by 7 inches and weighs 38.5 pounds. MDMs use less than 80 watts of power.



MDM Power Switches on Panel O6



## Mass Memory Units

There are two mass memory units (MMUs) aboard the orbiter. Each is a coaxially mounted, reel-to-reel read/write digital magnetic tape storage device for GPC software and orbiter systems data.

Computing functions for all mission phases requires approximately 400,000 words of computer memory. The orbiter GPCs are loaded with different memory groups from the MMUs containing the desired program. In this way, software can be stored in MMUs and loaded into the GPCs when actually needed.

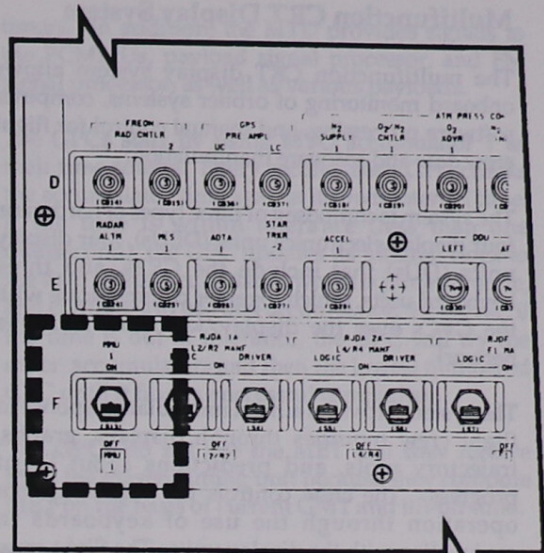
To fit the required software into the available GPC memory space, programs are subdivided into nine memory groups corresponding to functions executed during specific flight and checkout phases. Thus, in addition to the central memory in the GPCs themselves, 34 million bytes of information can be stored in each of the two MMUs. Critical programs and data are loaded in both MMUs and protected from erasure.

The principal function of the MMU, besides storing the basic flight software, is to store background formats for certain CRT displays and the checkpoints that are written periodically to save system data in case the systems management GPC fails.

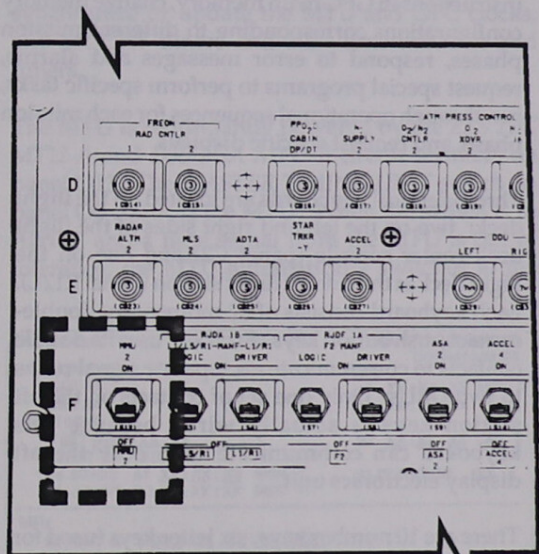
Operations are controlled by logic and the read and write electronics that activate the proper tape heads (read or write/erase) and validate the data.

Each MMU interfaces with its mass memory data bus through MIAs that function like the ones in the GPCs. Each mass memory data bus is connected to all five computers; however, each MMU is connected to only one mass memory data bus. All MMU operations are on an on-demand basis only.

The power switches are located on panel O14 for MMU 1 and panel O15 for MMU 2. The MMU 1 switch on panel O14 positioned to ON allows control bus power to activate a remote power controller, which allows MNA power to MMU 1. The MMU 2 switch on panel O15 positioned to ON operates in a similar manner with MNB power. An MMU uses 20 watts of power in standby and 50 watts when the tape is moving.



MMU 1 Power Switch on Panel O14



MMU 2 Power Switch on Panel O15

MMU 1 is located in crew compartment middeck avionics bay 1, and MMU 2 is in avionics bay 2. Each unit is cooled by water coolant loop cold plates. Each MMU is 7.6 inches high, 11.6 inches wide and 15 inches long and weighs 25 pounds.

## Multifunction CRT Display System

The multifunction CRT display system allows onboard monitoring of orbiter systems, computer software processing, and manual control for flight crew data and software manipulation.

The system is composed of three types of hardware: four display electronics units (DEUs), four display units (DUs) that include the CRTs, and three keyboard units, which together communicate with the GPCs over the display/keyboard data bus network.

The system provides almost immediate response to flight crew inquiries through displays, graphs, trajectory plots, and predictions about flight progress. The crew controls the vehicle system operation through the use of keyboards in conjunction with the display units. The flight crew can alter the system configuration, change data or instructions in GPC main memory, change memory configurations corresponding to different mission phases, respond to error messages and alarms, request special programs to perform specific tasks, run through operational sequences for each mission phase, and request specific displays.

Three identical keyboards are located on the flight deck: two on the left and right sides of the flight deck center console (panel C2) and one on the flight deck at the side aft flight station (panel R12L). Each keyboard consists of 32 momentary double-contact push button keys. Each key uses its double contacts to communicate on separate signal paths to two DEUs. Only one set of contacts on the aft station keys is actually wired because this keyboard can communicate with only the aft display electronics unit.

There are 10 number keys, six letter keys (used for hexadecimal inputs), two algebraic keys, a decimal key, and 13 special key functions. Using these keys, the flight crew can ask the GPC more than 1,000 questions about the mission and condition of the vehicle. (Keyboard operations are discussed in detail later in this section.)

Each of the four DEUs responds to computer commands, transmits data, executes its own software to process keyboard inputs, and sends signals to drive displays on the CRTs (or display

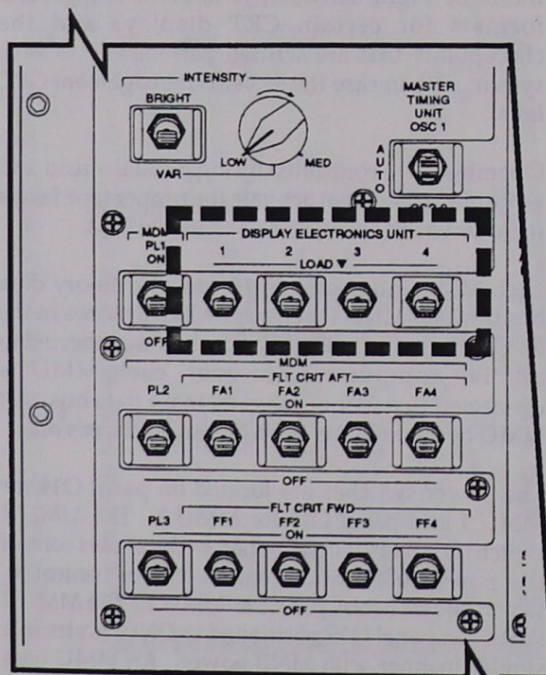
units). The units store display data, generate the GPC/keyboard unit and GPC/display unit interface displays, update and refresh on-screen data, check keyboard entry errors, and echo entries to the CRT.

There are three CRTs on flight deck forward display and control panel F7 and one at the side aft flight deck station on panel R12L. Each CRT is 5 by 7 inches.

The display unit uses a magnetic-deflected, electrostatic-focused CRT. When supplied with deflection signals and video input, the CRT displays alphanumeric characters, graphic symbols, and vectors on a green-on-green phosphorous screen activated by a magnetically controlled beam. Each CRT has a brightness control for ambient light and flight crew adjustment.

The DEUs are connected to the display/keyboard data buses by MIAs that function like those of the GPCs. Inputs to the DEU are from a keyboard or a GPC.

Positioning the *DISPLAY ELECTRONICS UNIT 1, 2, 3, 4* switches on panel O6 to *LOAD* initiates a GPC request for a copy of DEU software stored in



*DISPLAY ELECTRONICS UNIT* Switches on Panel O6

mass memory before operations begin. The information is sent from the mass memory to the GPC and then loaded from the GPC into the DEU memory.

It is possible to do in-flight maintenance and exchange CRT 4 with CRT 1 or 2. CRT 3 cannot be changed out because of interface problems with the orbiter jettison T-handle. Also, either forward keyboard can be replaced by the aft keyboard. The DEUs are located behind panels on the flight deck. DEUs 1 and 3 are on the left, and DEUs 2 and 4 are on the right. DEU 4 can replace any of the others; however, if DEU 2 is to be replaced, only the cables are changed because 2 and 4 are next to each other.

The display electronics units and display units are cooled by the cabin fan system. The keyboard units are cooled by heat dissipation.

### Master Timing Unit

The GPC complex requires a stable, accurate time source because its software uses Greenwich mean time (GMT) to schedule processing. Each GPC uses the master timing unit (MTU) to update its internal clock. The MTU provides precise frequency outputs for various timing and synchronization purposes to the GPC complex and many other orbiter subsystems. Its three time accumulators provide GMT and mission elapsed time (MET), which can be updated by external control. The accumulator's timing is in days, hours, minutes, seconds, and milliseconds up to 1 year.

The MTU is a stable, crystal-controlled frequency source that uses two oscillators for redundancy. The signals from one of the two oscillators are passed through signal shapers and frequency drivers to the three GMT/MET accumulators.

The MTU outputs serial digital time data (GMT/MET) on demand to the GPCs through the accumulators. The GPCs use this information for reference time and indirectly for time-tagging GNC and systems management processing. The MTU also provides continuous digital timing outputs to drive the four digital timers in the crew compartment: two mission timers and two event

timers. In addition, the MTU provides signals to the PCMMUs, payload signal processor, and FM signal processor, as well as various payloads.

The GPCs start by using MTU accumulator 1 as their time source. Every second, each GPC checks the accumulator time against its own internal time. If the time is within tolerance (less than one millisecond), the GPC updates its internal clock to the time of the accumulator, which is more accurate, and continues to use that accumulator. However, if the time is out of tolerance, the GPC will try the other accumulators and then the lowest numbered GPC until it finds a successful comparison.

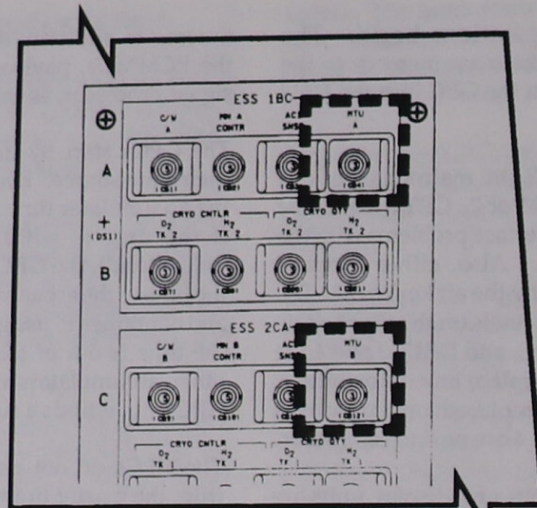
The GPCs do not use the MET that they receive from the master timing unit because they compute MET on the basis of current GMT and lift-off time.

The TIME display (SPEC 2) provides the capability to observe the current MTU and GPC clock status, synchronize or update the MTU and GPC clocks, and set CRT timers and alert tone duration and timers.

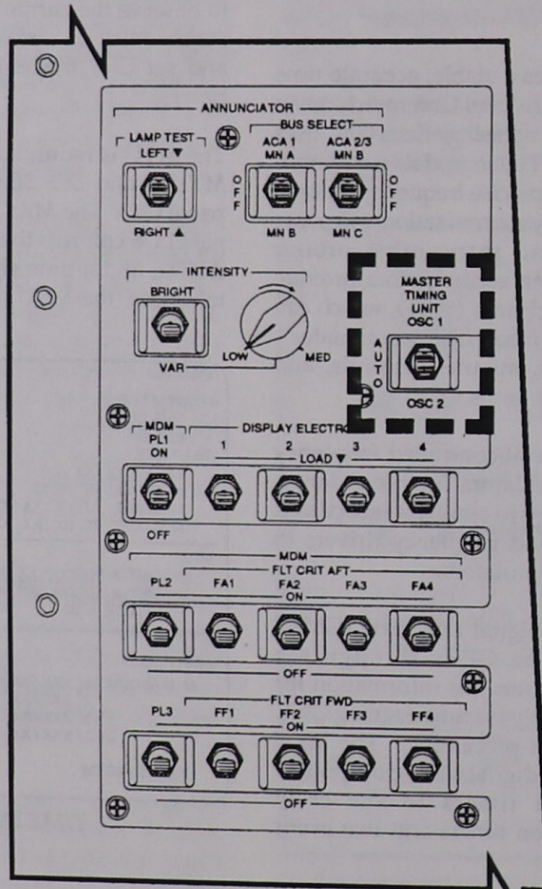
The MTU is redundantly powered by the *ESS 1BC MTU A* and *ESS 2CA MTU B* circuit breakers on panel O13. The *MASTER TIMING UNIT* switch on panel O6 controls the MTU. When the switch is in *AUTO*, and a time signal from the MTU is out of tolerance, the MTU automatically switches to the

XXXX/00Z/	TIME	XX X DDD:HH:MM:SS DDD:HH:MM:SS
MISSION TIME		TONE
GMT 1X		3 XX:XX:XX MSN T
MET 2X		6 XX:XX:XX
CRT TIMER		
9 SET ±:XX:XX:XX		20 XX:XX:XX CRT T
START 12 STOP 13		
14 START AT XX:XX:XX MSN T		23 DURATION XX
17 COUNT TO XX:XX:XX MSN T		
MTU		
24 GMT Δ ±:XX:XX:XX:XX:XX		
28 MET Δ ±:XXX/XX:XX:XX:XXX		MET RESET 33
UPDATE 32		
GPC TIME	GMT	GPC
MTU ACCUM 1	XXX/XX:XX:XX.XXXS	TRY 1 XX
2	XXX/XX:XX:XX.XXXS	34 2 XX
3	XXX/XX:XX:XX.XXXS	35 3 XX
GPC	XXX/XX:XX:XX.XXXS	36 4 XX
		37 5 XX
TIME SYNC 38		(XX)

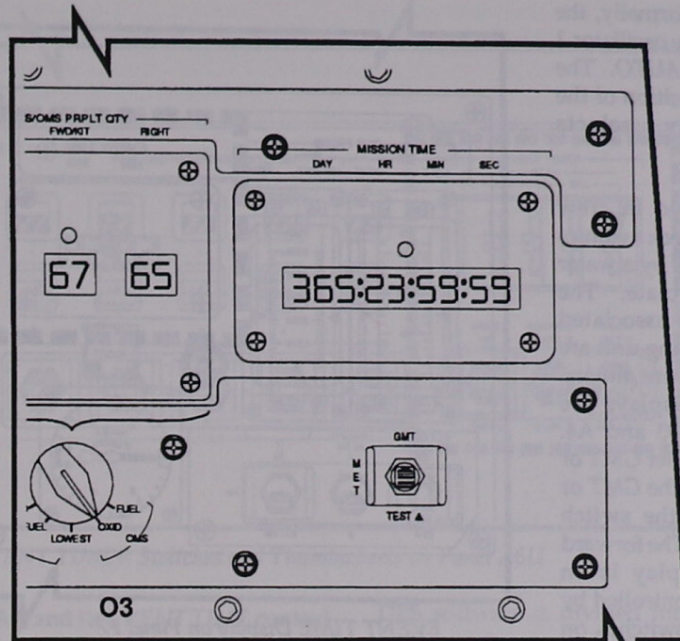
TIME Display (SPEC 2)



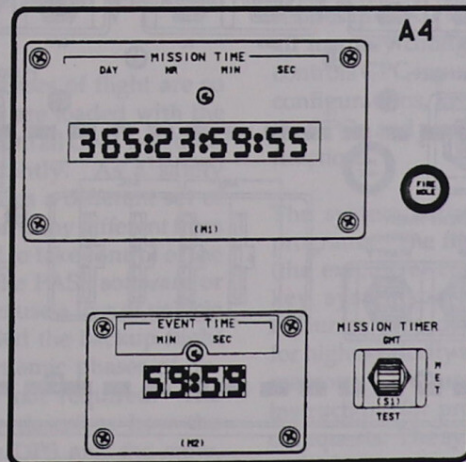
ESS 1BC MTU A and ESS 2CA MTU B  
Circuit Breakers on Panel O13



MASTER TIMING UNIT Switch on Panel O6



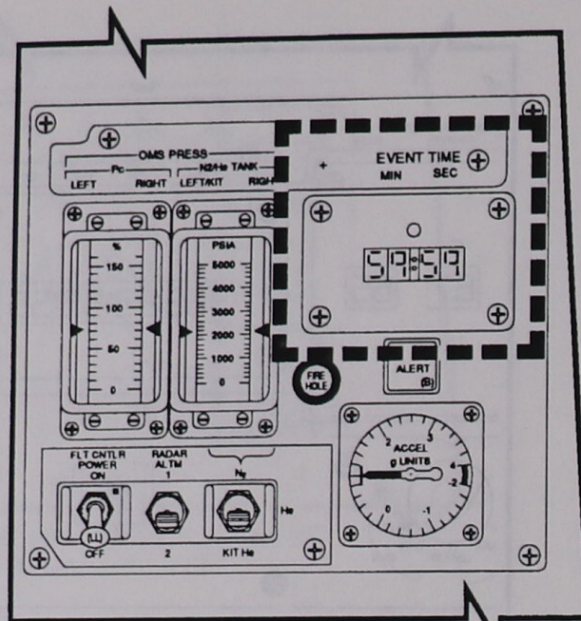
MISSION TIME Display and Switch on Panel O3



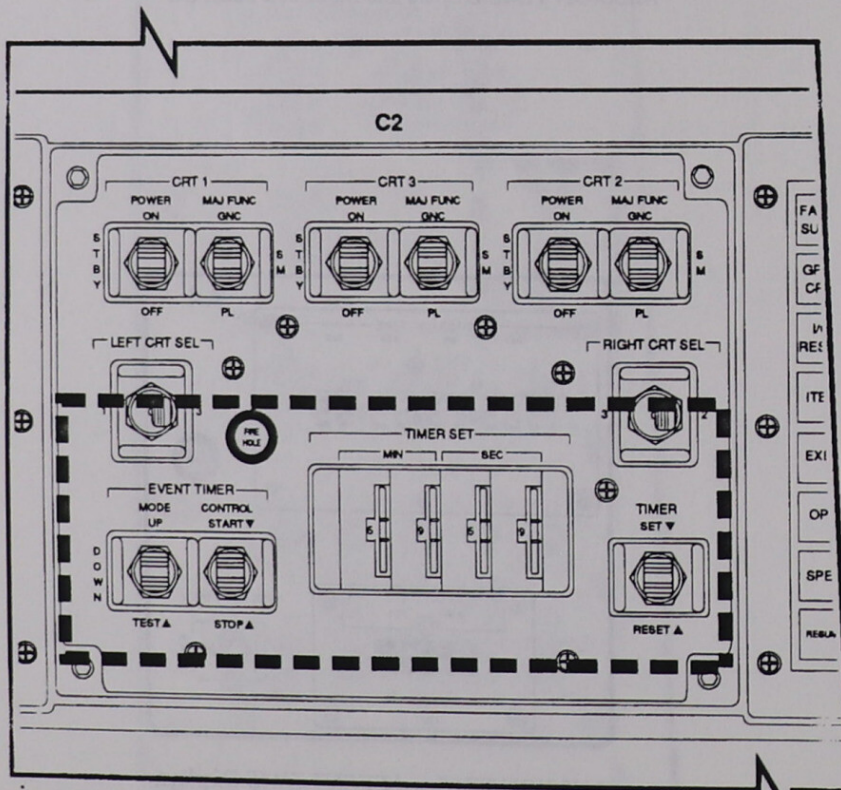
MISSION TIME and EVENT TIME Displays  
and MISSION TIMER Switch on Panel A4

other oscillator. Normally, the MTU is activated by oscillator 1 with the switch in *AUTO*. The *OSC 1* or *OSC 2* position of the switch manually selects oscillator 1 or 2.

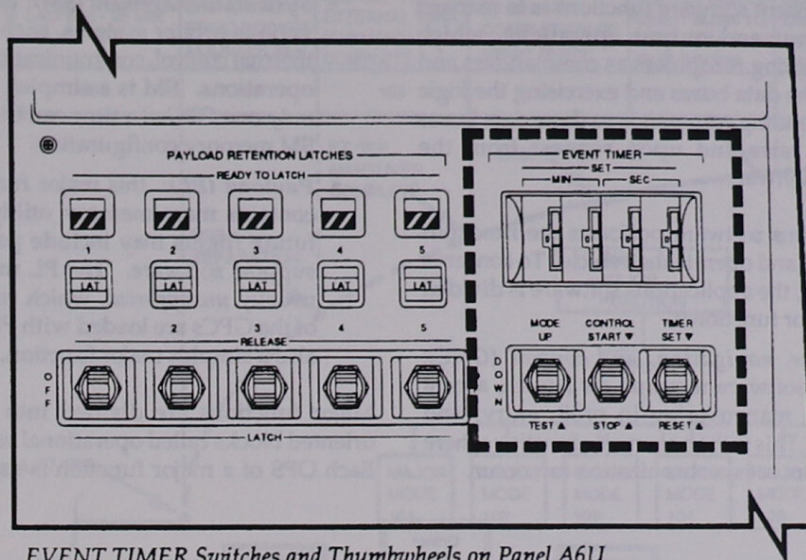
The MTU is located in crew compartment middeck avionics bay 3B and is cooled by a water coolant loop cold plate. The hardware displays associated with the master timing unit are the mission and event timers. MISSION TIME displays are located on panels O3 and A4. They can display either GMT or MET in response to the *GMT* or *MET* positions of the switch below the displays. The forward EVENT TIME display is on panel F7, and it is controlled by the *EVENT TIME* switches on panel C2. The aft EVENT TIME



EVENT TIME Display on Panel F7



EVENT TIMER Switches and TIMER SET Thumbwheels on Panel C2



EVENT TIMER Switches and Thumbwheels on Panel A6U

display is on panel A4, and its *EVENT TIME* control switches are on panel A6U.

## Software

### Primary Avionics Software System (PASS)

The PASS (also referred to as primary flight software (PFS)) is the principal software used to operate the vehicle during a mission. It contains all the programming needed to fly the vehicle through all phases of the mission and manage all vehicle and payload systems.

Since the ascent and entry phases of flight are so critical, four of the five GPCs are loaded with the same PASS software and perform all GNC functions simultaneously and redundantly. As a safety measure, the fifth GPC contains a different set of software, programmed by a company different from the PASS developer, designed to take control of the vehicle if a generic error in the PASS software or other multiple errors should cause a loss of vehicle control. This software is called the backup flight system (BFS). In the less dynamic phases of on-orbit operations, the BFS is not required. The information provided below describes how the PASS software relates to the DPS and the crew. Much of the material is common between PASS and BFS; therefore, only BFS differences are discussed immediately after the PASS discussion.

DPS software is divided into two major groups, system software and applications software. The two groups are combined to form a memory configuration for a specific mission phase. The programs are written in HAL/S (high-order assembly language/Shuttle) especially developed for real-time space flight applications.

The system software is the GPC operating software that controls the interfaces among the computers and the rest of the DPS. It is loaded into the computer when it is first initialized. It always resides in the GPC main memory and is common to all memory configurations. The system software controls GPC input and output, loads new memory configurations, keeps time, monitors discretes into the GPCs, and performs many other DPS operational functions.

The system software consists of three sets of programs. The flight computer operating system (the executive) controls the processors, monitors key system parameters, allocates computer resources, provides for orderly program interrupts for higher priority activities, and updates computer memory. The user interface programs provide instructions for processing flight crew commands or requests. The system control program initializes each GPC and arranges for multi-GPC operation during flight-critical phases.

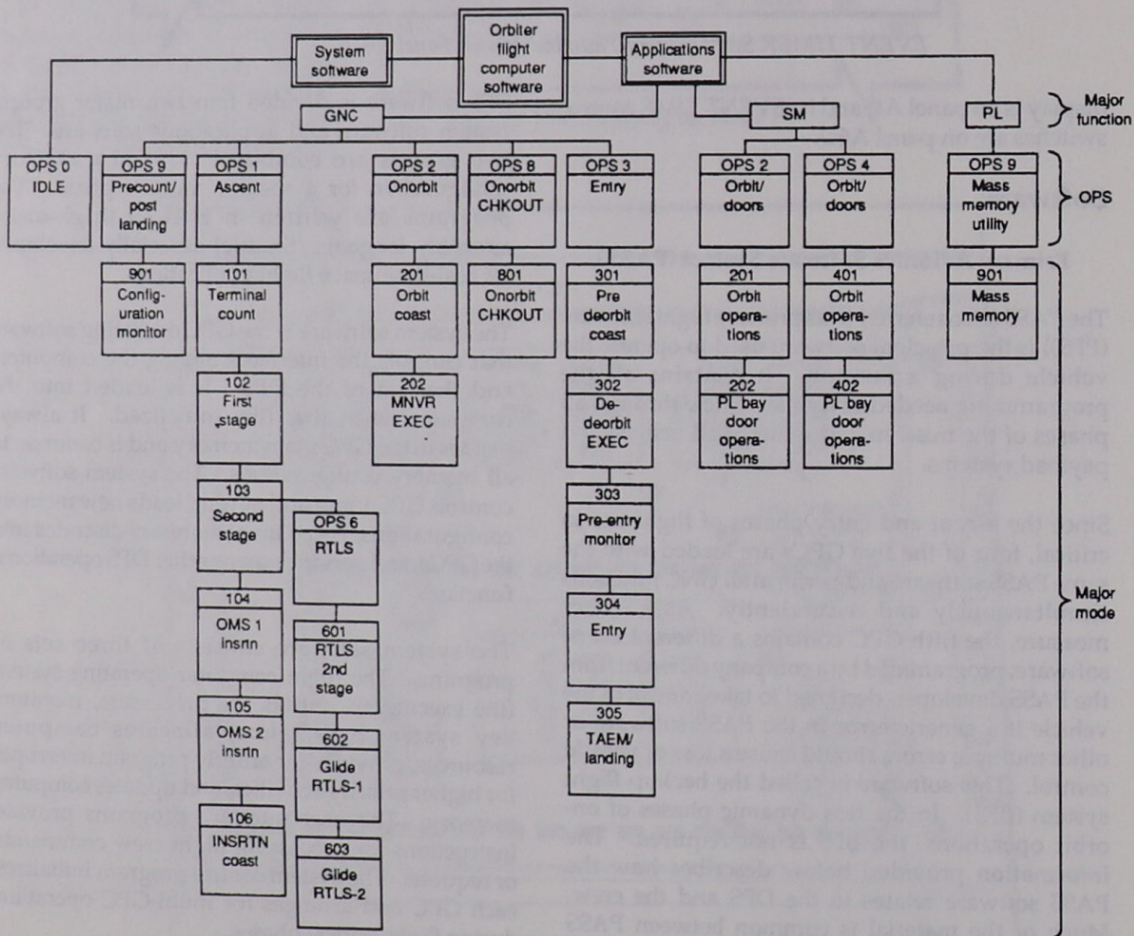
One of the system software functions is to manage the GPC input and output operations, which includes assigning computers as commanders and listeners on the data buses and exercising the logic involved in sending commands to these data buses at specified rates and upon request from the applications software.

The applications software performs the functions required to fly and operate the vehicle. To conserve main memory, the applications software is divided into three major functions:

- **Guidance, navigation, and control (GNC):** specific software required for launch, ascent to orbit, maneuvering in orbit, entry, and landing. This is the only major function where redundant set synchronization can occur.

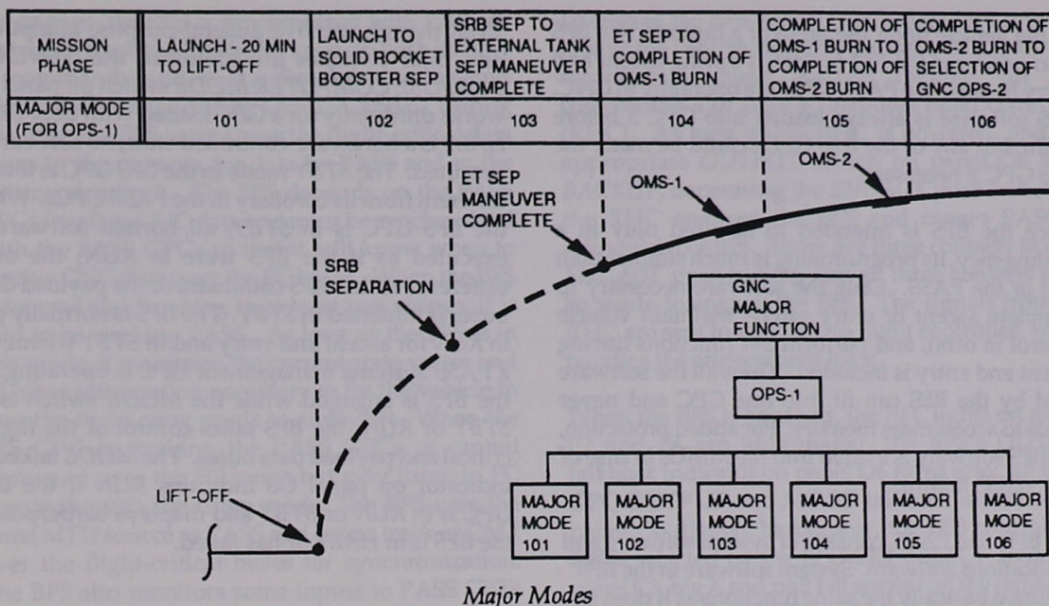
- **Systems management (SM):** tasks that monitor various orbiter systems, such as life support, thermal control, communications, and payload operations. SM is a simplex major function; only one GPC at a time can be loaded with an SM memory configuration.
- **Payload (PL):** this major function currently contains mass memory utility software, but future flights may include payload interface support software. The PL major function is usually *unsupported*, which means that none of the GPCs are loaded with PL software. It is also a simplex major function.

Major functions are divided into mission phase oriented blocks called operational sequences (OPS). Each OPS of a major function is associated with a



Orbiter Flight Computer Software





particular memory configuration that must be loaded separately into a GPC from the MMUs. Therefore, all the software residing in a GPC at any given time consists of system software and an OPS major function; i.e., one memory configuration. Except memory configuration 1, each memory configuration contains one OPS. Memory configuration 1 is loaded for GNC at launch and contains both OPS 1 (ascent) and OPS 6 (RTLs), since there would be no time to load in new software for an RTLs abort.

During the transition from one OPS to another, called an OPS transition, the flight crew requests a new set of applications software to be loaded in from the MMU. Every OPS transition is initiated by the flight crew. When an OPS transition is requested, the redundant OPS overlay contains all major modes of that sequence.

Each OPS is further subdivided into software blocks called major modes (MM), which relate to specific portions of a mission phase. As part of one memory configuration, all major modes of a particular OPS are resident in GPC main memory at the same time. The transition from one major mode to another can be automatic (e.g., in GNC OPS 1 from precount MM 101 to first stage MM 102 at lift-off) or manual (e.g., in SM OPS 2 from on-orbit MM 201 to payload bay door OPS 202 and back).

Each major mode has an associated CRT display, called a major mode display or OPS display, that provides the flight crew with information concerning the current portion of the mission phase and allows flight crew interaction. There are three levels of CRT displays. Certain portions of each OPS display can be manipulated by flight crew keyboard input (or ground link) to view and modify system parameters and enter data. The specialist function (SPEC) of the OPS software is a block of displays associated with one or more operational sequences and enabled by the flight crew to monitor and modify system parameters through keyboard entries. The display function (DISP) of the OPS software is a block of displays associated with one or more OPS. These displays are for parameter monitoring only (no modification capability) and are called from the keyboard. Display hierarchy and usage are described in detail later in this section.

### Backup Flight System

Even though the four PASS GPCs control all GNC functions during the critical phases of the mission, there is always a possibility that a generic failure could cause loss of vehicle control. Therefore, the fifth GPC is loaded with the BFS software. To take over control of the vehicle, the BFS monitors the PASS GPCs to keep track of the current state of the vehicle. If required, the BFS can take over control

of the vehicle upon the press of a button. The BFS also performs the SM functions during ascent and entry because the PASS GPCs are operating in GNC. BFS software is always loaded into GPC 5 before flight, but any of the five GPCs could be made the BFS GPC if necessary.

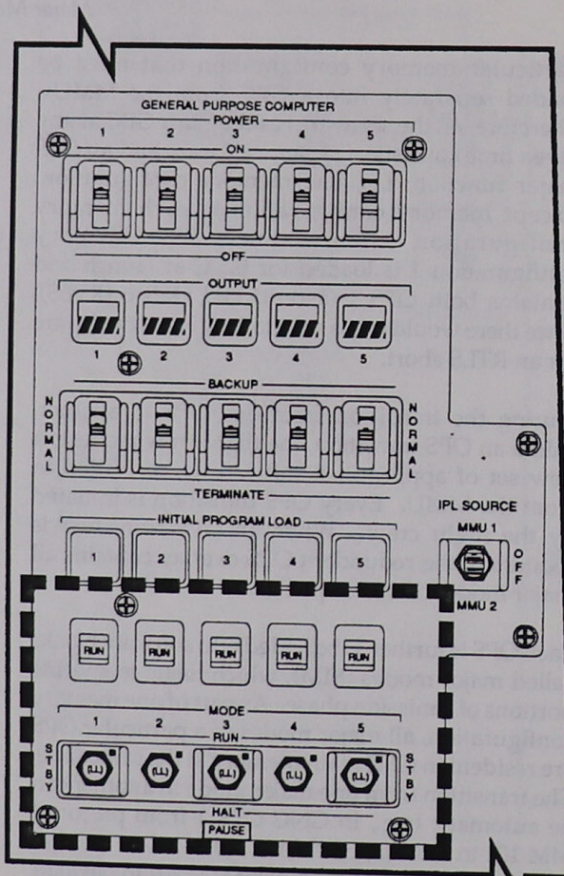
Since the BFS is intended to be used only in a contingency, its programming is much simpler than that of the PASS. Only the software necessary to complete ascent or entry safely, maintain vehicle control in orbit, and perform SM functions during ascent and entry is included. Thus, all the software used by the BFS can fit into one GPC and never needs to access mass memory. For added protection, the BFS software is loaded into the MMUs in case of a BFS GPC failure.

The BFS, like PASS, consists of system software and applications software. System software in the BFS performs basically the same functions as it does in PASS. These functions include time management, PASS/BFS interface, multifunction CRT display system, input and output, uplink and downlink, and engage and disengage control. The system software is always operating when the BFS GPC is not in HALT.

Applications software in the BFS has two different major functions, GNC and systems management, but all its applications software resides in main memory at one time, and the BFS can process software in both major functions simultaneously. The GNC functions of the BFS, designed as a backup capability, support the ascent phase beginning at MM 101 and the deorbit/entry phase beginning at MM 301. In addition, the various ascent abort modes are supported by the BFS. The BFS provides only limited support for on-orbit operations via MM 106 or MM 301. Because the BFS is designed to monitor everything the PASS does during ascent and entry, it has the same major modes as the PASS in OPS 1, 3, and 6.

The BFS SM contains software to support the ascent and entry phases of the mission. Whenever the BFS GPC is in the RUN or STBY mode, it runs continuously; however, the BFS does not control the payload buses in STBY. The SM major function in the BFS is not associated with any operational sequence.

Even though the five general-purpose computers and their switches are identical, the GENERAL PURPOSE COMPUTER MODE switch on panel O6 works differently for a GPC loaded with BFS. Since HALT is a hardware-controlled state, no software is executed. The STBY mode in the BFS GPC is totally different from its corollary in the PASS GPCs. When the BFS GPC is in STBY, all normal software is executed as if the BFS were in RUN; the only difference is that BFS command of the payload data buses is inhibited in STBY. The BFS is normally put in RUN for ascent and entry and in STBY whenever a PASS systems management GPC is operating. If the BFS is engaged while the MODE switch is in STBY or RUN, the BFS takes control of the flight-critical and payload data buses. The MODE talkback indicator on panel O6 indicates RUN if the BFS GPC is in RUN or STBY and displays barberpole if the BFS is in HALT or has failed.



GENERAL PURPOSE COMPUTER MODE  
Switches and Talkbacks on Panel O6

Pre-engage, the BFS is synchronized with PASS so that it can track the PASS and keep up with its flow of commands and data. Synchronization and tracking take place during OPS 1, 3, and 6. During this time, the BFS listens over the flight-critical data buses to the requests for data by PASS and to the data coming back. The BFS depends on the PASS GPCs for all its GNC data and must be synchronized with the PASS GPCs so that it will know when to receive GNC data over the FC buses. When the BFS is in sync and listening to at least two strings, it is said to be tracking PASS. As long as the BFS is in this mode, it maintains the current state vector and all other information necessary to fly the vehicle in case the flight crew needs to engage it. When the BFS GPC is tracking the PASS GPCs, it cannot command over the FC buses but may listen to FC inputs through the listen mode. The BFS uses the same MTU source as PASS and keeps track of GMT over the flight-critical buses for synchronization. The BFS also monitors some inputs to PASS CRTs and updates its own GNC parameters accordingly.

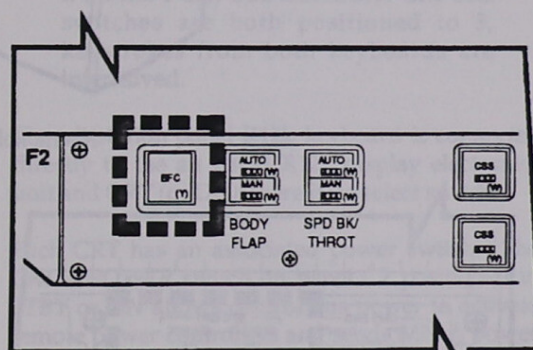
The BFS GPC controls its own instrumentation/PCMMU data bus. The BFS GPC IC data bus is not used to transmit status or data to the other GPCs. The mass memory data buses are not used except during initial program load, which uses the same IPL SOURCE switch on panel O6 used for PASS IPL.

The *BFC* lights on panels F2 and F4 remain unlighted as long as PASS is in control, and the BFS is tracking. The lights flash if the BFS loses track of the PASS and goes standalone. The flight crew must then decide whether to engage the BFS or try to initiate BFS tracking again by an I/O RESET on the keyboard. When BFS is engaged and in control of the flight-critical buses, the *BFC* lights are illuminated and stay on until the BFS is disengaged.

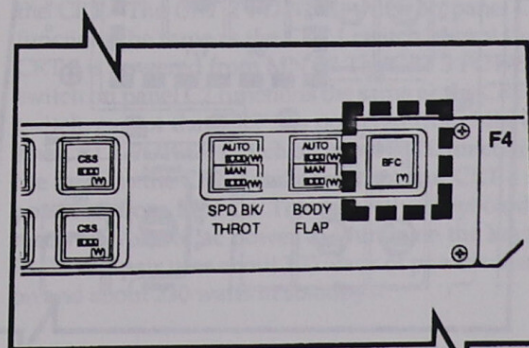
Since the BFS does not operate in a redundant set, its fail votes from and against other GPCs are not enabled; thus, the *GPC STATUS* light matrix on panel O1 for the BFS GPC does not function as it does in PASS. The BFS can illuminate its own light on the *GPC STATUS* matrix if the watchdog timer in the BFS GPC times out when the BFS GPC does not complete its cyclic processing.

To engage the BFS, which is considered a last resort to save the vehicle, the crew presses a *BFS ENGAGE* momentary push button located on the commander's or pilot's rotational hand controller (RHC). As long as the RHC is powered, and the appropriate *OUTPUT* switch on panel O6 is in *BACKUP*, depressing the *ENGAGE* push button on the RHC engages the BFS and causes PASS to relinquish control. There are three contacts in each *ENGAGE* push button, and all three contacts must be made to engage the BFS. The signals from the RHC are sent to the backup flight controller, which handles the engagement logic.

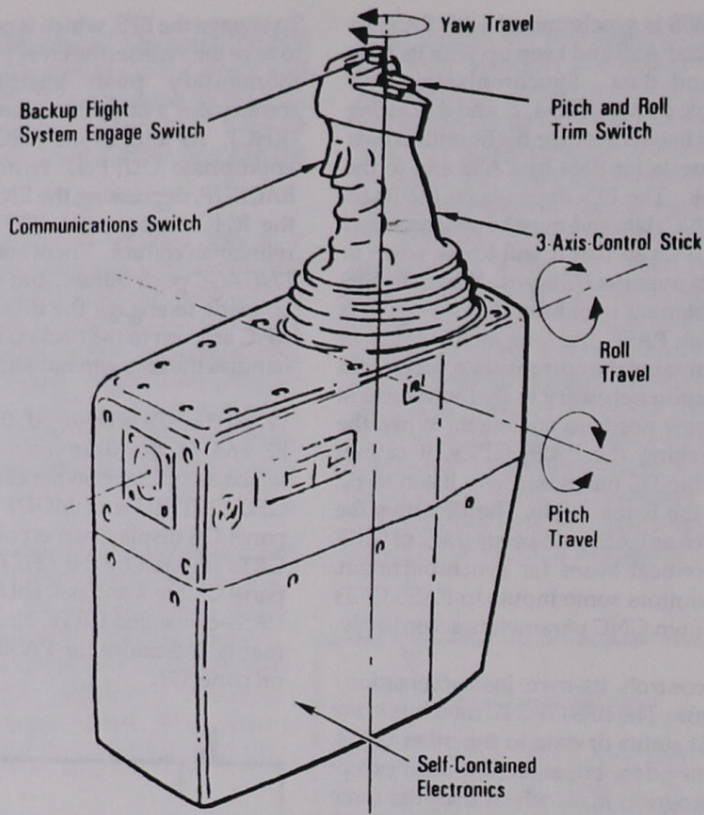
When the BFS is engaged, the *BFC* lights on panels F2 and F4 are illuminated, the BFS's *OUTPUT* talkback indicator on panel O6 turns gray, all PASS GPC *OUTPUT* and *MODE* talkback indicators on panel O6 display barberpole, the BFS controls the CRTs selected by the *BFC CRT SELECT* switch on panel C3, big X and poll fail appear on the remaining PASS-controlled CRTs, and all four *GPC STATUS* matrix indicators for PASS GPCs are illuminated on panel O1.



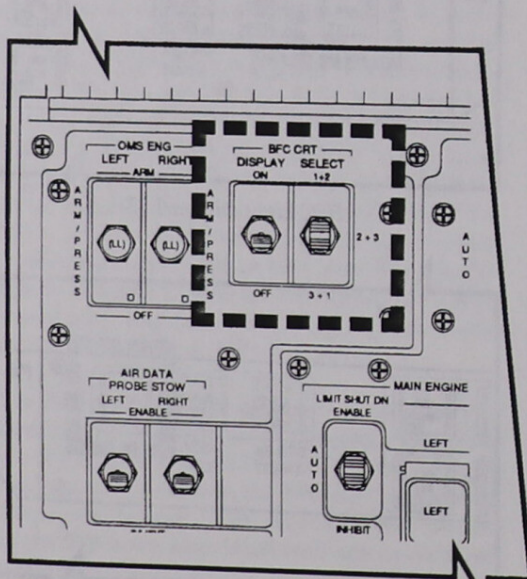
*BFC* Light on Panel F2



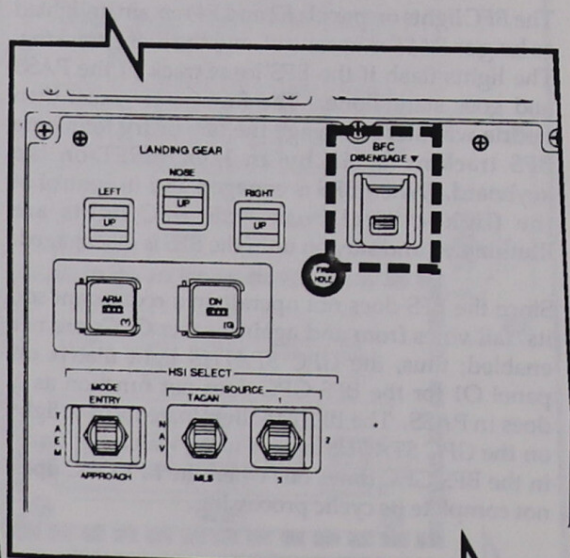
*BFC* Light on Panel F4



*Rotational Hand Controller*



*BFC CRT DISPLAY and SELECT Switches on Panel C3*



*BFC DISENGAGE Switch on Panel F6*

When the BFS is disengaged, and the *BFC CRT DISPLAY* switch on panel C3 is positioned to *ON*, the BFS commands the first CRT indicated by the *BFC CRT SELECT* switch. The *BFC CRT SELECT* switch positions on panel C3 are 1 + 2, 2 + 3, and 3+1. When the BFS is engaged, it assumes control of the second CRT as well.

If the BFS is engaged during ascent, the PASS GPCs can be recovered on orbit to continue a normal mission. This procedure takes about 2 hours, since the PASS inertial measurement unit reference must be reestablished. The BFS is disengaged after all PASS GPCs have been hardware-dumped and loaded with PASS software. Positioning the *BFC DISENGAGE* switch on panel F6 to the *UP* position disengages the BFS. The switch sends a signal to the BFS that resets the engage discrettes to the GPCs. The BFS then releases control of the flight-critical buses as well as the payload buses if it is in *STBY*, and the PASS GPCs assume command.

After disengagement, the PASS and BFS GPCs return to their normal pre-engaged state. Indications of the PASS engagement and BFS disengagement are as follows: *BFC* lights on panels F2 and F4 are out, BFS's *OUTPUT* talkback on panel O6 displays barberpole, all PASS *OUTPUT* talkback indicators on panel O6 are gray, and BFS releases control of one of the CRTs.

If the BFS is engaged, there is no manual thrust vector control or manual throttling capability during first- and second-stage ascent. If the BFS is engaged during entry, the speed brake can be positioned using the speed brake/thrust controller, and the body flap can be positioned manually. Control stick steering by either the commander or pilot is required during entry.

Pre-engage, the BFS supplies attitude errors on the CRT trajectory display, whereas PASS supplies attitude errors to the attitude director indicators; however, when the BFS is engaged, the errors on the CRT are blanked, and attitude errors are supplied to the attitude director indicators.

## Operations

The crew interfaces with the five GPCs via four CRTs and various dedicated display instruments. This section first discusses crew operations using PASS, and then discusses crew operations using the BFS.

### CRT Switches

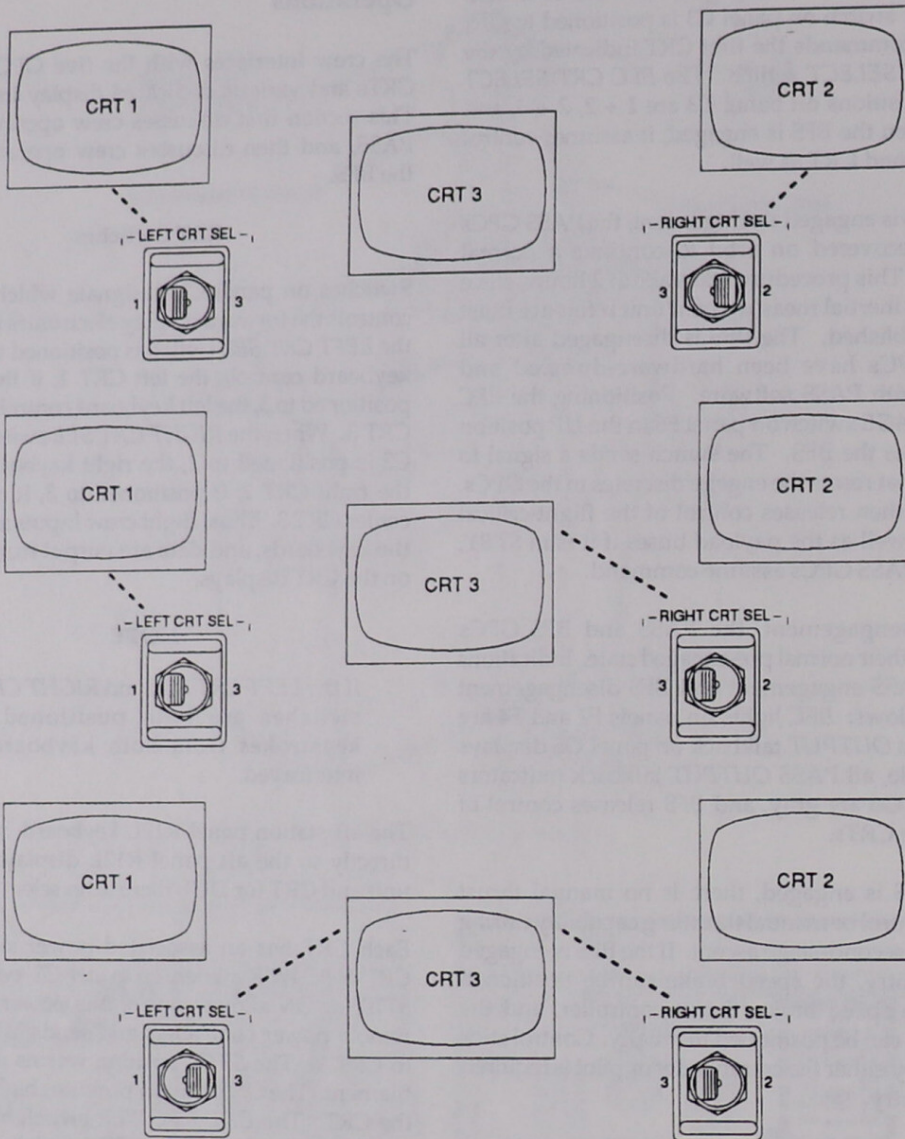
Switches on panel C2 designate which keyboard controls the forward display electronics unit. When the *LEFT CRT SEL* switch is positioned to 1, the left keyboard controls the left CRT 1; if the switch is positioned to 3, the left keyboard controls the center CRT 3. When the *RIGHT CRT SEL* switch on panel C2 is positioned to 2, the right keyboard controls the right CRT 2; if positioned to 3, it controls the center CRT 3. Thus, flight crew inputs are made on the keyboards, and data are output from the GPCs on the CRT displays.

### NOTE

If the *LEFT CRT SEL* and *RIGHT CRT SEL* switches are both positioned to 3, keystrokes from both keyboards are interleaved.

The aft station panel R12L keyboard is connected directly to the aft panel R12L display electronics unit and CRT (or DU); there is no select switch.

Each CRT has an associated power switch. The *CRT 1 POWER* switch on panel C2 positioned to *STBY* or *ON* allows control bus power to activate remote power controllers and sends MN A power to CRT 1. The *STBY* position warms up the CRT filament. The *ON* position provides high voltage to the CRT. The *CRT 2 POWER* switch on panel C2 functions the same as the *CRT 1* switch, except that CRT 2 is powered from MN B. The *CRT 3 POWER* switch on panel C2 functions the same as the *CRT 1* switch, except that CRT 3 is powered from MN C. The *CRT 4 POWER* switch on panel R12L functions the same as the *CRT 1* switch, except that CRT 4 is powered from MN C. The respective keyboards receive 5 volts of ac power to illuminate the keys. Each CRT pair uses about 300 watts of power when on and about 230 watts in standby.



Possible CRT/Keyboard Assignments in the Forward Flight Station

**NOTE**

Crewmembers should always check that keyboard information is accepted on the proper CRT prior to entering the data.

Each CRT has an associated MAJ FUNC switch. The CRT 1, 3, 2, MAJ FUNC switches on panel C2 tell the GPCs which of the different functional software groups is being processed by the keyboard units

and what information is presented on the CRT. The CRT 4 MAJ FUNC switch on panel R12L functions in the same manner. This three-position toggle switch allows the crew access to the GNC, SM, or PL software on a desired CRT. The GPC loaded with the desired major function applications software will then drive this CRT. Each major function accesses an independent set of display data and functional software.

### Display Hierarchy

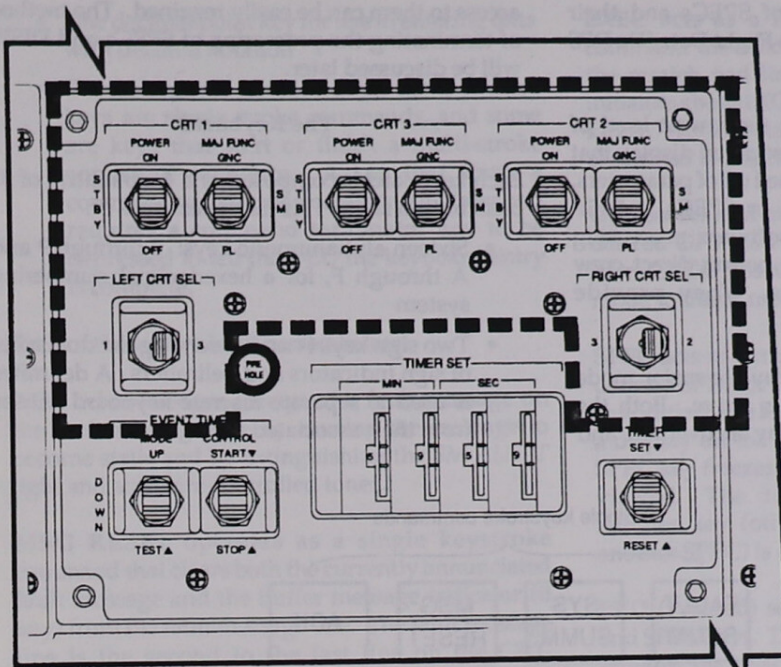
CRT display organization consists of three levels of crew software displays within any given major function. The display types parallel the different types of modules used in the GPC software. The established display hierarchy within applications software is operational sequences (OPS), specialist functions (SPEC), and display (DISP) functions. Each has a type of CRT page associated with it.

The OPS is the highest level of crew software control within a major function. Each memory configuration contains one or more OPS. Each OPS allows the crew to accomplish an associated mission phase task. Several

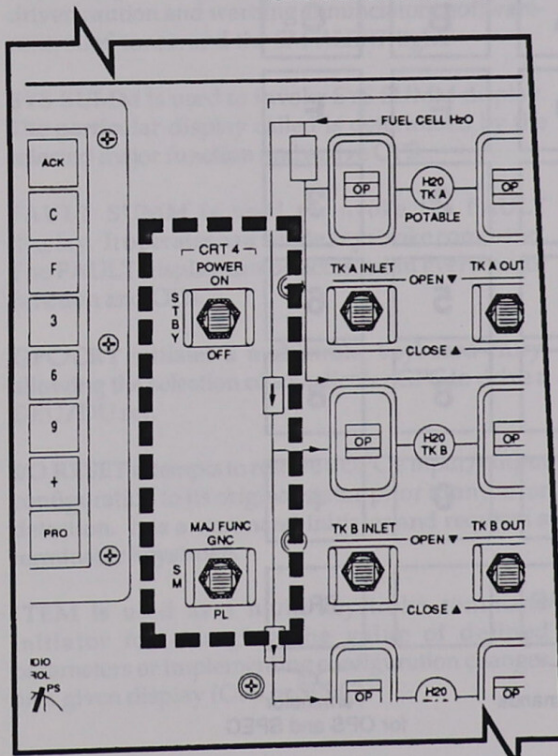
operational sequences are defined, each covering some portion of the mission. For example, OPS 1 contains ascent software, OPS 2 contains on-orbit software, and OPS 3 contains entry software.

Each operational sequence is further divided into major modes. Each major mode has an associated display that allows direct crew interface with the software. These are OPS pages, and are also referred to as major mode pages.

Specialist functions (SPECs) are second in the hierarchy. A SPEC allows crew execution of other activities in conjunction with a particular OPS. SPEC displays, like major mode displays, allow direct crew interface with the software. Each SPEC has an associated display that will overlay the major mode display when called. When a SPEC is called, its display rolls in on top of the major mode display, which is still active underneath. The SPEC provides access to an associated portion of the software located in the GPC. Some SPECs are contained in systems software, whereas others are resident in the applications load. A SPEC can be associated with a major function or an OPS, but the systems software SPECs can be obtained in most OPS and



CRT Switches on Panel C2



CRT 4 POWER and MAJ FUNC Switches on Panel R12L

major functions. (The list of SPECs and their availability can be found in the Flight Data File DPS Dictionary.)

Display functions (DISPs) are the lowest level of software. Each DISP has an associated display that presents the status of a predefined set of parameters. Unlike major mode displays or SPECs, a DISP cannot initiate a change in software processing because DISP displays do not permit direct crew interface with the software. They provide information only.

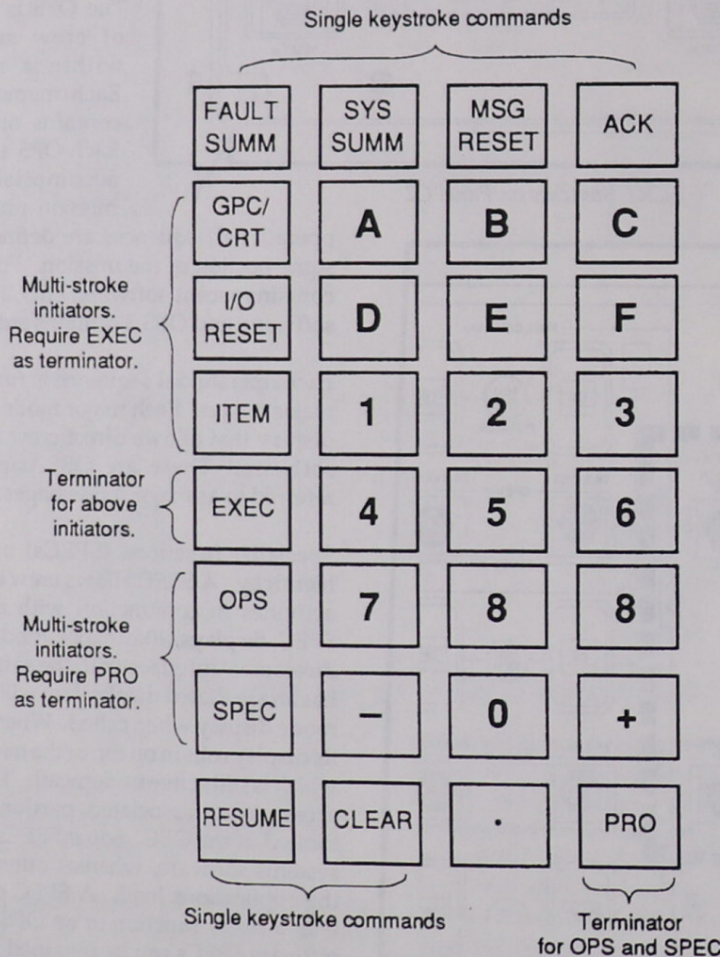
When called, a DISP will overlay the major mode display and the SPEC, if one is active. Both the SPEC and the major mode display are overlaid, and

access to them can be easily regained. The method of terminating the processing of SPECs and DISPs will be discussed later.

### The Keyboard

Each keyboard is composed of a 4 x 8 matrix of 32 push button keys. This matrix consists of:

- Sixteen alphanumeric keys: 0 through 9 and A through F, for a hexadecimal numbering system
- Two sign keys (+ and -) serving the dual roles of sign indicators and delimiters. A delimiter is used to separate discrete keyboard entries from their associated data.



Multifunction CRT Display System Keyboard Unit Found on Panels C2 and R12L



- One decimal point key for use in entering data with decimal notation
- Thirteen special function keys: some of these keys are single stroke commands, and some are keys that start or finish a multi-stroke command sequence. A key that starts a command sequence is a command initiator and requires a command terminator key to be depressed to tell the DEU the keyboard entry is complete.

Each of these keys is discussed below.

**ACK** acknowledges receipt of a fault message on the fault message line by causing the message to become static and by extinguishing the *SM ALERT* light and software controlled tones.

**MSG RESET** operates as a single keystroke command that clears both the currently annunciated fault message and the buffer message indicator (if any) from the fault message line. The fault message line is the second to the last line on the CRT. Depressing this key will also extinguish all software-driven caution and warning annunciators, software-controlled tones, and the *SM ALERT* light.

**SYS SUMM** is used to invoke **SYS SUMM** display. The particular display called is determined by the selected major function and active OPS.

**FAULT SUMM** is used to invoke the **FAULT** display. It operates as a single keystroke command. The **FAULT** display can be accessed in every major function and OPS.

**GPC/CRT** initiates a multistroke keyboard entry, allowing the selection of a particular GPC to drive a DEU/DU set.

**I/O RESET** attempts to restore a GPC's input/output configuration to its original status prior to any error detection. It is a command initiator and requires a terminator keystroke.

**ITEM** is used as a multi-keystroke command initiator for changing the value of defined parameters or implementing configuration changes on a given display (OPS or SPEC).

**EXEC** acts as a multi-keystroke terminator to command the execution of the action specified on the scratch pad line. It is the terminator for the initiators above it (**GPC/CRT**, **I/O RESET**, and **ITEM** keys). **EXEC** may also be a single keystroke command to enable an OMS burn.

**OPS** serves as a multi-keystroke initiator to load a desired OPS load from mass memory into one or more GPCs. It is also used to transition from major mode to major mode within an OPS.

**SPEC** acts as a multi-keystroke initiator to select a defined **SPEC** or **DISP** display within a given OPS. In addition, this key provides the capability to freeze a display on the CRT. A single depression of the **SPEC** key freezes the display so it may be statically viewed. The display will remain frozen until another key (other than **ACK**, **MSG RESET**, or another **SPEC**) is entered.

**PRO** (Proceed) serves as a terminator to the OPS and **SPEC** keys. The completed command sequence initiates the selection of a desired OPS, **SPEC**, or **DISP** display.

**RESUME** is used to terminate a displayed **SPEC** or **DISP**. CRT control is restored to the underlying display upon depression of this key.

**CLEAR** clears the last echoed keystroke from the bottom line (scratch pad line) of the CRT. For each depression, one additional keystroke is removed, proceeding from right to left. After a command sequence is completed, a single depression of the **CLEAR** key will erase the static command from the scratch pad line.

#### Display Selection Procedures

The crew can select a variety of CRT displays. Some of the different ways to select an OPS display and its available **SPEC** and **DISP** displays are as follows:

- Selection of the major function is done by placing the *MAJ FUNC* switch (on panel C2) associated with the CRT in use in the *GNC*, *SM*, or *PL* position.
- An OPS is loaded from the MMU via a three-step keyboard entry. A new OPS is called from mass memory by its first major mode. The OPS is loaded into the GPC that is

currently driving the DEU/DU on which the keyboard entry is done. Once the OPS is loaded, access is provided to all major modes in that OPS. Major mode displays are advanced by the same keyboard command. The steps for selecting an OPS display are as follows:

1. *Depress the OPS key.*
2. *Key in the three numbers of the desired OPS.* The first digit defines the OPS and the next two digits specify the major mode.
3. *Depress the PRO key.* Once the OPS is loaded into one or more GPCs, that software can be accessed at any time through any CRT in the proper major function.

Selection of a major mode does not involve a mass memory access. Advancing major modes is done by the same keyboard command as loading an OPS. The first digit will be the same as the OPS number, but the last two digits specify the major mode. For example, to go to GNC MM 202, enter OPS 2 0 2 PRO.

Within each OPS, certain SPEC and DISP displays are available. The steps for selecting a SPEC or a DISP are as follows:

1. *Depress the SPEC key.* The SPEC key is used in calling both SPEC and DISP displays.
2. *Key in the SPEC or DISP number omitting all leading zeros.* SPEC and DISP numbers have three digits. They are differentiated by their numbering scheme. The display is a DISP only if the first digit is a 9, or if the last digit is a 6 through 9. To illustrate the method for keying in SPEC and DISP numbers, DISP number 106 would be keyed in as "106"; SPEC number 034 would be keyed "34"; DISP number 066 would be keyed "66"; and SPEC number 001 would be keyed "1."
3. *Depress the PRO key.*

#### OPS and Major Mode Transitions

Transitions from major mode to major mode or to another OPS are accomplished by either automatic transitions or proper command entry.

- **Automatic transitions:** Some major mode transitions occur automatically, usually as a function of some mission event. Examples of automatic transitions are between major modes 101 and 102 (SRB ignition) and between major modes 102 and 103 (SRB separation). Selection of an RTLS abort also results in an automatic OPS transition.
- **Command entry:** Proper command entry (OPS XXX PRO) is always used to transition from one OPS to another. In most cases, it is also a legal transition operation for proceeding from one major mode to the next (e.g., 301 to 302).

#### Display Sequencing, Overlaying, and Retention

Certain rules have been established for proceeding from one display to another. These can be categorized into treatment of proper display sequencing, the overlaying of current displays by new displays, and the display retention hierarchy.

#### SPEC and DISP Displays

The hierarchy of overlaying SPECs and DISPs makes sense if one remembers that a SPEC allows crew interaction and control of specialized operations, whereas a DISP provides display information only. Both SPECs and DISPs overlay the current major mode display when called.

A SPEC need not be selected to call a DISP. If a DISP is on the CRT, and another SPEC or DISP is called, the current DISP is terminated. The terminated DISP can only be viewed again by entering its calling command once more.

If a SPEC is selected, and a DISP is called to overlay it, the SPEC is retained underneath the DISP. If another SPEC is then selected, the underlying SPEC as well as the DISP over it is terminated. The terminated SPEC can only be viewed again if it is recalled.

The RESUME key is used as a single keystroke entry to terminate the SPEC or DISP currently being displayed and to restore the underlying display. If the display being terminated is a DISP, CRT control will be restored to the underlying SPEC, or to the OPS display if no SPEC has been selected. If a SPEC display is terminated, CRT control is restored to the major mode display. It is advisable to press

RESUME after viewing any SPEC or DISP to avoid confusion and to decrease the possibility of attempting to retain more SPEC displays than the software allows. The RESUME key cannot be used to transition from one major mode display to another or to page backwards through major mode displays.

#### *Display Retention Hierarchy*

- Major mode transitions: Both SPECs and DISPs are retained during a major mode transition. If a SPEC or DISP is overlaying the major mode display, the new major mode display can't be seen until the overlaying displays are terminated with the RESUME key.
- Major function change: OPS and SPEC displays on the CRT screen are retained within their major function when major function positions are switched. When the crew returns to the first major function, the SPEC last viewed will appear on the screen. Depression of the RESUME key will restore the underlying OPS. If no SPEC had been selected, return to a major function would restore the last major mode display. DISP displays are not retained during major function transitions.
- OPS transition: SPECs, DISPs, and major mode displays are not retained through an OPS transition, since this involves loading an entirely new module of applications software in the GPC. The SPECs may be called again if they are available in the new OPS.

#### *Standard Display Characteristics*

##### *Standard Display Features*

Two discrete brightness intensities for displayed characters are designated "bright" and "overbright." The bulk of all material is displayed in the "bright" intensity. Special messages and special characters, such as parameter status indicators, are displayed in "overbright" to direct the crew's attention during their display scan.

Certain words and messages are designed to flash on and off. Fault messages will flash, indicating a message that needs to be acknowledged. Command initiators are designed to flash until the command is completed, and an incorrect keyboard entry will result in a flashing "ERR" to the right of the erroneous entry.

#### *Formatting Similarities*

**OPS number:** The four-digit field in the upper left corner of the first line designates the number of the OPS display being processed. The first digit represents the OPS; the next two digits indicate the major mode. The last digit is always a "1," and it is not used when making keyboard entries.

**SPEC number:** Directly to the right of the OPS number is a three-digit field. This field displays the number of the SPEC overlaying the OPS. This field is blank if no SPEC is selected.

**DISP number:** The last field in the upper left corner represents the DISP number. It is a three-digit field. This field is blank if no DISP is currently being displayed.

**Display title:** Centered on the top line of the display is the title of the display. Portions of some titles are dynamic and will specify the mission phase.

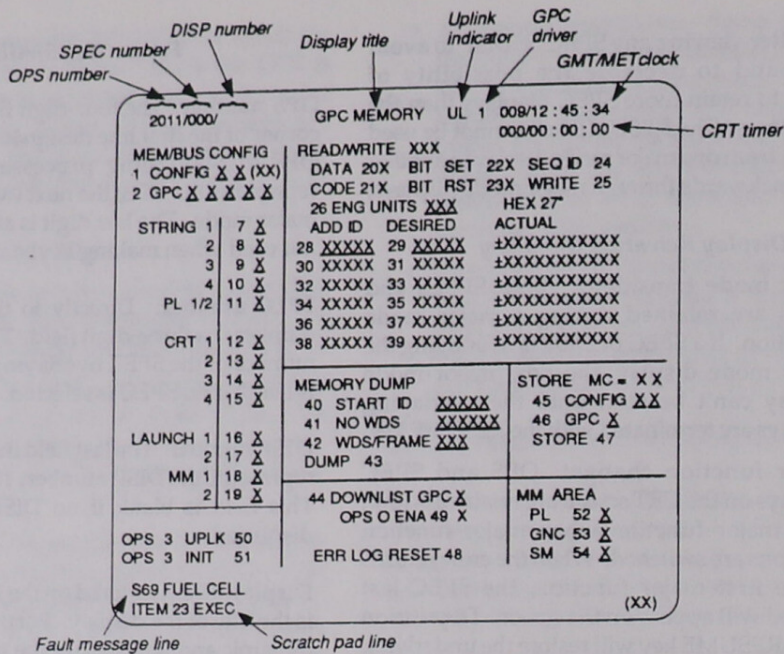
**Uplink indicator:** Directly to the right of the display title is a two-space field. When an uplink to the GPC is in progress, a flashing "UL" will be displayed. Otherwise this field is blank.

**GPC driver:** To the right of the uplink indicator is a one-digit field. A number in this field indicates the particular GPC (1, 2, 3, 4, or 5) that is commanding the CRT.

**GMT/MET clock:** This field displays time in days, hours, minutes, and seconds (DDD/HH:MM:SS). The field is updated every second. The time displayed may be either GMT or MET selectable via a keyboard entry to the TIME SPEC 2 display.

**CRT timer:** Directly below the GMT/MET clock is a CRT timer field also displayed in days, hours, minutes, and seconds (DDD/HH:MM:SS). This field is also updated every second, and can be set via a keyboard entry to the TIME SPEC display.

**Fault message line:** The second line from the bottom is reserved for fault messages. Illegal keyboard entry messages and systems fault messages are displayed on this line. In the case of system faults, a number in parentheses to the far right on this line indicates the number of fault messages that have



*Formatting Conventions Common to All Displays*

not been viewed and acknowledged (further discussion of fault messages is covered in a later section).

**Scratch pad line:** The bottom line of the display echoes keyboard entries made by the crew. Command initiators (OPS, SPEC, ITEM, GPC/CRT, and I/O RESET) will flash on the scratch pad line until the command is terminated. The keystrokes remain on the scratch pad line in a static mode until (a) a new command is initiated, (b) the CLEAR key is depressed, or (c) the MAJOR FUNC switch position is changed. Keyboard syntax errors detected by the DEU will result in a flashing "ERR" on the scratch pad line following the keyboard entry.

*Specially Defined Symbols*

These symbols include an asterisk and a set of parameter status indicators. Parameter status indicators are displayed in "overbright" intensity for quick recognition. These special symbols are defined as follows:

**M:** This symbol indicates missing data. It is displayed directly to the right of the affected parameter. The parameter value may be blanked,

or the last value received by the GPC may be displayed. If data are missing for a parameter that has no numerical value associated with it, then an M is used to indicate the parameter status.

**H:** This symbol indicates that a parameter is off-scale high. This indicates a transducer limit has been reached, and the scale is registering its highest possible value. The actual parameter being measured may, in fact, be higher than the recorded data, but the instrument in use does not have the capacity to measure the value. Off-scale high indicators do not appear on the display until several (normally two) consecutive readings have verified this finding. This symbol is displayed to the right of the data affected.

**L:** This symbol indicates off-scale low parameters. This means that the parameter value displayed is the lowest possible reading due to transducer limitations. The actual value of the parameter may exceed the displayed value, but the range of the hardware is not defined to evaluate this reading. As with the "H," the off-scale low indicator is not displayed until a set number of consecutive readings have verified this status.

**Up arrow:** This symbol, displayed to the right of the affected parameter, indicates a parameter driven out-of-limits high. The value displayed is a true reading but has equaled or exceeded the operational high limit established by the software. The fault detection and annunciation (FDA) software keeps track of the low and high limits for each parameter and annunciates any violation of these limits to the crew by displaying the appropriate "up arrow" or "down arrow" next to the parameter on the appropriate display.

In the case where the transducer limit is the same as the operational limit, the "H" symbol overrides the "up arrow" symbol. Several (normally two) consecutive readings verify this status before the "up arrow" symbol is displayed.

**Down arrow:** This symbol indicates that a parameter value is equal to or less than the operational low limit. The value displayed is outside the software limits placed upon the parameter. When the software limit established is the same as the transducer limit, the "L" symbol takes precedence over the "down arrow" symbol. A set number of consecutive readings verifies this indication before the "down arrow" is displayed.

In addition, the down arrow is used to indicate a discrete state that does not agree with the nominal state. For example, a high pressure gas supply valve state reading "closed" when its position is normally "open" would drive the "down arrow" symbol.

The down arrow is also used to indicate that a hardware unit has been declared failed by a GPC.

?: This symbol indicates a redundancy management dilemma. That is, if two hardware units measuring the same parameter disagree, and the software cannot isolate which of the two is failed, a "?" will be displayed in both places.

\*: This symbol indicates an active state or the selected item of mutually exclusive items.

### Item Operations

Within a given display, certain operations can be performed by the crew. Those items that may be altered are identified by an item number. The item number is a maximum of two digits and is placed

2011/094/078			SM SYS SUMM 1			4 000/02 : 48 : 18		
SMOKE 1/A 2/B			DC VOLTS 1/A 2/B 3/C			000/00 : 00 : 00		
AV BAY 1	- 0.0	- 0.0	FC	31.4	31.4	31.2		
2	- 0.0	- 0.0	MAIN	31.2	31.1	31.3		
3	- 0.0	- 0.0	CNTL AB	30.1	30.1	30.0		
dP/dT	±.00		BC	30.0	30.0	30.0		
CABIN			CA	30.0	30.0	30.0		
PRESS	15.71		ESS	29.9	30.0	30.0		
PPO2	3.04	3.04	AC					
FAN ΔP	9.93		VOLT #A	117	114 M	01		
HX OUT T	145 H		#B	117	114 M	01		
O2 FLOW	0.0 L	0.0 L	#C	117	114 M	01		
N2 FLOW	0.0 L	0.0 L	AMPS #A	2.2	3.0	2.4		
IMU FAN A B* C			#B	2.2	3.2	2.4		
AV FC1 FC2 FC3			#C	2.2	3.2	2.1		
SS1	23	26	26					
SS2	18	22	13					
SS3	9	13	13					
TOTAL AMPS	463		FUEL CELL					
KW	14		AMPS	156	158	OL		
SYS SUMM			REAC VLV	OP	OP	OL		
			STACK T	+202	+300 H	100		
			EXIT T	151	151	151		
			COOL P	61	61	61		
			PUMP					

1031/051/018			GNC SYS SUMM 1			4 001/19 : 54 : 43		
RCS JET ISOL			SURF POS MOM			DPS 1 2 3 4 5		
MANF FAIL VLV			L OB			GPC		
F1	OP		IB			MDM FF	↓	
2	CLM		R IB			FA	↓	
3	OP		OB					
4	OP		ALL			FCS CH 1 2 3 4		
5			RUD			M	↓	
L1	OP		SPD BRK					
2	OP		BDY FLP					
3	CLM							
4	OP		CNTLR 1 2 3					
5			RHC L			IMU ? M ?		
R1	OP		R			ACC M		
2	OP		A			RGA M		
3	CLM		THC L			TAC M		
4	OP		A			MLS M		
5			SBTC L			ADTA		
			R					
SYS SUMM								

2011/001/006		GPC/BUS STATUS					4 000 / 02 : 30 : 53	
		1S	2S	3S	4S	5S		
GPC	MODE	RUN	RUN	RUN	RUN	HALT		
OPS	OPS	G2	G2	0	S2	0		
STRING 1	FF	.	.	.	.	.		
FA	.	.	.	.	.	.		
2	FF	.	.	.	.	.		
FA	.	.	.	.	.	.		
3	FF	.	.	.	.	.		
FA	.	.	.	.	.	.		
4	FF	.	.	.	.	.		
FA	.	.	.	.	.	.		
PL 1	↓	↓	↓	↓	↓	↓		
2	↓	↓	↓	↓	↓	↓		
LAUNCH 1	↓	↓	↓	↓	↓	↓		
2	↓	↓	↓	↓	↓	↓		
CRT 1	↓	↓	↓	↓	↓	↓		
2	↓	↓	↓	↓	↓	↓		
3	↓	↓	↓	↓	↓	↓		
4	↓	↓	↓	↓	↓	↓		
SPEC 6 PRO								

Specially Defined Symbols on CRT Displays

in such a way that it is readily identifiable with the parameter or status configuration with which it is associated. When item numbering is obvious, item numbers may be implied and will not appear on the display. Item numbering is sequentially ordered for each display. There are never more than 99 items per display. The two basic types of manipulations that the crew can perform are item configuration change and item data entry.

#### *Item Configuration Change*

This operation allows the crew to choose any of a number of options or to initiate a specific action as defined by the particular display format. Typical purposes of this operation include selecting or deselecting an item, initiating and executing an action, and altering software configurations. The procedure used in performing an item configuration change within a selected display is as follows:

1. Depress the *ITEM* key.
2. Key in the item number.
3. Depress the *EXEC* key.

#### *Item Data Entry*

This operation allows the crew to load data into the software. Typical purposes of this operation include initializing parameters, changing software limits, and specifying memory locations. The procedure used in performing an item data entry is as follows:

1. Depress the *ITEM* key.
2. Key in the item number. Item numbers are ordered sequentially (1, 2, 3, . . .) on each display. They are located next to the parameter to which they are assigned. Some item numbers must be inferred by their surrounding item numbers.
3. Key in a delimiter (“+” or “-”). A delimiter serves to separate item number codes from their corresponding data. The delimiter whose sign corresponds to the sign of the data should be used, but if no sign is associated with the data, it doesn't matter which delimiter is used. A “[ ]” after the data field indicates that the entry is sign-dependent.
4. Key in the data. Data size specifications depend on the format established for that particular data load. Usually, the data size will be indicated with an underline for each digit. As

a general rule, leading and trailing zeros need not be entered. Remember that the sign of the delimiter is the sign of the data.

5. Depress the *EXEC* key.

#### *Multiple Data Entries*

Multiple item configuration changes cannot be done; however, multiple item data entries can. Multiple data entries can be made with separate command strings, but because this is time-consuming, the software allows more than one data entry to be made with one command sequence. The procedure is the same as described above except step 4 (after data are keyed in). Add step 4a to make more than one item data entry at once.

- 4a. Key in a delimiter. Consecutive data entries may be loaded by using a delimiter to separate each parameter. Item entries are incremented sequentially so the item number need not be entered for each parameter following the one already entered. Just hit another delimiter, and the next item number will appear, ready to receive its associated data. To skip an item number, hit a delimiter twice. In this way, any amount of item numbers may be skipped until the desired item number is reached.

Both the “+” and the “-” keys may be used interchangeably as delimiters. However, when skipping item numbers, it is a good idea to use the delimiter corresponding to the sign of the next data entry if there is any sign associated with it. Using the sign key corresponding to the next data entry ensures that the GPC receives the proper data entry.

An example of a multiple item data keyboard entry is:

```
ITEM 7 + 2 + 1 + + 2 + - - 2 EXEC
```

In this example, Items 7, 8, 10, and 13 have no sign associated with them so the sign of the delimiters doesn't matter. Although there was room for four item entries here, the actual number allowed on the scratch pad line is a function of the size of the data.

This entry will appear on the scratch pad line of the corresponding CRT as:

```
ITEM (07) + 2 (08) + 1 (10) + 2 (13) - 2 EXEC.
```

All item operations will be one of these two basic manipulations. However, data size and form will differ for each display.

Remember, only OPS and SPEC displays allow item operations. A DISP display does not.

### Special Operations and Displays

#### GPC/CRT Assignment

GPC assignment to a particular DEU/CRT set is determined via a predefined table of assignments. This table is stored in all the common set GPCs' systems software and can be manipulated by the crew. There is a table for each memory configuration (MC) that is valid when that MC is active (loaded in one or more GPCs), and the particular major function is selected. This table can be changed using the GPC MEMORY display (SPEC 0). The current GPC driver for a CRT is controlled by the MAJ FUNC switch. That is, the position of the MAJ FUNC switch (GNC, SM, or PL) will determine the GPC with which the DEU communicates. In some cases, a redundant set of GPCs is formed for GNC, and the GNC CRTs must be split among them. This is done with the predefined table. The table is looked at by the GPCs when they are loaded with the applications software, and that is when the assignments take effect or when the MAJ FUNC switch is moved to a new major function.

Another way to change the current GPC assignment logic is with the GPC/CRT key. The GPC/CRT key allows the crew to reassign a CRT to a different GPC commander. The steps for selecting a GPC to command a given DEU/CRT are as follows:

1. Depress the GPC/CRT key.
2. Key in the desired GPC number (1, 2, 3, 4, or 5)
3. Key in the desired CRT number (1, 2, 3, or 4). No delimiter is needed between the GPC and the CRT numbers.
4. Depress the EXEC key.

An assignment is not executed if the GPC being assigned doesn't have the applications software in memory to support the DEU/CRT in its current major function. If the GPC specified by a keyboard entry is not a valid assignment, the reassignment does not occur, and the current GPC driver retains

the CRT. Thus, if a CRT is in GNC, and an attempt is made to assign a GPC that is not in the redundant set to drive it, a redundant set (or valid) GPC will drive the CRT instead of the invalid GPC. If GPC 4 is the SM machine, then it is the only valid GPC to drive a CRT whose MAJ FUNC switch is in SM.

Payloads major function is usually *unsupported*. This means that none of the GPCs have payload applications software loaded in them. Any GPC can be assigned to drive a CRT in an unsupported major function. Usually, the GPC that was driving the CRT in the previous major function will retain the CRT when it is placed in PL.

If the keyboard entry specifies a valid GPC, it will override any assignment made by the software. The keyboard entry assignment will remain in effect whenever the MAJ FUNC switch is in a position supported by that GPC. A new assignment can be made via the keyboard.

The GPC/CRT key can also be used to isolate a DEU from communication with all GPCs. This is accomplished by using "0" for the number of the GPC. PASS can drive only three CRTs at one time, so one DEU is always isolated from PASS.

The GPC provides a big X over an isolated CRT to remind the crew not to use the data. The DEU annunciates the POLL FAIL message to inform the crew that the GPC is no longer polling the DEU (not attempting to communicate with the DEU).

#### Memory Configurations

After a GPC has been IPL'd, the only software resident is the systems software, and the GPC is in OPS 0 when moded to RUN. Any applications software is loaded in from the MMU during an OPS transition. There are two levels of applications software: the major function base (MFB) and the OPS overlay. The MFB is that software common to all OPS in particular major function. For GNC, the MFB contains flight-critical software and data that are retained from one mission phase to another, such as the current state vector and inertial measurement unit processing. When a GPC is transitioned from one OPS to another in the same major function (e.g., from GNC OPS 1 [ascent] to OPS 2 [orbit]), the MFB remains in main memory, and only the OPS overlay is loaded from the MMU

and written over the old OPS. Of course, when the major function changes (e.g., when GPC 4 is transitioned from GNC OPS 1 to SM OPS 2), the new MFB is loaded in from the MMU along with the OPS overlay.

The controls for performing an OPS transition (i.e., loading a new memory configuration into the GPC from the MMU) are on the GPC MEMORY display (SPEC 0), which is also the OPS 0 OPS display. Item 1 determines the memory configuration (CONFIG) to be loaded. Currently, there are eight different memory CONFIGs, besides memory CONFIG 0, which is the post-IPL OPS 0 (no applications software loaded).

**Nominal Bus Assignment Table**

Associated with each memory configuration is a nominal bus assignment table (NBAT). It is displayed via items 2-19 on SPEC 0 whenever a memory configuration is entered, and it tells which GPCs are to be in command of each data bus. The nominal assignments are already loaded in GPC main memory preflight. However, these bus assignments may be changed any time, including when an OPS transition is performed.

An example of a typical nominal bus assignment table is shown below on SPEC 0 GPC MEMORY for GNC OPS 3.

MEMBUS CONFIG		GPC MEMORY		XX X	DOD/HH:MM:SS	DOD/HH:MM:SS
1	CONFIG 04	READ/WRITE	XXX			
2	GPC 0 0 0 4 0	DATA 20X	BIT SET	22X	SEQ ID	24
		CODE 21X	BIT RST	23X	WRITE	25
		26	ENG UNITS	XXX	HEX 27*	
STRING 1	7 1	ADD ID	DESIRED		ACTUAL	
2	8 2	28	XXXXX	29	XXXXX	±XXXXXXXXXXXX
3	9 3	30	XXXXX	31	XXXXX	±XXXXXXXXXXXX
4	10 4	32	XXXXX	33	XXXXX	±XXXXXXXXXXXX
PL 1/2	11 1	34	XXXXX	35	XXXXX	±XXXXXXXXXXXX
		36	XXXXX	37	XXXXX	±XXXXXXXXXXXX
		38	XXXXX	39	XXXXX	±XXXXXXXXXXXX
CRT 1	12 1	MEMORY DUMP			STORE MC = X X	
2	13 2	40	START ID	XXXXX	45	CONFIG X X
3	14 3	41	NO WDS	XXXXXX	46	GPC X
4	15 4	42	WDS/FRAME	XXX	STORE	47
LAUNCH 1	16 0	DUMP	43			
2	17 0	44	DOWNLIST GPC	X	MM AREA	
MM 1	18 1	OPS 0	ENA	49 X	PL	52 X
2	19 2	ERR LOG	RESET	48	GNC	53 X
OPS 3	UPLK 50				SM	54 X
OPS 3	INIT 51					

Sample NBAT Data on GPC MEMORY Display (SPEC 0)

- Items 2-6 determine which GPCs will be in the OPS. They are referred to as the "target" GPCs. In this case, GPCs 1-4 are in a redundant set. If a GPC is not to be in that OPS, a 0 is entered in that GPC's item number, which is one more than the GPC number. (Item 2 is for GPC 1, etc.)
- The commanders of the flight-critical data buses or strings are entered in items 7-10. (String 1 is FF1 and FA1, etc.) In this case, each GPC is set to command its same-numbered string.
- The two PL buses are assigned together. For OPS 3 they are assigned to GPC 1 via item 11 in case the BFS fails. When the BFS is in RUN (as it is for entry), it commands the PL data buses.
- CRTs 1, 2, 3 are assigned to GPCs 1, 2, 3 respectively, via items 12-14. Since the PASS can only control three CRTs at a time, no GPC is assigned to CRT 4 during entry. Note that CRT assignments are for a particular major function only.
- The launch data buses are assigned via items 16 and 17. Since they have no function during entry, they are deassigned.
- Items 18 and 19 show that GPC 1 will command mass memory bus 1 for the OPS 3 transition, and GPC 2 will command mass memory bus 2 either if the transaction fails on mass memory bus 1 or if MMU 2 is prime selected on SPEC 1 DPS UTILITY.

**MMU Assignment**

Since there are two identical MMUs, there must be a method to tell the GPCs which one to use for a particular transaction. This is done on DPS UTILITY SPEC 1 display via items 1 through 8. On orbit, only one MMU (and its data bus) is assigned to each major function. A post-IPL OPS 0 GPC also has an MMU assigned to it for requesting the DEU initialization software for a DEU load. This display is initialized with all assigned to MMU 1, and execution of any of the item numbers causes the appropriate MMU to be assigned. Note that each of the pairs of item numbers is mutually exclusive.

When a GPC needs to access mass memory, this table tells it which MMU to use. For example, the SM GPC may need to call a roll-in SPEC or take a



checkpoint (discussed later). In the case of OPS transitions, if the MMU selected is busy or fails twice, then the other is automatically tried. For a GNC OPS transition where a redundant set is involved, one GPC is assigned to each mass memory bus via items 18 and 19 on SPEC 0 GPC MEMORY. The indicated GPC will command the mass memory bus selected by item 1 or 2 on SPEC 1 DPS UTILITY, then the other GPC will command the next mass memory bus if the first transaction fails. Of course, all GPCs in the redundant set will be listening over both buses and receive the overlay.

XXXX/001/	DPS UTILITY	XX X DDD/HHMMSS	DD/HHMMSS
MMU ASSIGN	PORT ASSIGN	PRI SEC	UL CNTL
1 2	15X 18X		AUTO 35X
GNC 1X 2X	2 17X 18X		ENA 36X
SM 3X 4X	3 19X 20X		INH 37X
PL 5X 6X	4 21X 22X		
OPS 0 7X 8X	PL 1/2 23X 24X		IPL SOURCE SW
MMU STATUS			MASK 38X
1 XXX			
2 XXX			
	VAR PARAM ID LIST		
MMU SOURCE/BUS	25 XXXX	G3 ARCHIVE	
GPC/MMU 9X	26 XXXX	LOAD 48X	
MMU/MMU 10X	27 XXXX	RETRIEVE 49X	
GPC/LDB 11X	28 XXXX		
	29 XXXX		
	30 XXXX		
CKPT RETRV	31 XXXX	GROUND OPS	
ENA 12X	32 XXXX	GSE POLL ENA 50X	
	33 XXXX	SM GSE INH 51X	
	34 XXXX	SM C/O ENA 52X	
RTC		GNC C/O ENA 53X	
13 XXXX XXXX		BFC C/O ENA 54X	
CMD 14		ALT PL9 TB 55X	
		(XX)	

DPS UTILITY Display (SPEC 1)

### Software Memory Source Selection

During an initial program load (IPL), an MMU is selected as the software source via the *IPL SOURCE* switch on panel O6. This switch is a three-position toggle switch that will be either in the *MMU 1* or *MMU 2* position during the IPL sequence. At all other times, this switch will nominally be in the *OFF* position.

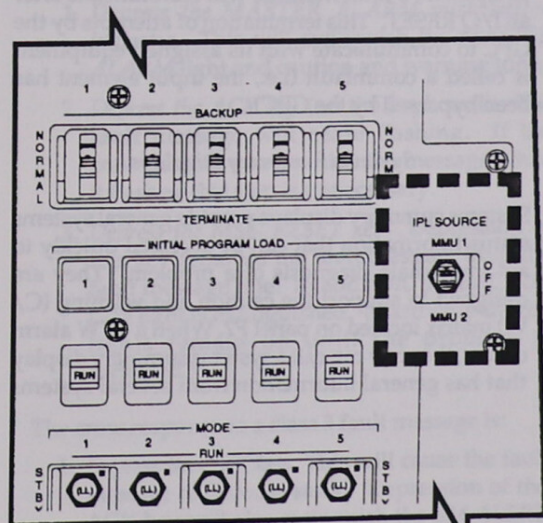
The controls for selecting the memory source for an OPS transition and the bus over which it is loaded into the GPCs are on SPEC 1 DPS UTILITY (items 9 through 11). The display is initialized with item 9 selected, which is almost always used. As part of the GPC status exchanged at common set sync, each GPC exchanges its current resident memory configuration. When a request is made for a memory configuration, the software determines whether or not another GPC already has the requested OPS or a current major function base. If

another GPC already has any of the requested software, the lowest numbered such GPC will be used as a source for the other GPCs. Such a GPC-to-GPC overlay of software will be done over the mass memory data buses. An overlay that is not available from a GPC will be loaded from an MMU. Note that the major function base may come from another GPC and the OPS overlay from mass memory.

If there is a problem with both of the mass memory data buses, or the MMUs do not indicate *RDY*, then item 11 may be selected if there is a GPC source for both overlays. In this case, the GPC-to-GPC overlay is done over the launch data buses.

Memory reconfiguration may be forced from an MMU, regardless of other GPC sources, by selection of item 10 on the DPS UTILITY display. In this case, whether both are required or not, both the major function base and the OPS overlay will be loaded from mass memory. This would only be used if the software in a current GPC was suspect for some reason.

If there is no usable GPC source and/or the selected MMU is off or being used for another memory transaction, the class 3 fault message *MMU OFF/BSY* is initiated. The current status of each MMU is shown on the DPS UTILITY display as either *RDY* (ready to respond) or *BSY* (off or currently responding to a GPC command).



IPL SOURCE Switch on Panel O6

### Resetting I/O Configurations

When a GPC detects an error or is missing data from a piece of equipment, a fault message will be displayed on the CRTs, the SM ALERT light and tone will be activated, and further attempts by the GPC to communicate with the equipment will be terminated. Two common causes of detected errors or missing data are the powering down of equipment or an error in a data transmission. In these two cases, if the equipment is to be powered up, or if the error has been corrected, it is desirable to restore the GPC's data input to the nominal configuration. Restoring input is done through the I/O RESET key in the affected major function. If an I/O RESET is performed only on a GNC GPC, the entire redundant set of GNC GPCs will be restored to nominal I/O configuration. If it is performed on the SM GPC, only the SM GPC's I/O configuration will be restored to nominal. To reset I/O configurations, the procedure is as follows:

- Select desired MAJ FUNC.
- Depress the I/O RESET key.
- Depress the EXEC key.

If the powered down equipment has been powered on, or if a problem with a piece of equipment has been fixed, an I/O RESET will resume communication, and it will not cause another fault message annunciation. If the GPC still has a problem communicating with any piece of its assigned equipment, a fault message will reannunciate after an I/O RESET. This termination of attempts by the GPC to communicate with its assigned equipment is called a commfault (i.e., the input element has been bypassed by the GPC).

### Systems Summary Displays

Systems summary displays provide general systems status information that can be accessed quickly to aid immediate diagnosis of a problem. They are designed to support the caution and warning (C/W) matrix located on panel F7. When a C/W alarm occurs, the crew can call a systems summary display that has general information from several systems

to pinpoint the problem to a specific system, then continue troubleshooting the problem on system-specific SPECs, DISPs, and hardware panels. The systems summary displays are DISPs and provide information only.

The systems summary displays are major function-specific and are called with the SYS SUMM key. If a CRT's MAJ FUNC switch is in GNC, and the SYS SUMM key is pressed, then GNC SYS SUMM 1 will appear on that CRT. GNC SYS SUMM 1 is DISP 18 so it may also be called with a SPEC 18 PRO, but it is faster to use the SYS SUMM key.

There are four PASS systems summary displays: GNC SYS SUMM 1, GNC SYS SUMM 2, SM SYS SUMM 1, and SM SYS SUMM 2.

The SYS SUMM key is a toggle function in each major function. In SM on-orbit, hitting SM SYS SUMM will cause SM SYS SUMM (DISP 78) to appear on the CRT. If SYS SUMM is depressed again, SM SYS SUMM 2 (DISP 79) will appear, and if SYS SUMM is depressed once more, SM SYS SUMM 1 reappears.

The same toggle function exists in GNC between GNC SYS SUMM 1 (DISP 18) and GNC SYS SUMM 2 (DISP 19).

XXXX/XXX/018		GNC SYS SUMM 1				XX X DDD/HH:MM:SS DDD/HH:MM:SS					
RCS	JET	ISOL	SURF	POS	MOM	DPS	1	2	3	4	5
F1	XXX	XXS	L OB	XXX.XS	XXS	GPC	S	S	S	S	S
2	XXX	XXS	IB	XXX.XS	XXS	MDM	FF	S	S	S	S
3	XXX	XXS	R IB	XXX.XS	XXS	FA	S	S	S	S	S
4	XXX	XXS	OB	XXX.XS	XXS						
5	XXX	XXS	AIL	XXX.X							
L1	XXX	XXS	RUD	XXX.X		FCS	CH	1	2	3	4
2	XXX	XXS	SPD BRK	XXX.X				S	S	S	S
3	XXX	XXS	BDY FLP	XXX.X							
4	XXX	XXS		XXXXXX							
5	XXX	XXS				NAV	1	2	3	4	
R1	XXX	XXS				IMU	S	S	S		
2	XXX	XXS	CNTRL	1	2	3	ACC	S	S	S	S
3	XXX	XXS	RHC	L	S	S	RGA	S	S	S	S
4	XXX	XXS		R	S	S	TAC	S	S	S	
5	XXX	XXS		A	S	S	MLS	S	S	S	
			THC	L	S	S	ADTA	S	S	S	S
				A	S	S					
			SBTC	L	S	S					
				R	S	S					

PASS GNC SYS SUMM 1, available in GNC OPS  
1, 6, 2, 8, and 3

```

      XXXX/XXX/019   GNC SYS SUMM 2   XX X DDD/HHMM:SS
      BBS DDD/HHMM:SS
      OMS AFT QTY L R OMS P HE L R
      OXID XX.XS XX.XS OXID XXXS XXXS
      FU XX.XS XX.XS FU XXXS XXXS
      FU INJ T XXXS XXXS
      RCS OXID FU JETT SOL
      FWD HE XXXS XXXS VLV
      TK F XXXS XXXS
      QTY XXXS XXXS
      MANF 1 F XXXS XXXS XXXS
      2 F XXXS XXXS XXXS
      3 F XXXS XXXS XXXS
      4 F XXXS XXXS XXXS
      5 F XXXS XXXS XXXS
      AFT HE F XXXS XXXS HE F XXXS XXXS
      L TK F XXXS XXXS R TK F XXXS XXXS
      QTY XXXS XXXS QTY XXXS XXXS
      MANF 1 F XXXS XXXS XXXS XXXS
      2 F XXXS XXXS XXXS XXXS
      3 F XXXS XXXS XXXS XXXS
      4 F XXXS XXXS XXXS XXXS
      5 F XXXS XXXS XXXS XXXS
      (XX)
  
```

GNC SYS SUMM 2, available in GNC OPS 2 and 8

```

      XXXX/XXX/078   SM SYS SUMM 1   XX X DDD/HHMM:SS
      DDD/HHMM:SS
      SMOKE 1/A 2/B DC VOLTS 1/A 2/B 3/C
      CABIN XX.XS FC XX.XS XX.XS XX.XS
      L/R FD XX.XS XX.XS MAIN XX.XS XX.XS XX.XS
      AV BAY 1 XX.XS XX.XS CNTL AB XX.XS XX.XS XX.XS
      2 XX.XS XX.XS BC XX.XS XX.XS XX.XS
      3 XX.XS XX.XS CA XX.XS XX.XS XX.XS
      CABIN ESS XX.XS XX.XS XX.XS
      PRESS XX.XS
      dP/dT-EQ ±.XXX±.XXXSAC
      O2 CONC XXX.XS
      PPO2 X.XXS X.XXS
      FAN ΔP X.XXS
      HX OUT T XXXS
      O2 FLOW XX.XS XX.XS
      N2 FLOW XX.XS XX.XS
      IMU FAN AXS BXS CXS
      ΔV FC1 FC2 FC3
      SS1 XXXS XXXS XXXS
      SS2 XXXS XXXS XXXS
      SS3 XXXS XXXS XXXS
      TOTAL AMPS XXXXS
      K W XXXS
      AMPS XXXS XXXS XXXS
      REAC VLV XX XX
      STACK T ±XXXS ±XXXS ±XXXS
      EXIT T XXXS XXXS XXXS
      COOL P XXXS XXXS XXXS
      PUMP XXXS XXXS XXXS
      (XX)
  
```

PASS SM SYS SUMM 1, available in SM OPS 2

```

      XXXX/XXX/079   SM SYS SUMM 2   XX X DDD/HHMM:SS
      DDD/HHMM:SS
      CRYO TK 1 2 3 4 5
      -2 PRESS XXXS XXXS XXXS XXXS XXXS
      O2 PRESS XXXXS XXXXS XXXXS XXXXS XXXXS
      HTR T1 ±XXXS ±XXXS ±XXXS ±XXXS ±XXXS
      T2 ±XXXS ±XXXS ±XXXS ±XXXS ±XXXS
      APU 1 2 3
      TEMP EGT XXXXS XXXXS XXXXS
      B/U EGT XXXXS XXXXS XXXXS
      OIL IN XXXS XXXS XXXS
      OUT XXXS XXXS XXXS
      SPEED * XXXS XXXS XXXS
      FUEL QTY XXXS XXXS XXXS
      PMP LK P XXXS XXXS XXXS
      OIL OUT P XXXS XXXS XXXS
      HYD 1 2 3
      PRESS XXXXS XXXXS XXXXS
      RSVR T XXXS XXXS XXXS
      P XXXS XXXS XXXS
      QTY XXXS XXXS XXXS
      W/B
      H2O QTY XXXS XXXS XXXS
      BYP VLV XXXS XXXS XXXS
      THERM CNTL 1 2
      H2O PUMP P XXXS XXXS
      FREDN FLOW XXXXS XXXXS
      EVAP OUT T XXXS XXXS
      (XX)
  
```

PASS SM SYS SUMM 2, available in SM OPS 2

### Fault Detection and Annunciation

Five classes of alarms have been established. Class 1, Emergency, has no interface with software. Class 2, Caution and Warning (C/W), is the second highest alarm class. It is divided into primary (hardware-driven) and backup (software-driven) systems. An alarm of the software-driven class will result in the annunciation of the *BACKUP C/W ALARM* light on the C/W matrix on panel F7, the *MASTER ALARM* lights, and an associated tone. In addition, a fault message will be displayed upon the fault message line of the CRT. Class 3, Alert, triggers the *SM ALERT* light and corresponding tone. A fault message is displayed upon the fault message line. Class 5, Operator Errors, is the lowest priority alarm and is caused only by a crew entry error. It results in an *ILLEGAL ENTRY* fault message being displayed. Class 0, Limit Sense, provides a status indicator (down arrow, up arrow) to the right of the affected parameter on an appropriate CRT. No fault message, tone, or light is triggered.

The output of a fault message to the fault message line results in several indications requiring crew interface. Although generally the crew keyboard responses are similar, the effects of these responses differ for each class alarm.

The crew response to a class 2 backup fault message is:

1. Depress the *MASTER ALARM* push button indicator. This will extinguish the *MASTER ALARM* light and caution and warning tone.
2. Depress the *ACK* key (on the keyboard). The fault message will cease flashing. If the crewmember can examine the message while it flashes, this step is unnecessary.
3. Depress the *MSG RESET* key. Depression of this key removes the fault message from the fault message line. In addition, the *BACKUP C/W* light is extinguished. (Hardware-driven lights remain on until the problem is corrected.)

The crew response to a class 3 fault message is:

1. Depress the *ACK* key. This will cause the fault message to become static. Depression of the *ACK* key will also extinguish the *SM ALERT*



The minor field is a four-character field that further identifies the fault. It will specify the subdivision, direction, location, parameter, or specific unit of the subsystem or problem identified in the major field. In the example fault message, "1" is the minor field message and means that the temperature sensor 1 is the area in which the fault was detected.

The C/W field is used only with caution and warning class 2 backup messages. An asterisk appears in this column across from the corresponding fault to denote that the condition is a class 2 backup alarm.

The GPC field identifies the GPC that detected this fault. This characteristic aids the crewmember in locating or identifying internal GPC or I/O errors.

The far right field is the TIME field. This field indicates the time at which the fault occurred. The time is MET and is displayed in hours, minutes, and seconds (HH:MM:SS).

A complete listing of all possible fault messages can be found in the Flight Data File Reference Data Book and in Section 2.2.

A class 5 alarm is announced by an "ILLEGAL ENTRY" in the major field, and all other fault message fields are blank. When a class 5 message is received, it is displayed instantaneously on the fault message line of the CRT where the error occurred, rather than on all CRTs like class 2 and 3 errors. To get rid of the class 5 message, a MSG RESET must be done to the CRT where the error occurred. Class 2 backup and class 3 messages are extinguished by a MSG RESET on any CRT.

#### The Fault Summary Display

A historical summary of class 2 backup and class 3 fault messages is provided via the FAULT display (DISP 99). Class 5 errors are not displayed as they are caused by illegal crew entries to a single DEU. The FAULT display is a DISP available in all OPS. It is selected for viewing by depression of the FAULT SUMM key.

The PASS fault summary display consists of up to 15 fault message lines. They appear in reverse chronological order. The oldest message appears

XXXX/XXX/099		FAULT		XX X DDD/HH:MM:SS DDD/HH:MM:SS	
CRT ID	FAULT	C/W	GPC	TIME	
XXX	XXXXXXXXXX	XXXX	X	XXXXX	XXX / XX : XX : XX
XXX	XXXXXXXXXX	XXXX	X	XXXXX	XXX / XX : XX : XX
XXX	XXXXXXXXXX	XXXX	X	XXXXX	XXX / XX : XX : XX
XXX	XXXXXXXXXX	XXXX	X	XXXXX	XXX / XX : XX : XX
XXX	XXXXXXXXXX	XXXX	X	XXXXX	XXX / XX : XX : XX
XXX	XXXXXXXXXX	XXXX	X	XXXXX	XXX / XX : XX : XX
XXX	XXXXXXXXXX	XXXX	X	XXXXX	XXX / XX : XX : XX
XXX	XXXXXXXXXX	XXXX	X	XXXXX	XXX / XX : XX : XX
XXX	XXXXXXXXXX	XXXX	X	XXXXX	XXX / XX : XX : XX
XXX	XXXXXXXXXX	XXXX	X	XXXXX	XXX / XX : XX : XX
XXX	XXXXXXXXXX	XXXX	X	XXXXX	XXX / XX : XX : XX
XXX	XXXXXXXXXX	XXXX	X	XXXXX	XXX / XX : XX : XX
XXX	XXXXXXXXXX	XXXX	X	XXXXX	XXX / XX : XX : XX
XXX	XXXXXXXXXX	XXXX	X	XXXXX	XXX / XX : XX : XX
XXX	XXXXXXXXXX	XXXX	X	XXXXX	XXX / XX : XX : XX
XXX	XXXXXXXXXX	XXXX	X	XXXXX	XXX / XX : XX : XX
XXX	XXXXXXXXXX	XXXX	X	XXXXX	XXX / XX : XX : XX
XXX	XXXXXXXXXX	XXXX	X	XXXXX	XXX / XX : XX : XX
XXX	XXXXXXXXXX	XXXX	X	XXXXX	XXX / XX : XX : XX
XXX	XXXXXXXXXX	XXXX	X	XXXXX	XXX / XX : XX : XX
XXX	XXXXXXXXXX	XXXX	X	XXXXX	XXX / XX : XX : XX

FAULT Display (DISP 99)

on the bottom line. When a new fault message is generated, it appears on the top line. The other messages are pushed down, and the 15th message (the oldest) disappears.

The only difference between the fault messages on the FAULT display and the fault message on the fault message line is the TIME field. On the FAULT display, the time field includes days as well as hours, minutes, and seconds (DDD/HH:MM:SS).

Sometimes, a subsystem failure or malfunction results in the output of several fault messages, some of which may be identical. The fault detection and annunciation logic can prevent the annunciation of identical fault messages. When a fault message is generated, its major and minor fields are compared to those of the top message of the display. If the fields are the same, and if the new fault message has occurred within a 4.8 second window, the new message is inhibited.

The last message displayed on the fault message line of any CRT is not necessarily the most recent fault message. Unless the fault message line was cleared with a MSG RESET, the crewmember will not see any new messages that came in after the flashing or frozen message. In that case, the crewmembers can see if a new message has been annunciated by looking at a two-character field. This field is called the buffer message indicator and is located in the last field on the far right of the fault message line.

The buffer message indicator serves to indicate the number of messages in the fault buffer on the FAULT display since the last MSG RESET. This number includes class 2 backup and class 3 messages only. Class 5 messages and the currently displayed messages are not included in this counter. The number is enclosed by parentheses. If no fault messages are in the stack, this field is blank. To view any of these messages, the crewmember must look at the FAULT display. A MSG RESET clears both the fault message line and the buffer message indicator.

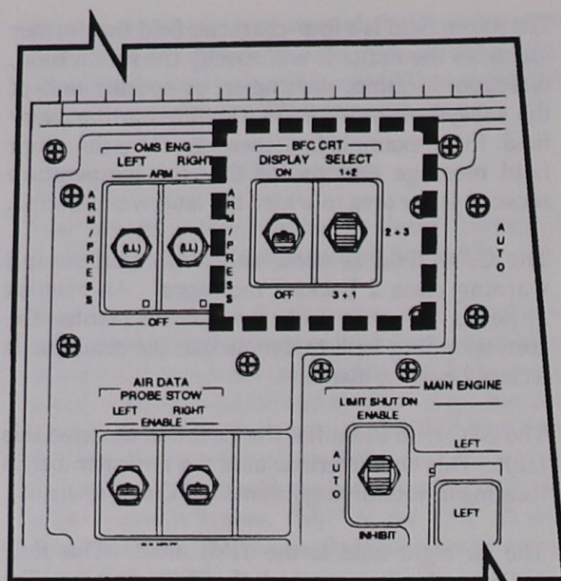
In addition to using the FAULT SUMM key, the FAULT display may also be selected by the keyboard entry "SPEC 99 PRO." However, this command will clear all fault messages from the FAULT display and the fault message lines. This capability is useful if and when the fault messages displayed are no longer significant (i.e., they are old, or they have been dealt with).

#### Crew Software Interface with the BFS

The crew software interface with the BFS is designed to be as much like PASS as possible, but there are some differences. This section covers the differences between the PASS's and BFS's crew and CRT interfaces. If something is not mentioned in this section, it can be assumed to operate the same as the PASS interface.

#### BFC CRT Switches

Panel C3 contains two switches relevant to BFS operations. The BFC CRT DISPLAY switch is a two-position ON/OFF switch. In the ON position, the CRT(s) specified by the BFC CRT SELECT switch is driven by the BFS computer. (The BFC CRT SELECT switch controls CRT assignment to the BFS computer.) The switch is read by the GPC only when the BFC CRT DISPLAY switch is in the ON position. The BFC CRT SELECT switch has three positions. In each position, the first digit is the CRT commanded by the BFS pre-engage. Post-engaged, the BFS also commands a second CRT indicated by the second number. For example, when the BFC CRT SELECT switch is in the 1 + 2 position, CRT 1 is connected to the BFS GPC prior to engaging the BFS. After the BFS is engaged, this switch position allows the BFS computer to command both CRT 1



BFC CRT DISPLAY and SELECT Switches on Panel C3

and CRT 2. In the 2 + 3 position, CRT 2 is commanded by the BFS GPC prior to engaging the BFS. Post-engaged, this switch allows CRT 2 and CRT 3 to be supported by the BFS computer. In the 3 + 1 position, CRT 3 is driven by the pre-engaged BFS GPC. Upon engaging the BFS, both CRT 3 and CRT 1 will be assigned to the BFS computer.

During ascent and entry, one CRT will normally be assigned to the BFS via the BFC CRT SELECT switch. The nominal position of the switch is the 3+ 1 position. However, this switch position may be changed at any time, pre-engage or post-engage. If the BFS is engaged with the BFC CRT DISPLAY switch OFF, the BFS will automatically assume command of CRTs 1 and 2.

No set of BFC CRT switches exists for the CRT in the aft station.

#### BFS Functions of the MAJ FUNC Switch

The MAJ FUNC switches on panels C2 and R12L are also functional for the BFS. However, the display data and functional software accessed by the three-position switch are slightly different. The BFS functions of the MAJ FUNC switch are defined as follows:

- **GNC:** Flight critical software including limited guidance, navigation, and control software is contained in this major function. The BFSGNC major function contains only that software necessary for safe orbital insertion and return, including ascent abort logic.
- **SM:** This major function contains limited nonredundant systems management and payload software. There is no room in the BFS for the redundancy management found in PASS. When the *MAJFUNC* switch is set in the *SM* position, the THERMAL display is invoked. This display is unique to the BFS.
- **PL:** This major function is not functional for the BFS. Should the *MAJFUNC* switch be set in this position, no display change would occur. If the *BFC CRT DISPLAY* switch is turned on, allowing the BFS to drive a CRT already in the *PL* major function, the CRT will be blank except for time and GPC driver fields because the BFS has no software to support this major function.

#### **BFS ENGAGE Push Button**

The BFS ENGAGE push button is located on the commander's and pilot's rotational hand controllers (RHCs). During the dynamic flight phases (ascent and entry), the commander and pilot usually rest their hands on or near the RHC. In this way, BFS engagement can occur as quickly as possible. If the crew delays engagement during these flight phases, they could lose control of the vehicle, or the BFS' navigation calculations could degrade very quickly so that control would be essentially lost after engagement.

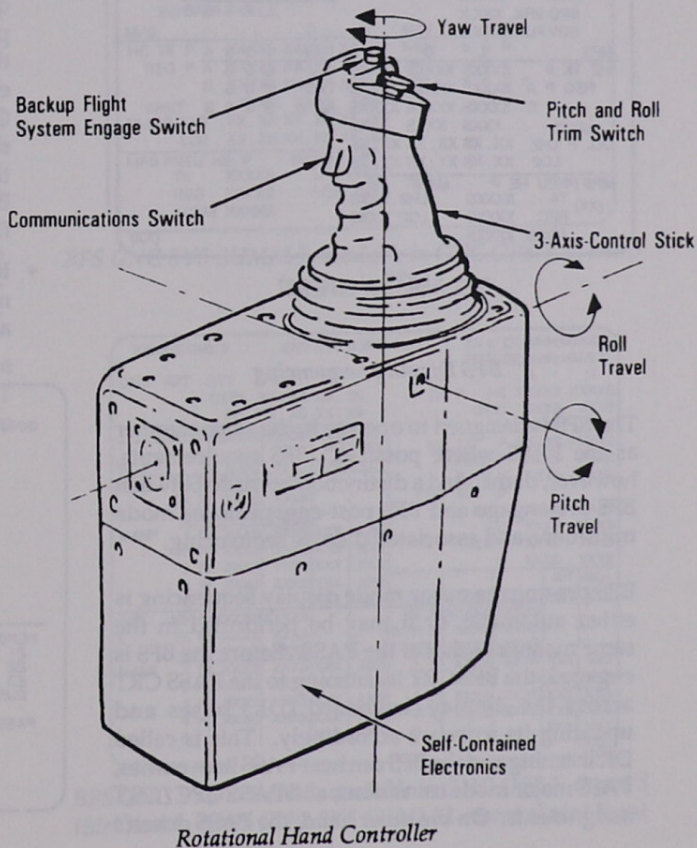
Some force (8 lb) is required to depress this push button to prevent inadvertent engages. While on-orbit, the push button is essentially disabled by reconfiguring another switch. The BFS cannot track PASS while it is in OPS 2 and is turned off on-orbit. If the BFS needs to be engaged on-orbit, the BFS must be

powered up, and the only software that will be of any use is entry and systems management software.

#### **Keyboard and Display Differences for the BFS**

The keyboard operates exactly the same way for the BFS as for the PASS. A few additional capabilities need to be mentioned.

- **The GPC/CRT key:** In addition to the *BFC CRT DISPLAY* switch, this key provides the capability to assign a CRT to (or isolate a CRT from) the BFS GPC. Both methods can be used interchangeably, but as long as the *BFC CRT DISPLAY* switch is working, it is the fastest method of allowing the BFS to drive a CRT or to change BFS CRTs. The *BFC CRT DISPLAY* switch allows PASS to automatically begin driving the CRT again when the BFS is turned off. When the BFS is assigned a CRT with the GPC/CRT key, it is the same as



deassigning that screen from PASS with a GPC/CRT 0X EXEC. PASS must be reassigned to resume commanding of that CRT.

- The BFS INDICATOR: When the BFS is commanding a CRT, the BFS indicator will appear on the CRT being commanded. On the second line of every BFS display a three-character space field has been reserved for the message "BFS." This field is located directly below the GPC indicator. The BFS indicator is displayed in the overbright intensity and is intended to prevent possible confusion of a PASS display with a BFS display. Often the BFS display will be identical or very close to the corresponding PASS display.

XXXX/XXX/018		GNC SYS SUMM 1		XX X DDD/HH:MM:SS	
				BFS DDD/HH:MM:SS	
SURF	POS	MOM	DPS	2	3 4
L OB	XXX.XS	XXS	MDM	FF	S S S S
IB	XXX.XS	XXS	FA	S	S S S S
R IB	XXX.XS	XXS	PL	S	S
OB	XXX.XS	XXS			
AIL	XXX.X				
RUD	XXX.X		FCS	CH	1 2 3 4
SPD BRK	XXX.X				S S S S
BDY FLP	XXX.X				
MPS	L	C	R	NAV	1 2 3 4
HE TK P	XXXXX	XXXXX	XXXXX	IMU	S S S
REG P A	XXXXX	XXXXX	XXXXX	TAC	S S S
B	XXXXX	XXXXX	XXXXX	ADTA	S S S S
dP/dT	XXXX	XXXX	XXXX		
ULL P LH2	XX.XS	XX.XS	XX.XS		
LO2	XX.XS	XX.XS	XX.XS		
MPS PNEU	HE P	MANF	P		
TK	XXXXX	LH2	XXXXX		
REG	XXXXX	LO2	XXXXX		
ACUM	XXXXX				

BFS Indicator on CRT

**BFS Display Sequencing**

The BFS is designed to operate in the same manner as the PASS where possible. BFS requirements, however, demanded a distinction be made between BFS pre-engage and BFS post-engage major mode transitions and associated display sequencing.

BFS pre-engage major mode display sequencing is either automatic, or it may be performed in the same manner as that of the PASS. Before the BFS is engaged, the BFS CRT is listening to the PASS CRT across the display/keyboard (DK) buses and updating its software accordingly. This is called DK listening and the BFS can hear PASS item entries, PASS major mode transitions, and PASS GPC/CRT assignments. On the other hand, the PASS doesn't

know that the BFS exists, so it never DK listens to the BFS. Therefore, BFS major mode transitions are performed automatically as a function of the major mode transitions performed on a PASS keyboard. If the BFS does not follow the PASS major mode transitions, then the BFS must receive a manual OPS XXX PRO on its CRT.

BFS post-engage major mode display sequencing is the same as that of the PASS. After the BFS is engaged, the BFS GPC is on its own. It no longer listens to the PASS GPCs. Therefore, major mode display sequencing has been designed to be the same as that of the PASS.

Three operational sequences are defined for BFS GNC; one operational sequence is defined for the BFS SM. Transactions to and from these OPS displays differ considerably from the PASS. BFS keyboard and CRT peculiarities are outlined as follows:

- BFS GNC OPS 0 - BFS MEMORY display: This display is forced to the CRT when BFS is not processing either GNC OPS 1 or 3. Nominally, this occurs prior to ascent and again prior to entry. This display corresponds to the PASS GPC MEMORY display and performs the same functions for the BFS. GPC MEMORY is the default display for PASS OPS 0, and the BFS MEMORY display is the default display for BFS GNC OPS 0.
- BFS GNC OPS 1 and 6 - Ascent: This OPS must be manually selected via a keyboard assigned to the BFS prelaunch. BFS GNC OPS

0001 /		BFS MEMORY		XX X DDD/HH:MM:SS	
				BFS DDD/HH:MM:SS	
READ/WRITE					
DATA	1X	BIT	SET	3X	SEQ ID
CODE	2X	BIT	RST	4X	WRITE
7	ENG	UNITS	XX	HEX	8X
ADD	ID	DESIRED		ACTUAL	
9	XXXXX	10	XXXX	XXXXXXXXXXXX	
11	XXXXX	12	XXXX	XXXXXXXXXXXX	
13	XXXXX	14	XXXX	XXXXXXXXXXXX	
15	XXXXX	16	XXXX	XXXXXXXXXXXX	
17	XXXXX	18	XXXX	XXXXXXXXXXXX	
19	XXXXX	20	XXXX	XXXXXXXXXXXX	
MEMORY DUMP			LAUNCH BUS		
21	START	ID	XXXXX	1	26X
22	NUMBER	WDS	XXXXXX	2	27X
23	WDS/FRAME	XXX		OFF	28X
DUMP	24				
PASS/BFS	XFER	ENA	25X	TFL	ENA
					29X

BFS MEMORY Display





- **SM SYS SUMM.** There are two SM SYS SUMM displays. SM SYS SUMM 1 is identical to the PASS SM SYS SUMM 1, while BFS SM SYS SUMM 2 is a unique display. They are called in the same manner as the PASS SM SYS SUMM displays.
- **THERMAL.** This is a systems summary DISP available as the SM OPS 0 display in BFS. It is forced to the screen anytime the MAJ FUNC switch is placed in the SM position (unless an SM SPEC is called up over it). This display is unique to the BFS. It cannot be obtained with a SPEC key, and it never requires a keyboard entry.

```

XXXX/XXX/078  SM SYS SUMM 1  XX X DDD/HH/HH/MISS
                    BFS DDD/HH/HH/MISS
SMOKE 1/A 2/B
CABIN XX.XS
L/R FD XX.XS XX.XS
AV BAY 1 XX.XS XX.XS
      2 XX.XS XX.XS
      3 XX.XS XX.XS
CABIN
PRESS XX.XS
dP/dT 1.XXS
BU/EQ 1.XXS 1.XXS
PP02 X.XXS X.XXS
FAN ΔP X.XXS
HX OUT T XXXS
O2 FLOW X.XS X.XS
N2 FLOW X.XS X.XS
AV FAN ΔP X.XXS
SS1 XXXS XXXS XXXS
SS2 XXXS XXXS XXXS
SS3 XXXS XXXS XXXS
TOTAL AMPS XXXXS
      KW XXS
DC VOLTS 1/A 2/B 3/C
FC XX.XS XX.XS XX.XS
MAIN XX.XS XX.XS XX.XS
CNTL AB XX.XS XX.XS XX.XS
      BC XX.XS XX.XS XX.XS
      CA XX.XS XX.XS XX.XS
ESS
AC
VOLT ΔA XXXS XXXS XXXS
      ΔB XXXS XXXS XXXS
      ΔC XXXS XXXS XXXS
AMPS ΔA XX.XS XX.XS XX.XS
      ΔB XX.XS XX.XS XX.XS
      ΔC XX.XS XX.XS XX.XS
FUEL CELL PH XXXS XXXS
REAC VLV XXXS XXXS
STACK T 1XXXS 1XXXS
EXIT T 1XXXS XXXS
COOL P 1XXXS XXXS
      PUMP XXXS XXXS
  
```

BFS SM SYS SUMM 1, available in SM OPS 0  
(Identical to PASS SM SYS SUMM 1)

```

XXXX/XXX/079  SM SYS SUMM 2  XX X DDD/HH/HH/SS
                    BFS DDD/HH/HH/SS
CRYO TK 1 2 3 4 5
H2 PRESS XXXS XXXS XXXS XXXS XXXS
O2 PRESS XXXS XXXS XXXS XXXS XXXS
HTR T1 1XXXS 1XXXS 1XXXS 1XXXS 1XXXS
      T2 1XXXS 1XXXS 1XXXS 1XXXS 1XXXS
APU 1 2 3
TEMP EGT XXXXS XXXXS XXXXS
B/U EGT XXXXS XXXXS XXXXS
OIL IN XXXS XXXS XXXS
      OUT XXXS XXXS XXXS
GG BED XXXS XXXS XXXS
INJ XXXS XXXS XXXS
SPEED % XXXS XXXS XXXS
FUEL QTY XXXS XXXS XXXS
PMP LK P XXS XXS XXS
OIL OUT P XXXS XXXS XXXS
FU TK VLV
      A T XXXS XXXS XXXS
      B T XXXS XXXS XXXS
AV BAY 1 2 3
TEMP XXXS XXXS XXXS
FAN ΔP X XXS X XXS X XXS
PRESS XXXS XXXS XXXS XXXS XXXS
ACUM P XXXS XXXS XXXS
RSVR T XXXS XXXS XXXS
QTY XXXS XXXS XXXS
W/B
H2O QTY XXXS XXXS XXXS
BYP VLV XXXS XXXS XXXS
THERM CNTL 1 2
H2O PUMP P XXXS XXXS
FREON FLOW XXXXS XXXXS
EVAP OUT XXXS XXXS
  
```

BFS SM SYS SUMM 2, available in SM OPS 0  
(unique to BFS)

**BFS Fault Messages**

Several crew interface characteristics of fault annunciation in the BFS differ from those in the PASS.

- **The BFS FAULT display.** The BFS FAULT display functions in the same manner as the PASS. The BFS FAULT display is composed of 20 fault lines as compared to 15 in the PASS. The C/W field displays an asterisk when the message annunciated is a class 2 backup alarm. The BFS FAULT display provides a history of only class 2 backup and class 3 messages annunciated by the BFS GPC itself.
- **BFS Unique CRT IDs.** In BFS SM, all messages referring to SM SYS SUMM 1 or SM SYS SUMM 2 are indicated by the CRT IDs SM1 and SM2. Fault messages referring to the THERMAL display are indicated by the CRT ID SM0.

```

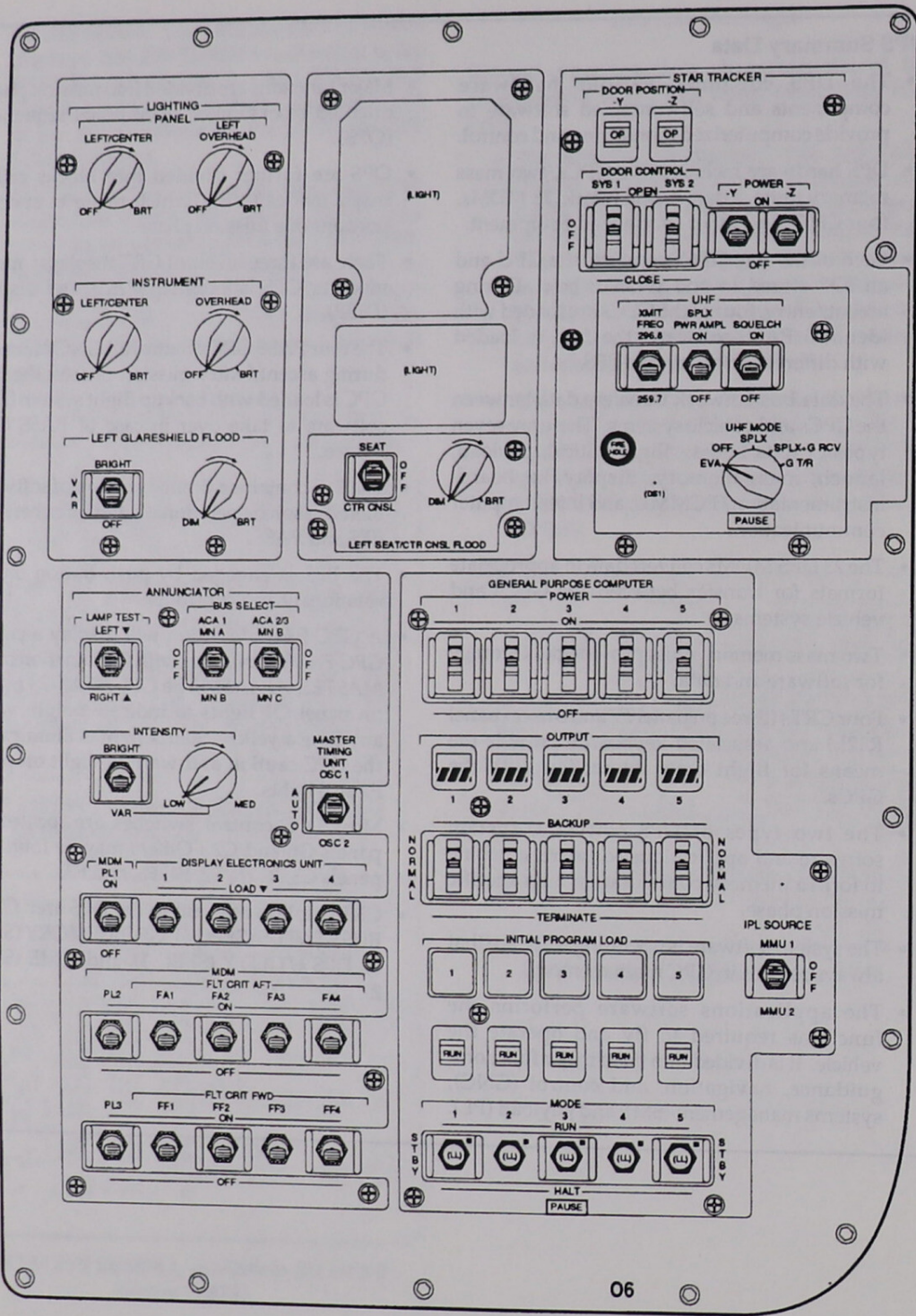
0001 / / THERMAL XX X DDD/HH MM SS
                    BFS DDD/HH MM SS
SYS TEMP BDFL P RD/SB L OB L IB R IB P OB
PRIME 1 :XXXS :XXXS :XXXS :XXXS :XXXS :XXXS
STBY 1 :XXXS :XXXS :XXXS :XXXS :XXXS :XXXS
BRAKE PRESS
HYD SYS 1/3 XXXXS XXXXS XXXXS XXXXS
      2/3 XXXXS XXXXS XXXXS XXXXS
HTR TEMP L/A R/B FREON LOOP 1 2
PRPLT ACCUM QTY XXXS XXXS
POD RAD IN T XXXS XXXS
OMS CRSF D H2O SUP P XXXS
EVAP TIRE PRESS
HI LOAD SSS MG LEFT RIGHT
TOP DUCT SS IB XXXS XXXS XXXS XXXS
NOZ S OB XXXS XXXS XXXS XXXS
FDLN SSSS NG XXXS XXXS XXXS XXXS
HYD BLR/HTR 1 2 3
APU S S S
GG FU PMP HTR SSSS SSSS SSSS
TK/FU LN HTR SSSSSSSSS SSSSSSSSS SSSSSSSSS
PUMP/VLV COOL SS SS SS
FC END HTR A/B XXXX/XXXXS XXXX/XXXXS XXXX/XXXXS
  
```

BFS THERMAL, available in SM OPS 0

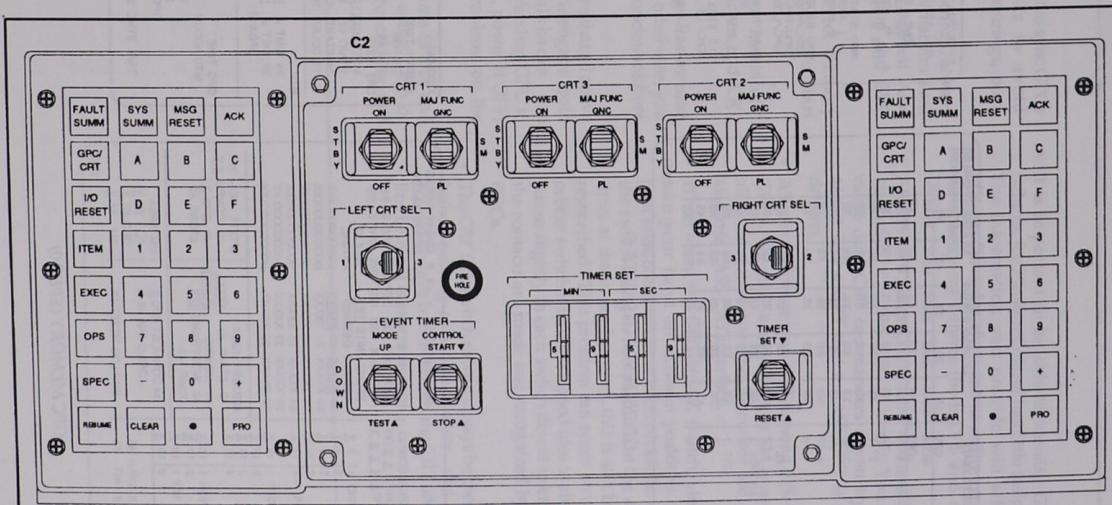
### DPS Summary Data

- The DPS combines various hardware components and self-contained software to provide computerized monitoring and control.
- DPS hardware includes five GPCs, two mass memory units, a data bus network, 23 MDMs, four CRTs, and other specialized equipment.
- Each of the five GPCs consists of a CPU and an IOP stored in one avionics box. During ascent/entry, four of the GPCs are loaded with identical PASS software; the fifth is loaded with different software, the BFS.
- The data bus network transfers data between the GPCs and vehicle systems. There are seven types of data buses: flight-critical, payload, launch, mass memory, display/keyboard, instrumentation/PCMMU, and intercomputer communication.
- The 23 DPS MDMs convert data to appropriate formats for transfer between the GPCs and vehicle systems.
- Two mass memory units provide bulk storage for software and data.
- Four CRTs (three on panel F7 and one on panel R12L) and associated keyboards provide the means for flight crew interaction with the GPCs.
- The two types of DPS software, system software and applications software, combine to form a memory configuration for a specific mission phase.
- The system software is operating software that always resides in GPC main memory.
- The applications software performs the functions required to fly and operate the vehicle. It is divided into three major functions: guidance, navigation, and control (GNC); systems management (SM); and payload (PL).
- Major functions are divided into mission phase oriented blocks called operational sequences (OPS).
- OPS are further divided into blocks called major modes (MM), which relate to specific portions of a mission phase.
- There are three levels of CRT displays: major mode or OPS, specialist (SPEC), and display (DISP).
- The four PASS GPCs control all GNC functions during ascent/entry mission phases; the fifth GPC is loaded with backup flight system (BFS) software to take over in case of PASS GPC failure.
- The BFS contains a limited amount of software; there are some operational differences between BFS and PASS.
- The BFS is engaged by push button on the rotational hand controller.
- A GPC FAIL detection will display a class 2 GPC FAULT message with illumination of the MASTER ALARM. The GPC STATUS matrix on panel O1 lights to indicate failure votes; any time a yellow matrix light is illuminated, the GPC caution and warning light on panel F7 also lights.
- Most DPS control switches are located on panels O6 and C2. Others may be found on panels C3, R12L, F2, F4, F6, and F7.
- CRT displays relevant to the DPS are: GPC/BUS STATUS (SPEC 6), GPC MEMORY (SPEC 0), DPS UTILITY (SPEC 1), and TIME (SPEC 2).

2. SYSTEMS  
2.6 Data Processing System



Panel O6



Panel C2

XXXX/XXX/006		GPC/BUS STATUS					XX X DDD/HH:MM:SS DDD/HH:MM:SS	
GPC	1S	2S	3S	4S	5S			
MODE	XXXX	XXXX	XXXX	XXXX	XXXX			
OPS	XX	XX	XX	XX	XX			
STRING 1	FF	XS	XS	XS	XS	XS		
	FA	XS	XS	XS	XS	XS		
2	FF	XS	XS	XS	XS	XS		
	FA	XS	XS	XS	XS	XS		
3	FA	XS	XS	XS	XS	XS		
	FA	XS	XS	XS	XS	XS		
4	FA	XS	XS	XS	XS	XS		
	FA	XS	XS	XS	XS	XS		
PL 1	XS	XS	XS	XS	XS	XS		
2	XS	XS	XS	XS	XS	XS		
LAUNCH 1	XS	XS	XS	XS	XS	XS		
2	XS	XS	XS	XS	XS	XS		
CRT 1	XS	XS	XS	XS	XS	XS		
2	XS	XS	XS	XS	XS	XS		
3	XS	XS	XS	XS	XS	XS		
4	XS	XS	XS	XS	XS	XS		

(XX)

GPC/BUS STATUS (SPEC 6)

XXXX/001/		DPS UTILITY		XX X DDD/HH:MM:SS DDD/HH:MM:SS	
MMU ASSIGN	1 2	PORT ASSIGN	PRI SEC	UL CNTL	
GNC 1X 2X		STRING 1	15X 16X	AUTO 35X	
SM 3X 4X			2 17X 18X	ENA 36X	
PL 5X 6X			3 19X 20X	INH 37X	
OPS 0 7X 8X			4 21X 22X		
		PL 1/2	23X 24X	IPL SOURCE SW	
MMU STATUS	1 XXX			MASK 38X	
	2 XXX				
		VAR PARAM ID LIST			
MMU SOURCE/BUS	25 XXXX			G3 ARCHIVE	
GPC/MMU 9X	26 XXXX			LOAD 48X	
MMU/MMU 10X	27 XXXX			RETRIEVE 49X	
GPC/LDB 11X	28 XXXX				
	29 XXXX			GROUND OPS	
	30 XXXX			GSE POLL ENA 50X	
CKPT RETRV	31 XXXX			SM GSE INH 51X	
ENA 12X	32 XXXX			SM C/O ENA 52X	
	33 XXXX			GNC C/O ENA 53X	
RTC	34 XXXX			BFC C/O ENA 54X	
13 XXXX XXXX				ALT PL9 TB 55X	
CMD 14					(XX)

DPS UTILITY (SPEC 1)

0001 / /		GPC MEMORY		XX X DDD/HH:MM:SS DDD/HH:MM:SS	
MEMBUS CONFIG	1	READ/WRITE	XXXX		
	2	DATA 20X BIT SET	22X SEQ ID 24		
	3	CODE 21X BIT RST	23X WRITE 25		
	4	26 ENG UNITS	XXX HEX 27		
STRING 1	7 X	ADD ID DESIRED	ACTUAL		
2	8 X	28 XXXXX	29 XXXXX	±XXXXXXXXXXXX	
3	9 X	30 XXXXX	31 XXXXX	±XXXXXXXXXXXX	
4	10 X	32 XXXXX	33 XXXXX	±XXXXXXXXXXXX	
PL 1/2	11 X	34 XXXXX	35 XXXXX	±XXXXXXXXXXXX	
		36 XXXXX	37 XXXXX	±XXXXXXXXXXXX	
CRT 1	12 X	38 XXXXX	39 XXXXX	±XXXXXXXXXXXX	
2	13 X				
3	14 X				
4	15 X				
LAUNCH 1	16 X	MEMORY DUMP		STORE MC = X X	
2	17 X	40 START ID	XXXXX	45 CONFIG	XX
MM 1	18 X	41 NO WDS	XXXXXX	46 GPC	X
2	19 X	42 WDS/FRAME	XXX	STORE 47	
		DUMP 43			
OPS 3 UPLK	50	44 DOWNLIST GPC	X	MM AREA	
OPS 3 INIT	51	OPS O ENA	49 X	PL 52	X
		ERR LOG RESET	48	GNC 53	X
				SM 54	X

(XX)

GPC MEMORY (SPEC 0)

XXXX/002/		TIME		XX X DDD/HH:MM:SS DDD/HH:MM:SS	
MISSION TIME		TONE			
GMT 1X		3	XX:XX:XX	MSN T	
MET 2X		6	XX:XX:XX		
CRT TIMER					
9 SET [±]XX:XX:XX		20	XX:XX:XX	CRT T	
START 12 STOP 13					
14 START AT XX:XX:XX		23	DURATION	XX	
17 COUNT TO XX:XX:XX					
MTU					
24 GMT Δ [±]XXX/XX:XX:XX					
28 MET Δ [±]XXX/XX:XX:XX					
UPDATE 32					
GPC TIME					
MTU ACCUM 1	XXX/XX:XX:XX.XXXS	TRY 1	XX		
2	XXX/XX:XX:XX.XXXS	34	2	XX	
3	XXX/XX:XX:XX.XXXS	35	3	XX	
GPC   XXX/XX:XX:XX.XXXS		36	4	XX	
		37	5	XX	
TIME SYNC 38					

(XX)

TIME (SPEC 2)

### *DPS Rules of Thumb*

- Always deassign CRTs from fail to sync GPCs and reassign to good GPCs to avoid inadvertent entries (NBATs/restrings, burn targets, etc.).
- Before OPS transitions and restrings, always verify the appropriate NBAT is what you want it to be; never assume that it is correct! Also check the proper major function and GPC switch configuration.
- Make sure you have the correct memory configuration called up before you start making NBAT changes.
- During OPS transitions, keep "hands off" everything, including all switches and CRT entries.
- Always clear the Fault Message line as soon as you have seen the message; otherwise, you will likely miss subsequent annunciations from other failures.
- Post BFS engage, check to ensure that all active PASS GPCs have recognized the engage (both *MODE* and *OUTPUT* talkbacks are barberpole). If not, take the offending GPC to *HALT* (or if this doesn't work, power it *OFF*) immediately to avoid I/O problems on the flight critical strings.
- It is a very good idea to resume SPECs and DISPs from CRTs when not using them or before going to another major function on that CRT.
- It is important to be able to identify GPC failures, for Mission Control has little insight. The information you provide will affect Mission Control analysis and its ability to plan for subsequent failures (both DPS and non DPS).
- Always hard assign CRTs (both PASS and BFS) via PASS CRTs (BFS will DK listen). You can cause dual CRT commanders if you try to assign BFS a CRT that a PASS CRT is still driving.
- Always distribute your CRTs among different GPCs. On orbit, always be sure SM is not on all CRTs at the same time; if you lose SM, you also lose PASS CRT interface.
- When using the *GPC MODE* switch, always take your hand off between positions. On past missions there have been problems with the switch being in two positions at the same time; at the time of writing, this is still being researched. This problem can occur on other orbiter switches too. It is a good idea to always pause slightly in each switch detent to ensure the contacts are made and recognized by the GPCs.
- The *CRT SEL* switch should always be checked before making a keyboard entry, and data should always be checked on the CRT scratch line before it is entered.

## 2.7 DEDICATED DISPLAY SYSTEMS

### Description

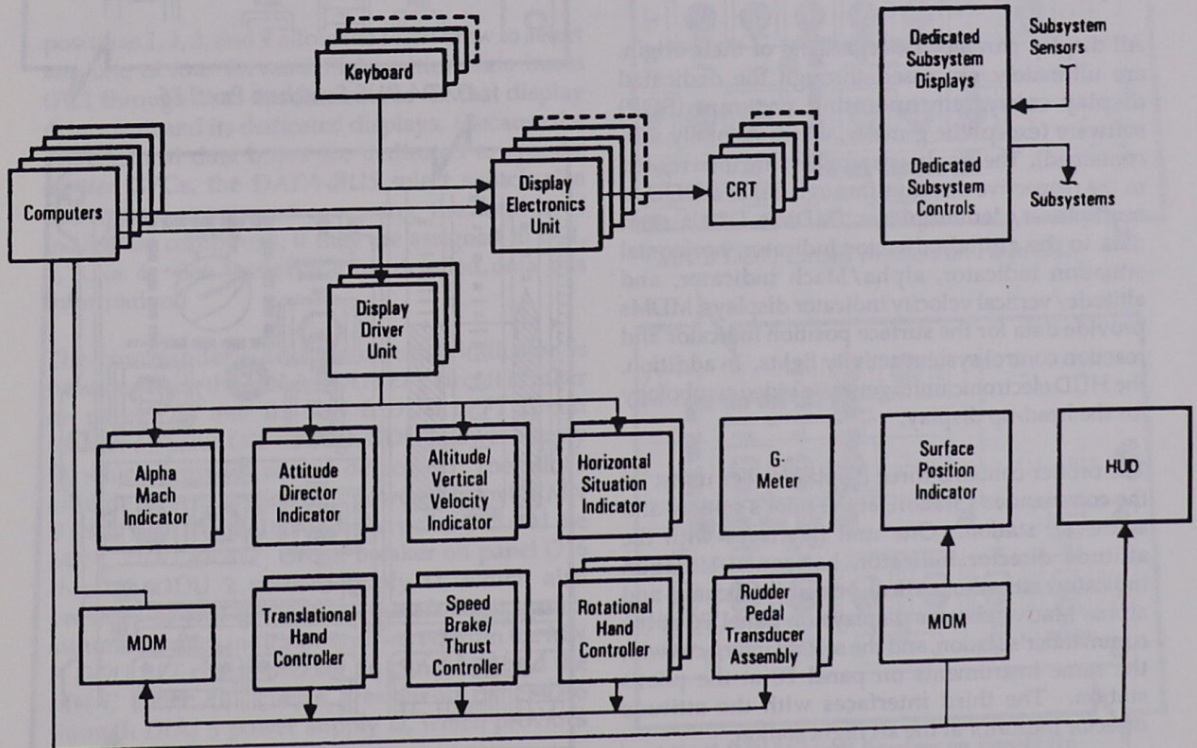
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G-Meter .....	2.7-20
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Dedicated displays provide the flight crew with information required to fly the vehicle manually or to monitor automatic flight control system performance. The data on the dedicated displays may be generated by the navigation or flight control system software or more directly by one of the navigation sensors. The dedicated displays are located in front of the commander's and pilot's seats and on the aft flight deck panel by the aft-facing windows.

The dedicated displays are:

- Attitude director indicators on panels F6, F8, and A1U
- Horizontal situation indicators on panels F6 and F8
- Alpha/Mach indicators on panels F6 and F8
- Altitude/vertical velocity indicators on panels F6 and F8



*Dedicated Display and Control System*



- Surface position indicator on panel F7
- Reaction control system activity lights on panel F6
- G-meter on panel F7
- Head-up display on the glareshield in front of the commander's and pilot's seats.

Not all the dedicated displays are available in every operational sequence or major mode. Their availability is related to the requirements of each flight phase.

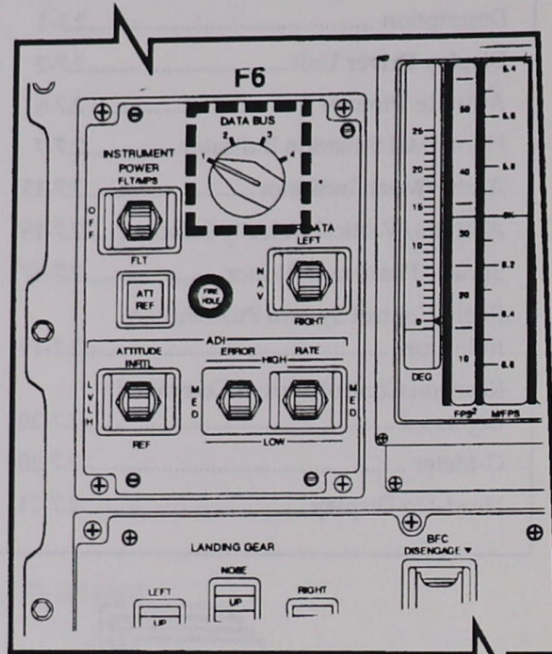
### Display Driver Unit

The display driver unit (DDU) is an electronic mechanism that connects the GPCs and the primary flight displays. The display driver unit receives data signals from the computers and decodes them to drive the dedicated displays. The unit also provides dc and ac power for the attitude director indicators and the rotational and translational hand controllers. It contains logic for setting flags on the dedicated instruments for such items as data dropouts and sensor failures.

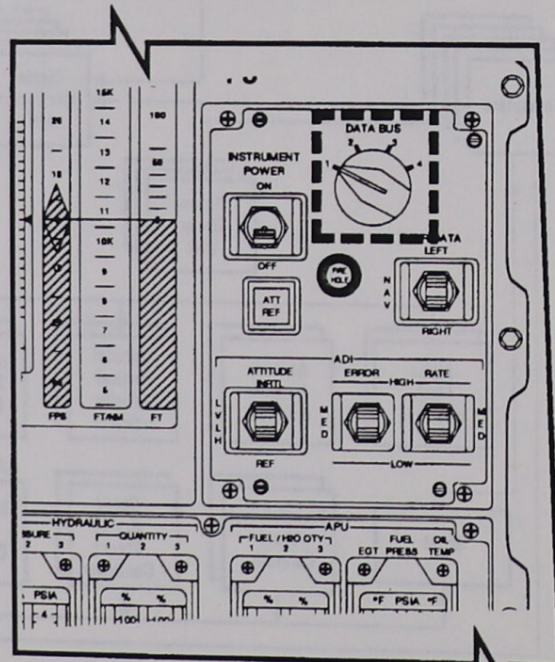
All display parameters, regardless of their origin, are ultimately processed through the dedicated display subsystem operating program (SOP) software (except the g-meter, which is totally self-contained). The display parameters are then routed to the respective displays through either a DDU or multiplexer/demultiplexer (MDM); DDUs send data to the attitude director indicator, horizontal situation indicator, alpha/Mach indicator, and altitude/vertical velocity indicator displays; MDMs provide data for the surface position indicator and reaction control system activity lights. In addition, the HUD electronic units generate video symbology for the head-up display.

The orbiter contains three display driver units: at the commander's station, at the pilot's station, and at the aft station. One unit interfaces with the attitude director indicator, horizontal situation indicator, altitude/vertical velocity indicator, and alpha/Mach indicator displays on panel F6 at the commander's station, and the second interfaces with the same instruments on panel F8 at the pilot's station. The third interfaces with the attitude director indicator at the aft flight station.

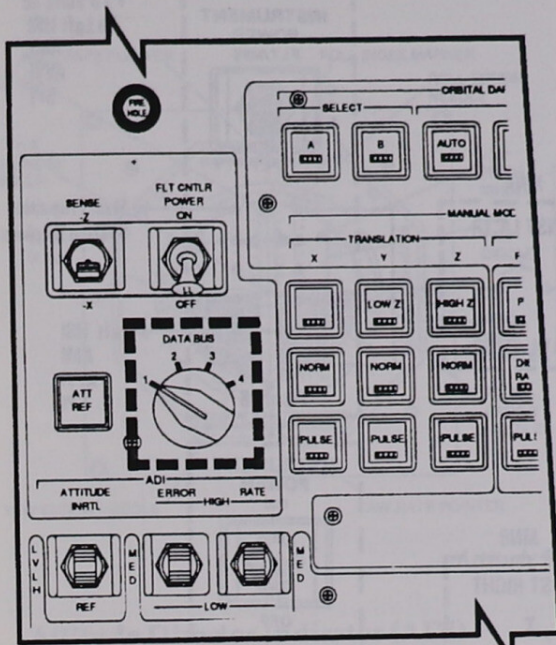
Each display driver unit has an associated DATA BUS rotary switch. The commander's switch is on panel F6, and the pilot's is on panel F8. The switch for the aft flight station is on panel A6U. Switch



DATA BUS Switch on Panel F6



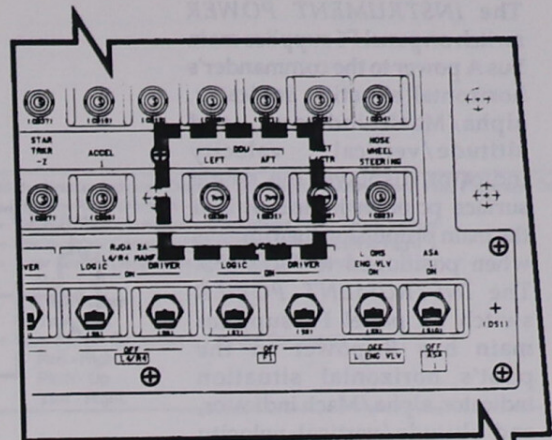
DATA BUS Switch on Panel F8



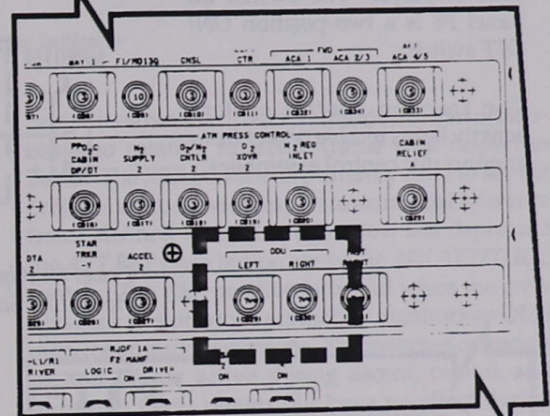
DATA BUS Switch on Panel A6U

positions 1, 2, 3, and 4 allow the flight crew to select any one of four forward flight-critical data buses (FC1 through 4) as the data source for that display driver unit and its dedicated displays. (Because the flight-critical data buses are dedicated to specific orbiter GPCs, the DATA BUS select switch also provides a means of assessing the health of individual computers, if they are assigned to FC1, 2, 3, or 4. See Section 2.6 for detailed data bus information.)

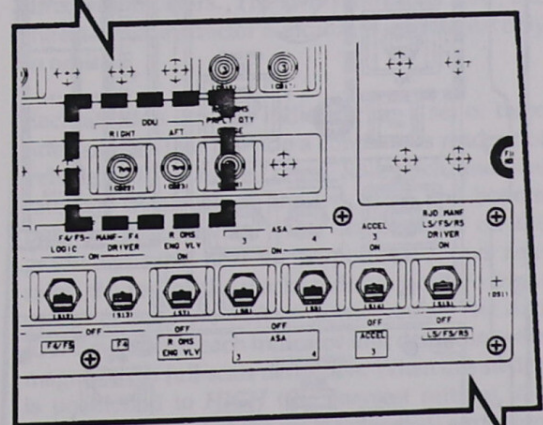
The commander's attitude director indicator is powered from the MN A DDU LEFT circuit breaker on panel O14 and the MN B DDU LEFT circuit breaker on panel O15 through DDU 1 power supply D, which provides ac and dc power. The pilot's attitude director indicator is powered from the MN B DDU RIGHT circuit breaker on panel O15 and the MN C DDU RIGHT circuit breaker on panel O16 through DDU 2 power supply D, which also provides ac and dc power. The aft flight station attitude director indicator is powered from the MN A DDU AFT circuit breaker on panel O14 and the MN C DDU AFT circuit breaker on panel O16 through DDU 3 power supply D, which provides ac and dc power.



MN A DDU Circuit Breakers on Panel O14



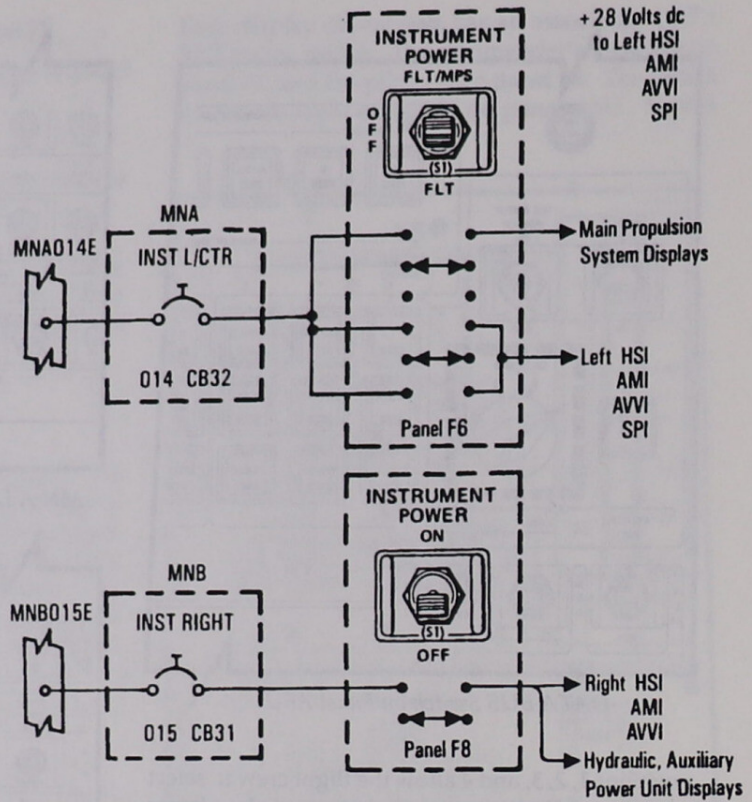
MN B DDU Circuit Breakers on Panel O15



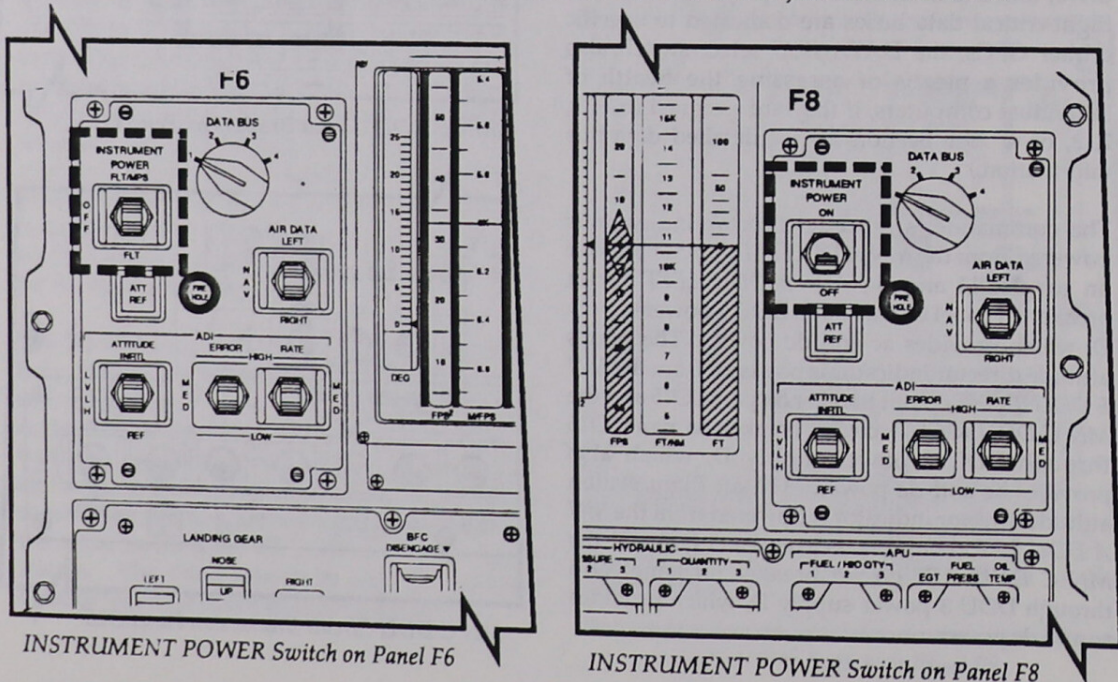
MN C DDU Circuit Breakers on Panel O16

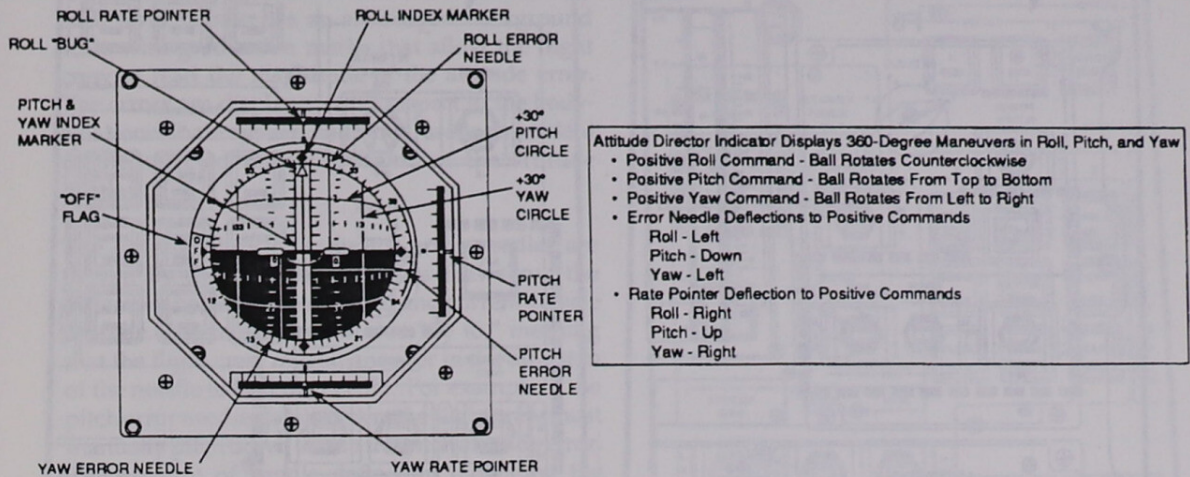
The *INSTRUMENT POWER* switch on panel F6 supplies main bus A power to the commander's horizontal situation indicator, alpha/Mach indicator, and altitude/vertical velocity indicator displays, the single surface position indicator, and the main propulsion instruments when positioned to *FLT/MPS*. The *INSTRUMENT POWER* switch on panel F8 supplies main bus B power to the pilot's horizontal situation indicator, alpha/Mach indicator, and altitude/vertical velocity indicator displays and the hydraulic and auxiliary power unit displays. The switch on panel F8 is a two-position *ON/OFF* switch.

The reaction control system activity lights receive power from annunciator control assemblies.



Power for Alpha/Mach Indicator, Altitude/Vertical Velocity Indicator, Horizontal Situation Indicator, and Surface Position Indicator





Attitude Director Indicator

### Attitude Director Indicator (ADI)

The commander's and pilot's attitude director indicators are supported throughout the mission; the aft attitude director indicator is active only during orbital operations. The indicators give the crew attitude information as well as attitude rate and attitude errors, which can be read from the position of the pointers and needles.

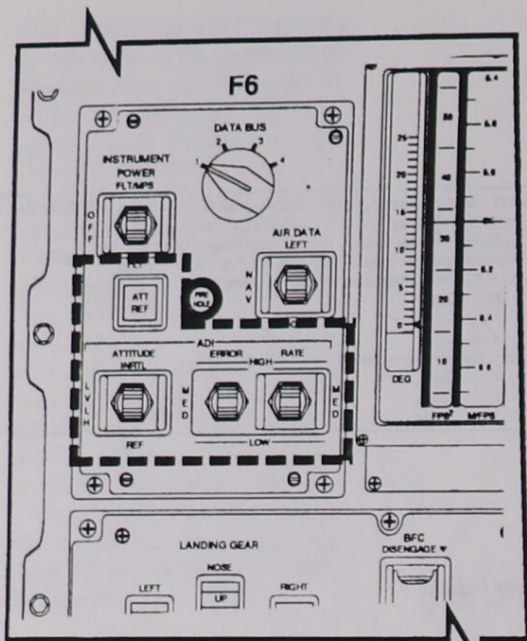
The orbiter's attitude is displayed to the flight crew by an enclosed ball (sometimes called the eight ball) that is gimballed to represent 3 degrees of freedom. The ball, covered with numbers indicating angle measurements (a 0 is added as the last digit of each), moves in response to software-generated commands to depict the current orbiter attitude in terms of pitch, yaw, and roll.

Each attitude director indicator has a set of switches by which the crew can select the mode or scale of the readout. The commander's switches are located on panel F6, the pilot's on panel F8, and the aft switches on panel A6U.

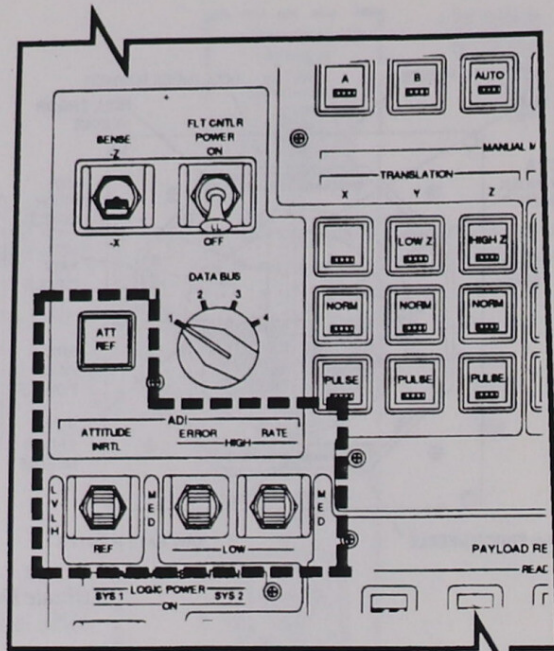
The *ADI ATTITUDE* switches determine the unit's frame of reference: *INRTL* (inertial), *LVLH* (local vertical/local horizontal), and *REF* (reference). The *INRTL* position allows the flight crew to view the orbiter's attitude with respect to the inertial reference frame, useful in locating stars. The *LVLH*

position shows the orbiter's attitude from an orbiter-centered rotating reference frame with respect to Earth. The *REF* position is primarily used to see the orbiter's attitude with respect to an inertial reference frame defined when the flight crew last depressed the *ATT REF* push button above the *ADI ATTITUDE* switch. The *REF* position is useful when the crew flies back to a previous attitude or monitors an OMS burn for attitude excursions. The switches on panels F6 and F8 are active during ascent, orbital, and transition flight phases but have no effect during entry, the latter part of a return to launch site, or when the backup flight system is driving the attitude director indicators. The switch on panel A6U, like the aft attitude director indicator, is operational only in orbit.

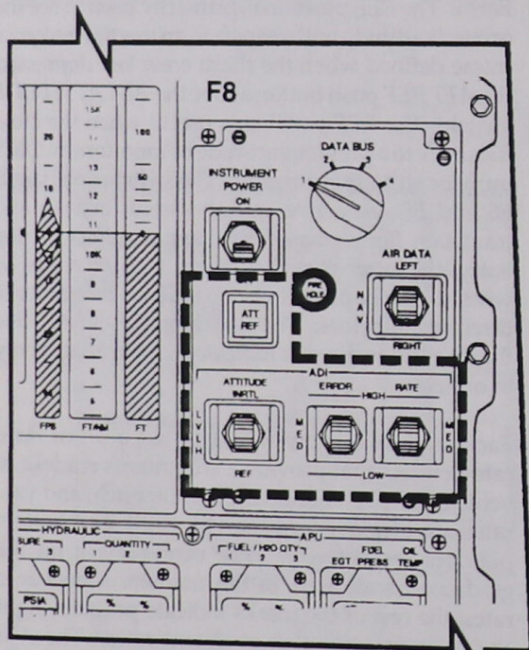
Each attitude director indicator has a set of three rate pointers that provide a continuous readout of vehicle body rotational rates. Roll, pitch, and yaw rates are displayed on the top, right, and bottom pointers respectively. The center mark on the graduated scale next to the pointers shows zero rates; the rest of the marks indicate positive (right or up) or negative (left or down) rates. The *ADI RATE* switch for each indicator unit determines the magnitude of full-scale deflection. When this switch is positioned to *HIGH* (the coarsest setting), the pointer at the end of the scale represents a rotation rate of 10 degrees per second. When the switch is positioned to *MED*, a full-range deflection



Commander's ADI Switches and ATT REF Push Button on Panel F6



Aft ADI Switches and ATT REF Push Button on Panel A6U



Pilot's ADI Switches and ATT REF Push Button on Panel F8

represents 5 degrees per second. In the LOW position (the finest setting), a pointer at either end of the scale is read at a rate of 1 degree per second. These pointers are "fly to" in the sense that the rotational hand controller must be moved in the same direction as the pointer to null a rate.

Attitude director indicator rate readings are independent of the selected attitude reference. During ascent, the selected rates come directly from the solid rocket booster or orbiter rate gyros to the attitude director indicator processor for display on the rate pointers. During entry, only the pitch rate follows the direct route to the attitude director indicator display. The selected roll and yaw rates first flow through flight control, where they are processed and output to the attitude director indicator as stability roll and yaw rates. (This transformation is necessary because, in aerodynamic flight, control is achieved about stability axes, which in the cases of roll and yaw differ from body axes.)

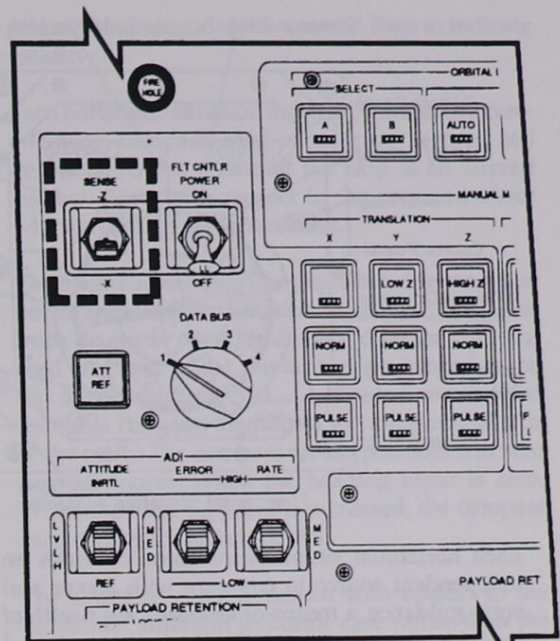
Three yellow needles on each attitude director indicator display vehicle attitude errors. These needles extend in front of the attitude director

indicator ball, with roll, pitch, and yaw arranged just as the rate pointers are. Like the rate indicators, each error needle has an arc-shaped background scale with graduation marks that allow the flight crew to read the magnitude of the attitude error. The errors are displayed with respect to the body-axis coordinate system and, thus, are independent of the selected reference frame of the attitude display.

The attitude director indicator error needles are driven by flight control outputs that show the difference between the required and current vehicle attitude. These needles are also "fly to," meaning that the flight crew must maneuver in the direction of the needle to null the needle. For example, if the pitch error needle points down, the flight crew must manually pitch down to null the pitch attitude error. The amount of needle deflection indicating the number of degrees of attitude error depends upon the position of the ADI ERROR RATE switch for each attitude director indicator and the flight phase. For ascent, orbit, and transition, in the *HIGH* position, the error needles represent 10 degrees, *MED* represents 5 degrees, and *LOW* represents 1 degree. For entry, the needles signify different errors in different phases (see table below).

MISSION PHASE	ROLL	PITCH	YAW
Ascent/ On-orbit/ Transition			
(101-106, 601)			
(201, 202, 801)			
(301, 303)			
Transition	(Deg)	(Deg)	(Deg)
High	10	10	10
Medium	5	5	5
Low	1	1	1
ENTRY (MM 304, 602)	(Deg)	(Deg)	(Deg)
High	25	10	2.5
Medium	25	5	2.5
Low	10	1	2.5
MM 603 IPH = 4,6			
TAEM (MM 305, 603)	(Deg)	(g's)	(Deg)
High	25	1.25	2.5
Medium	25	1.25	2.5
Low	10	0.5	2.5
IPH ≠ 4,5 WOWLON = 0			
WOWLON = 1 Rollout (MM 305, 603)	(Deg)	(Deg/s)	(Deg)
High	20	10	2.5
Medium	5	5	2.5
Low	1	1	2.5

ADI Error Switch vs. Full Range Deflection



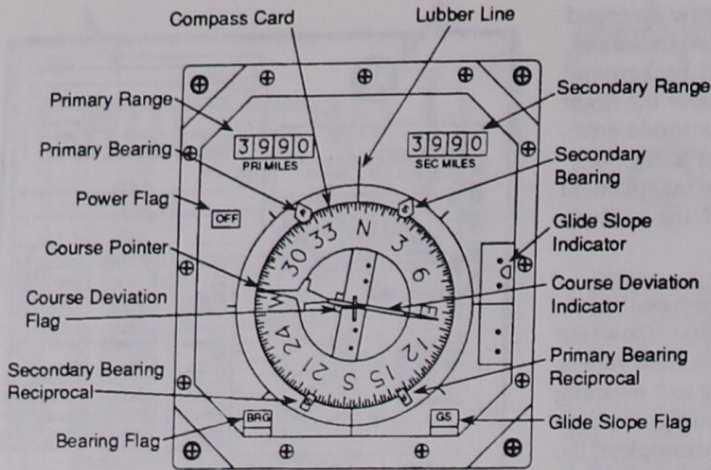
SENSE Switch on Panel A6U

The *SENSE* switch on panel A6U allows the flight crew to use the aft attitude director indicator, rotational hand controller, and translational hand controller in a minus X or minus Z control axis sense. These two options of the aft attitude director indicator and hand controllers correspond to the visual data out of the aft viewing (negative X) or overhead viewing (negative Z) windows.

Each attitude director indicator has a single flag labeled *OFF* on the left side of the display whenever any attitude drive signal is invalid. There are no flags for the rate and error needles; these indicators are driven out of view when they are invalid.

### Horizontal Situation Indicator (HSI)

The horizontal situation indicator for the commander (panel F6) and pilot (panel F8) displays a pictorial view of the vehicle's position with respect to various navigation points and shows a visual perspective of certain guidance, navigation, and control parameters, such as direction, distance, and course/glide path deviation. The flight crew uses this information to control or monitor vehicle performance. The horizontal situation indicators are active during the entry and landing and ascent/return to launch site phases.



Horizontal Situation Indicator

Each horizontal situation indicator provides an independent source to compare with ascent and entry guidance, a means of assessing the health of individual navigation aids during entry, and information needed by the flight crew to fly manual ascent, return to launch site, and entry.

**HSI Ascent Displays**

During ascent major modes 102 and 103 (first and second stage) and return to launch site, the horizontal situation indicator provides information about the target insertion orbit. The compass card displays heading with respect to target insertion orbit, and north on the compass card points along the target insertion orbit plane. The heading of the body plus X axis with respect to the target insertion orbit is read at the lubber line.

The course pointer provides the heading of the Earth-relative velocity vector with respect to the target insertion orbit plane. The course deviation indicator deflection indicates the estimated sideslip angle, the angle between the body X axis and the relative velocity vector.

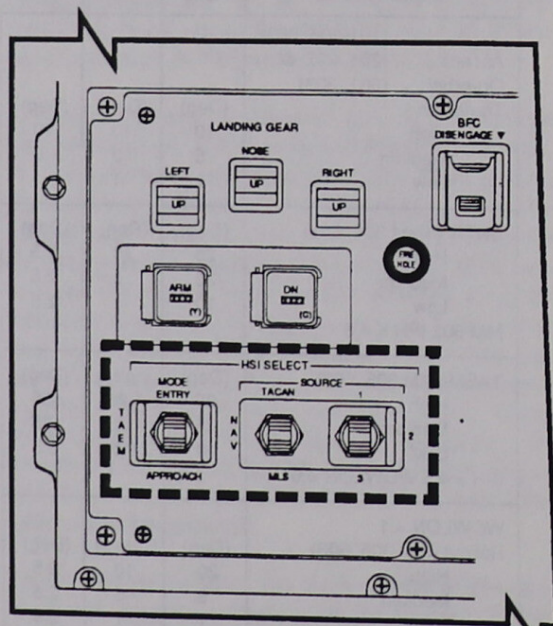
The primary bearing pointer during major modes 102 and 103 (pre-TAL abort) is fixed on the compass card at a predetermined value to provide a turnaround heading in the event of a return to launch site (RTLS) abort. During RTLS major mode 601, or post-TAL abort, MM103, the pointer

indicates the heading to the landing site runway. The secondary bearing provides the heading of the inertial velocity vector with respect to the target insertion orbit plane.

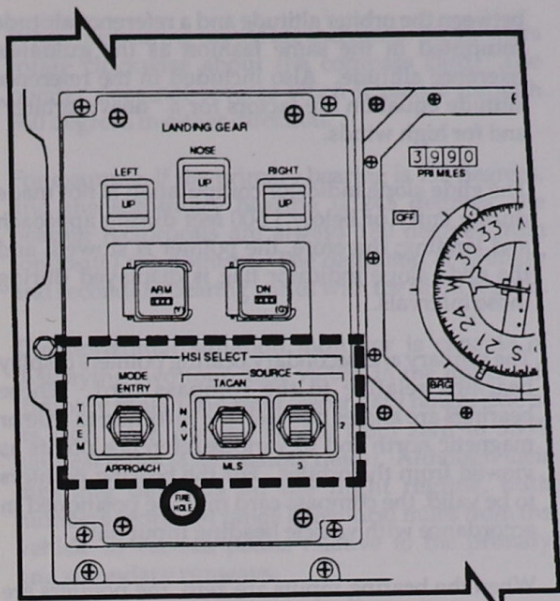
**HSI Entry Displays**

The commander's horizontal situation indicator switches are on panel F6, and the pilot's are on panel F8. The *HSI SELECT MODE* switch selects the mode: *ENTRY*, *TAEM*, or *APPROACH*. The *HSI SELECT SOURCE* switch selects TACAN, navigation, or microwave scanning beam landing system; the 1, 2, 3 switch

selects one of three state vectors maintained during entry. When the *HSI SELECT SOURCE* switch is positioned to *NAV*, the HSI is supplied with data from the navigation processor, and the 1, 2, 3 switch is not used. In *TACAN*, the horizontal situation indicator is supplied with data derived from the 1, 2, 3 switch (TACAN 1, 2, or 3). In *MLS*, the horizontal situation indicator is supplied with data derived from the 1, 2, 3 switch (microwave landing system 1, 2, or 3).



Commander's HSI SELECT Switches on Panel F6



Pilot's HSI SELECT Switches on Panel F8

### HSI Display Parameters

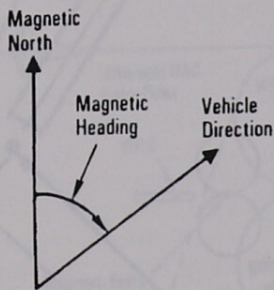
Each horizontal situation indicator displays magnetic heading (compass card), selected course, runway magnetic heading, course deviation, glide slope deviation, primary and secondary bearing,

primary and secondary range, and flags to indicate validity.

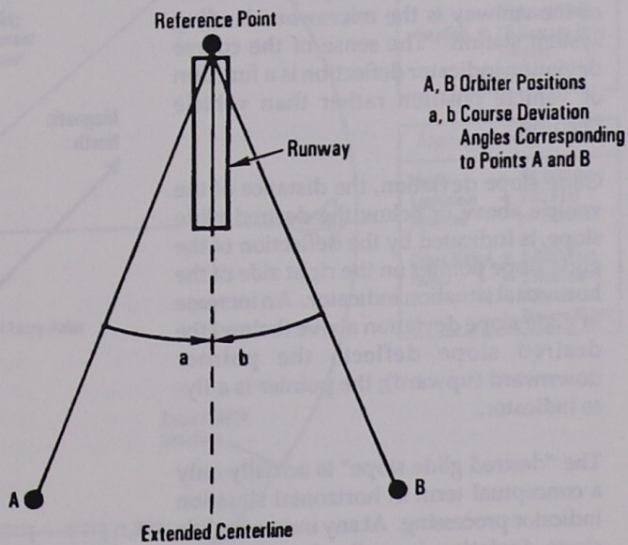
Each horizontal situation indicator consists of a case-enclosed compass card measuring zero to 360 degrees. At the center of the card is an aircraft symbol, fixed with respect to the case and about which the compass card rotates.

The magnetic heading (the angle between magnetic north and vehicle direction measured clockwise from magnetic north) is displayed by the compass card and read under the lubber line located at the top of the indicator dial. (A lubber line is a fixed line on a compass aligned to the longitudinal axis of the craft.) The compass card is positioned at zero degrees (north) when the heading input is zero. When the heading point is increased, the compass card rotates counterclockwise.

The course pointer is driven with respect to the horizontal situation indicator case rather than the compass card. Therefore, a course input (from the display driver unit) of zero positions the pointer at the top lubber line, regardless of compass card position. To position the course pointer correctly with respect to the compass card scale, the software must subtract the vehicle magnetic heading from the runway azimuth angle (corrected to magnetic north). As this subtraction is done continuously,



HSI Heading Geometry



Course Deviation Geometry

Horizontal Situation Indicator Geometry



the course pointer appears to rotate with the compass card, remaining at the same scale position. An increase in the angle defining runway heading results in a clockwise rotation of the course pointer.

Course deviation is an angular measurement of vehicle displacement from the extended runway centerline. On the HSI, course deviation is represented by the deflection of the deviation bar from the course pointer line. Full scale on the course deviation scale is  $\pm 10$  degrees in terminal area energy management and  $\pm 2.5$  degrees during approach and landing. The course deviation indicator is driven to zero during entry. When the course deviation input is zero, the deviation bar is aligned with the end of the course pointer. With the pointer in the top half of the compass card, an increase in course deviation to the left (right) causes the bar to deflect to the right (left). Therefore, the course deviation indicator is a fly-to indicator for flying the vehicle to the extended runway centerline. Software processing also ensures that the course deviation indicator remains fly to, even when the orbiter is heading away from the runway.

In course deviation geometry, if the orbiter is to the left of the runway, it must fly right (or if the orbiter is to the right of the runway, it must fly left) to reach the extended runway centerline. The corresponding course deviation bar would deflect to the right (or to the left in the latter case). The reference point at the end of the runway is the microwave landing system station. The sense of the course deviation indicator deflection is a function of vehicle position rather than vehicle heading.

Glide slope deviation, the distance of the vehicle above or below the desired glide slope, is indicated by the deflection of the glide slope pointer on the right side of the horizontal situation indicator. An increase in glide slope deviation above (below) the desired slope deflects the pointer downward (upward); the pointer is a fly-to indicator.

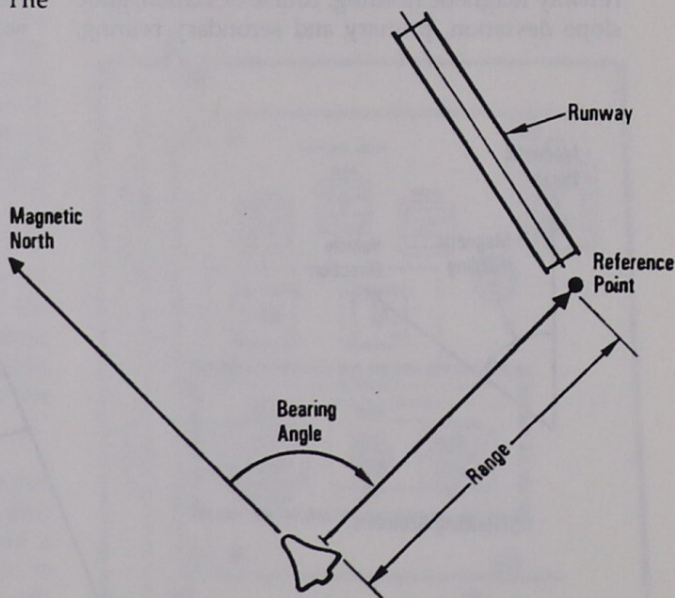
The "desired glide slope" is actually only a conceptual term in horizontal situation indicator processing. At any instance, glide slope deviation is really the difference

between the orbiter altitude and a reference altitude computed in the same fashion as the guidance reference altitude. Also included in the reference altitude equation are factors for a "heavy orbiter" and for high winds.

The glide slope indicator computation is not made during entry or below 1,500 feet during approach and landing; therefore, the pointer is stowed, and the glide slope indicator flag is displayed during those intervals.

The primary and secondary bearing pointers display bearings relative to the compass card. These bearings are angles between the direction to true or magnetic north and to various reference points as viewed from the orbiter. For the bearing pointers to be valid, the compass card must be positioned in accordance with vehicle heading input data.

When the bearing inputs are zero, the pointers are at the top lubber line, regardless of compass card position. Like the course pointer, the bearing pointer drive commands are developed by subtracting the vehicle heading from the calculated bearing values. This allows the pointers to be driven with respect to the horizontal situation indicator case but still be at the correct index point on the compass card scale.



Horizontal Situation Indicator Bearing and Range Geometry

When the bearing inputs are increased, the pointers rotate clockwise about the compass card. The pointer does not reverse when it passes through 360 degrees in either direction.

For example, if the primary bearing is 190 degrees, and the secondary bearing is 245 degrees, the bearing reciprocals are always 180 degrees from (opposite) the pointers. The definition of primary and secondary bearing varies with the flight regime.

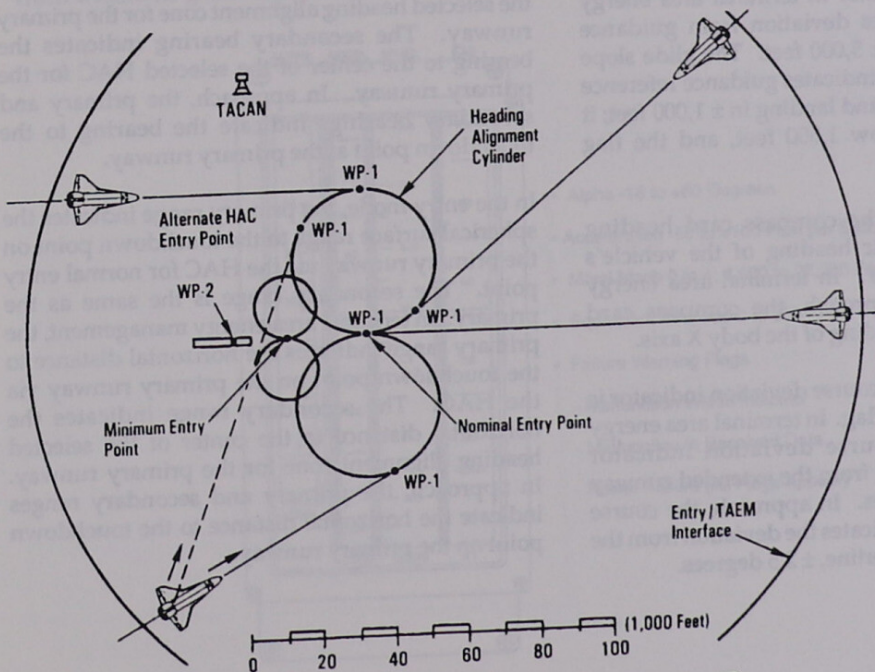
The horizontal situation indicator is capable of displaying two four-digit values in the upper left (primary range) and right (secondary range) side of its face. Each display ranges from zero to 3,999 nautical miles (4,602 statute miles). Although their meaning depends on the flight regime, both numbers represent range in nautical miles from the vehicle to various points relative to the primary and secondary runways.

The horizontal situation indicator has four flags — OFF, BRG (bearing), GS (glide slope), and CDI — and two barberpole indications that can respond to separate display driver unit commands, identifying invalid data. OFF indicates that the entire horizontal

situation indicator display is invalid because of insufficient power. BRG indicates invalid course, primary bearing, and/or secondary bearing data. GS indicates invalid glide slope deviation. CDI indicates invalid course deviation data. Barberpole in the range slots indicates invalid primary or secondary range data.

When the HSI SELECT SOURCE switch on panel F6 or F8 is positioned to NAV, the entire horizontal situation indicator display is driven by navigation-derived data from the orbiter state vector. This makes the horizontal situation indicator display dependent on the same sources as the navigation software (IMU, selected air data, selected navigational aids), but the display is independent of guidance targeting parameters. When the switch is in the NAV position, the SOURCE 1, 2, 3 switch is not processed.

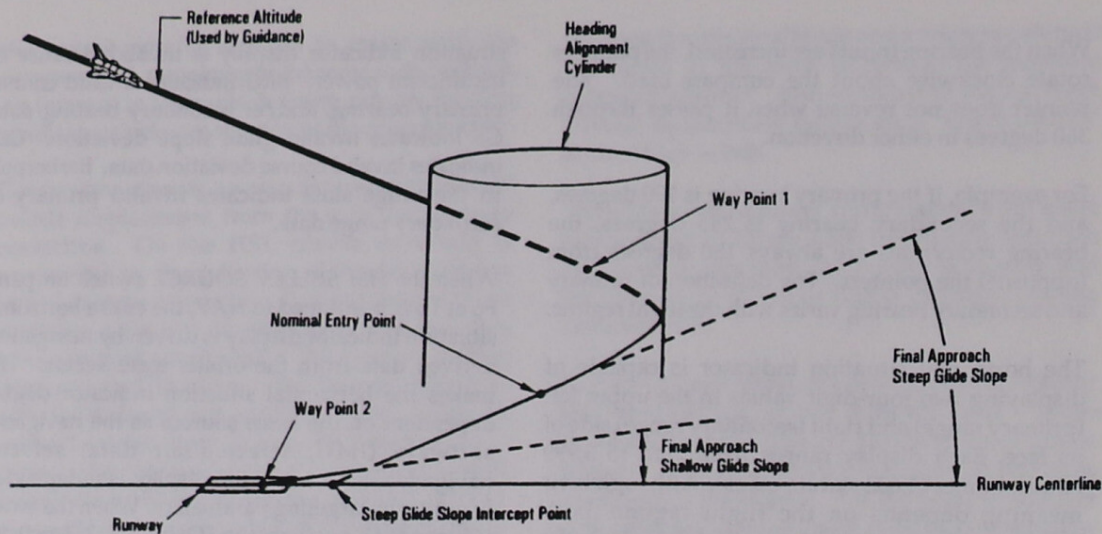
The TACAN or MLS position of the HSI SELECT SOURCE switch should be used only when TACAN or microwave landing system data are available. TACAN data can be acquired in Earth orbit, but are not processed by the onboard software. TACAN data are used during entry to update the navigation



TAEM Interface	
Height	= 85,000 Feet
Velocity	= 2,500 Feet per Second
Range	= 52 Nautical Miles (59 Statute Miles)
Heading	≤ 10 Degrees from Tangent to HAC

Approach/Landing Interface	
Height	= 10,000 Feet
Equivalent	= 290 Feet
Airspeed	per Second
Cross Range	≤ 1,000 Feet
Range	= 5 Nautical Miles (5 Statute Miles)

HSI Flight Path Geometry — Top View



HSI Flight Path Geometry—Side View

state, and are usually acquired about 300 nautical miles from the landing site. *MLS* has a range of 20 nautical miles and would be selected after the orbiter is on the heading alignment cone.

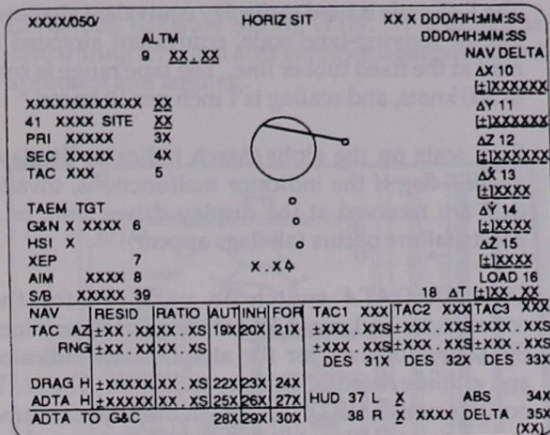
The glide slope deviation pointer is stowed when the entry mode is selected, and the flag is displayed. The glide slope indicator in terminal area energy management indicates deviation from guidance reference attitude in  $\pm 5,000$  feet. The glide slope indicator in approach indicates guidance reference altitude for approach and landing in  $\pm 1,000$  feet; it is not computed below 1,500 feet, and the flag deploys.

In the entry mode, the compass card heading indicates the magnetic heading of the vehicle's relative velocity vector. In terminal area energy management and approach, the compass card indicates magnetic heading of the body X axis.

In the entry mode, the course deviation indicator is driven to zero with no flag. In terminal area energy management, the course deviation indicator indicates the deviation from the extended runway centerline,  $\pm 10$  degrees. In approach, the course deviation indicator indicates the deviation from the extended runway centerline,  $\pm 2.5$  degrees.

In the entry mode, the primary bearing indicates the great circle bearing to the heading alignment cone (HAC) tangency point for the nominal entry point at the selected landing runway. The secondary bearing is identical to the primary bearing pointer. In terminal area management, the primary bearing indicates the bearing to the HAC tangency point on the selected heading alignment cone for the primary runway. The secondary bearing indicates the bearing to the center of the selected HAC for the primary runway. In approach, the primary and secondary bearings indicate the bearing to the touchdown point at the primary runway.

In the entry mode, the primary range indicates the spherical surface range to the touchdown point on the primary runway via the HAC for normal entry point. The secondary range is the same as the primary. In terminal area energy management, the primary range indicates the horizontal distance to the touchdown point on the primary runway via the HAC. The secondary range indicates the horizontal distance to the center of the selected heading alignment cone for the primary runway. In approach, the primary and secondary ranges indicate the horizontal distance to the touchdown point on the primary runway.



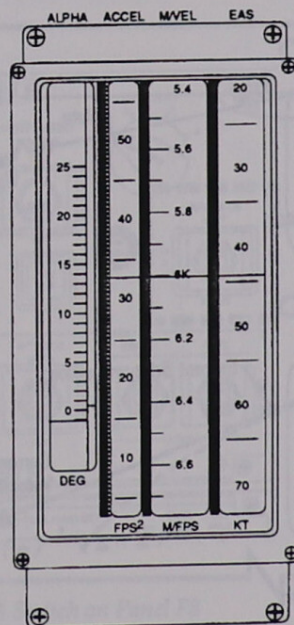
HORIZ SIT Display (SPEC 50)

The HORIZ SIT display (SPEC 50) allows the flight crew to configure the software for nominal winds or high head winds. The "XEP" item 7 entry determines the distance from the runway threshold to the intersection of the glide slope with the runway centerline or aim point. The high-wind aim point or close in aim point pushes the intercept point closer to the threshold. The distance selected is factored into the computation of reference altitude from which the glide slope deviation is derived.

### Alpha/Mach Indicator

The two alpha/Mach indicators are located to the left of the attitude director indicators on panels F6 and F8. The alpha Mach indicators consist of four tape meters displaying angle of attack (ALPHA), vehicle acceleration (ACCEL), vehicle velocity (M/VEL), and equivalent airspeed (EAS). The two units are driven independently but can have the same data source.

ALPHA displays vehicle angle of attack, defined as the angle between the vehicle plus X axis and the wind-relative velocity vector (negative wind vector). ALPHA is displayed by a combination moving scale and moving pointer. For angles between -4 degrees and +28 degrees, the scale remains stationary, and the pointer moves to the correct reading. For angles less than -4 degrees or greater than +28 degrees, the pointer stops (at -4 or +28 degrees), and the scale moves so that the correct reading is adjacent to the pointer. The ALPHA tape ranges from -18 to +60 degrees with no scale changes. The negative scale numbers (below zero) have no minus signs; the actual tape has black markings on a white background on the negative side, and white markings on a black background on the positive side.



- Alpha -18 to +60 Degrees
- Acceleration -50 to +100 Feet per Second<sup>2</sup>
- M/vel Mach 0 to 4; 4,000 to 27,000 Feet per Second
- Equivalent Airspeed 0 to 500 Knots
- Failure Warning Flags
  - Malfunction Within Indicator
  - Malfunction in Received Data
  - Power Failure (All Flags Appear)

Alpha/Mach Indicator

The *ACCEL* scale displays vehicle drag acceleration, which is the deceleration along the flight path, normal acceleration, which is acceleration in the normal axis, or total load factor. This is a moving tape upon which acceleration is read at the fixed lubber line. The tape range is -50 to +100 with a scale change at zero feet per second squared. Minus signs are assumed on the *ACCEL* scale also; the negative region has a black background and the positive side has a white background. (Normal acceleration and total load factor are measured in g's, with 10 equal to 1 g, 20 equal to 2 g's, etc.)

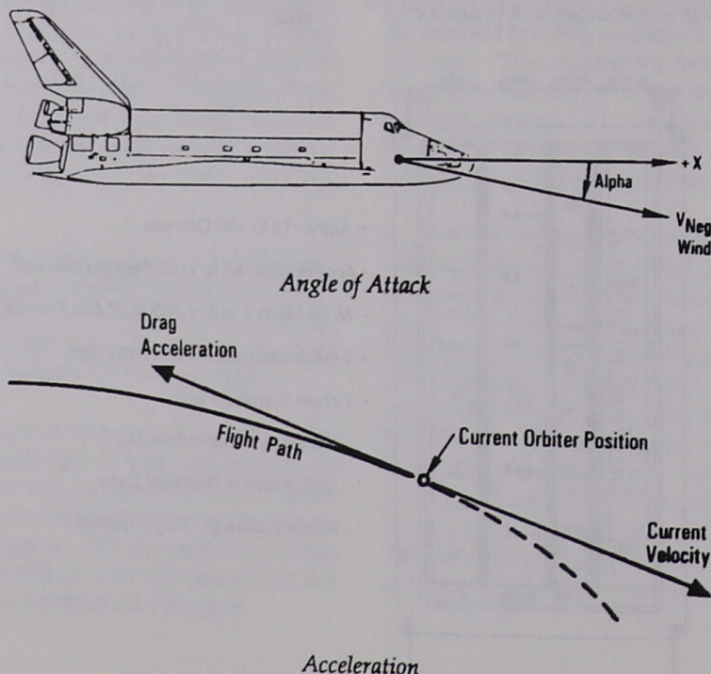
The *M/VEL* scale displays Mach number or relative velocity. Mach number is the ratio of vehicle airspeed to the speed of sound in the same medium. Relative velocity in this case is the vehicle airspeed. The actual parameter displayed is always Mach number; the tape is simply rescaled above Mach 4 to read relative velocity in thousands of feet per second (above 2,500 feet per second, Mach number =  $V_{REL}/1,000$ ). The *M/VEL* scale is a moving tape from which Mach/velocity is read at the fixed lubber line. The scale ranges from zero to 27 with a scale change at Mach 4.

The *EAS* scale is used to display equivalent airspeed. On the moving-tape scale, equivalent airspeed is read at the fixed lubber line. The tape range is zero to 500 knots, and scaling is 1 inch per 10 knots.

Each scale on the alpha/Mach indicator displays an *OFF* flag if the indicator malfunctions, invalid data are received at the display driver unit, or a power failure occurs (all flags appear).

The *AIR DATA* switch on panel F6 for the commander and panel F8 for the pilot determines the source of data for the alpha/Mach indicator and altitude/vertical velocity indicator. The *NAV* position of the *AIR DATA* switch displays the same parameters (*ALPHA*, *MACH*, and *EAS*) that are sent to guidance, flight control, navigation, and other software users; *ACCEL* comes from navigation software.

The *LEFT* and *RIGHT* positions of the *AIR DATA* switch select data from the left or right air data probe assembly after deployment of the left and right air data probes at Mach 5 for *ALPHA*, *M/VEL*, and *EAS* display. *ACCEL* is always derived from



navigation software during entry. It is driven to zero during terminal area energy management and approach and landing.

### Altitude/Vertical Velocity Indicator

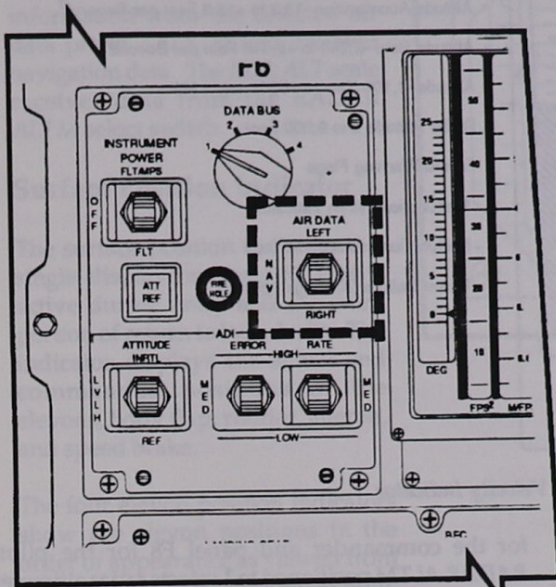
The altitude/vertical velocity indicators (AVVIs) are located on panel F6 for the commander and panel F8 for the pilot. These indicators display vertical acceleration (*ALT ACCEL*), vertical velocity (*ALT RATE*), altitude (*ALT*), and radar altitude (*RDR ALT*).

The *ALT ACCEL* indicator, which displays altitude acceleration of the vehicle, is read at the intersection of the moving pointer and the fixed scale. The scale range is  $-13.3$  to  $13.3$  feet per second squared, and the scaling is 6.67 feet per second squared per inch. Software limits acceleration values to  $\pm 12.75$  feet per second squared.

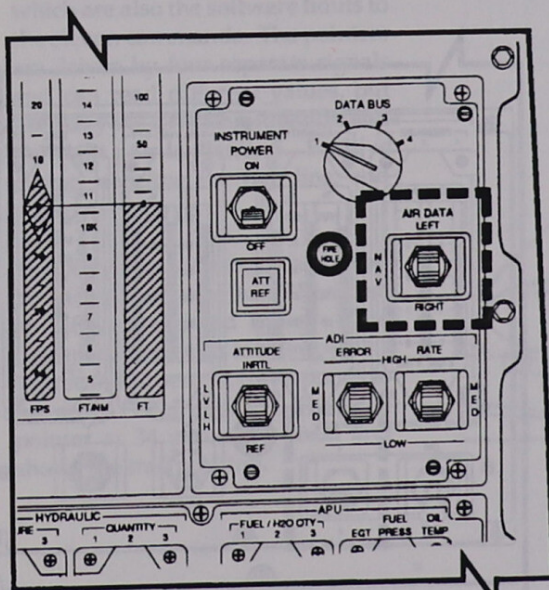
The *ALT RATE* scale displays vehicle altitude rate, which is read at the intersection of the moving tape and the fixed lubber line. The scale range is  $-2,940$  to  $+2,940$  feet per second with scale changes at  $-740$  feet per second and  $+740$  feet per second. The negative and positive regions are color-reversed: negative numbers are white on a black background and positive numbers are black on white.

The *ALT* scale, a moving tape read against a fixed lubber line, displays the altitude of the vehicle above the runway (barometric altitude). The scale range is  $-1,100$  feet to  $+165$  nautical miles, with scale changes at  $-100$ ,  $0$ ,  $500$  feet, and  $+100,000$  feet. The scale is in feet from  $-1,100$  to  $+400,000$  and in nautical miles from  $+40$  to  $+165$ . Feet and nautical miles overlap from  $+40$  to  $+61$  nautical miles.

The *RDR ALT* scale is a moving tape read against a fixed lubber line. It displays radar altitude (corrected to wheels) during major mode 305, below 9,000 feet (normally not locked on until below 5,000 feet; prior to radar altimeter lock-on, the meter is "parked" at 5,000 feet). The scale ranges from zero to 9,000 feet with a scale change at 1,500 feet. Each scale on the altitude/vertical velocity indicator displays an *OFF* flag in the event of indicator malfunction, invalid data received at the display driver unit, or power failure (all flags appear).

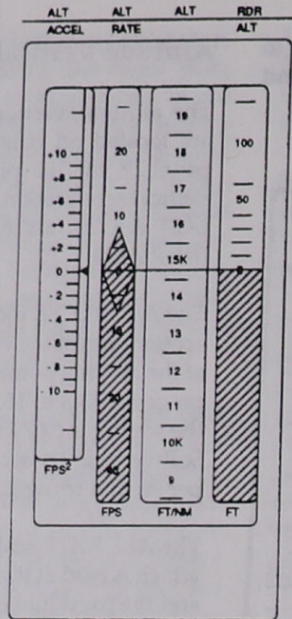


Commander's AIR DATA Switch on Panel F6



Pilot's AIR DATA Switch on Panel F8

2. SYSTEMS  
2.7 Dedicated Display Systems

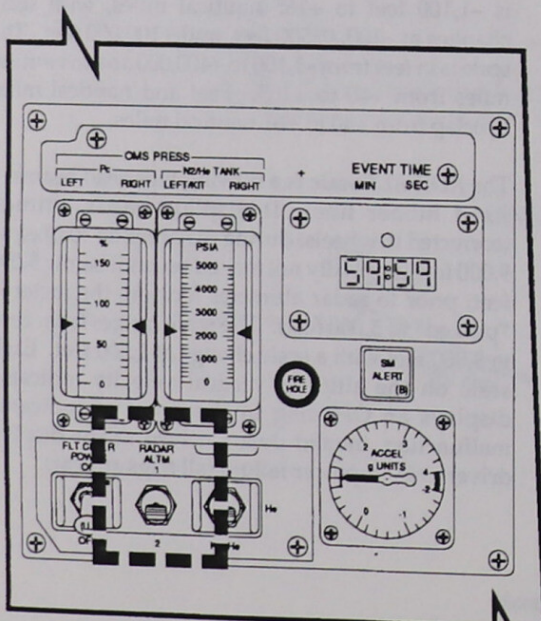


- Altitude Acceleration -13.3 to +13.3 Feet per Second<sup>2</sup>
- Altitude Rate -2,940 to +2,940 Feet per Second
- Altitude -1,100 Feet to 165 Nautical Miles
- Radar Altitude 0 to 9,000 Feet
- Failure Warning Flags
  - Malfunction Within Indicator
  - Malfunction in Received Data
  - Power Failure (All Flags Appear)

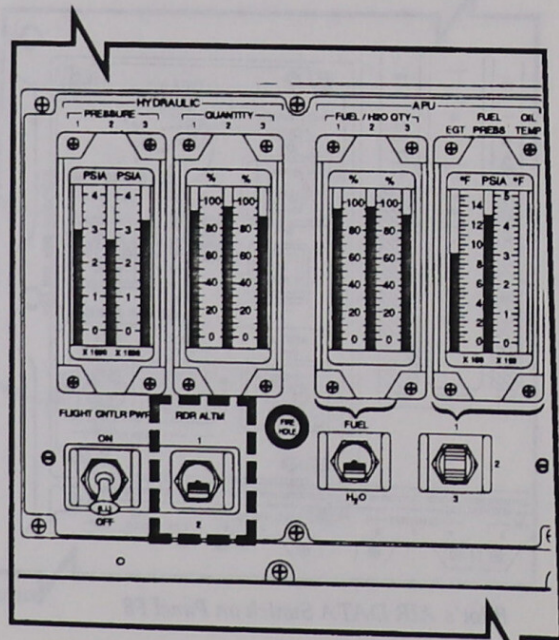
Altitude/Vertical Velocity Indicator

With the AIR DATA source switch in the NAV position, the ALT ACCEL, ALT RATE, and ALT scales are navigation-derived. The RDR ALT indicator is controlled by the RADAR ALTM switch on panel F7

for the commander and panel F8 for the pilot. RADAR ALTM positioned to 1 selects radar altimeter 1; 2 selects radar altimeter 2.



Commander's RADAR ALTM Switch on Panel F7



Pilot's RADAR ALTM Switch on Panel F8

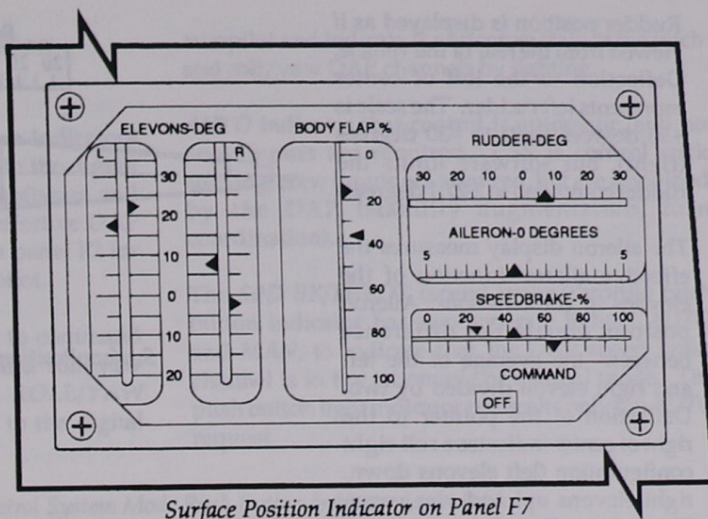
The AIR DATA switch is positioned to LEFT or RIGHT to select the right or left air data probe after air data probe deployment at Mach 5. The ALT and ALT RATE scales receive information from the selected air data probe. ALT ACCEL receives navigation data. The RDR ALT scale receives data from the RADAR ALTM select switch.

### Surface Position Indicator

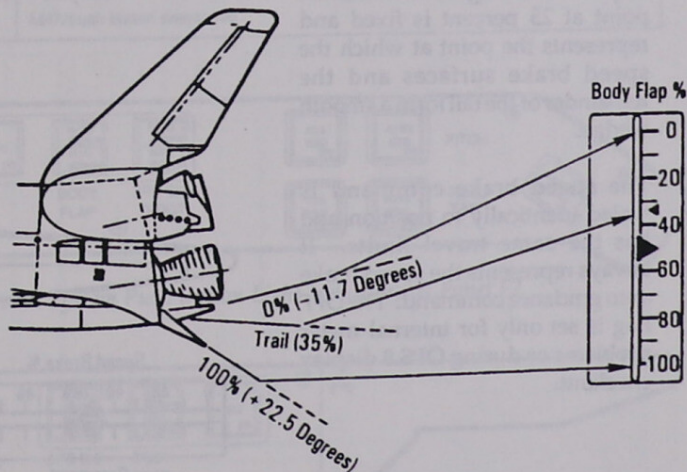
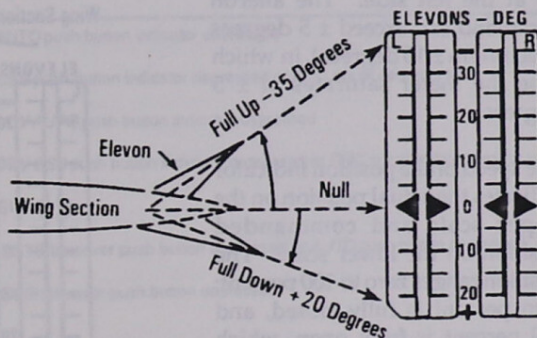
The surface position indicator is a single display on panel F7 that is active during entry and the entry portion of return to launch site. The indicator displays the actual and commanded positions of the elevons, body flap, rudder, aileron, and speed brake.

The four elevon position indicators show the elevon positions in the order of appearance as viewed from behind the vehicle (from left to right: left outboard, left inboard, right inboard, right outboard). The scales all range from +20 to -35 degrees, which are also the software limits to the elevon commands. The pointers are driven by four separate signals and can read different values, but normally the left pair is identical and the right pair is identical. Positive elevon is below the null line, and negative is above.

The body flap scale reads body flap positions from zero to 100 percent of software-allowed travel. Zero percent corresponds to full up (-11.7 degrees); 100 percent corresponds to full down (+22.5 degrees). The small pointer at 34 percent is fixed and shows the trail position.



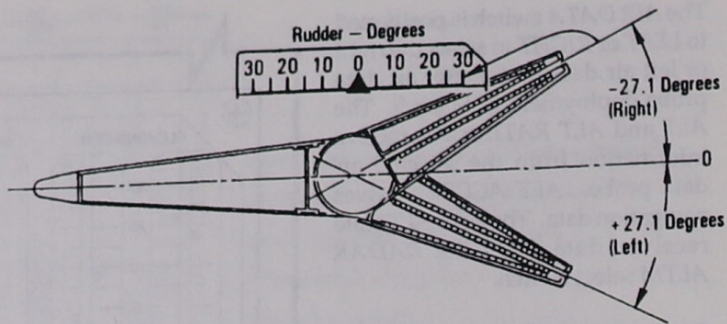
Surface Position Indicator on Panel F7



Surface Position Indicator Elevon Travel

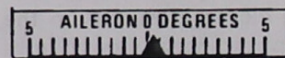
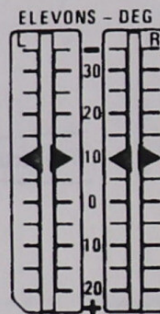
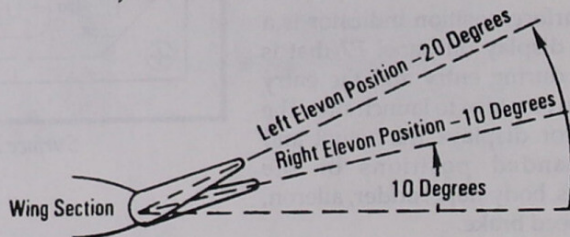


Rudder position is displayed as if viewed from the rear of the vehicle. Deflection to the left of center represents left rudder. The scale is +30 degrees (left) to -30 degrees (right), but software limits the rudder command to  $\pm 27.1$  degrees.



Surface Position Indicator Rudder Travel

The aileron display measures the effective aileron function of the elevons in combination. Aileron position equals the difference between the average of the left and right elevon divided by two. Deflection of the pointer to the right of center indicates a roll-right configuration (left elevons down, right elevons up) and vice versa. The scale is -5 to +5 degrees, with -5 at the left side. The aileron command can exceed  $\pm 5$  degrees (maximum  $\pm 10$  degrees), in which case the meter saturates at  $\pm 5$  degrees.

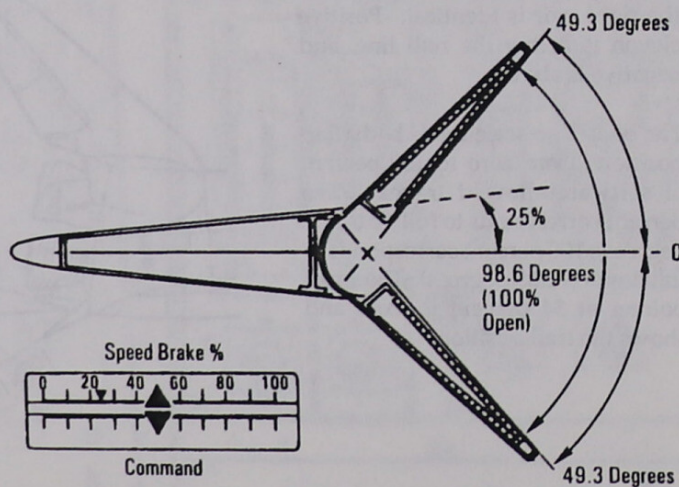


$$\text{Aileron} = \frac{-20 + 10}{2} = -5 \text{ Degrees}$$

The speed brake position indicator indicates the actual position on the upper scale and commanded position on the lower scale. The position ranges zero to 100 percent; zero percent is fully closed, and 100 percent is fully open, which corresponds to 98 degrees with respect to the hinge lines. The small point at 25 percent is fixed and represents the point at which the speed brake surfaces and the remainder of the tail form a smooth wedge.

Surface Position Indicator Aileron Travel

The speed brake command is scaled identically to position and has the same travel limits. It always represents the speed brake auto guidance command. The OFF flag is set only for internal meter problems or during OPS 8 display checkout.



Surface Position Indicator Top View of Open Speed Brake

## Flight Control System Push Button Indicators

The flight control system's push button indicators transmit flight crew moding requests to the digital autopilot (DAP) in the flight control software and reflect selection by illuminating the effective DAP state. These indicators are located on panel F2 for the commander and panel F4 for the pilot.

The push button indicators are used to command and reflect the status of the pitch and roll/yaw control modes. The *PITCH* and *ROLL/YAW* indicators transmit moding requests to the digital

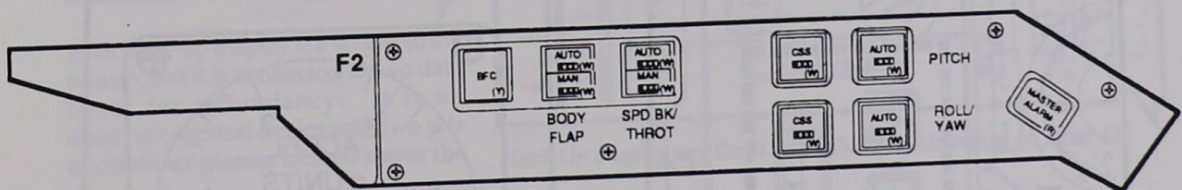
autopilot and indicate the effective state of the pitch and roll/yaw DAP channels by lighting.

*AUTO* indicates that control is automatic, and no crew inputs are required. *CSS* is control stick steering; crew inputs are required, but are smoothed by the DAP (stability augmentation, turn coordination).

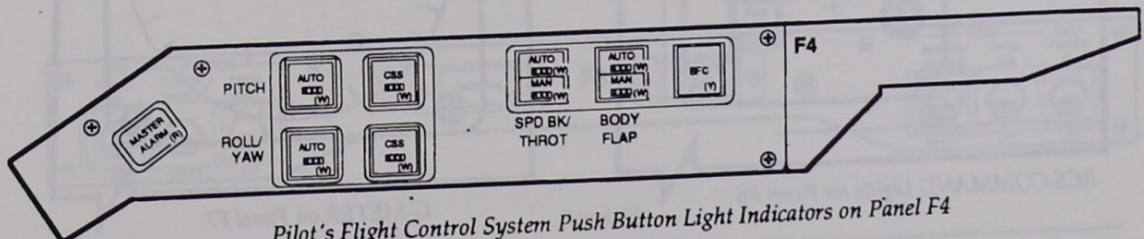
The *SPD BK/THROT* (speed brake/throttle) push button indicator has two separate lights, *AUTO* and *MAN*, to indicate that the DAP speed brake channel is in the automatic or manual mode. The push button light indicator transmits only the *AUTO* request.

Entry Flight Control System Mode Push Button Indicator Light Logic

LIGHTS	LEFT/RIGHT LIGHT LOGIC	CAUSES
<i>PITCH AUTO</i>	Both on or both off } Auto, CSS mutually exclusive	<i>PITCH AUTO</i> push button indicator depressed
<i>PITCH CSS</i>		<i>PITCH CSS</i> push button indicator depressed or RHC out of detent in pitch
<i>ROLL/YAW AUTO</i>	Both on or both off } Auto, CSS mutually exclusive	<i>ROLL/YAW AUTO</i> push button indicator depressed
<i>ROLL/YAW CSS</i>		<i>ROLL/YAW CSS</i> push button indicator depressed or RHC out of detent in roll or yaw
<i>SPD BK/THROT</i>		
<i>AUTO</i>	Both on or both off } Auto, man. mutually exclusive	Neither SBTC takeover push button depressed or <i>AUTO</i> push button depressed
<i>MAN</i>		Either SBTC takeover push button depressed
<i>BODY FLAP</i>		
<i>AUTO</i>	Both on or both off } Auto, man. mutually exclusive	<i>AUTO</i> push button indicator depressed
<i>MAN</i>		<i>MAN</i> push button depressed



Commander's Flight Control System Push Button Light Indicators on Panel F2



Pilot's Flight Control System Push Button Light Indicators on Panel F4

The *BODY FLAP* push button indicator also has separate *AUTO* and *MAN* lights, indicating the state of the body flap channel. Like the *SPD BK/THROT* push button indicator, the *BODY FLAP* indicator transmits only the *AUTO* request.

### Reaction Control System Command Lights

The *RCS COMMAND* lights on panel F6 are active during OPS 104-106 and OPS 602 and 603. Their primary function is to indicate reaction control system (RCS) jet commands by axis and direction; secondary functions are to indicate when more than two yaw jets are commanded, and when the elevon drive rate is saturated.

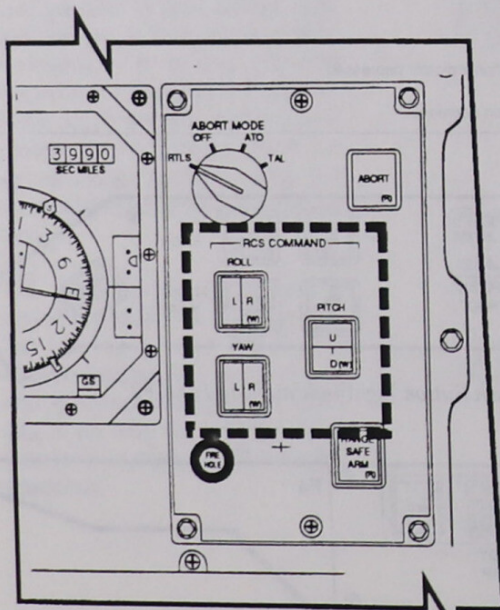
During major modes 301 through 304, until the roll jets are no longer commanded (dynamic pressure exceeds 10 pounds per square foot), the *ROLL L* and *R* lights indicate that left or right roll jet commands have been issued by the DAP. The minimum light-on duration is extended so that the light can be seen even during minimum-impulse firings. When dynamic pressure is greater than or equal to 10 pounds per square foot, the *ROLL* lights are quiescent until 50 pounds per square foot, after which time both lights are illuminated whenever more than two yaw jets are commanded on.

The *PITCH U* and *D* lights indicate up and down pitch jet commands until dynamic pressure equals 40 pounds per square foot, after which the pitch jets are no longer used. When dynamic pressure is 50 pounds per square foot or more, the *PITCH* lights, like the *ROLL* lights, assume a new function: both light whenever the elevon surface drive rate exceeds 20 degrees per second (14 degrees per second if only one hydraulic system is left).

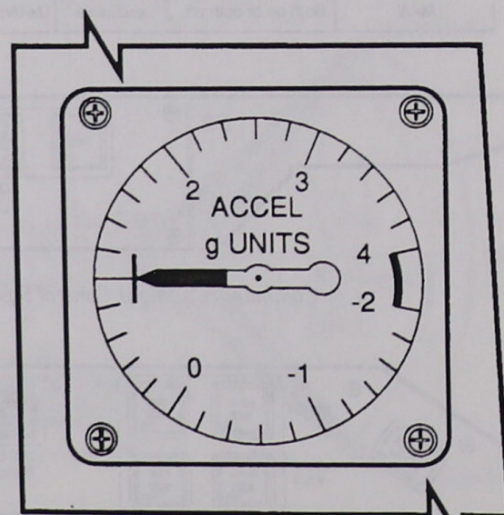
The *YAW L* and *R* lights function as yaw jet command indicators throughout entry until the yaw jets are disabled at Mach 1. The yaw lights have no other functions.

### G-Meter

The g-meter is a self-contained accelerometer and display unit mounted on panel F7. It senses linear acceleration along the Z axis (normal) of the vehicle. A mass weight in the unit is supported vertically by two guide rods and is constrained by a constant-rate helical spring. The inertial force of the mass is proportional to the inertial force of the vehicle and, hence, to the input acceleration, under conditions of constant acceleration. Displacement of the mass is translated to pointer displacement through a rack-and-pinion gear train, the output of which is linear with input acceleration. The display indicates acceleration from -2 g's to +4 g's. The g-meter requires no power and has no software interface. Like all the dedicated displays, it has an external variable incandescent lamp.



RCS COMMAND Lights on Panel F6



G-METER on Panel F7

## Head-Up Display

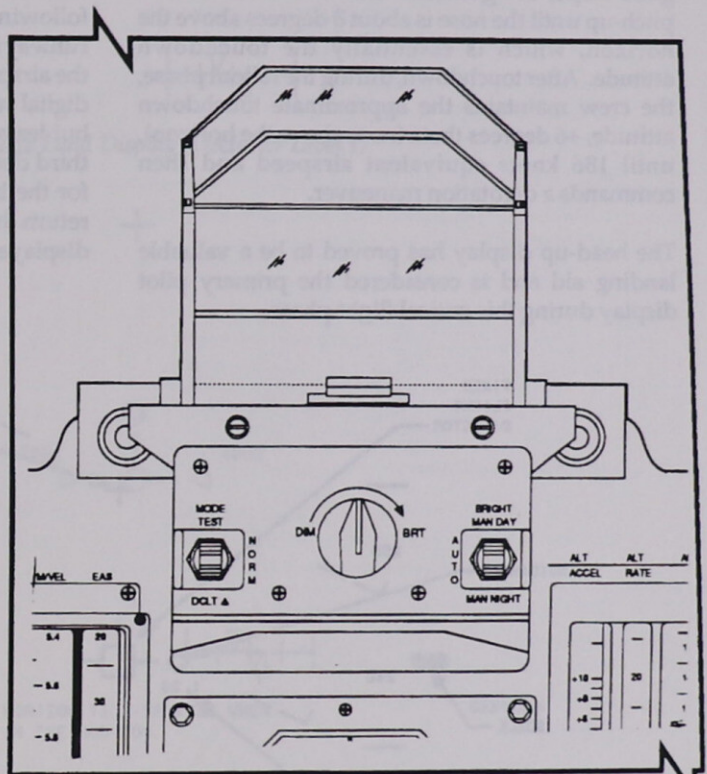
The head-up display (HUD) is an optical miniprocessor that cues the commander and/or pilot during the final phase of entry and particularly in the final approach to the runway. With minimal movement of their eyes from the forward windows (head up) to the dedicated display instruments (head down), the commander and pilot can read data from head-up displays located in the front of them on their respective glareshields. The head-up display presents the same data presented on several other instruments, including the attitude director indicator, surface position indicator, alpha/Mach indicator, and altitude/vertical velocity indicator.

The head-up display allows out-of-the-window viewing by superimposing flight commands and information on a transparent combiner in the window's field of view. Since the orbiter avionics systems are digital, and minimal impact on the orbiter was paramount, the head-up display drive electronics were designed to receive data from the orbiter data buses. The head-up display drive electronics utilize, to the maximum extent possible, the same data that drive the existing electromechanical display devices. The orbiter display device uses a CRT to create the image, which is then projected through a series of lenses onto a combining glass.

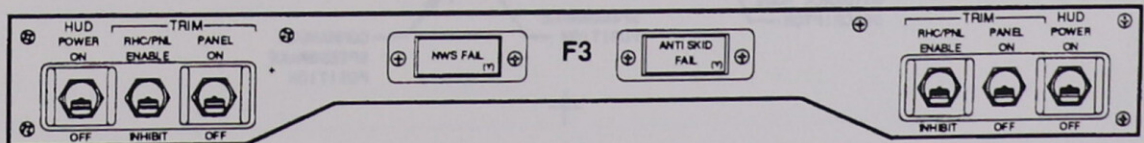
Each head-up display is a single-string system, but it is connected to two data buses for redundancy. It is an electronic/optical device with two sets of combiner glasses located above the

glareshield in the direct line of sight of the commander and the pilot. Essential flight information for vehicle guidance and control during approach and landing is projected on the combiner glasses and focused at infinity.

The images, generated by a small CRT and passed through a series of lenses, are displayed to the flight crew on the combiners as lighted symbology. The transmissiveness of the combiner allows the crew to look through it and see actual targets like the runway.



Head-Up Display and Controls on Panel F6 (Identical on Panel F8)



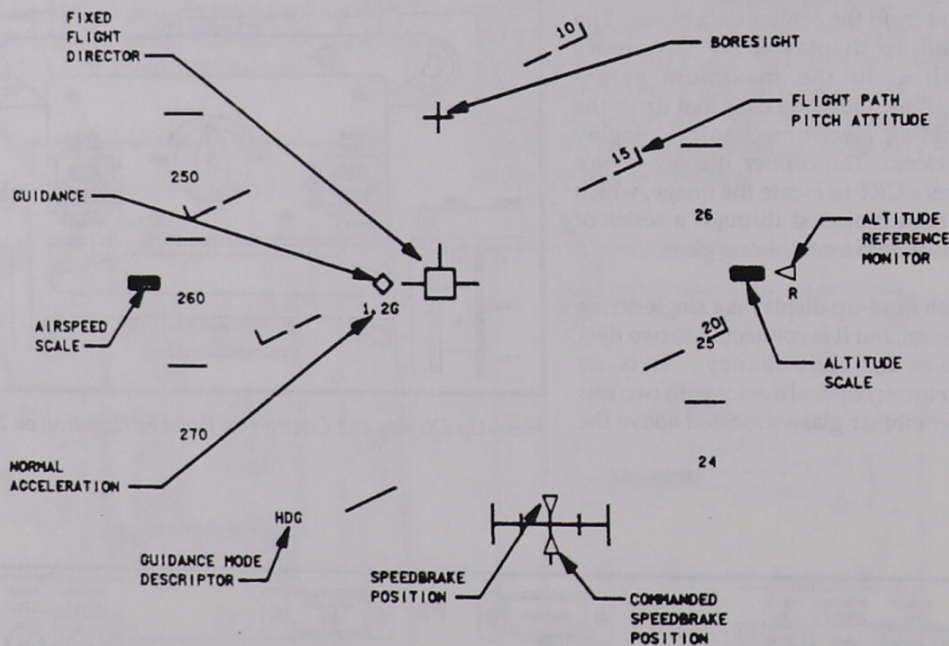
Panel F3

For instance, if the crew is 9,000 feet on the final approach course in a solid overcast, the base of which is at 8,000 feet, the lighted outline of the runway would be displayed on the combiner. However, when the orbiter exits the overcast at 8,000 feet, the lighted outline of the runway would be superimposed on the real runway. As the orbiter proceeds down the steep glide slope, the velocity vector is superimposed over the glide slope aim point. At preflare altitude, flare triangles move up to command the pullout. The pilot maintains the velocity vector symbol between the triangles. After a short period of stabilized flight on the shallow glide slope, the guidance diamond commands a pitch-up until the nose is about 8 degrees above the horizon, which is essentially the touchdown attitude. After touchdown, during the rollout phase, the crew maintains the approximate touchdown attitude, +6 degrees theta (nose above the horizon), until 186 knots equivalent airspeed and then commands a derotation maneuver.

The head-up display has proved to be a valuable landing aid and is considered the primary pilot display during this critical flight phase.

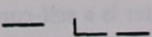
A HUD POWER ON/OFF switch located on the left side of panel F3 provides and terminates electrical power to the commander's head-up display on panel F6. A second switch is located on the right side of panel F3 for the pilot's head-up display on panel F8.

A three-position MODE switch is located below the HUD. In the NORM position, automatic sequencing of formats and symbology is provided. The TEST position forces up a test display for 5 seconds. Selection of the momentary DCLT position initiates a symbol blanking routine. Successive selections of DCLT will serially remove display elements in the following order. The first activation removes the runway symbology. The second activation removes the airspeed and altitude tapes (replacing them with digital values) and the horizon/pitch attitude scales, but leaves the horizon line when within FOV. The third declutter level removes all symbology except for the boresight. A fourth declutter attempt will return the HUD to its original form with all symbols displayed.



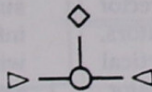
Approach and Land Display (TAEM Heading Phase); no Declutter

270



9

280



8

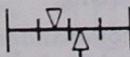


290



7

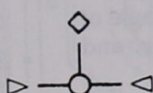
OGS



*Approach and Land Display (Declutter Level 1)*

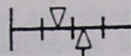


285



8000

OGS



NOTE: HORIZON IS DISPLAYED WHEN  
IN THE HUD FOV.

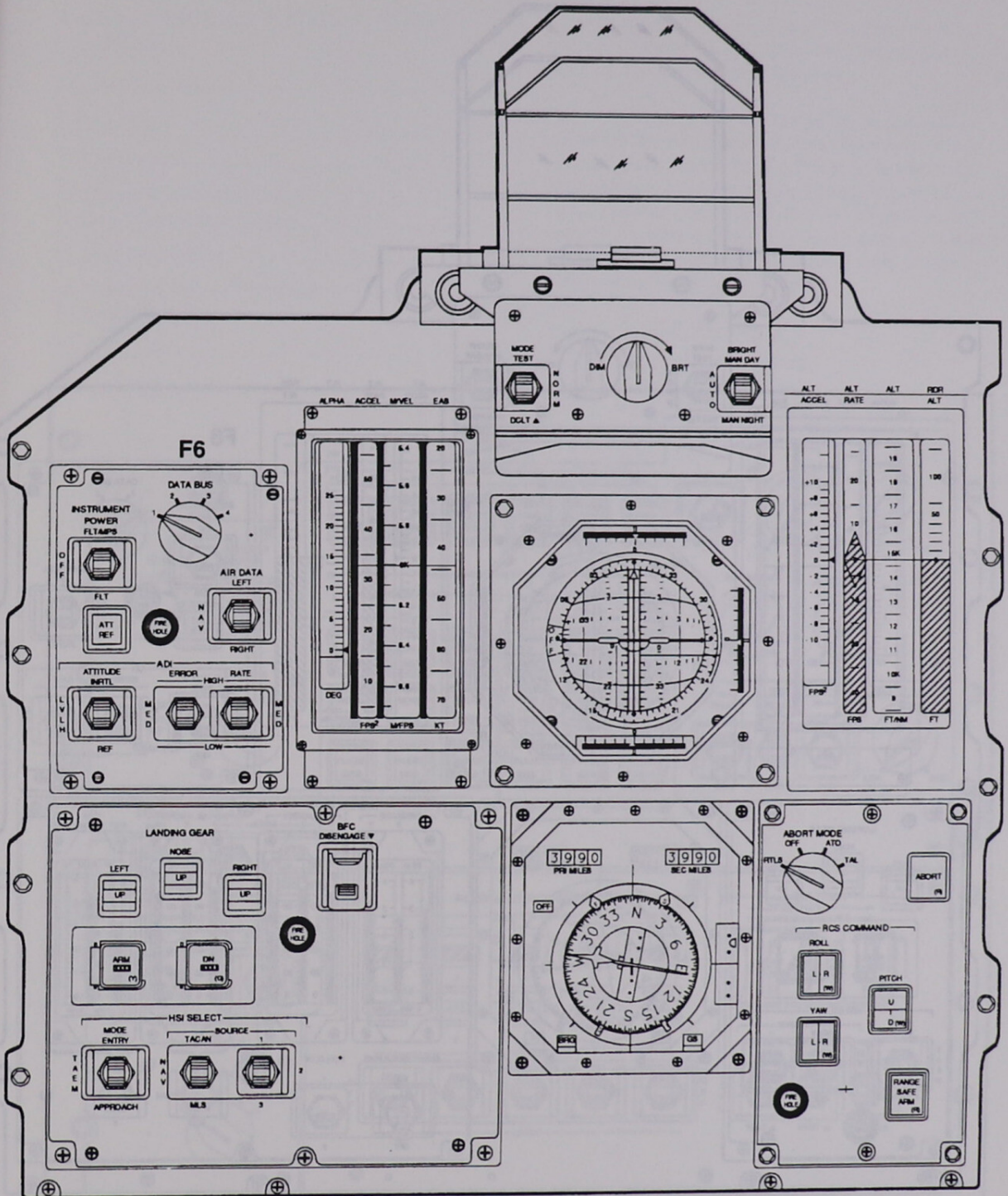
*Approach and Land Display (Declutter Level 2)*



*Approach and Land Display (Declutter Level 3)*

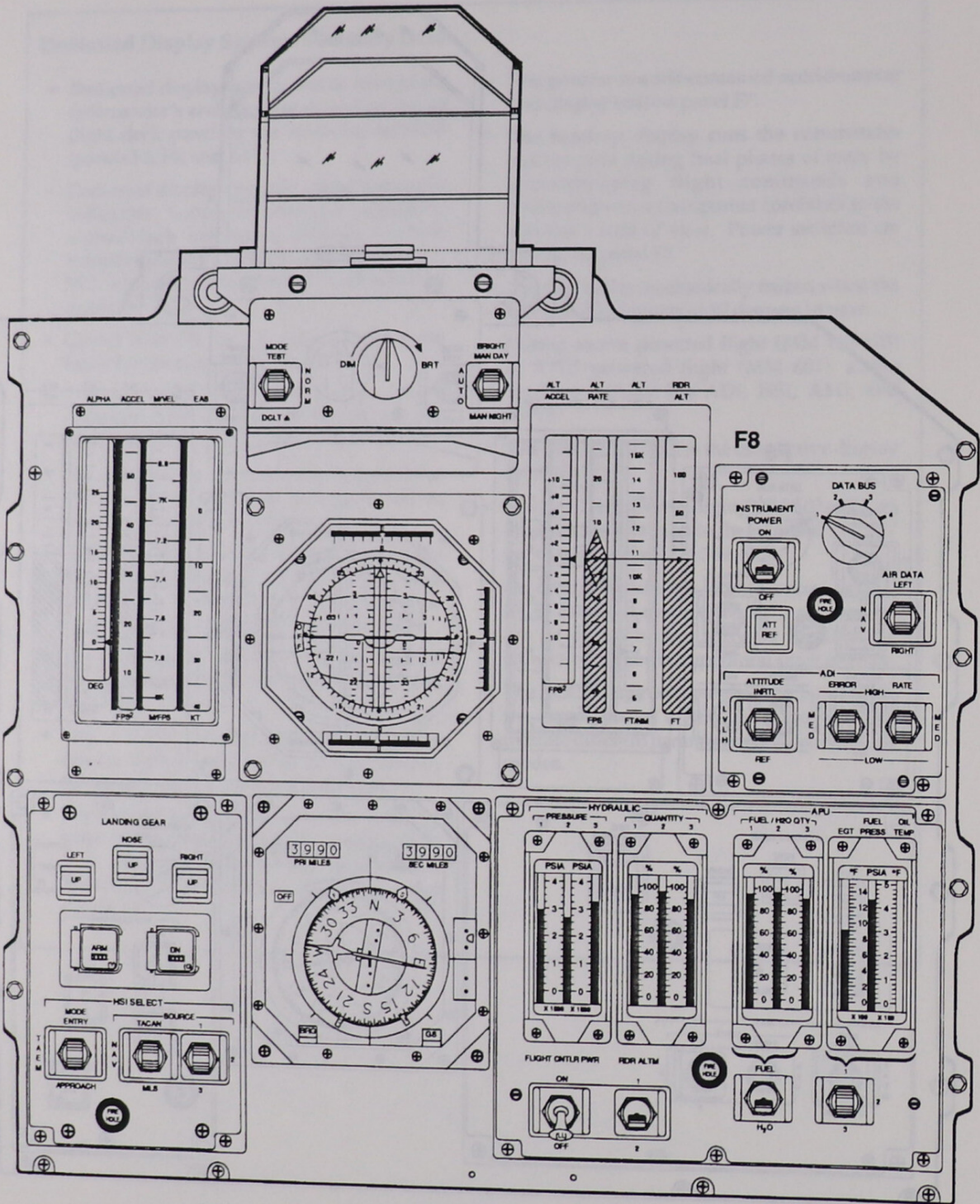
### Dedicated Display Systems Summary Data

- Dedicated displays are located in front of the commander's and pilot's seats and on the aft flight deck panel by the aft-facing window (panels F6, F8, and A1U).
- Dedicated displays include: attitude director indicators, horizontal situation indicators, alpha/Mach indicators, altitude/vertical velocity indicators, surface position indicator, RCS activity lights, g-meter, and head-up displays.
- Circuit breakers for dedicated displays are located on panels O14, O15, and O16.
- Power switches for the commander's dedicated displays are on panel F6; for the pilot's displays on panel F8.
- The attitude director indicators display orbiter attitude by an enclosed ball gimballed to represent three degrees of freedom.
- The horizontal situation indicators visually display certain guidance, navigation, and control parameters such as directions, distances, and course/glide path deviation.
- The alpha Mach indicator displays angle of attack, acceleration, vehicle velocity, and equivalent airspeed.
- The altitude/vertical velocity indicators display vertical acceleration, vertical velocity, barometric altitude, and radar altitude.
- The surface position indicator on panel F7 displays actual positions of the elevons, body flap, rudder, aileron, and speedbrake. Speedbrake commanded position is also displayed.
- The g-meter is a self-contained accelerometer and display unit on panel F7.
- The head-up display cues the commander and/or pilot during final phases of entry by superimposing flight commands and information on a transparent combiner in the window's field of view. Power switches are located on panel F3.
- The ADI ball is mechanically frozen when the ball is at 270 degrees or 90 degrees in yaw.
- During ascent powered flight (MM 102-103) or RTLS powered flight (MM 601), active displays include the ADI, HSI, AMI, and AVVI.
- Post MECO, the ADI is the only active display (MM 104-106).
- During RTLS gliding flight (MM 602-603), all displays are driven as in the nominal TAEM/approach phases (MM 304, 305).
- On orbit, when in the Flight Control System (FCS) checkout mode (MM 801), all displays can be driven by test software to allow the crew to verify correct operation prior to entry.
- The ACCEL tape on the alpha/Mach indicator, the error needles on the ADI, and the HSI indicate different parameters in different major modes.

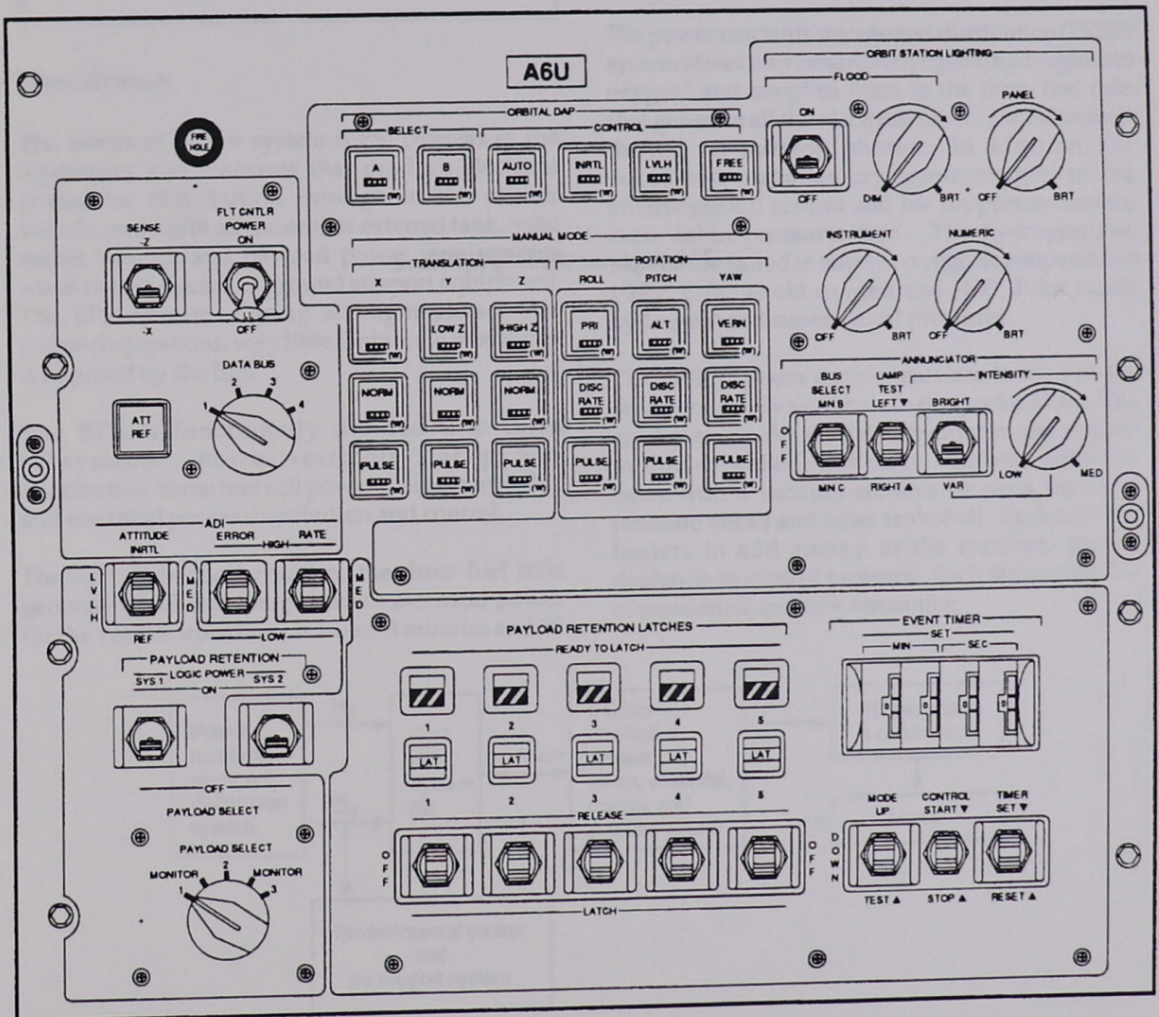


Panel F6





Panel F8



Panel A6U

## 2.8 ELECTRICAL POWER SYSTEM (EPS)

### CONTENTS

Description .....	2.8-1
Power Reactants Storage and Distribution System .....	2.8-1
Fuel Cell System .....	2.8-10
Electrical Power Distribution and Control .....	2.8-20
Operations .....	2.8-30

### Description

The electrical power system (EPS) consists of the equipment and reactants that produce electrical power for distribution throughout the orbiter vehicle, and fulfill all the orbiter external tank, solid rocket booster, and payload power requirements when not connected to ground support equipment. The EPS operates during all flight phases. For nominal operations, very little flight crew interaction is required by the EPS.

The EPS is functionally divided into three subsystems: power reactants storage and distribution, three fuel cell power plants (fuel cells), and electrical power distribution and control.

Through a chemical reaction, the three fuel cells generate all 28-volt direct-current electrical power for the vehicle from launch minus 3 minutes and 30

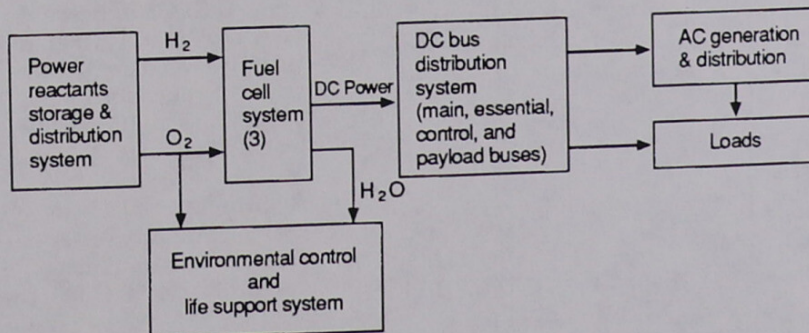
seconds through landing rollout. Prior to that, electrical power is provided by ground power supplies and the onboard fuel cells.

Power is controlled and distributed by assemblies located in the forward, mid, and aft sections of the orbiter. Each assembly is a housing for electrical components, such as remote switching devices, buses, resistors, diodes, and fuses. Each assembly usually contains a power bus or buses and remote switching devices for distributing bus power to subsystems located in its area.

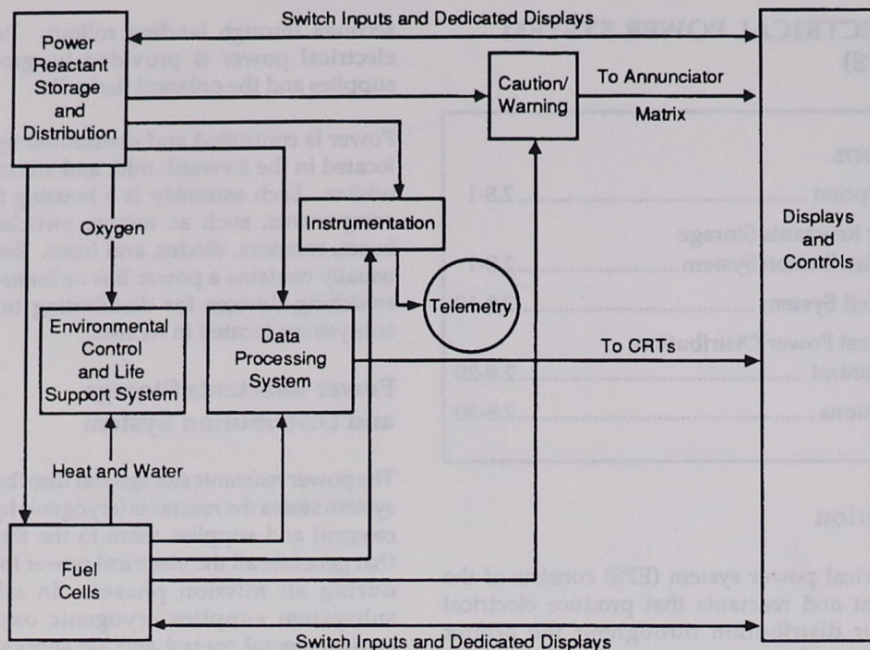
### Power Reactants Storage and Distribution System

The power reactants storage and distribution (PRSD) system stores the reactants (cryogenic hydrogen and oxygen) and supplies them to the three fuel cells that generate all the electrical power for the vehicle during all mission phases. In addition, the subsystem supplies cryogenic oxygen to the environmental control and life support system for crew cabin pressurization. The hydrogen and oxygen are stored in tanks at cryogenic temperatures (-285° F for liquid oxygen and -420° F for liquid hydrogen) and supercritical pressures.

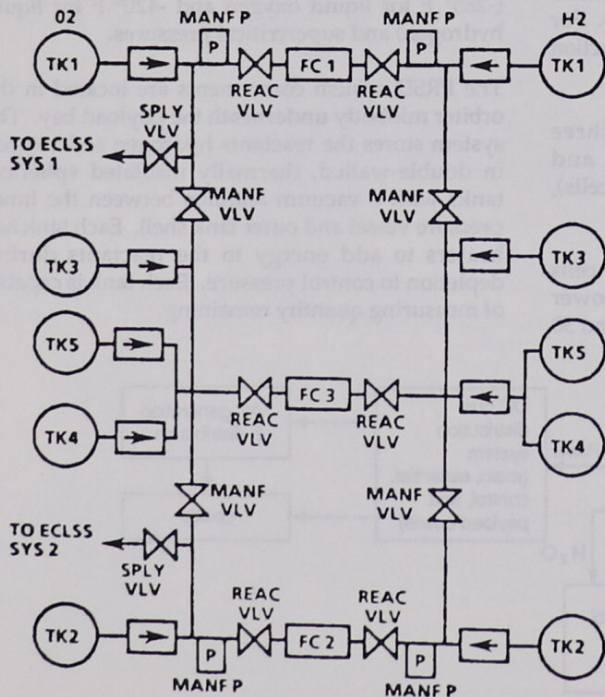
The PRSD system components are located in the orbiter midbody underneath the payload bay. The system stores the reactants hydrogen and oxygen in double-walled, thermally insulated spherical tanks with a vacuum annulus between the inner pressure vessel and outer tank shell. Each tank has heaters to add energy to the reactants during depletion to control pressure. Each tank is capable of measuring quantity remaining.



The Electrical Power System



Electrical Power System Interfaces



The PRSD System

The tanks are grouped in sets of one hydrogen and one oxygen tank. The number of tank sets installed depends on the specific mission requirement. Up to five tank sets can be installed in the midfuselage under the payload bay liner.

### Cryogenic Storage Tanks

All oxygen tanks are identical and consist of inner pressure vessels of Inconel 718 and outer shells of aluminum 2219. The inner vessel is 33.435 inches in diameter, and the outer shell is 36.8 inches in diameter. Each tank has a volume of 11.2 cubic feet and stores up to 781 pounds of oxygen. The dry weight of each tank is 215 pounds. Maximum fill time is 45 minutes.

All hydrogen tanks also are identical. Both the inner pressure vessel and the outer shell are constructed of aluminum 2219. The inner vessel's diameter is 41.51 inches and the outer shell's is 45.5 inches. The volume of each