

# **SSV FAM 1107**

## **Space Shuttle Vehicle**

### **Familiarization**

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**Basic Training Series**

**For Training Purposes Only**  
Crew Training and Procedures Division  
Training Integration Branch

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National Aeronautics and  
Space Administration

**Lyndon B. Johnson Space Center**  
Houston, Texas

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## FOREWORD

This training material is part of a series of lectures, handouts, and workbooks for instruction on the Orbiter systems. The student should refer to the Orbiter support system lesson sequence found in the latest version of the training catalog. This training package should be studied before attending any classroom session on this material or taking any lesson for which this is a prerequisite. This material is for training purposes only; it should not be used as a source of operational data.

The last two pages of the workbook are two forms: (1) "Lesson Critique Sheet" and (2) "Training Report."

- (1) The "Lesson Critique Sheet" is used to obtain comments on this workbook. Please fill it out and mail it to the instructor when this workbook is completed. (It need not be put in an envelope.)
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SECTION 1  
THE SPACE TRANSPORTATION SYSTEM

## SECTION 1 THE SPACE TRANSPORTATION SYSTEM

In July 1969 NASA publicly announced the inception of the Space Shuttle program. The program to build a recoverable payload transporter and an integrated system for space use was based on years of studies by NASA. By 1972 this system, the Space Transportation System (STS), became NASA's major program.

The STS is designed to achieve two goals for the United States. These goals are the reduction in the cost of space operations and the support of a wide variety of space activities.

The major component of the STS is the Space Shuttle Vehicle (SSV), which consists of a reusable Orbiter, an expendable External Tank (ET), and two refurbishable Solid Rocket Boosters (SRB's) (fig. 1-1). The SSV is also referred to as the Shuttle.

Another component of the STS is the payload carrier. A payload carrier is identified as a habitable module (such as Spacelab), an attached but uninhabitable module or pallet for equipment or instruments, free-flying systems, and upper stages. The major payload carriers are illustrated in figure 1-1 and are as follows.

- Spacelab - A general-purpose orbiting laboratory for manned and automated activities in near-Earth orbit
- Inertial Upper Stage (IUS) - An "intelligent" solid-propellant device, containing an onboard guidance package and Attitude Control System (ACS)
- Spinning Solid Upper Stage (SSUS) - A low cost solid-propellant device which is spin-stabilized and designed for Atlas-Centaur (SSUS-A) and Delta (SSUS-D) class payloads
- Multimission Modular Spacecraft (MMS) - A sophisticated, reusable device composed of various propulsion, power, guidance, and communication modules
- Long Duration Exposure Facility (LDEF) - A low-cost, unmanned, free-flying structure on which a variety of passive experiments or instruments can be mounted

The third component of the STS is made up of the required ground-based facilities, equipment, and personnel. The SSV will be launched from Kennedy Space Center (KSC) in Florida and the Orbiter will land on a runway not far from the launch pad. Early development flights will use Edwards Air Force Base (EAFB) for landing. (A similar complex at Vandenberg Air Force Base (VAFB) in California will be used by the Department of Defense.) Ground Support Equipment (GSE) and personnel at KSC will refurbish the Orbiter and SRB's and install payloads in the Orbiter. Johnson Space Center (JSC) in Texas is responsible for mission control, flight planning, crew training, and mission scheduling. The Mission

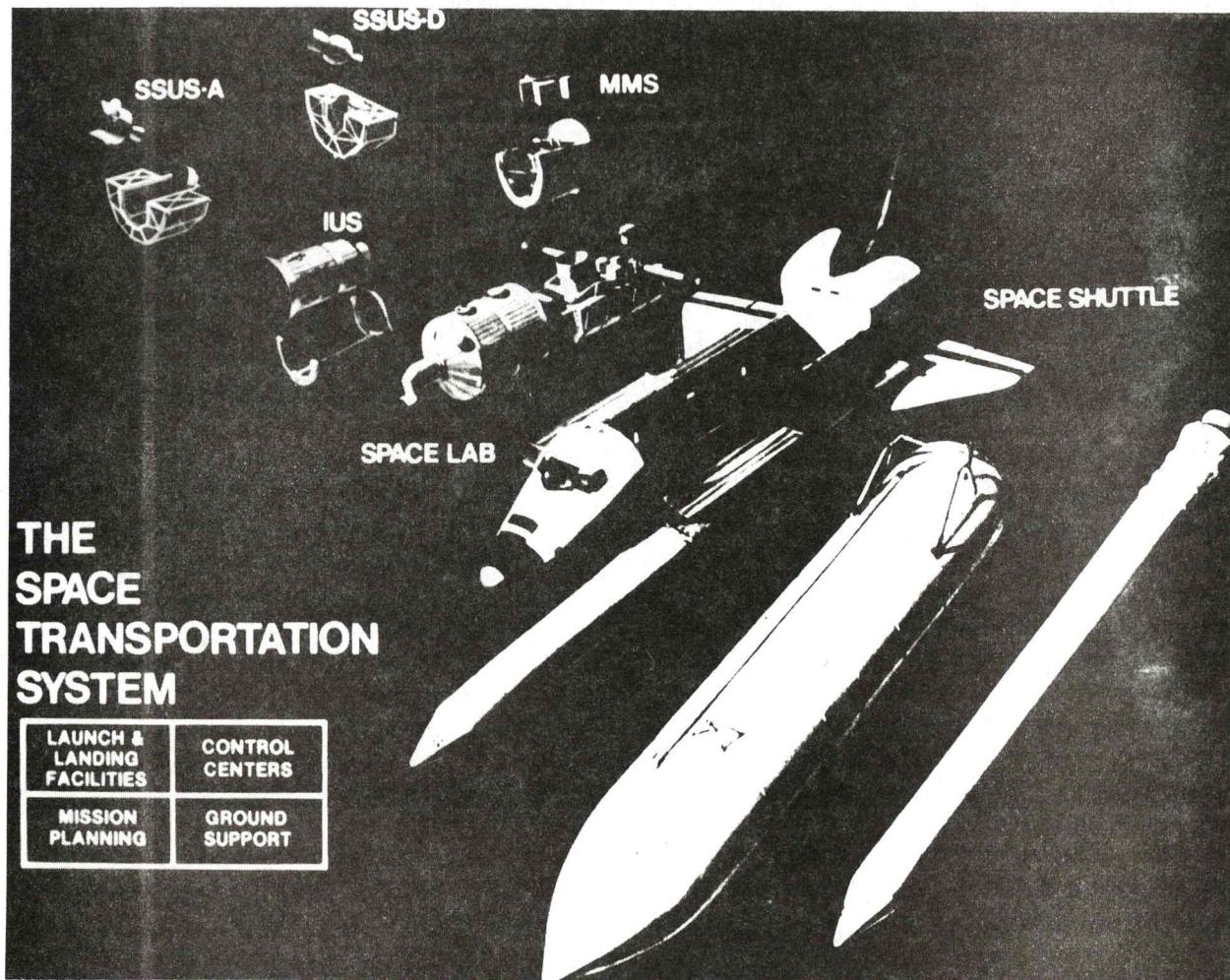


Figure 1-1.- The space transportation system.

Control Center (MCC) at JSC will be in contact with the Orbiter and payloads via the Tracking and Data Relay Satellite (TDRS) throughout the flight. The TDRS is a communications satellite which relays signals to and from a spacecraft and a ground station at White Sands Test Facility (WSTF) in New Mexico. There will be four TDRS's in geosynchronous orbits by the end of 1983. Early development flights will use the current Spacecraft Tracking and Data Network (STDN). Operating in conjunction with the MCC are three Payload Operations Control Centers (POCC's). The POCC at the Jet Propulsion Laboratory (JPL) in California is responsible for planetary payloads; the POCC at JSC is responsible for payloads that remain attached to the Orbiter; the POCC at the Goddard Space Flight Center (GSFC) in Maryland is responsible for Earth-orbiting payloads.

The Orbiter crew consists of the Commander (CDR) and Pilot (PLT). Additional crewmembers who may be required to conduct Orbiter and payload operations are a Mission Specialist (MS) and one or more Payload Specialists (PS's). A CDR plus a PLT or pilot-qualified MS are always required to operate and manage the Orbiter. The makeup of the rest of the crew depends on the mission requirements, complexity, and duration. Detailed responsibilities of the MS and PS are tailored to meet the requirements of each individual flight. A mission is defined as a coherent set of investigations or operations in space. A single mission might require more than one flight (or round trip from launch to landing of the Orbiter) or more than one mission could be accomplished on a single flight.

The cost of space operations will be reduced primarily because most of the SSV hardware is reusable. Further cost savings are due to the inherent ability of the Shuttle to retrieve satellites that experience premature failures, or update older satellites with new technology. The benign launch and entry environments of the Shuttle will relax the weight, volume, and g-loading constraints imposed on future payloads. Ground operations like those of commercial airlines are expected to have the SSV ready for relaunch within about two weeks. This will reduce manpower requirements. Standardized components and ingenious cargo handling devices will also help reduce turnaround costs. There will also be smaller flight control teams. In addition, the Orbiter requires no elaborate and expensive operation at sea to recover the crew (and payload) after each flight. If necessary the Orbiter can be transported from place to place atop a modified Boeing 747.

The STS will, by design, support a wide variety of satellites and scientific equipment. The Shuttle will transport up to 65,000 lb into a wide range of orbital inclinations and altitudes. The Orbiter's large payload bay contains flexible payload retention, umbilical, and deployment mechanisms. Inside the shirt-sleeve environment of the Orbiter's crew module, the flight controls, payload handling controls, and crew working and living areas have all been designed for maximum use and safety.

This document will familiarize you with the SSV, its operations, and elements.

SECTION 2  
SHUTTLE SPACE ACTIVITIES

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SECTION 2  
SHUTTLE SPACE ACTIVITIES

This section will demonstrate the versatility of the Space Shuttle by acquainting you with six of its primary missions. Virtually all military or civilian uses of the Shuttle will employ one or more of these six missions on each flight.

## 2.1 PLACEMENT AND RECOVERY OF SATELLITES

The principal mission of the Space Shuttle will be the placement and recovery of satellites (fig. 2-1). A satellite will be loaded into the Orbiter's payload bay and checked out by ground crews. The flight crew will board just before launch and perform a final checkout of all systems.

Once the Orbiter has achieved the proper orbit, the MS and PS will conduct predeployment checks of the satellite, open the payload bay doors, and position the satellite approximately 50 ft from the Orbiter. The satellite will then be released, activated, and monitored from the aft flight deck. If the satellite is functioning properly, the crew will close the payload bay doors and return to Earth. If a failure occurs, the satellite can be replaced in the payload bay and returned to Earth for service and re-launch.

A malfunctioning or deactivated satellite can be recovered in a similar manner. The Shuttle will be launched into orbit to rendezvous with the satellite. The crew will open the payload bay doors, retrieve the satellite, close the payload bay doors, and return to Earth.

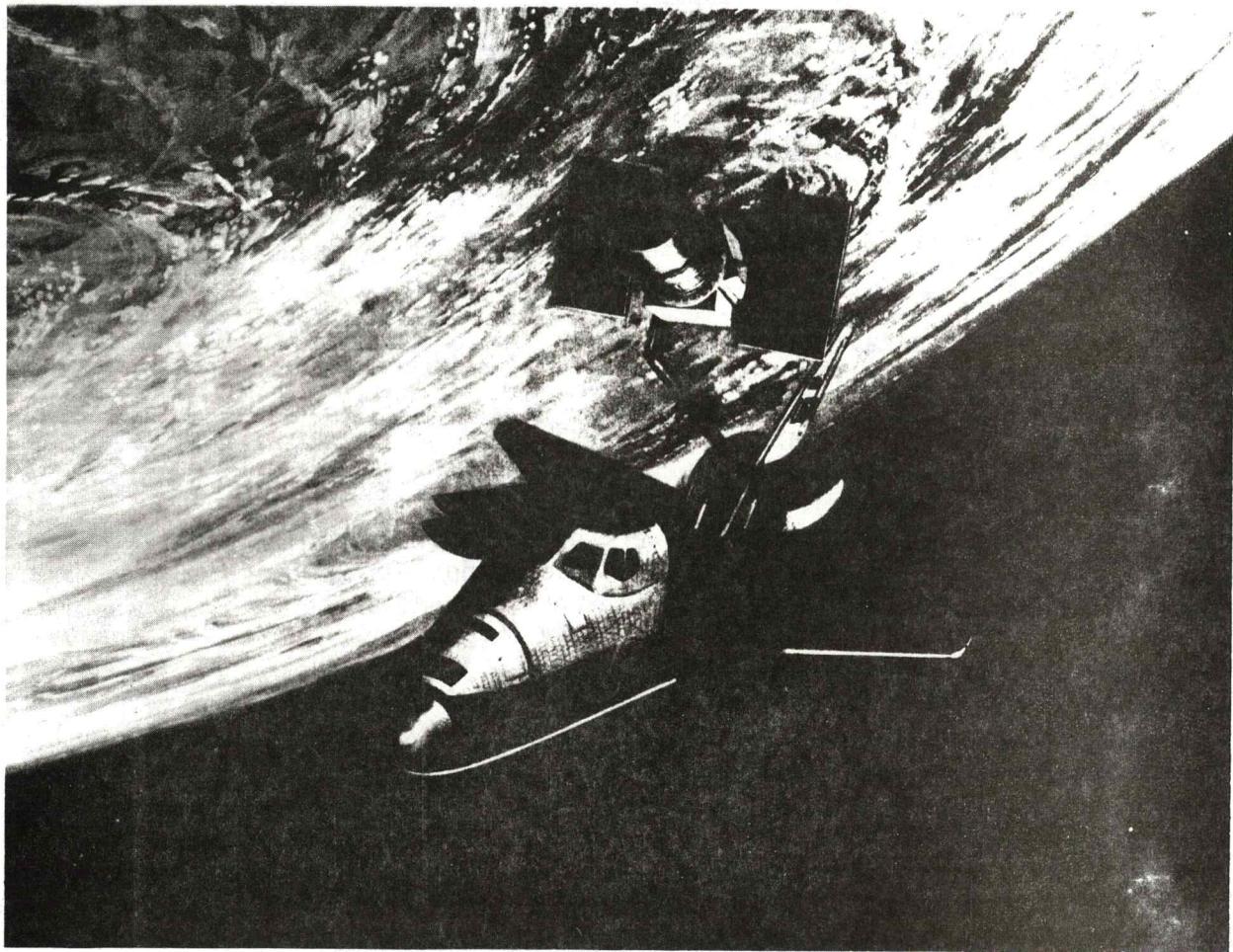


Figure 2-1.- Placement and recovery of satellites.

## 2.2 ON-ORBIT SATELLITE SERVICE

A typical sequence of satellite servicing in Earth orbit is shown in figure 2-2. The typical sequence is as follows.

- The satellite is maneuvered from its Sun-synchronous orbit to a lower-altitude servicing orbit.
- The Orbiter is inserted into the service orbit to rendezvous with the satellite.
- The crew captures the satellite.
- The crew attaches the satellite to a platform in the payload bay. The satellite can be attached remotely from an aft crew station inside the crew module.
- Replacement modules or repair work can be performed with automatic or preprogramed mechanisms. An alternate method is for one or more of the crew to exit the Orbiter in a spacesuit and perform the servicing. This is called Extravehicular Activity (EVA).
- The satellite is deployed, activated, and monitored by the crew. If the satellite is functioning properly, it is returned to its original orbit. A failure may require reservicing, and the option to return the satellite to Earth will be available.

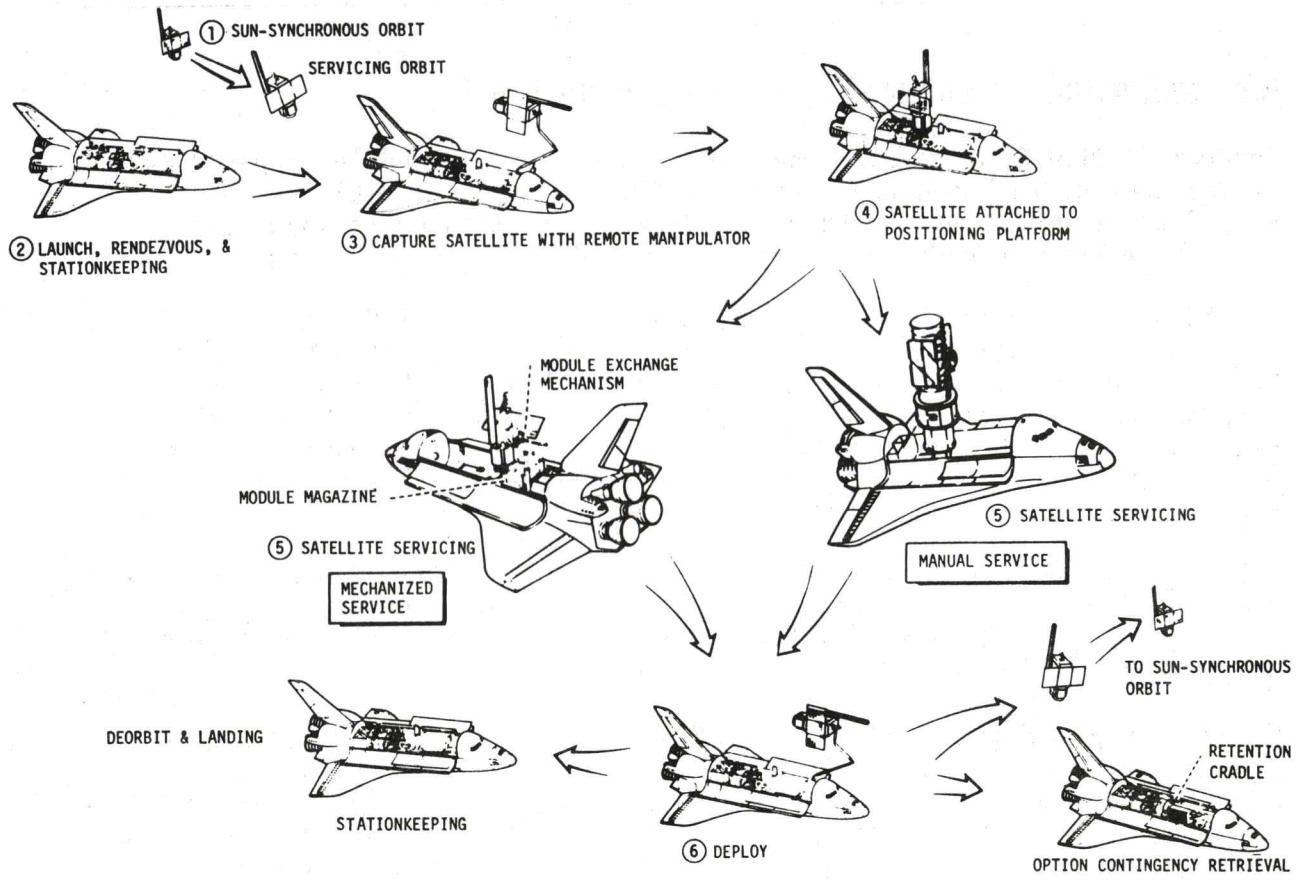


Figure 2-2.- On-orbit satellite service.

## 2.3 DELIVERING OF SPACECRAFT TO HIGH-ALTITUDE ORBITS

Spacecraft that require altitudes and trajectories beyond the capability of the Shuttle will use upper-stage systems. Specially designed solid-propellant carriers are being developed which will carry various satellites to geosynchronous orbits or on interplanetary trajectories.

The SSUS carrier and its payload are mounted on a spin table and a structural support cradle. This assembly is loaded into the Orbiter's payload bay just before launch. After a standard orbit has been attained, the SSUS and payload are checked out (if required), pointed in the proper direction by the Orbiter, spun to 40 to 100 rpm, and then separated from the Orbiter by springs at 3 to 4 ft/s. The Orbiter then performs a minor safety maneuver to clear the SSUS, and the SSUS motor is fired.

Operations using the IUS are similar; however, the IUS does not require a spin table. The IUS is an "intelligent" carrier containing an onboard guidance package and ACS. Payload weights can vary from 5000 to 10,000 lb by using a two-, three-, or four-stage IUS.

The MMS is a sophisticated carrier composed of several interchangeable modules, and can easily be adapted to support various experiments or instruments. Each module can contain an ACS, a propulsion system, a communication system, an electrical power system, and so on, depending on the mission requirements. The MMS is similar in function to the IUS, but does not have the weight or altitude capabilities of the IUS. The MMS is designed to be deployed, retrieved, and reused.

The delivering of spacecraft to high-altitude orbits is depicted in figure 2-3.

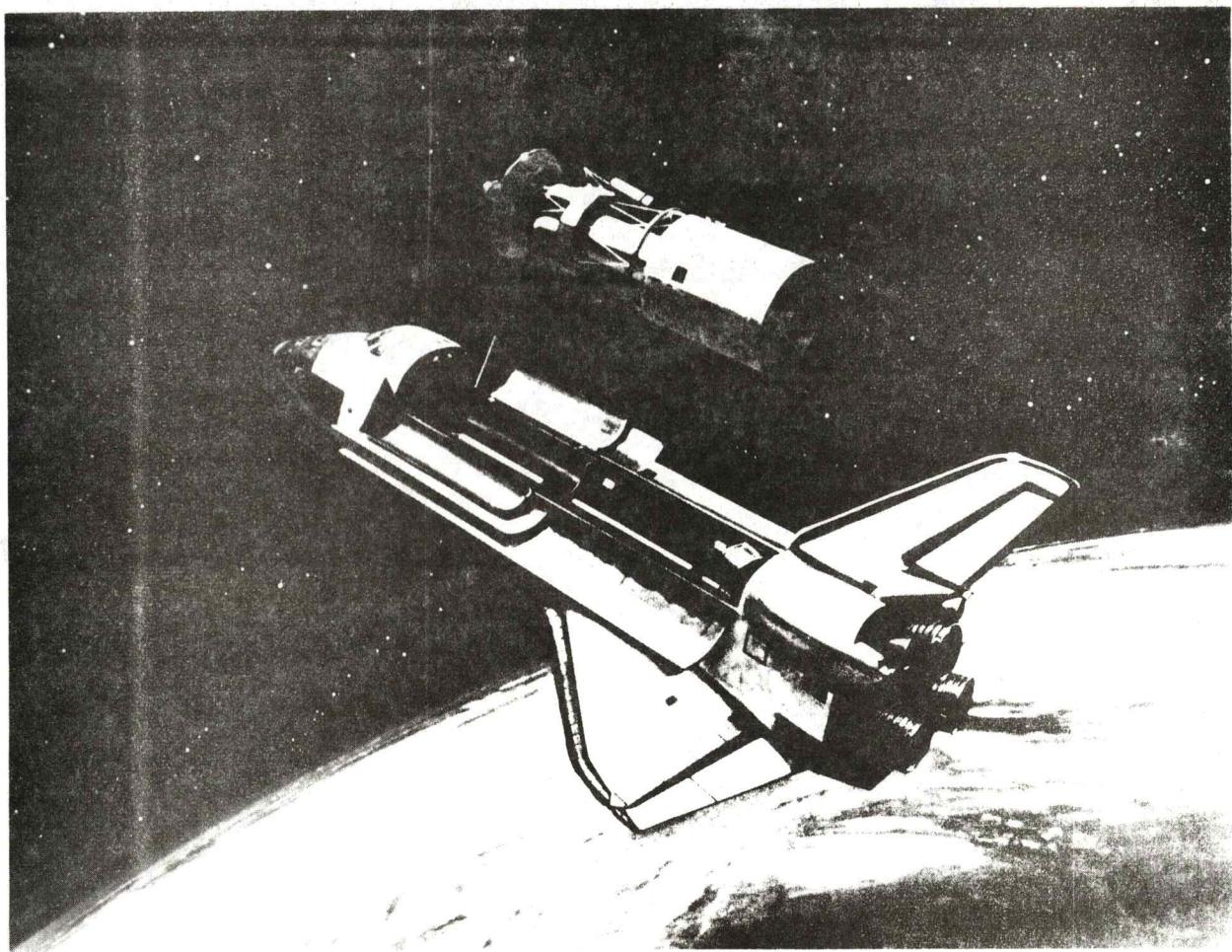


Figure 2-3.- Delivering of spacecraft to high-altitude orbits.

## 2.4 ON-ORBIT RESEARCH SPACELAB

Spacelab is a complete scientific laboratory designed to provide scientists with a shirt-sleeve environment and the facilities to conduct experiments in various fields. Personnel from many nations and disciplines will participate in the design and operation of the experiments carried in Spacelab.

Spacelab will be made up of workshop modules and equipment pallets attached in the Orbiter's payload bay. These modules and pallets are interchangeable, reusable, and adaptable to many types of space research (fig. 2-4).

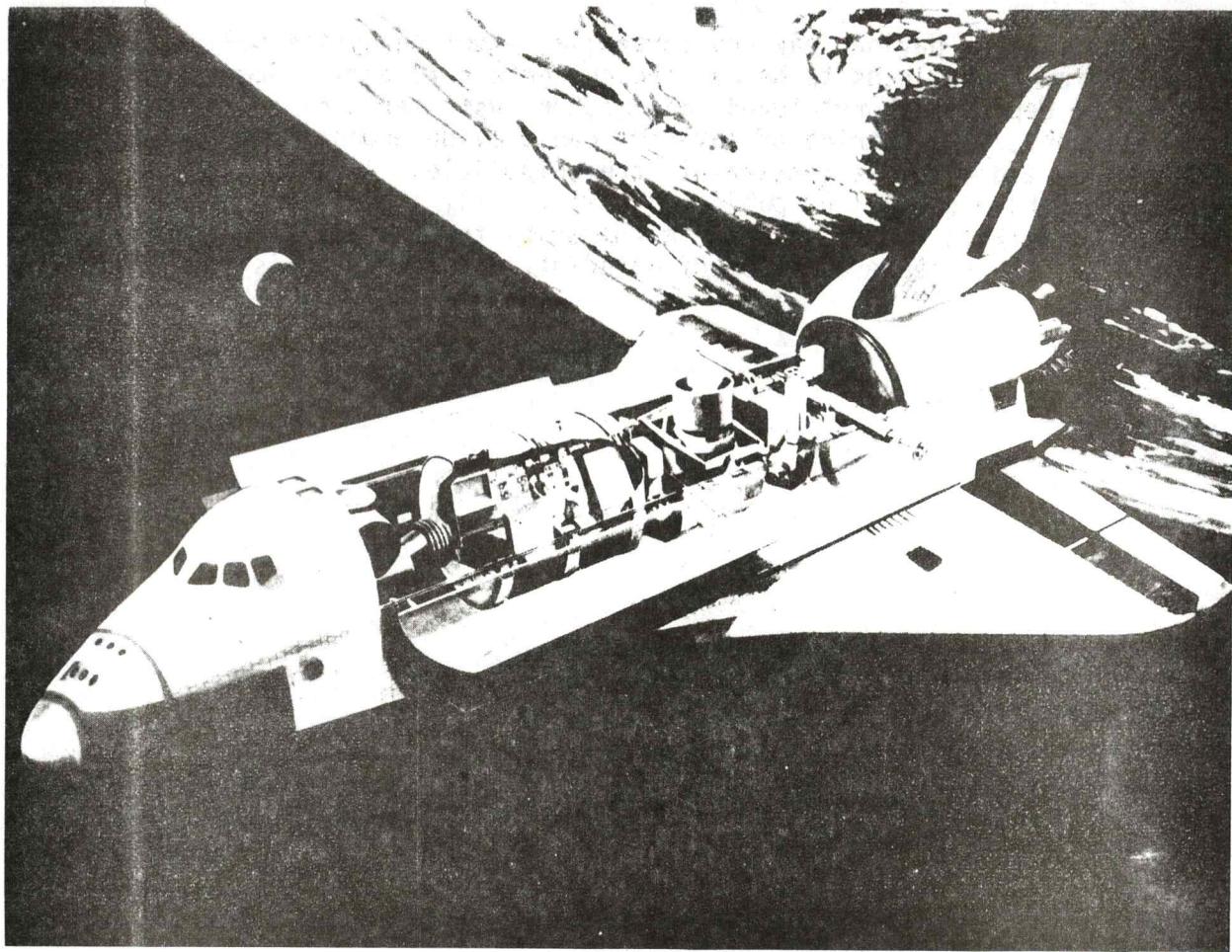


Figure 2-4.- On-orbit research Spacelab.

## 2.5 MIXED/ATTACHED PAYLOADS

The Orbiter's large payload bay and versatile retention system will allow several different payloads to be carried on certain flights. Some satellites may be deployed or retrieved while other instruments or equipment remain attached. The sharing of payloads can provide economic advantages where mission and schedule constraints are compatible. An announcement of flight opportunity will be published sufficiently in advance to enable commercial interests or the scientific community to take advantage of the available space. A representation of mixed/attached payloads is shown in figure 2-5.

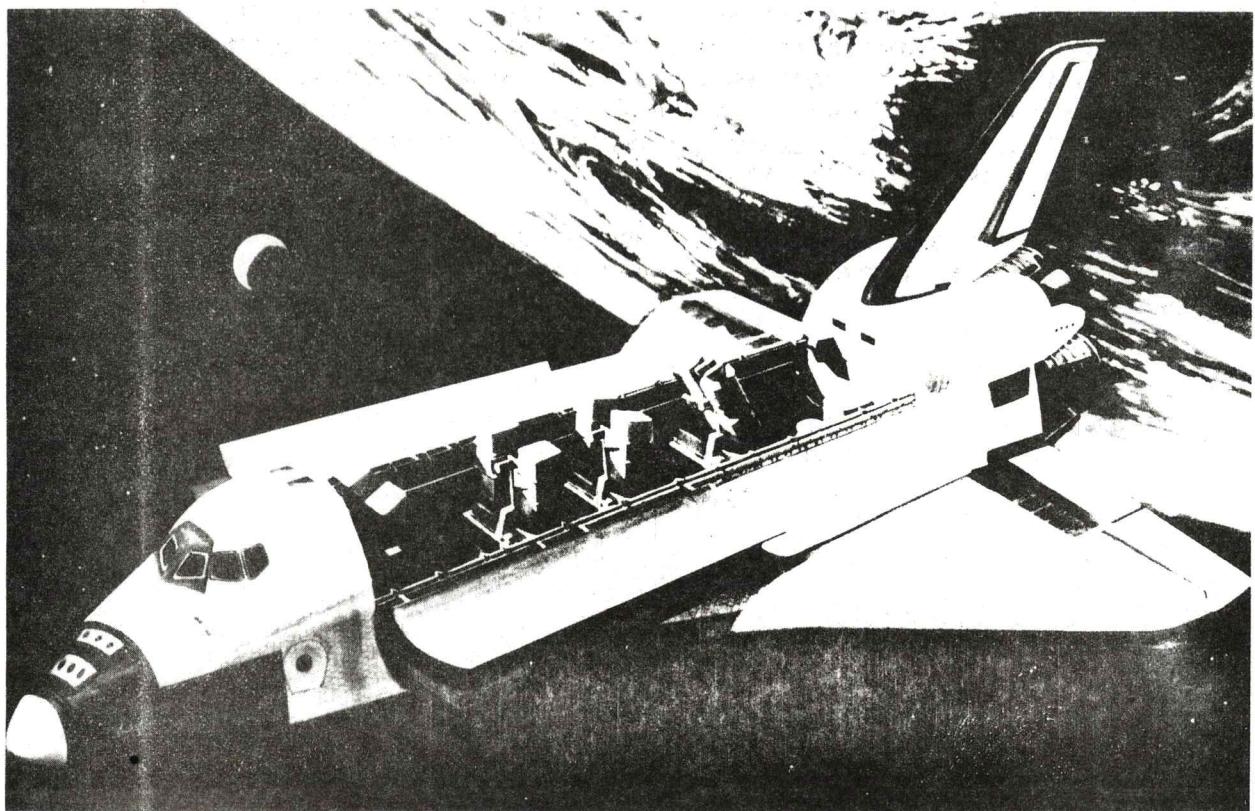


Figure 2.5.- Mixed/attached payloads.

## 2.6 LARGE SPACE SYSTEMS

The reusability and short turnaround time of the Space Shuttle will allow various construction projects in Earth orbit. Solar power platforms, manned orbiting laboratories, and space processing factories are a few of the applications (fig. 2-6). There are three general approaches to the construction of such large scale systems.

One approach is the deployment of structures which have been prefabricated and folded to fit within the Orbiter's payload bay. Another is the piece-by-piece erection of structures using several prefabricated struts and unions carried to orbit on several Shuttle flights. The third approach to construction of a large scale space system is space fabrication using specially designed beam extrusion devices.

The Shuttle can deliver equipment for large structures to orbit in one or more flights and support the crews needed to assemble (or repair) these structures.

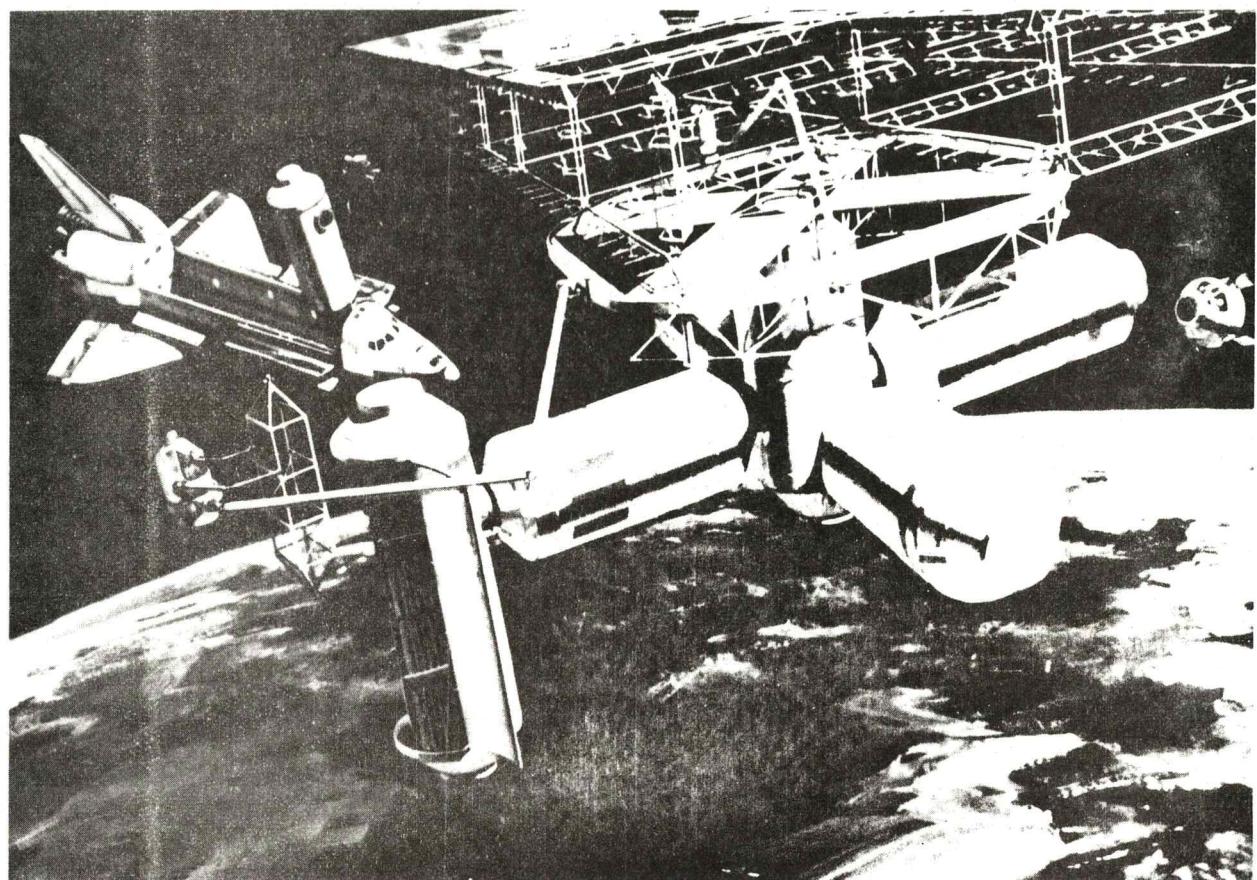


Figure 2-6.- Large space systems.

SECTION 3  
SHUTTLE FLIGHT PROFILE

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### SECTION 3 SHUTTLE FLIGHT PROFILE

This section will acquaint you with the following major phases of a Shuttle flight.

- Ascent
- Aborts
- On-Orbit
- Entry
- Ground Turnaround

### 3.1 ASCENT

The flight crew will board the Orbiter approximately 2 hr before lift-off in order to prepare the vehicle for ascent. At lift-off the three main engines are burning in parallel with the two SRB's. This is first-stage ascent. During first stage, aerodynamic loads, engine thrust, and vehicle weight are the primary factors used to shape the trajectory. The SRB's are used along with the main engines for steering. After about two min the boosters turn out, separate from the ET, and descend by parachute. The boosters are recovered, refurbished at the launch site, and reused on a later flight.

Second-stage ascent continues using the three main engines. During second stage, engine thrust and vehicle weight are used to shape the trajectory, and the main engines are used for steering. After about 9 min of flight, the main engines are shut down and the ET is jettisoned. This is referred to as Main Engine Cutoff (MECO) and ET separation. The tank reenters the atmosphere, begins to disintegrate, and falls harmlessly into a remote area of the Indian or the South Pacific Ocean (depending on the launch site). Some 2 min later, two small orbital maneuvering engines ignite to provide the energy necessary to insert the Orbiter into an elliptical orbit approximately 150 n. mi. by 80 n. mi. Final adjustments with the orbital maneuvering engines are made sometime later in the flight to circularize the orbit to about 150 n. mi.

The entire ascent trajectory (fig. 3-1) is designed to place the Orbiter and payload in the precise orbit with a minimum of stress on the crew, structure, and payload.

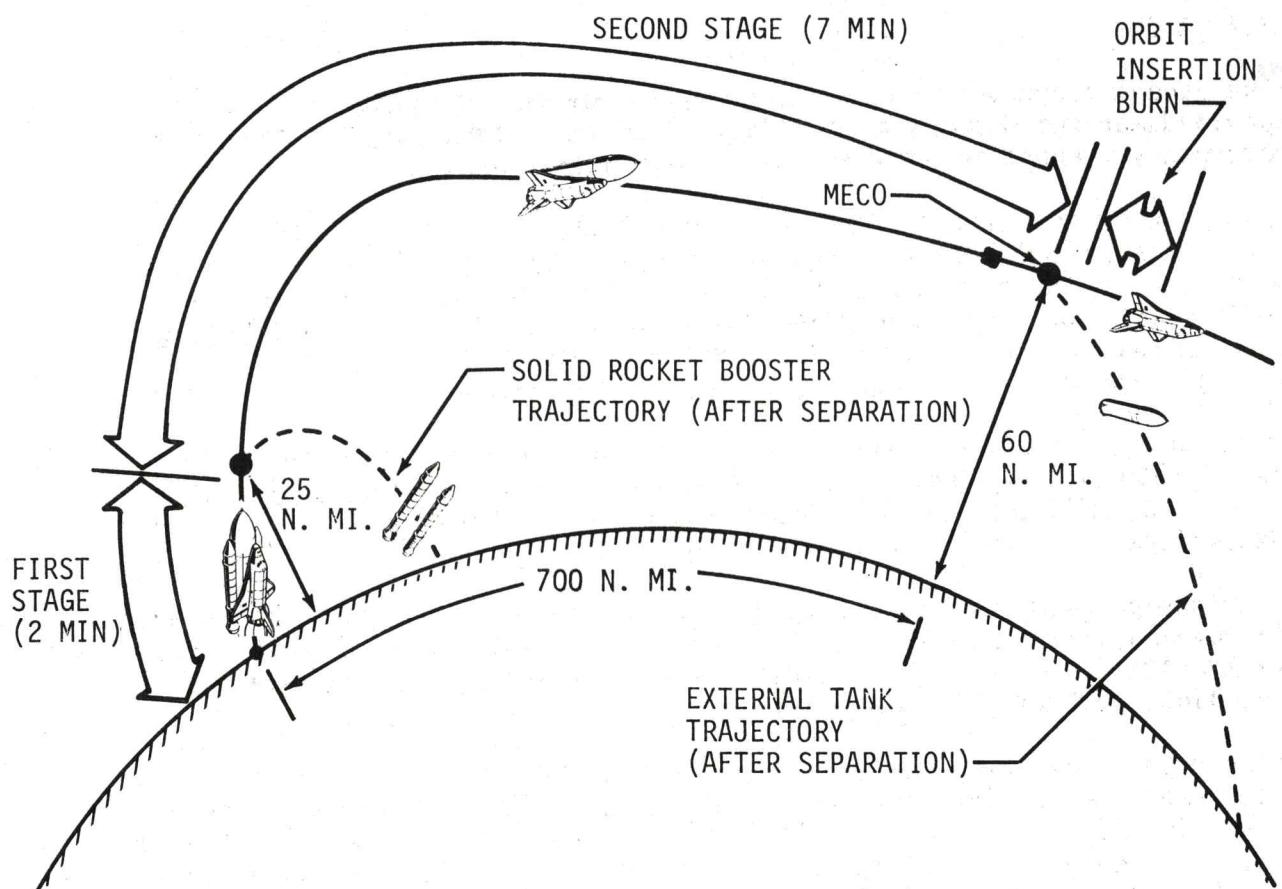


Figure 3-1.- Nominal ascent trajectory.

### 3.2 ABORTS

The ascent trajectory is also designed to provide the crew, Orbiter, and payload maximum safety, and the capability to return intact in case of emergency. Abort trajectories can be seen in figure 3-2.

During the first four min of the flight, the Orbiter can be returned for an emergency landing on the runway at the launch site. This is called a Return to Launch Site (RTLS) abort. After the boosters have separated, the Orbiter and ET continue downrange to use up fuel. The vehicle then turns around, begins to slow, and eventually starts back toward the runway. The tank (now empty) is jettisoned and the Orbiter glides to a safe landing.

After 4 min, the SSV has enough energy to continue downrange and reach nearly nominal MECO conditions. The decision to Abort to Orbit (ATO) is made by the MCC, and the two orbital maneuvering engines are used to place the Orbiter in a 105 n. mi. circular orbit.

A serious problem may require the Orbiter to land at EAFB in California or Holloman Air Force Base (HAFB) in New Mexico. This is called Abort Once Around (AOA). The orbital maneuvering engines are again used to adjust the flight path of the Orbiter.

Catastrophic failures require specialized flight procedures. A contingency abort generally involves flying the SSV to a remote area of the ocean, jettisoning the ET, and landing the Orbiter in the water (ditching). This is referred to as a nonintact abort because the Orbiter and payload cannot be recovered. For the early development flights of the STS, the Orbiter will be equipped with ejection seats. In any case, the safety of the crew is the prime concern.

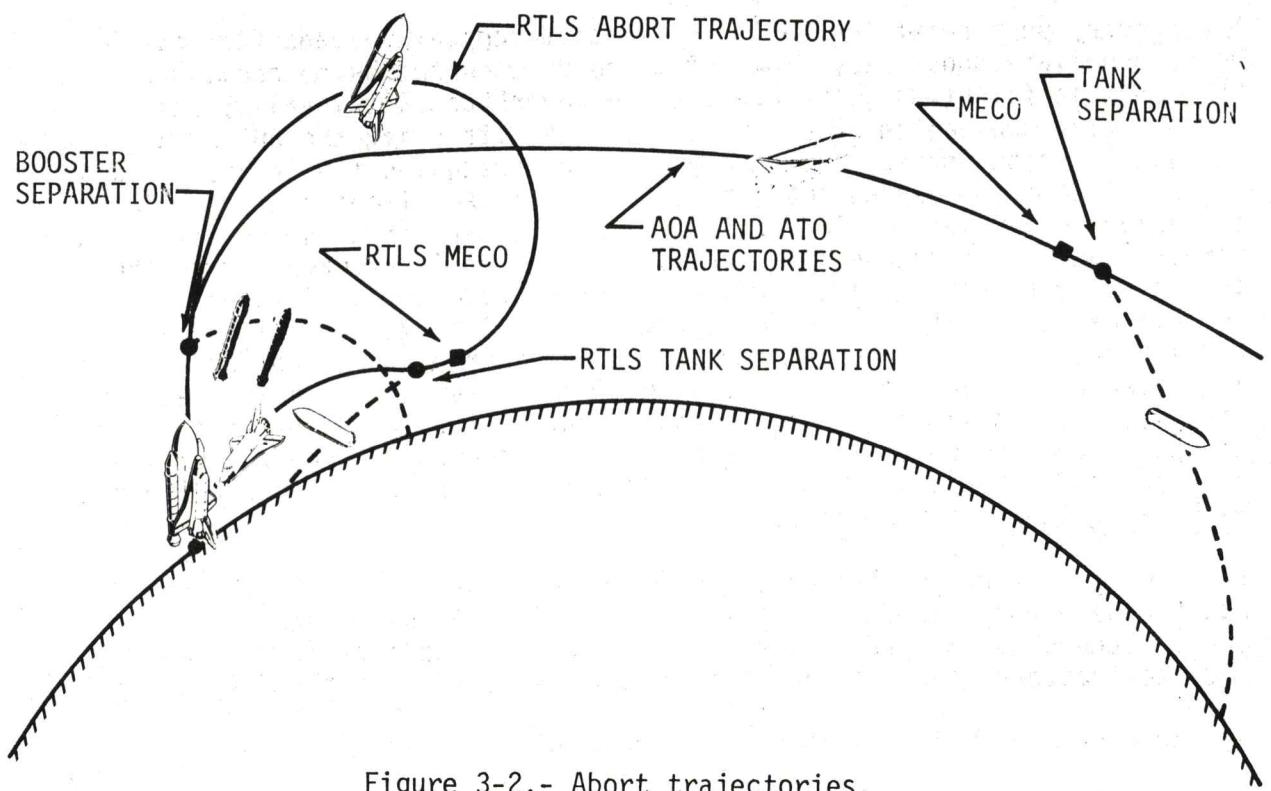


Figure 3-2.- Abort trajectories.

### 3.3 ON-ORBIT

The primary purpose of the Shuttle will be to deploy payloads for government or private industries. This will be done during the on-orbit phase of a Shuttle flight using the Payload Deployment and Retrieval System (PDRS). The Orbiter can also retrieve a satellite using the PDRS and return it to Earth for repair or analysis. This requires the Orbiter to maneuver close to, or rendezvous with, the satellite. The target vehicle is generally in a known, stable orbit, and the Orbiter, or chase vehicle, must perform a series of maneuvers to ensure that it will rendezvous with the target at a desirable position within a prescribed amount of time. The desired target position is dependent mainly on lighting conditions. The final approach to the target is referred to as proximity operations. Proximity operations can include station keeping, fly-arounds, approaches, and finally, after all mission objectives are satisfied, the separation of the Orbiter to a standoff position. Rendezvous maneuvers are performed with the two orbital maneuvering engines and proximity operations are performed with 44 attitude control jets.

If an emergency occurs on-orbit, the Orbiter can perform a deorbit burn, reenter the atmosphere, and land safely at a Contingency Landing Site (CLS). Each CLS has been strategically located around the Earth to provide the Orbiter, crew, and payload maximum safety during the flight.

A diagram of on-orbit operations is shown in figure 3-3.

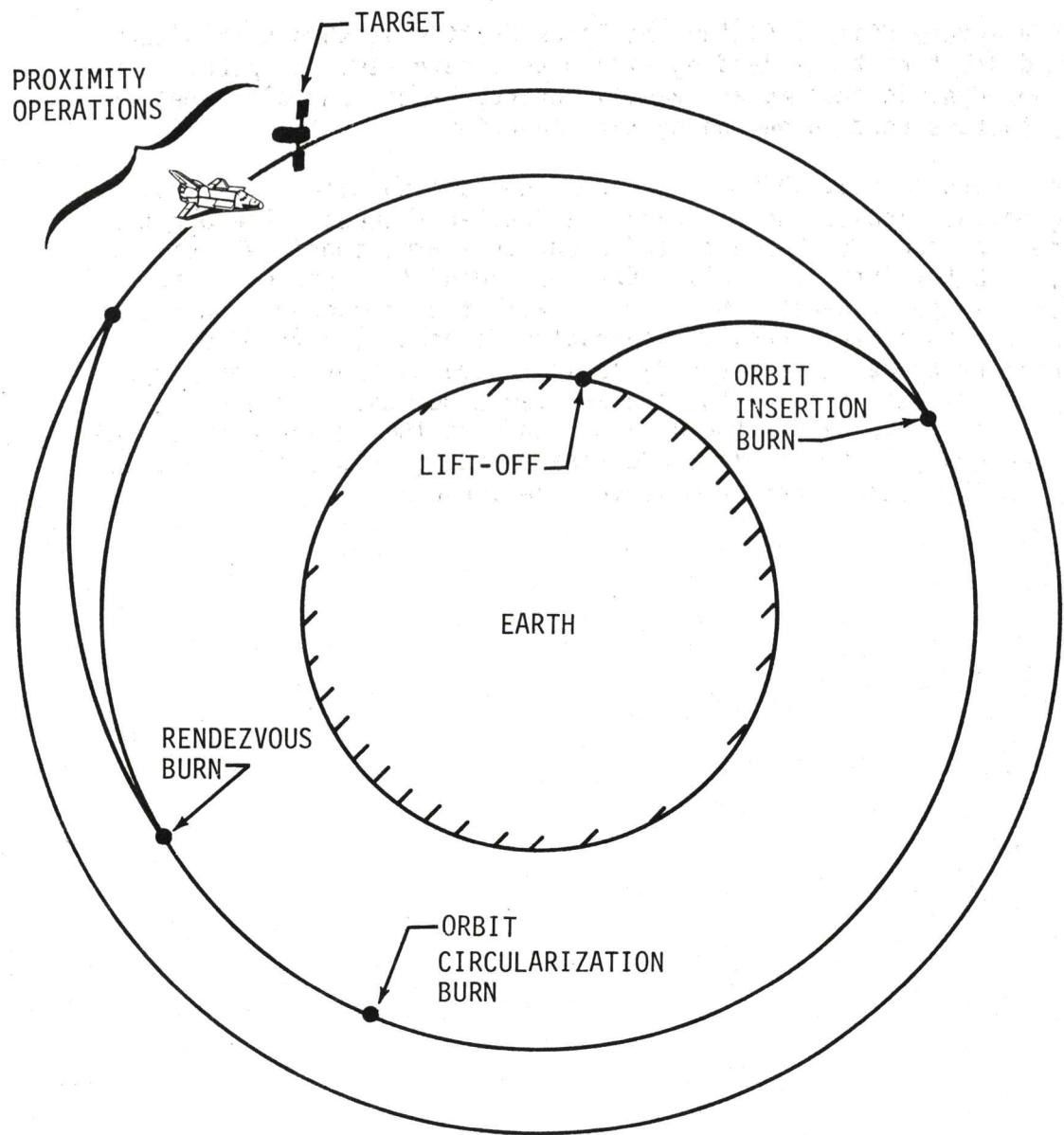


Figure 3-3.- On-orbit operations.

### 3.4 ENTRY

The entry trajectory (fig. 3-4) for the Space Shuttle is shaped to place the unpowered Orbiter at the landing site with a safe landing speed. During entry, aerodynamic heating and vehicle energy (speed and altitude) are the primary factors used in designing the trajectory.

Entry begins approximately 9000 n. mi. from the landing site. The orbital maneuvering engines ignite and decrease the Orbiter's speed. The Orbiter begins to descend towards the Earth and encounters atmospheric effects at 400,000 ft, or Entry Interface (EI). External insulation protects the Orbiter from the heat generated by friction with the atmosphere; however, radio communication is temporarily interrupted (blackout). At 70,000 ft Terminal Area Energy Management (TAEM) is initiated to provide the proper airspeed, altitude, and heading for the Orbiter's approach and landing. Using special navigation aids, the Orbiter lands on the runway with conventional landing gear. After rollout and final braking to a stop, the crew powers down the Orbiter systems and leaves the vehicle.

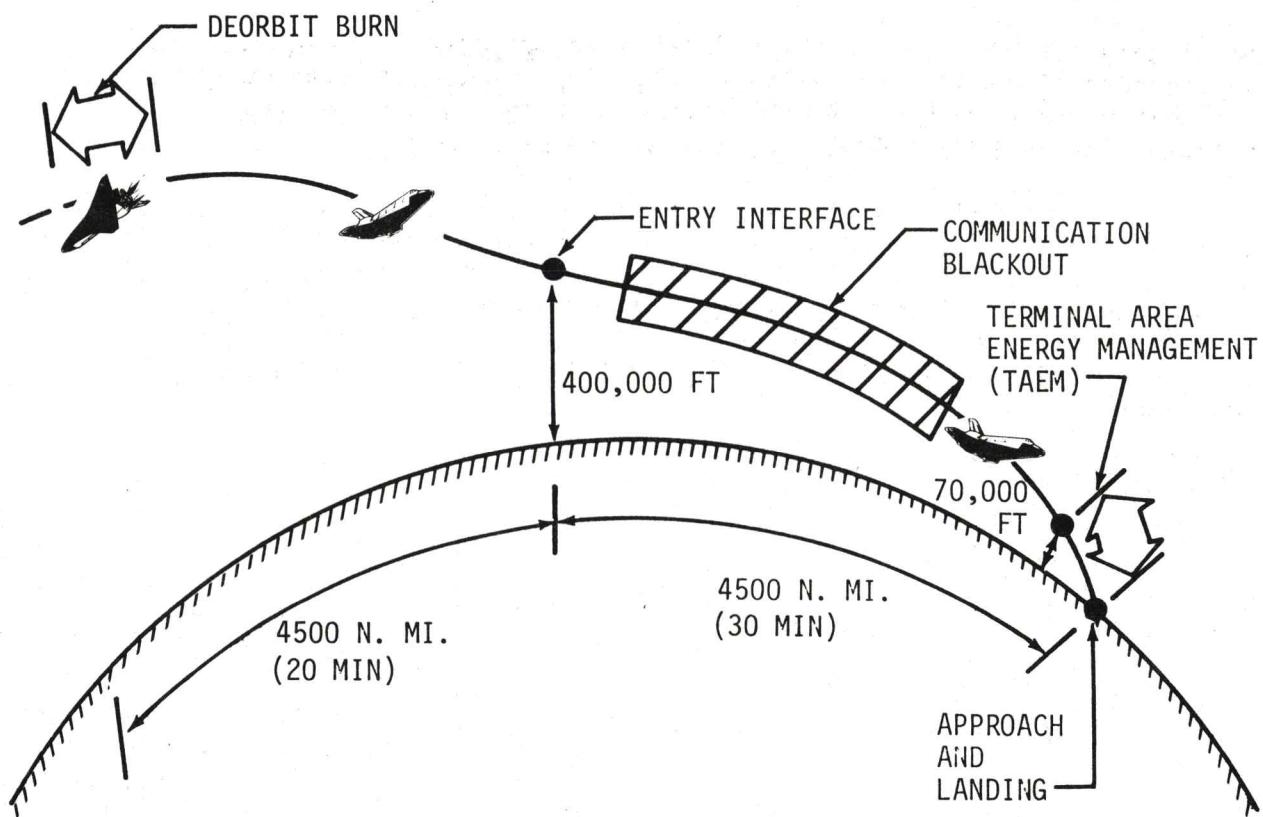


Figure 3-4.- Nominal entry trajectory.

### 3.5 GROUND TURNAROUND

Immediately after landing, selected Orbiter and payload systems are secured and ground-cooling equipment is connected. The Orbiter is then towed to the Orbiter Processing Facility (OPF) where safing payload removal, maintenance and checkout, and premate operations are performed.

In parallel with Orbiter operations, the SRB's are stacked and aligned on the Mobile Launch Platform (MLP) inside the Vehicle Assembly Building (VAB). The ET arrives by barge and is transported to the VAB where it is mated with the boosters. At this point the Orbiter is attached to the tank. The MLP with the stacked vehicle is then rolled out to the launch pad. Launch pad operations include systems checkouts, propellant loading, and the launch countdown.

Ground turnaround is depicted in figure 3-5.

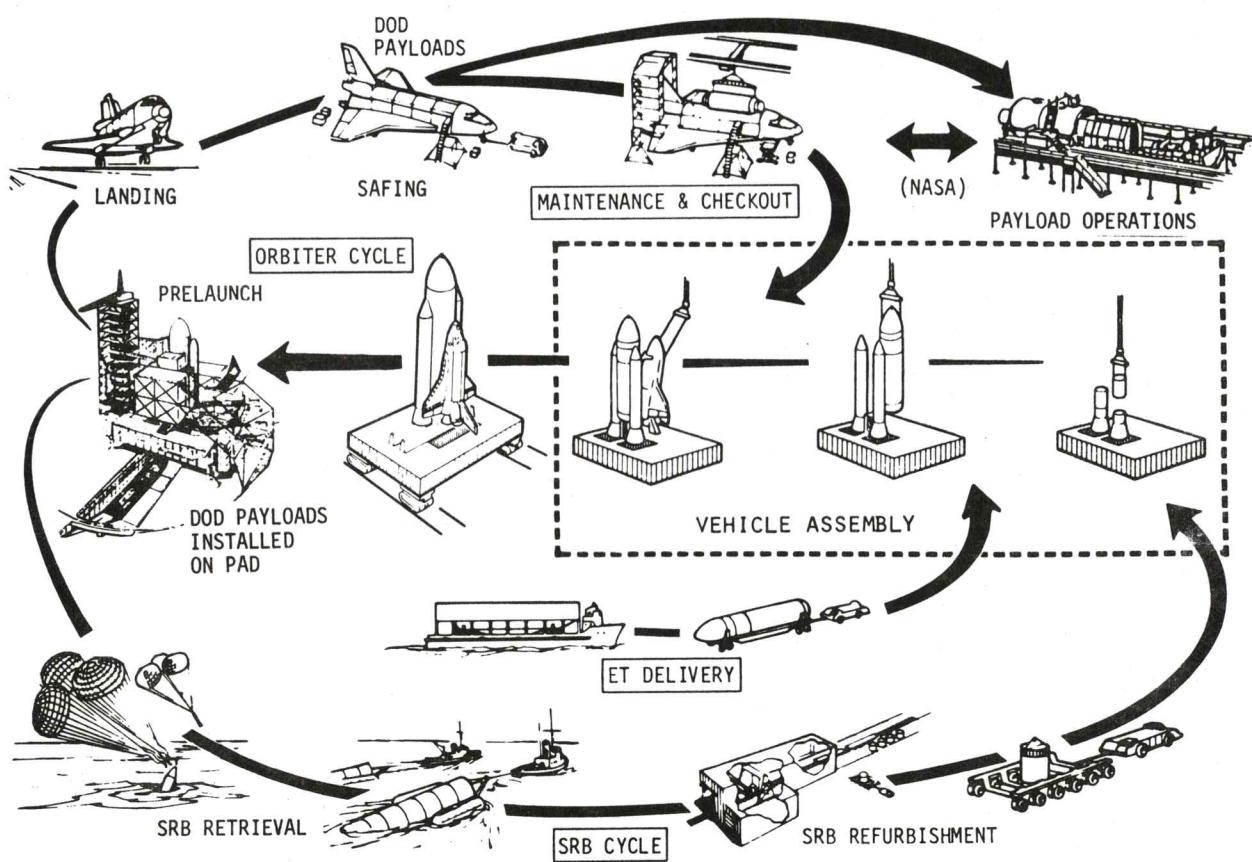


Figure 3-5.- Ground turnaround.

SECTION 4  
SHUTTLE VEHICLE ELEMENTS

SECTION 4  
SHUTTLE VEHICLE ELEMENTS

This section will familiarize you with the individual elements of the SSV (fig. 4-1).

In the years between 1969 and 1972 various private companies submitted their design proposals. The final selection was based on cost, reusability, and performance. Since 1972 the basic design has changed very little.

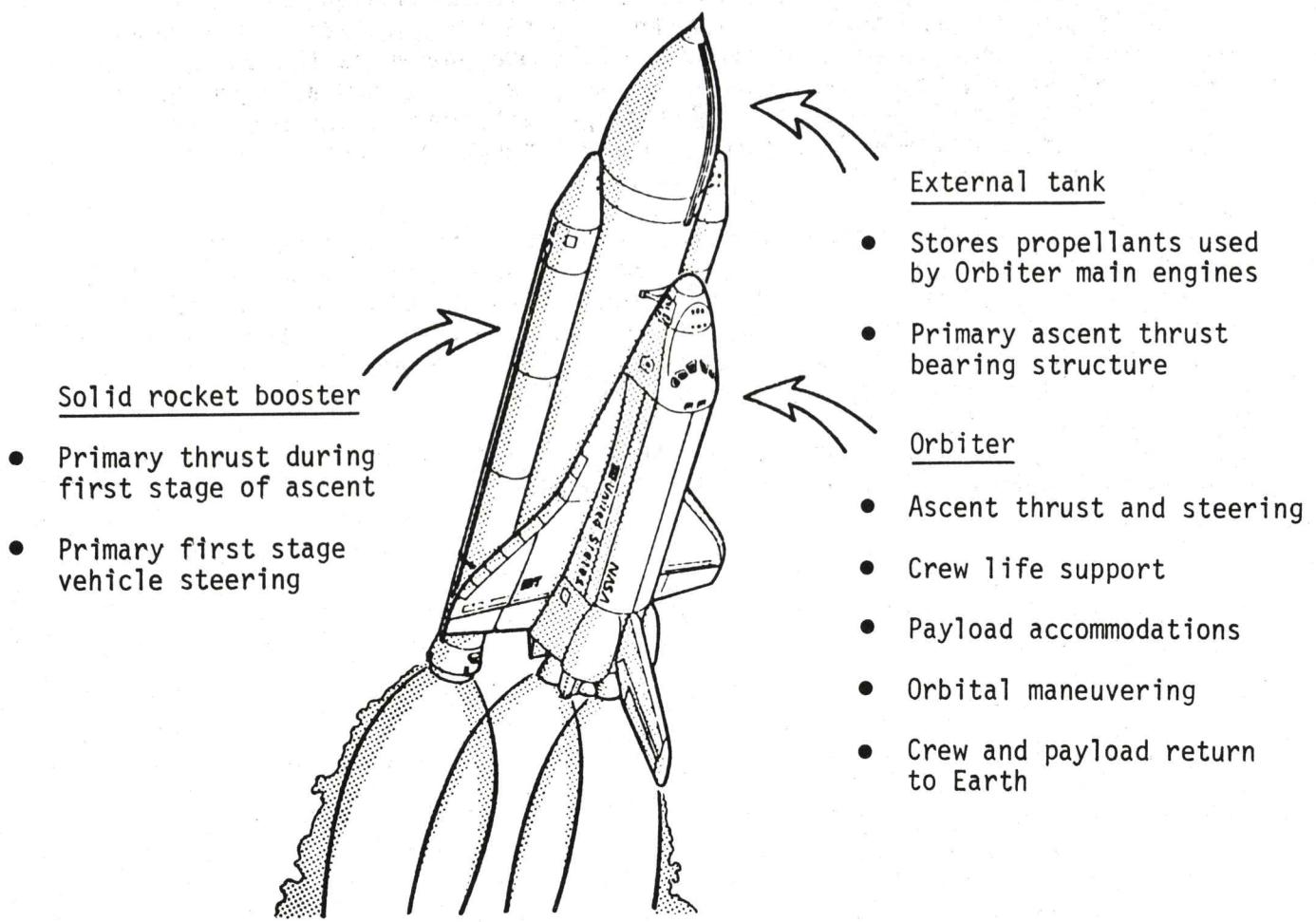


Figure 4-1.- Space Shuttle vehicle elements and functions.

#### 4.1 SOLID ROCKET BOOSTER

Two SRB's burn for 2 min in parallel with the three main engines of the Orbiter to provide the initial thrust during ascent (fig. 4-2). The propellant mixture consists of an aluminum perchlorate powder as the oxidizer, an aluminum powder as the fuel, iron oxide as a catalyst, and a polymer binder to hold the mixture together. The propellant grain is shaped to reduce thrust by approximately 30 percent halfway through the burn in order to reduce the aerodynamic forces on the SSV.

Each SRB is assembled from a Solid Rocket Motor (SRM), an aft skirt, a forward skirt containing avionics, and a nose cap containing parachutes and recovery aids. An SRM is built from 11 steel segments containing propellant. These segments are stacked on top of the aft skirt, which is attached to the mobile launch platform by four launch supports. The forward skirt and nose cap are then added to complete the SRB assembly.

The SRB's are attached to the ET at the forward skirt by a single thrust attachment and by sway braces at the aft segment.

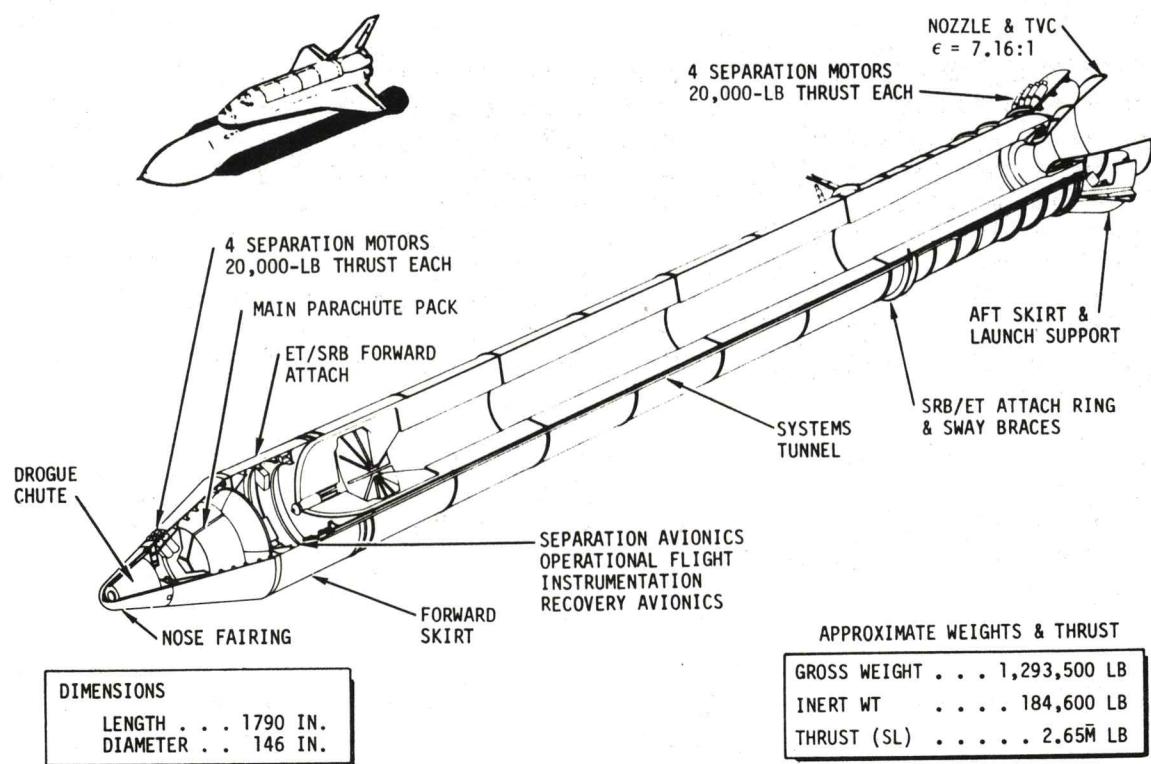


Figure 4-2.- Solid rocket booster.

## 4.2 EXTERNAL TANK

The ET contains the propellant for the Orbiter main engines. These propellants are liquid hydrogen ( $LH_2$ ) fuel and liquid oxygen ( $LO_2$ ) oxidizer. The ET (fig. 4-3) is composed of an  $LO_2$  tank ( $19,500\ ft^3$ ) and an  $LH_2$  tank ( $53,800\ ft^3$ ) held together by a rigid intertank sleeve. Slosh and anti-vortex baffles are mounted in the two tanks to damp fluid motion and to minimize liquid residuals. Five lines (three for  $LH_2$  and two for  $LO_2$ ) interface between the ET and Orbiter at the rear of the ET. All fluid control valves (except vent valves) for the operation of the Main Propulsion System (MPS) are located in the Orbiter to minimize throwaway costs. Spray-on foam insulation is applied to the outer surfaces of the ET to limit local heating during ascent.

The ET also forms the structural backbone of the Space Shuttle Vehicle. The SRB's are attached to the ET in a thrust fitting in the intertank, and two sway braces in the rear. The Orbiter is attached to the ET by a bipod in the intertank and two large struts in the rear.

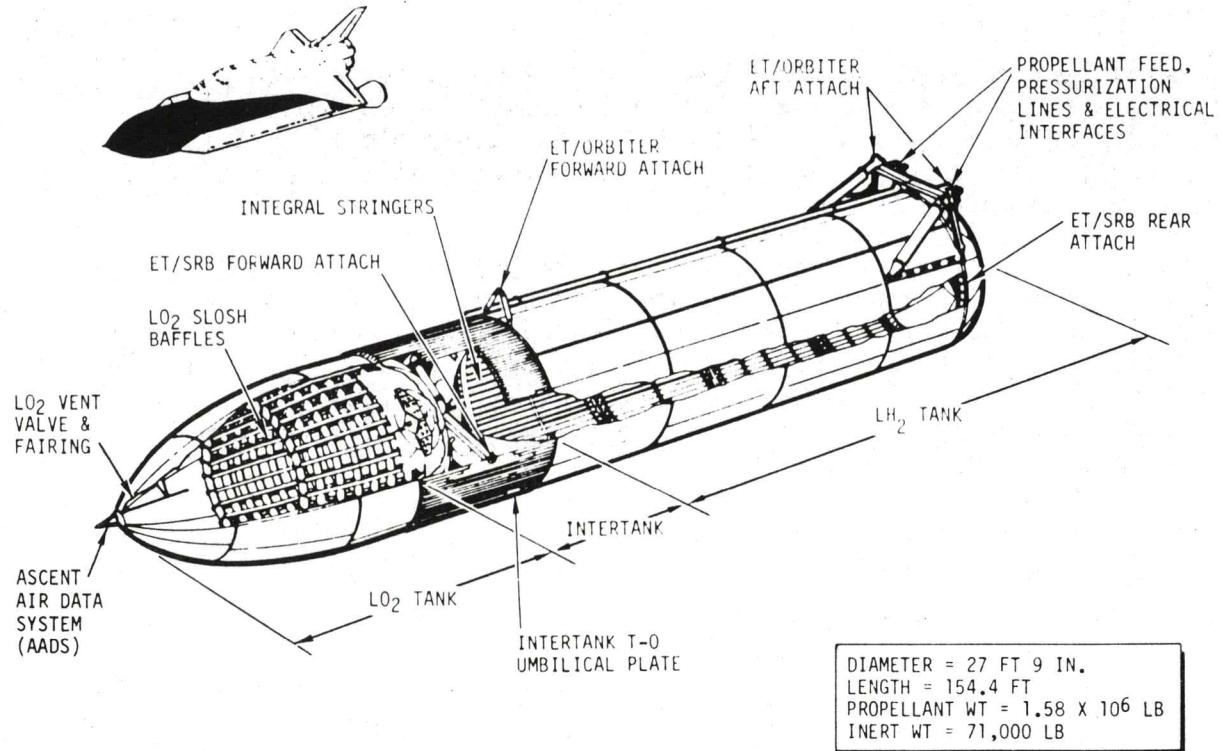


Figure 4-3.- External tank.

#### 4.3 ORBITER

The general configuration of the Orbiter (fig. 4-4) is determined by the requirements for crew and payload sizes and weights, aerodynamic performance, and ease of maintenance. The Orbiter is comparable in size to a DC-9 aircraft, and its basic structure uses conventional aircraft design, fabrication, and materials.

The rest of this section will be devoted to the Orbiter and its support systems. Most of the support systems in the Orbiter use three (sometimes more) items performing the same function. This redundancy has been designed into the Shuttle to make it fail-operational/fail-safe. For example, a failure of one hydraulic system will not jeopardize the flight (fail-operational); the failure of a second hydraulic system will not jeopardize the crew, Orbiter, or payload (fail-safe).

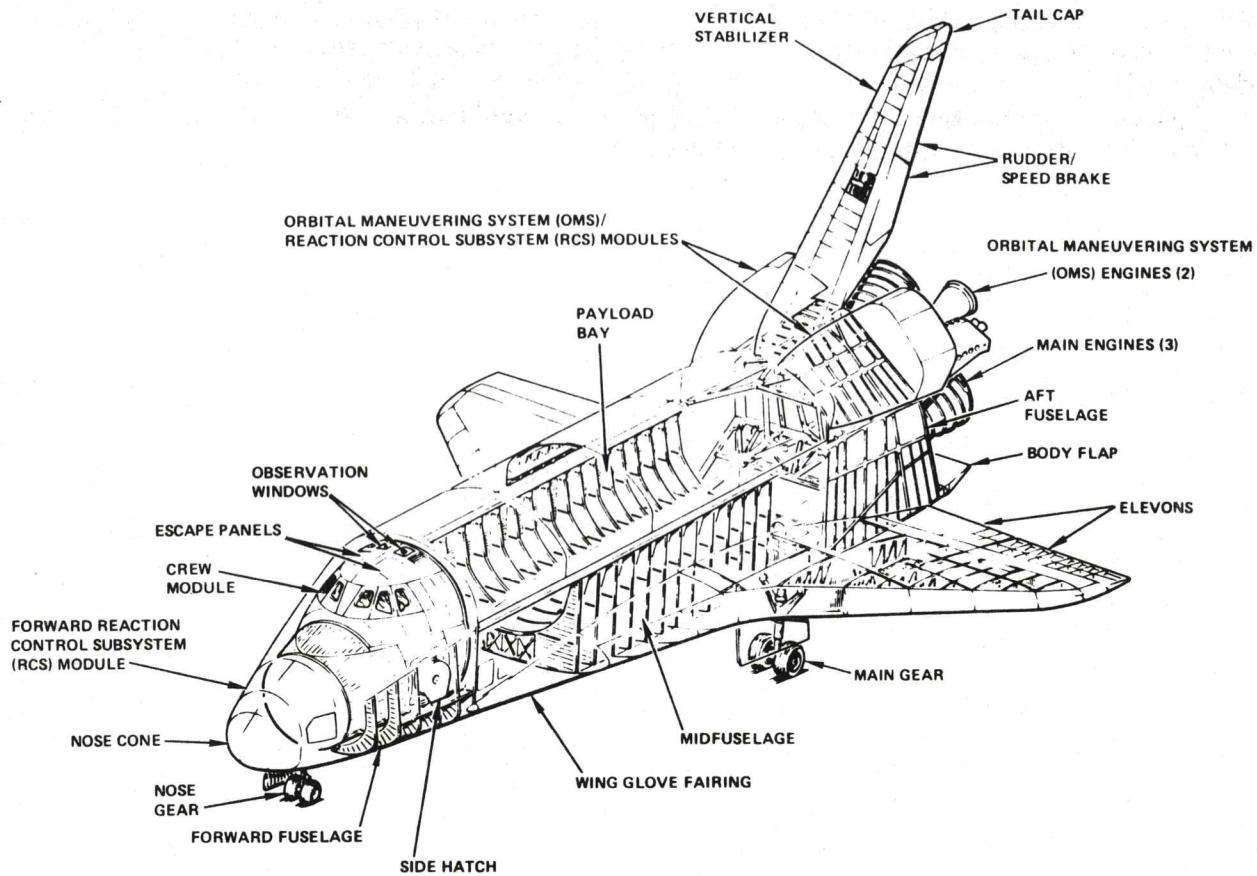


Figure 4-4.- Orbiter general arrangement.

#### 4.3.1 Orbiter Structure

The Orbiter is comprised of three major structural elements. These are the forward fuselage, mid fuselage, and aft fuselage. These elements are fastened by bolts and rivets, as are the wings and vertical tail. The outer skin is aluminum covered with special thermal protection. The Orbiter structural groups are shown in figure 4-5.

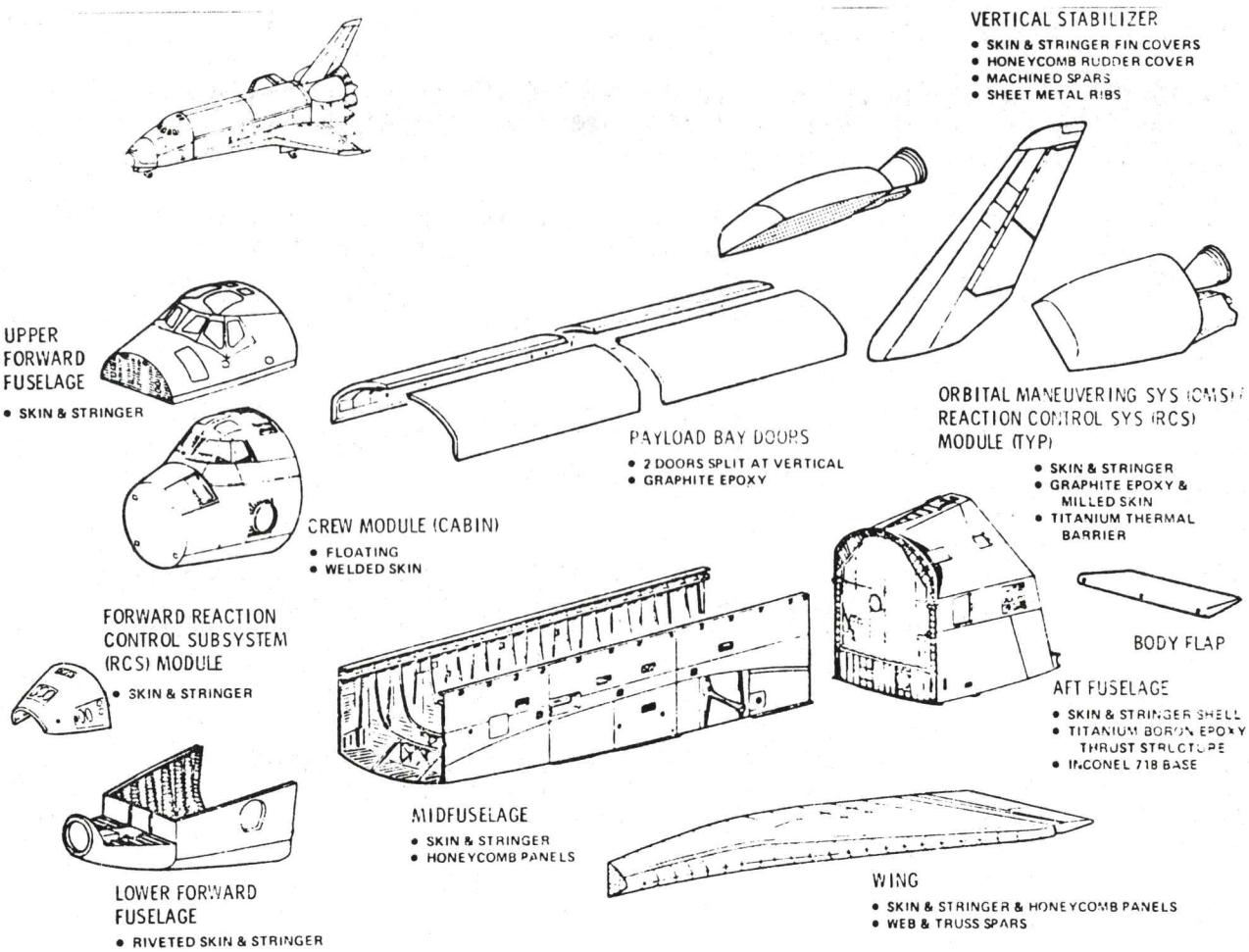


Figure 4-5.- Orbiter structural groups.

#### 4.3.2 Orbiter Forward Fuselage

The forward fuselage contains the Crew Module (CM) (fig. 4-6), the Nose Landing Gear (NLG), the forward ET attachment point, and the forward Reaction Control System (RCS) module.

The CM (cabin) is designed as a combination working and living area. It is pressurized to 14.7 psia, the temperature is maintained at 72° F, and the humidity below 50 percent. Cabin air is circulated to prevent stagnation and filtered to remove carbon dioxide and odors. The total volume is 2525 ft<sup>3</sup>.

The upper level (flight deck), contains the displays and controls used to pilot, monitor, and control the Orbiter, the integrated Shuttle vehicle, and the mission payloads. Seating for as many as four crewmembers can be provided.

The middeck contains a galley, personal hygiene facilities, an airlock, a side hatch, three avionics equipment compartments, and stowage lockers. The airlock may be mounted inside the cabin or outside in the payload bay for on-orbit EVA. The side hatch is used for normal crew ingress and egress on the ground.

Beneath the middeck is the equipment bay, which houses the water tanks, wet-trash stowage, and the Environmental Control and Life Support System (ECLSS). Hinged floor panels provide access to this area.

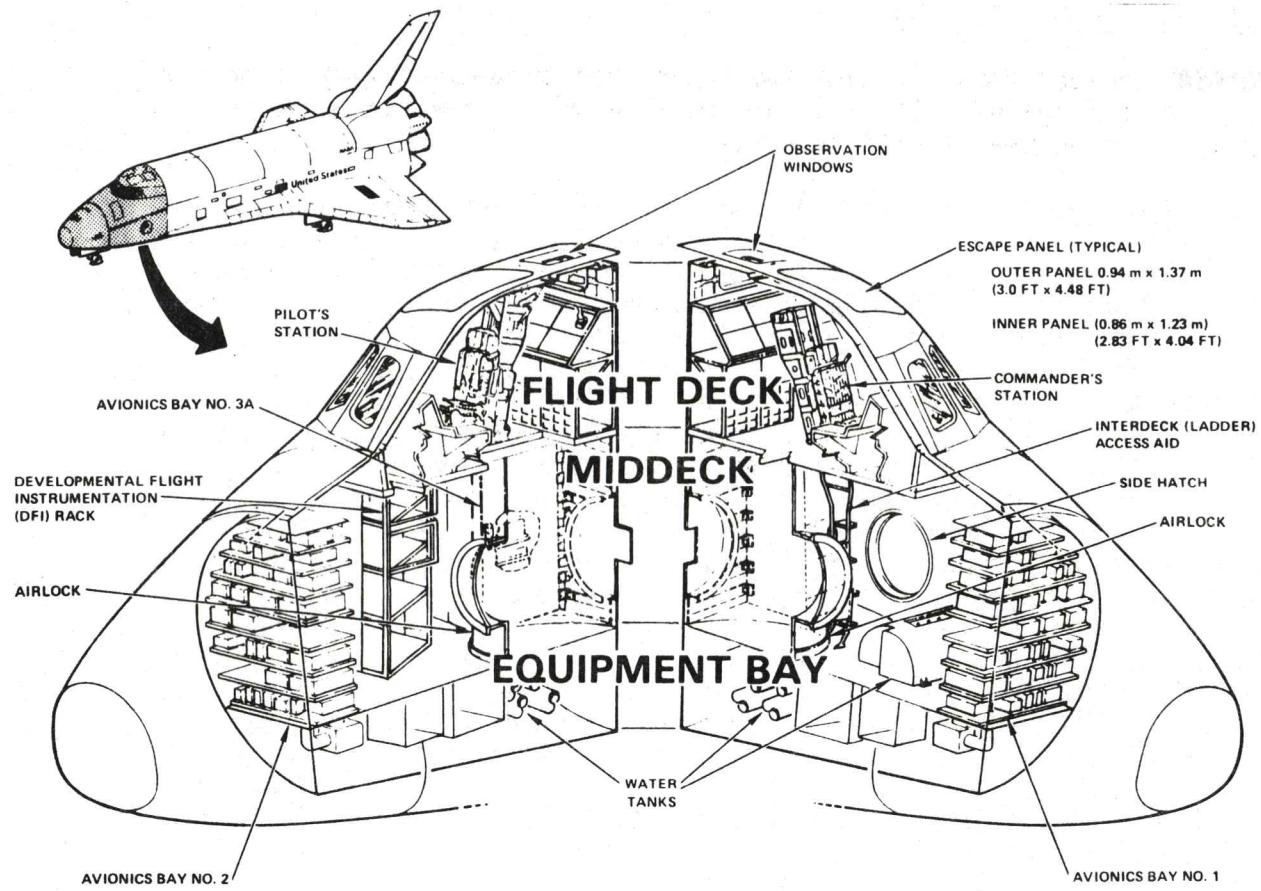


Figure 4-6.- Crew module.

#### 4.3.3 Orbiter Mid Fuselage

The mid fuselage is the primary load-carrying structure between the forward and aft fuselage. It also includes the wing carry-through structure and Main Landing Gear (MLG) supports.

The mid fuselage is also used as a payload bay. The envelope for payloads is a cylinder 60 ft long and 15 ft in diameter. Numerous attachment points along the sides and bottom of the payload bay provide for the many payloads to be accommodated. All primary attachment points along the sides accept longitudinal and vertical loads. All positions along the keel (bottom) take lateral loads. The design of the standard attachment fitting includes adjustment capability for specific payload weight distributions. The Orbiter also supplies payloads with electrical power, fluid and gas utilities, heating and cooling, and data transmission through interfaces in the mid fuselage. The deployment and retrieval of payloads can be accomplished by using a general purpose Remote Manipulator System (RMS). A 50-ft long, four-joint arm is attached at the forward end of the mid fuselage. The arm is controlled by the crew from the flight deck of the CM.

Attached to the upper portion of the mid fuselage are the two Payload Bay Doors (PLBD's) (fig. 4-7). These doors are closed during ascent and entry to protect the payload bay. The doors are opened on-orbit by the crew to deploy payloads, and are controlled from the flight deck of the CM. Attached to the inside of the doors are four radiator panels. These panels are used as the primary heat rejection system by radiating excess heat (from avionics and other equipment) into space.

The wings are attached to the mid fuselage along the bottom of the mid fuselage and the elevons are used for control of the Orbiter during reentry. The two MLG's are located in the wells in the wings.

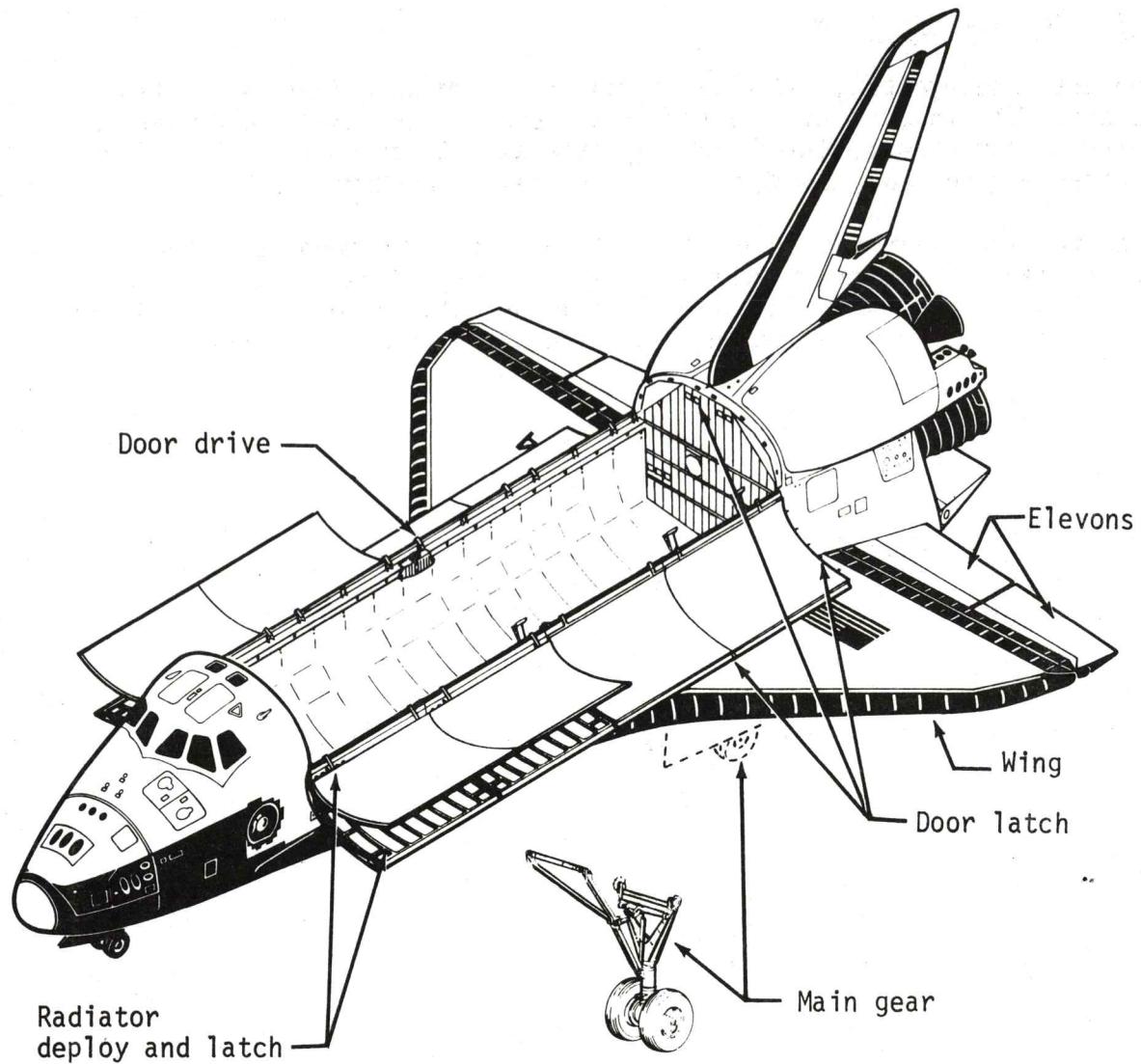


Figure 4-7.- Payload bay doors and radiators.

#### 4.3.4 Orbiter Aft Fuselage

The aft fuselage (fig. 4-8) houses the three main engines used during ascent. The thrust loads from the main engines are transmitted through a thrust structure to the ET through the two attach points and to the Orbiter mid fuselage through the outer shell structure.

A conventional aircraft vertical tail and rudder is mounted to the shell structure. The rudder is used for yaw control and can be split in two and used as a speed brake. The body flap is used to protect the main engines during reentry, and is movable to provide aerodynamic trim during entry.

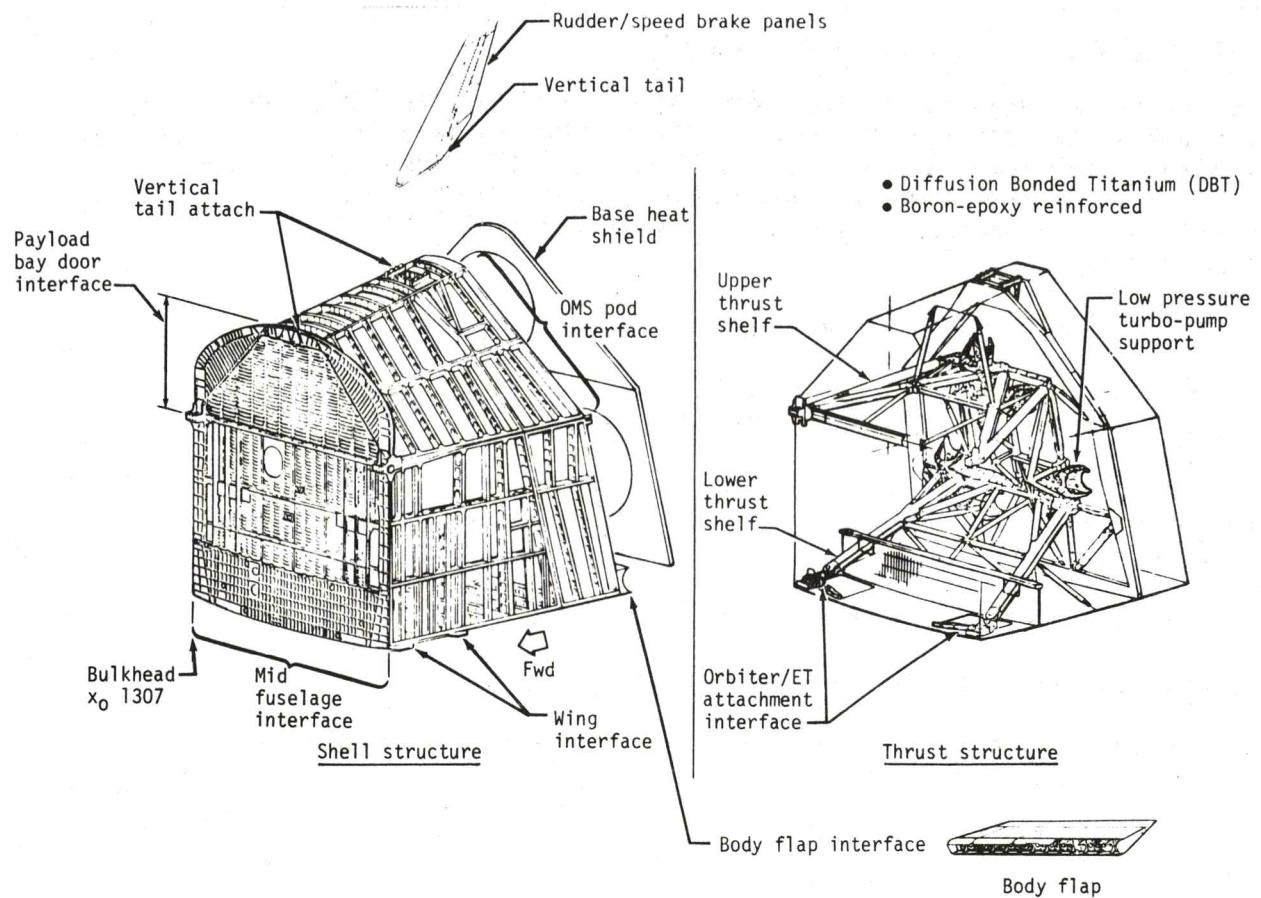


Figure 4-8.- Aft fuselage.

#### 4.3.5 Orbiter Thermal Protection System

The Thermal Protection System (TPS) (fig. 4-9) includes those materials which are installed on the outer surface of the Orbiter to protect it from the high temperatures generated during ascent and entry. The peak heating, however, occurs during entry when surface temperatures may range from 3000° F on the nose and wing leading edges to 600° F on the PLBD's and upper wing.

The TPS is composed of the following.

- Two types of reusable surface tiles - Low Temperature Reusable Surface Insulation (LRSI) and High Temperature Reusable Surface Insulation (HRSI)
- A very high temperature-resistant structure - Reinforced Carbon-Carbon (RCC)
- A flexible covering - Felt Reusable Surface Insulation (FRSI)
- Thermal window panes and high-temperature metals
- Thermal seals at the hinge lines of the rudder, elevons, body flap, PLBD's, and side hatch.

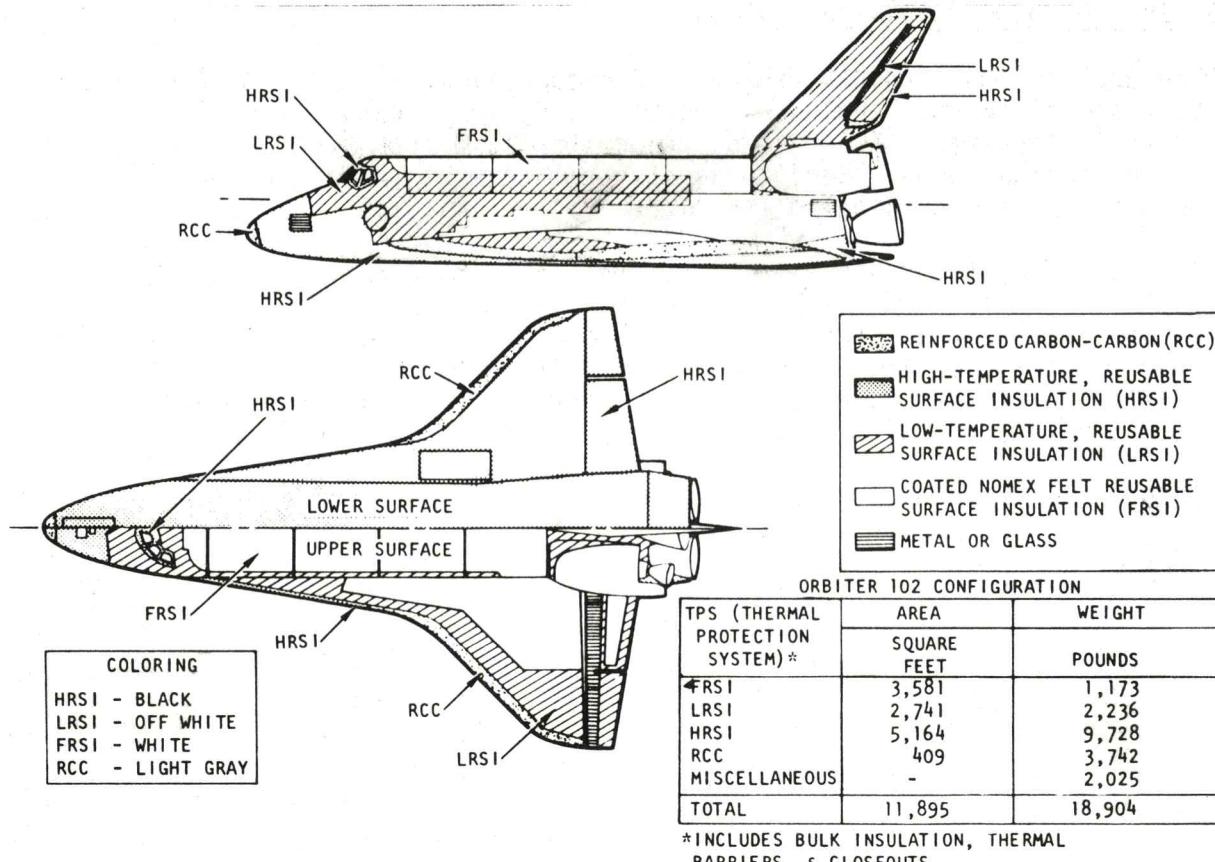


Figure 4-9.- Thermal protection system.

#### 4.3.6 Orbiter Main Propulsion System

The three Orbiter main engines are used for approximately 9 min during ascent. Each of the main engines is about 14 ft long and has a nozzle about 8 ft in diameter. The engines can be throttled from 65 to 109 percent of the nominal thrust level to limit the acceleration of the SSV. The engines can also be gimbaled for steering the vehicle.

The propellant for the engines is stored in the ET and the 17-in. feed-lines interface with the Orbiter through disconnects located in the bottom of the aft fuselage. These disconnect openings are covered by large doors immediately after the ET separates from the Orbiter. Just before launch, the ET is filled with LO<sub>2</sub> and LH<sub>2</sub> through the 8-in. fill-and-drain lines located in umbilical panels on both sides of the aft fuselage.

The MPS is shown in figure 4-10.

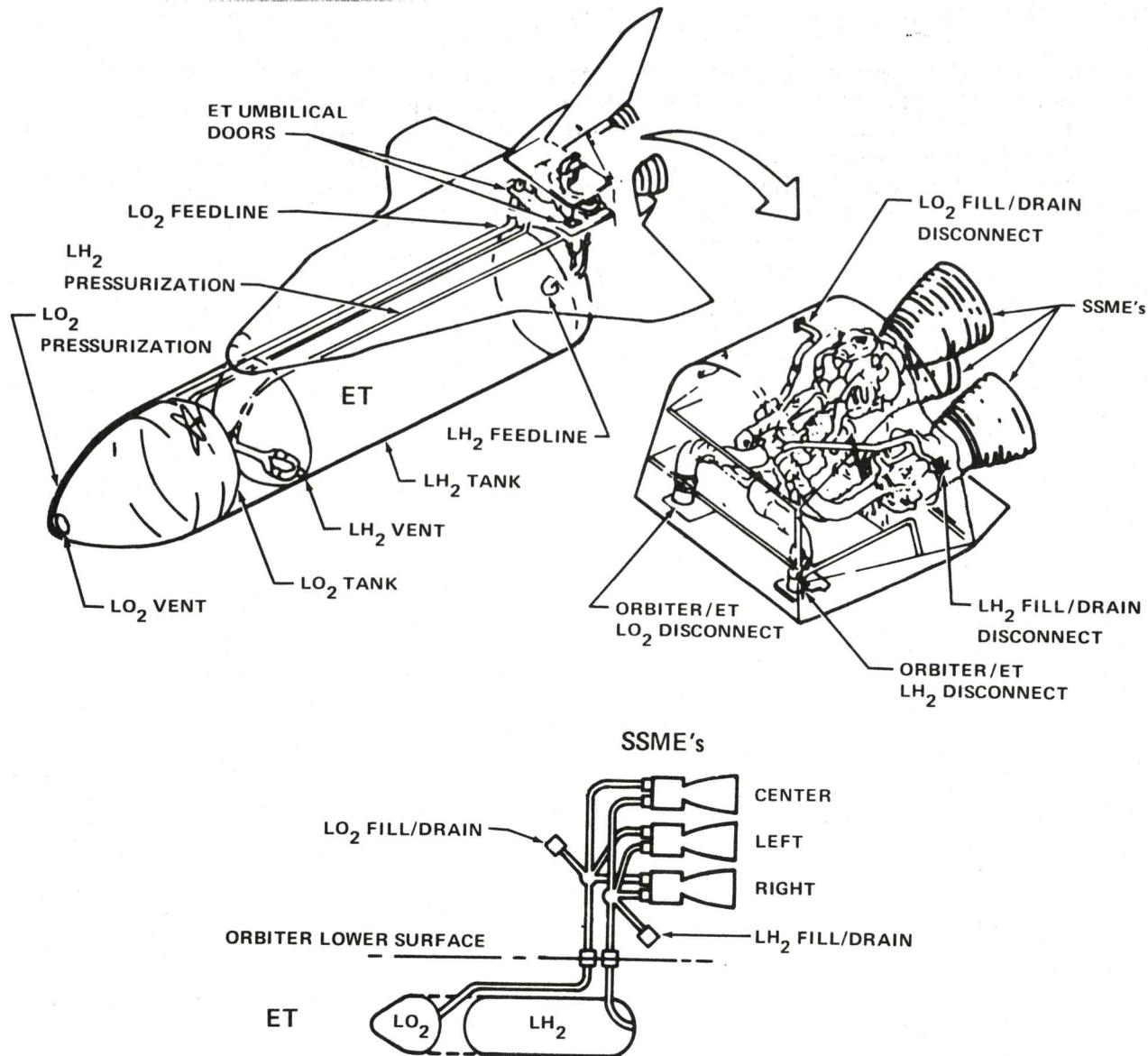
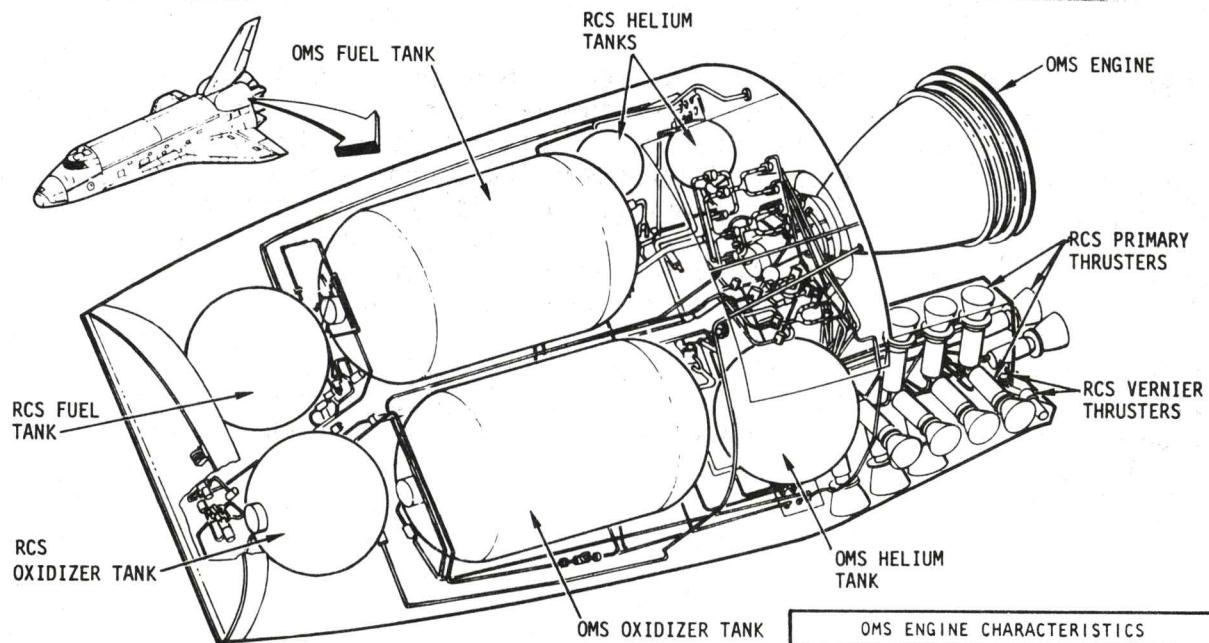


Figure 4-10.- Main propulsion system.

#### 4.3.7 Orbiter Orbital Maneuvering System

The Orbital Maneuvering System (OMS) (fig. 4-11) provides the thrust to perform orbit insertion, orbit circularization, orbit transfer, rendezvous and deorbit. The OMS engine and propellant tanks are located in two pods that are fastened to the upper portion on the aft fuselage. The OMS fuel is monomethyl hydrazine (MMH, or  $\text{CH}_3\text{NNH}_2$ ) and the oxidizer is nitrogen tetroxide ( $\text{N}_2\text{O}_4$ ). These two chemicals are hypergolic, i.e., they combust on contact. This eliminates the need for an ignition source inside the engine. Both the fuel and oxidizer tanks are pressurized with helium. The two pods are connected together by crossfeed lines in case one of the OMS engines fails. The OMS engine can be gimbaled to provide attitude control during a burn. The OMS kits, consisting of helium, fuel, and oxidizer, can be mounted in the payload bay to provide additional capability.



OMS  $\Delta V$  CAPABILITY      1000 FT/SEC (65,000 LB PAYLOAD)  
 USEABLE OMS PROPELLANT:      23,876 LB TOTAL  
                                     14,866 LB N<sub>2</sub>O<sub>4</sub>  
                                     9010 LB MMH

OMS ENGINE CHARACTERISTICS	
THRUST	6000 LB (VACUUM)
SPECIFIC IMPULSE	313 SEC
CHAMBER PRESSURE	125 PSIA
MIXTURE RATIO	1.65
GIMBAL CAPABILITY	$\begin{cases} \pm 6^\circ \text{ PITCH} \\ \pm 7^\circ \text{ YAW} \end{cases}$

Figure 4-11.- Orbital maneuvering system.

#### 4.3.8 Orbiter Reaction Control System

The Reaction Control System (RCS) is used to provide the Orbiter with attitude control on-orbit and whenever the aerosurfaces (elevons, rudder, etc.) are not effective. The RCS consists of 38 primary thrusters (870 lb vacuum thrust each) and 6 vernier thrusters (24 pounds vacuum thrust each, for fine adjustments). The 44 thrusters (or jets) are located in three propulsion modules (fig. 4-12). The jets in all three modules are used during ET separation, orbit insertion, and all orbital maneuvers. Only the jets in the two aft RCS modules are used during entry.

The RCS uses the same fuel and oxidizer as the OMS, and is also pressurized with helium. The aft RCS and OMS are located in the same pods. Although they are independent systems, they can be interconnected in case of failures.

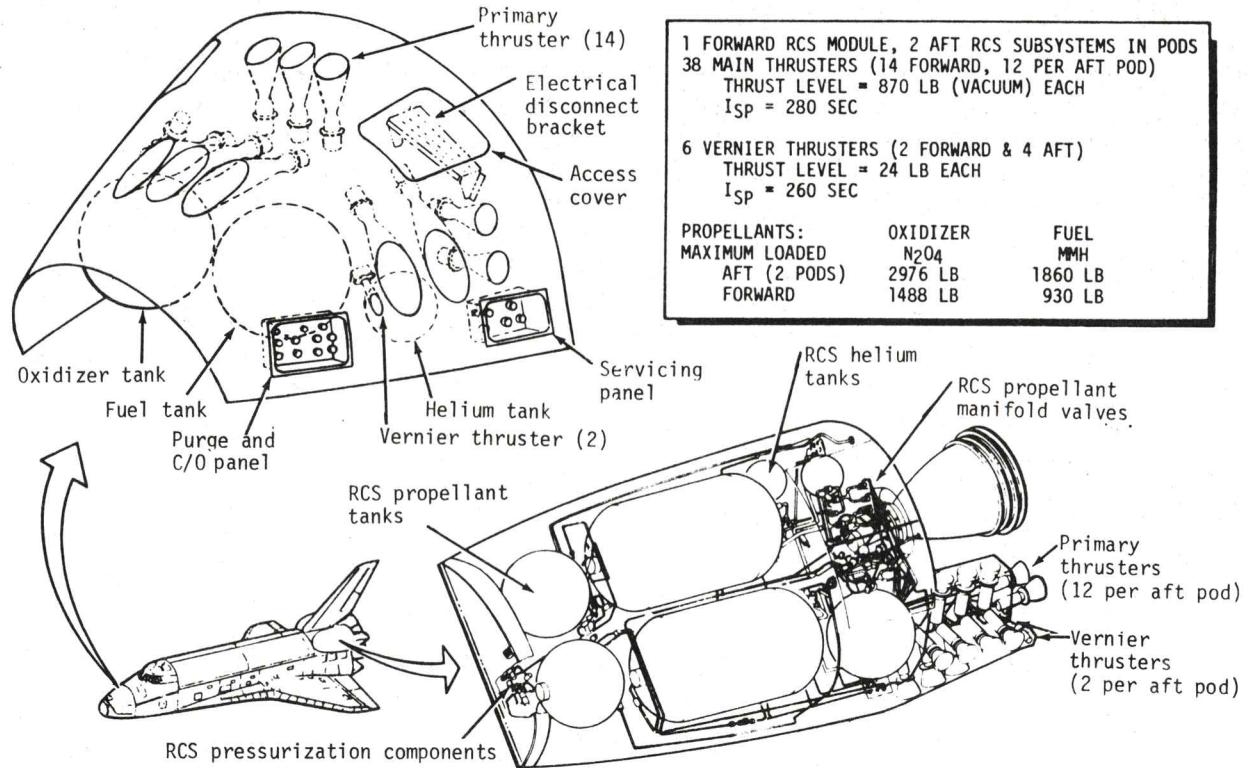
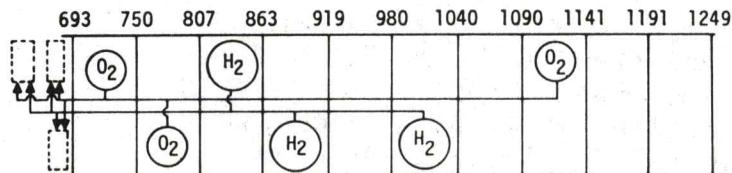


Figure 4-12.- Reaction control system.

#### 4.3.9 Orbiter Electrical Power System

Electrical power (fig. 4-13) for the Orbiter is generated by three separate Fuel Cells (FC's) that use cryogenically stored hydrogen and oxygen reactants. When liquid hydrogen and liquid oxygen are mixed (with a catalyst) in each FC, the chemical reaction forms electricity, heat, and water. The direct current (dc) power is used for everything from computers to lights in the Orbiter, and is also converted by inverters to alternating current (ac) power for all electromechanical actuators. Additional kits containing hydrogen and oxygen can be installed to increase the power for Orbiter equipment or payloads, or to provide for longer duration flights.

Electrical power is distributed by a network of three main dc buses, each of which is connected to an FC. Critical systems use two or three main dc buses for redundancy, and all three buses are protected by Remote Power Controllers (RPC's) and circuit breakers.



#### FCP SUBSYSTEM

- 14 KW CONTINUOUS/24 KW PEAK
- 27.5 TO 32.5 VDC

#### REACTANT STORAGE

- 2370 KWH DELIVERED ENERGY
- 168 POUNDS O<sub>2</sub> FOR ECLSS
- 92 LB H<sub>2</sub>/TANK } TOTAL LOADED
- 781 LB O<sub>2</sub>/TANK } QUANTITY/TANK

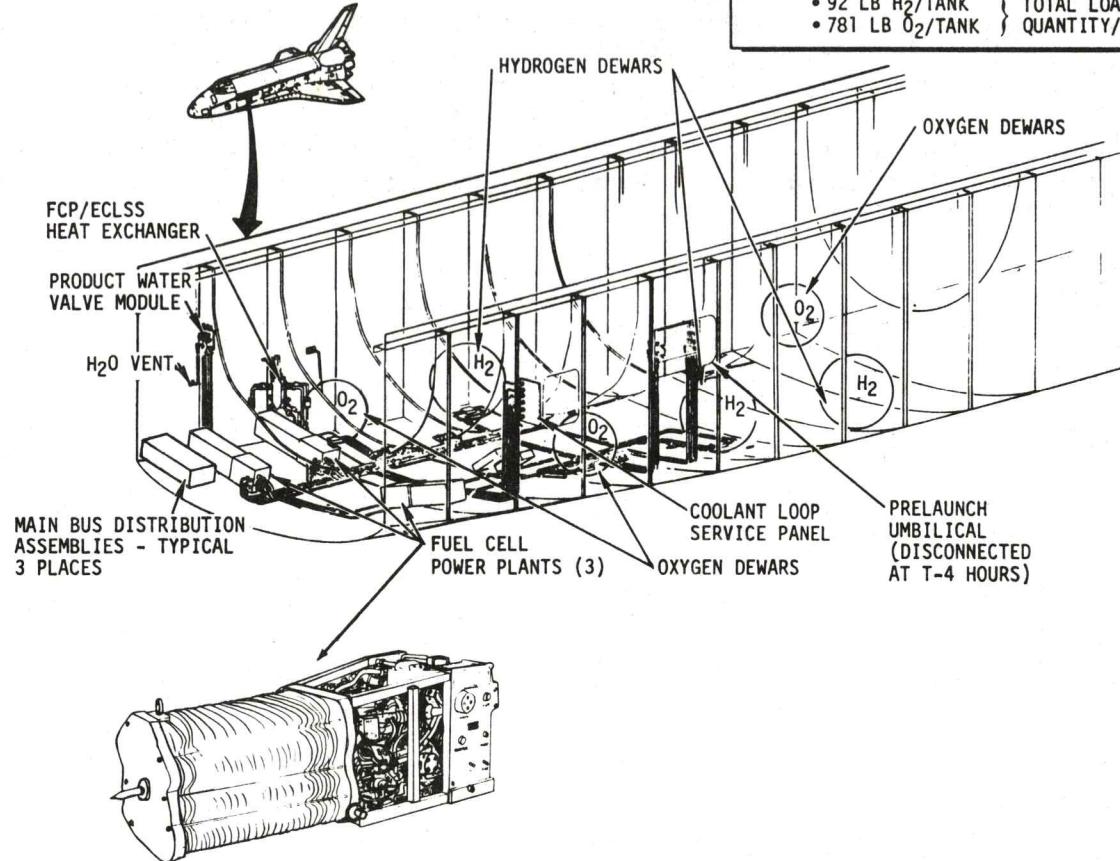


Figure 4-13.- Electrical power system.

#### 4.3.10 Orbiter Hydraulic System and Auxiliary Power Unit

There are three independent hydraulic systems which drive the aerosurfaces (rudder, speed brake, elevons, and body flaps), the main engine control valves and gimbal actuators, the brakes, nosewheel steering, and landing gear deployment. Each hydraulic system operates at 3000 psi and derives its pressure from a main pump. The only source of power for each main pump is an Auxiliary Power Unit (APU). The three APU's use hydrazine that is stored in separate fuel tanks. The hydrazine is decomposed in a gas generator (using a catalyst), and the hot gases drive a turbine, which, through a gearbox, drives the main pump. Each APU/hydraulic system (fig. 4-14) uses a water boiler to cool the APU gearbox lube oil and hydraulic fluid. All three systems are used for about 15 min during ascent, and about 1 hr during entry.

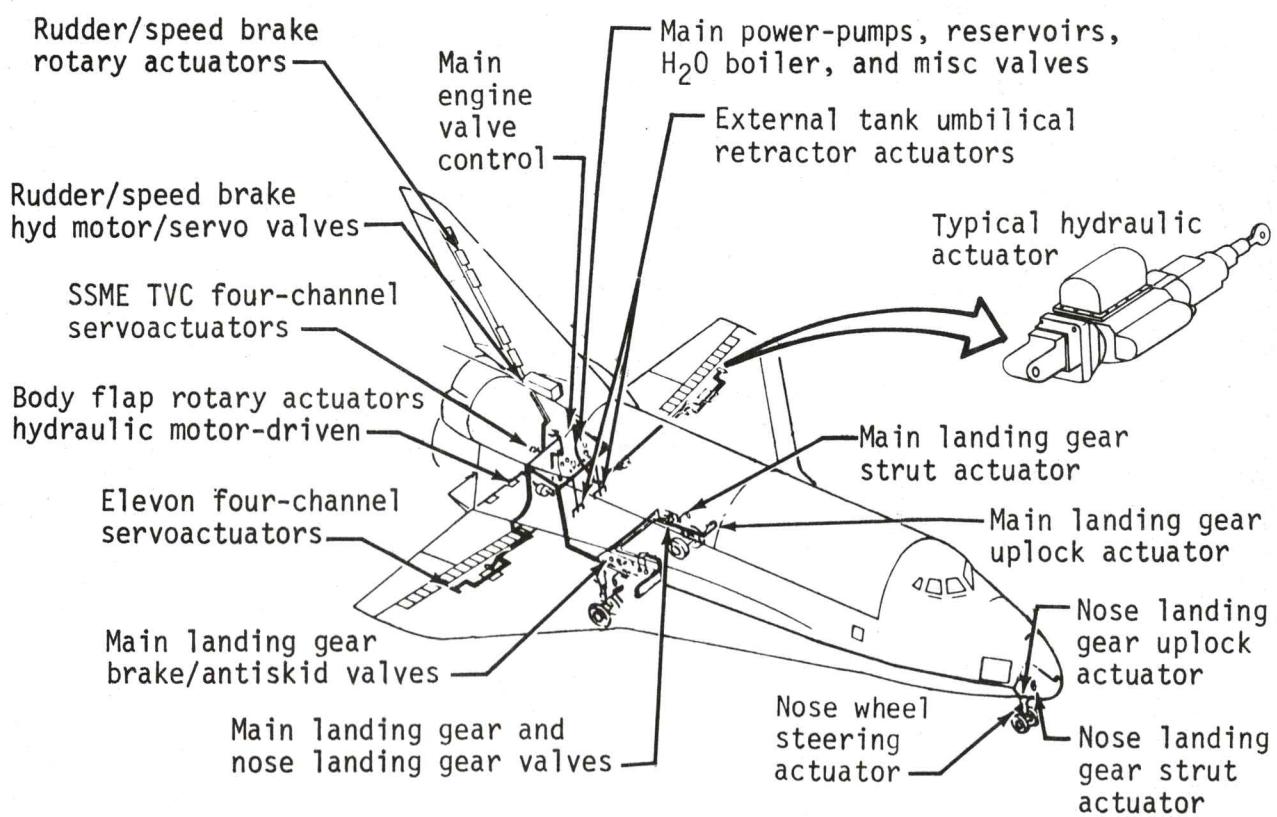
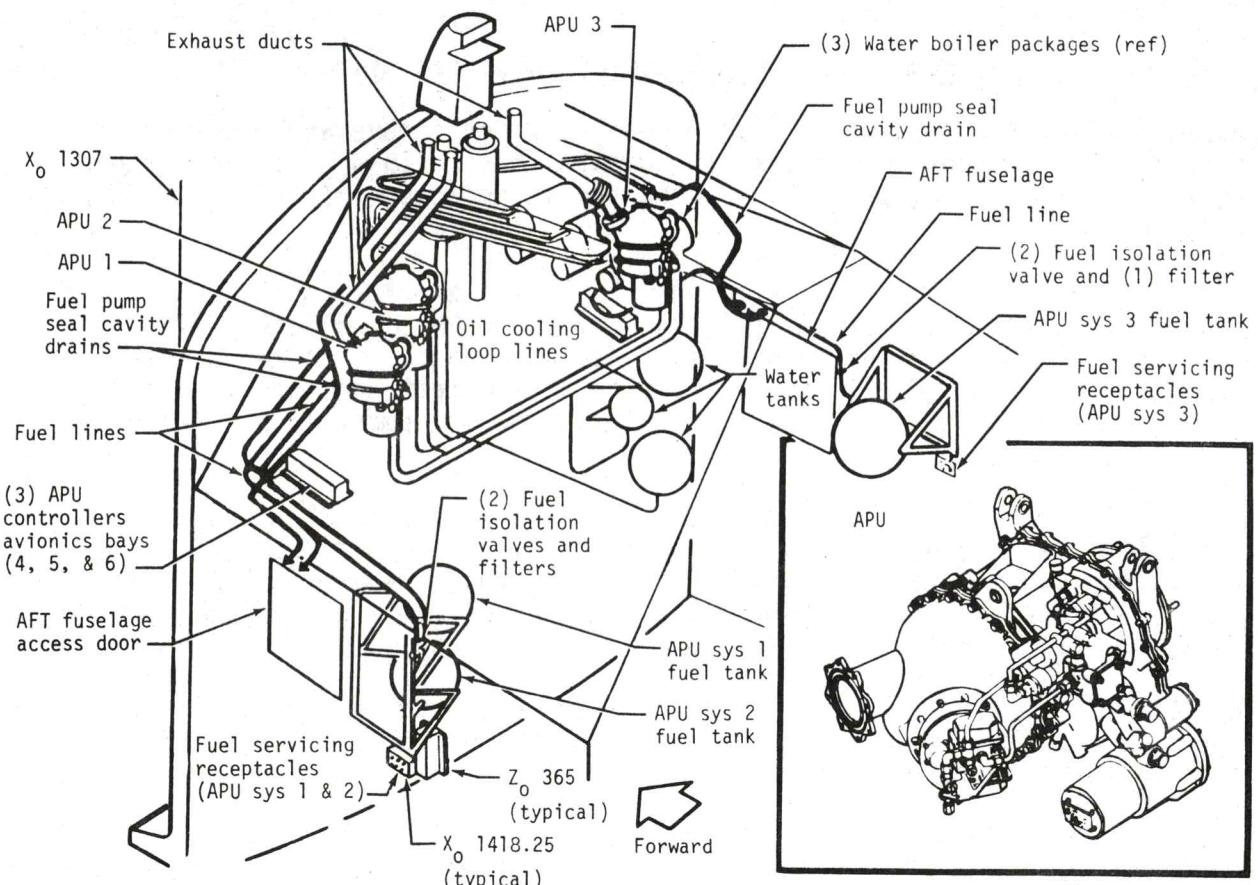


Figure 4-14.- Hydraulic system and auxiliary power unit.

#### 4.3.11 Orbiter Environmental Control and Life Support Systems

The ECLSS (fig. 4-15) provides a comfortable, shirt-sleeve environment inside the CM and rids the Orbiter of unwanted heat. This system operates continuously throughout the flight. The two major components of ECLSS are the following.

- Atmosphere Revitalization System (ARS). This system circulates the air in the CM, filters it over lithium hydroxide (LiOH), cools the avionics equipment, and is cooled by the cabin heat exchanger. The cabin heat exchanger uses water chilled by the water/Freon heat exchanger. The chilled water is also used to remove heat from equipment in the three avionics bays.
- Active Thermal Control System (ATCS). This system uses Freon 21 to remove heat from avionics bays in the mid fuselage and aft fuselage, the FC's, and the ARS water loop. The Freon is cooled by means of an ammonia boiler (below 100,000 ft), a flash evaporator (above 100,000 ft), and the radiators on the PLBD's (while on-orbit).

The cabin air is cooled by two water loops which are cooled by two Freon loops. This effectively isolates the CM atmosphere from possible contamination by Freon in case of a leak.

The cryogenically stored oxygen (also used for the FC's) is mixed with cryogenically stored nitrogen and the mixture is regulated down to 14.7 psi for the CM atmosphere. This is the Pressure Control System (PCS). The water formed in the FC's is used for drinking water and is chilled by the Freon heat exchanger. This water is also used to feed the flash evaporators.

The unpressurized compartments in the Orbiter are controlled by the Purge Vent and Drain System (PVDS). Small vent doors along the sides of the Orbiter open and close to relieve the rapid pressure changes associated with ascent and entry. These vent doors are closed during the high heating period of reentry to protect the payload and internal structure. Venting the Orbiter in this way allows a lightweight, economical structure. These same compartments are purged with cool, dry, nitrogen (or other inert gases) to control the temperature and humidity. Purging also dilutes any hazardous gases that may be present in the compartments.

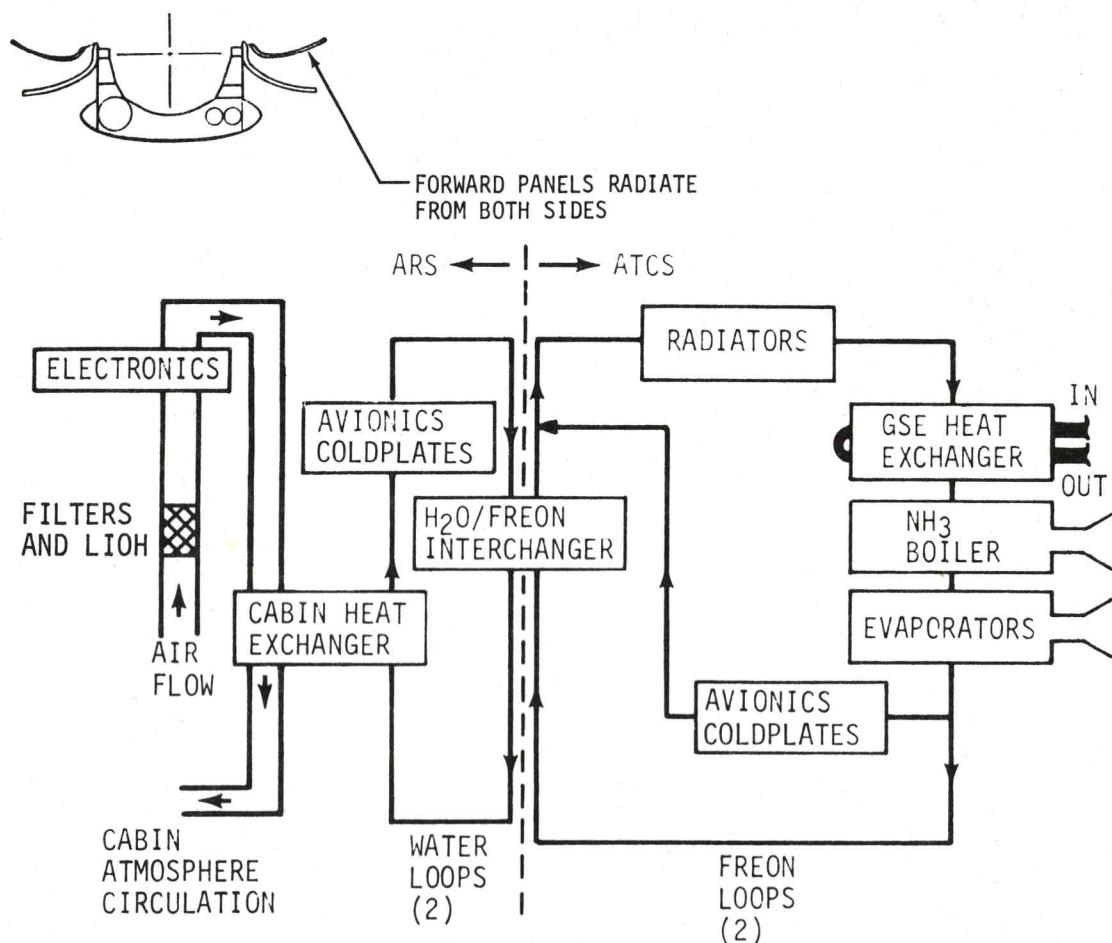
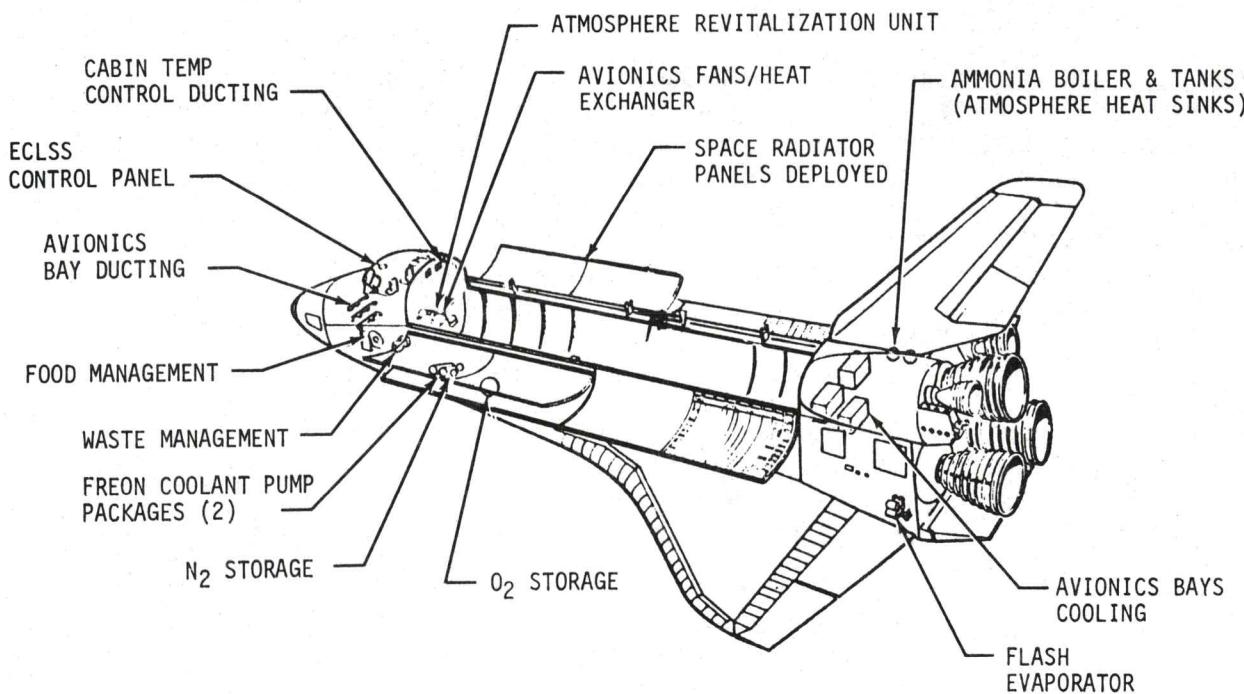


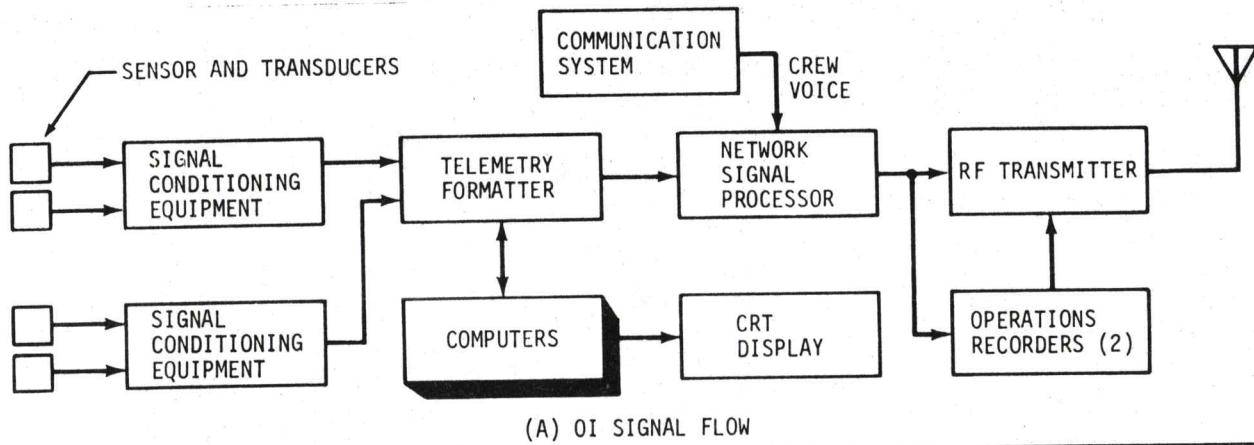
Figure 4-15.- Environmental control and life support systems.

#### 4.3.12 Orbiter Instrumentation System

The Operational Instrumentation (OI) system (fig. 4-16) senses, conditions, digitizes, formats, and distributes data for all the Orbiter systems. There are special-purpose sensors and transducers for vibration, temperatures, pressures, voltage, and power measurements. Signal conditioning equipment is used to convert the voltages produced by transducers into digital data for use by the computers and the Caution and Warning (C&W) system. A telemetry formatter receives these digital data and arranges the parameters in the proper order for sequential transmission to the Network Signal Processor (NSP). The telemetry formatter also sends these parameters to the computer. The computer monitors the data (for backup C&W and Systems Management (SM) alerts) and displays the data to the crew. The NSP mixes crew voice and sensor data and sends the composite signal to the Radio Frequency (RF) transmitter (which sends data to the ground stations) and to the two operations recorders. Ground stations relay the data to the MCC where flight controllers analyze the data to assist the crew. The data stored on the two operations recorders can be played back (dumped) and the data transmitted to ground stations. (Data can be recorded when the Orbiter is not over a ground station.)

A separate, additional Development Flight Instrumentation (DFI) system will be used on early flights of the Shuttle. The DFI will be removed after the development phase of the program. The DFI sensors and transducers are located throughout the Orbiter and provide additional data not covered by the OI system.

The DFI is similar to the OI in function; however, the data are not transmitted to the computers (or displayed to the crew). The DFI data are transmitted to the ground through a special transmitter. The two wide-band recorders are used to record analog data, and the DFI recorder is used to record digital (and formatted) data. These recorders can only be dumped while the Orbiter is on the ground.



(A) OI SIGNAL FLOW

(B) DFI SIGNAL FLOW

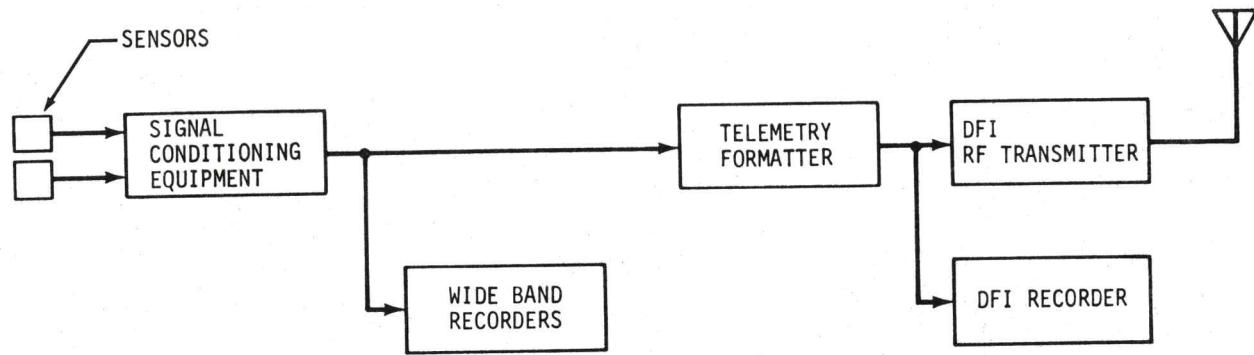


Figure 4-16.- Instrumentation system.

#### 4.3.13 Orbiter Caution and Warning System

The C&W system (fig. 4-17) uses audio and visual alerts to inform the crew of out-of-limit conditions and emergency situations.

The primary C&W hardware system senses temperatures, pressures, quantities, etc., from the various systems in the Orbiter. A failure of a component or out-of-limit condition will cause an audio alarm, illuminate a master alarm pushbutton indicator (pbi), and illuminate one of the 40 lights on the annunciator matrix located on the forward instrument panel of the flight deck. The backup C&W software system uses separate transducers for many of the same temperatures, pressures, and quantities as the primary system; however, software (programs) in the General Purpose Computers (GPC's) is used to sense out-of-limit conditions and generate alarms (not to be confused with the Backup Flight System (BFS)). The SM alert system also uses software in the computers to inform the crew of a situation which may be leading up to a C&W alarm, or a situation which may require additional procedures. (This software is referred to as the SM major function.)

The fire and smoke emergency system consists of three permanent fire extinguishers, located in the avionics bays in the middeck, and smoke detectors located throughout the CM. Portable fire extinguishers are also strategically located in the CM.

The rapid delta pressure emergency system uses a sensor mounted in the middeck to alert the crew when the CM pressure is changing at a greater than normal rate (i.e.,  $\Delta P/dt >$  some value).

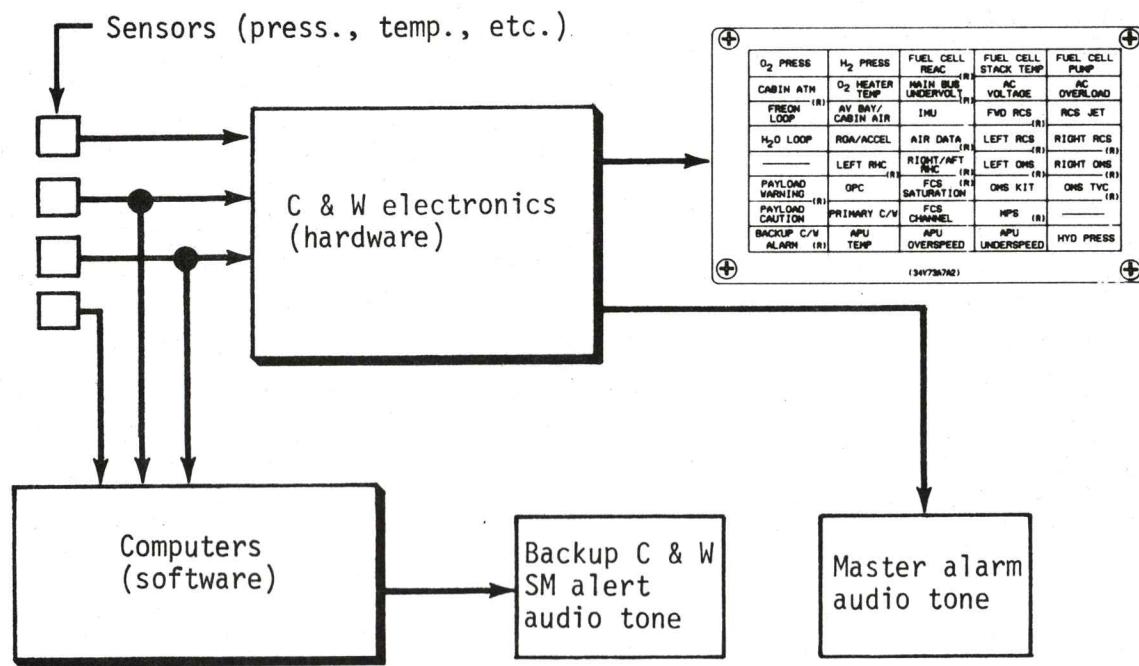
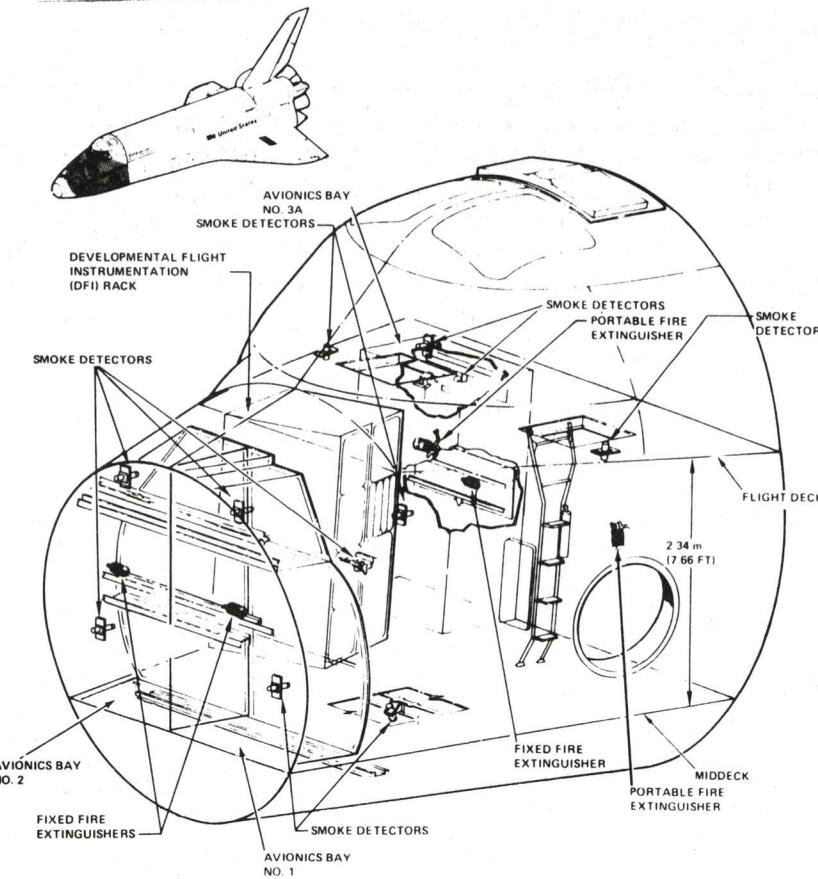


Figure 4-17.- Caution and warning system.

#### 4.3.14 Orbiter Closed Circuit Television System

The Closed Circuit Television (CCTV) system (fig. 4-18) provides the capability to visually document a wide variety of on-orbit activities. Cameras mounted in the payload bay are used to monitor vehicle hardware and environment and to aid in payload berthing and deployment. Cameras mounted on the RMS are used to aid the crew in grappling a satellite. Remote cameras in the CM are used to monitor crew activities and various hardware inspections. All video data are available to the crew, can be recorded on standard video cassettes, and can be transmitted to the ground. The onboard video is black-and-white. Special processing on the ground can convert the video signals to color for use by the flight controllers or national television networks.

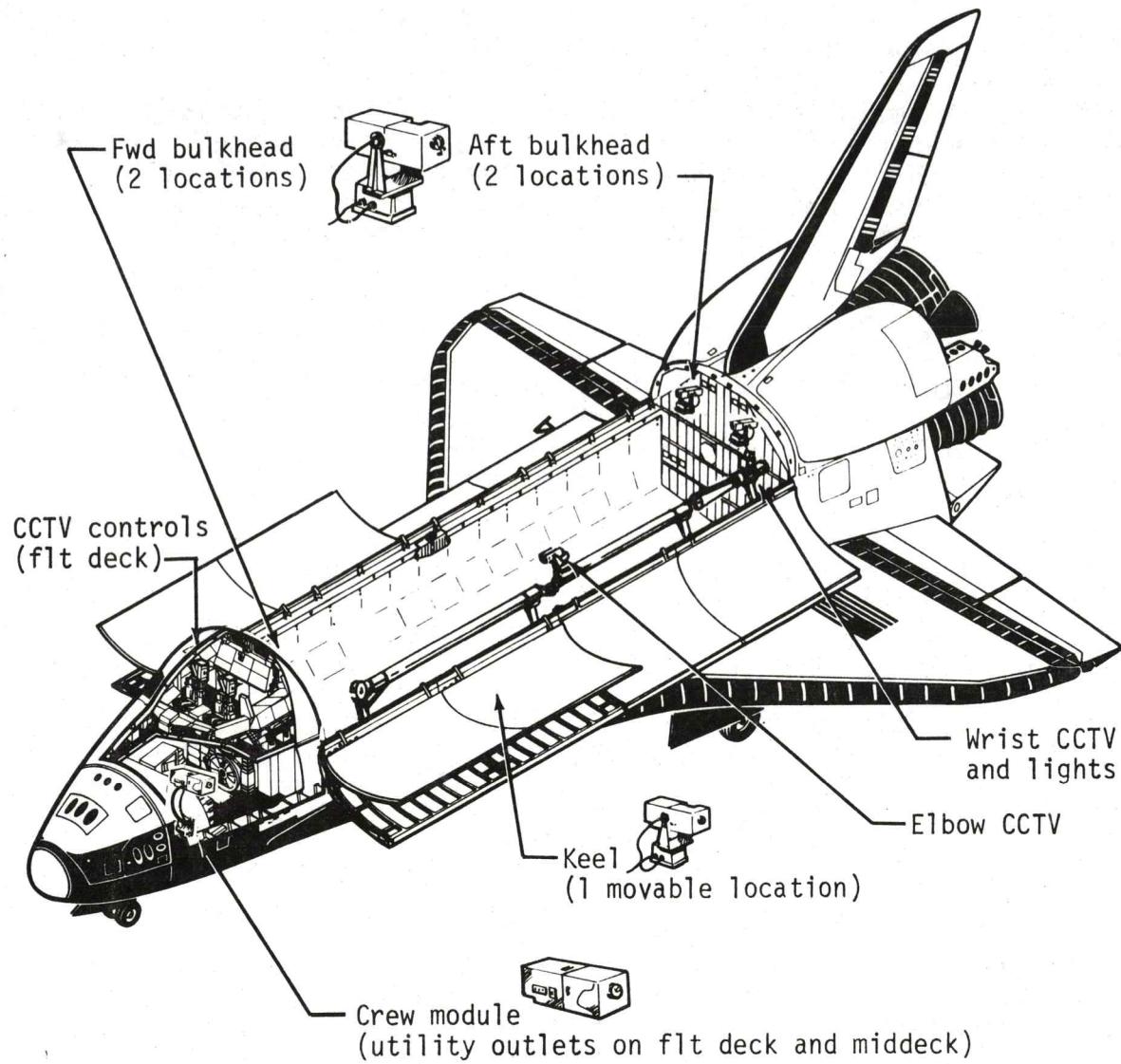
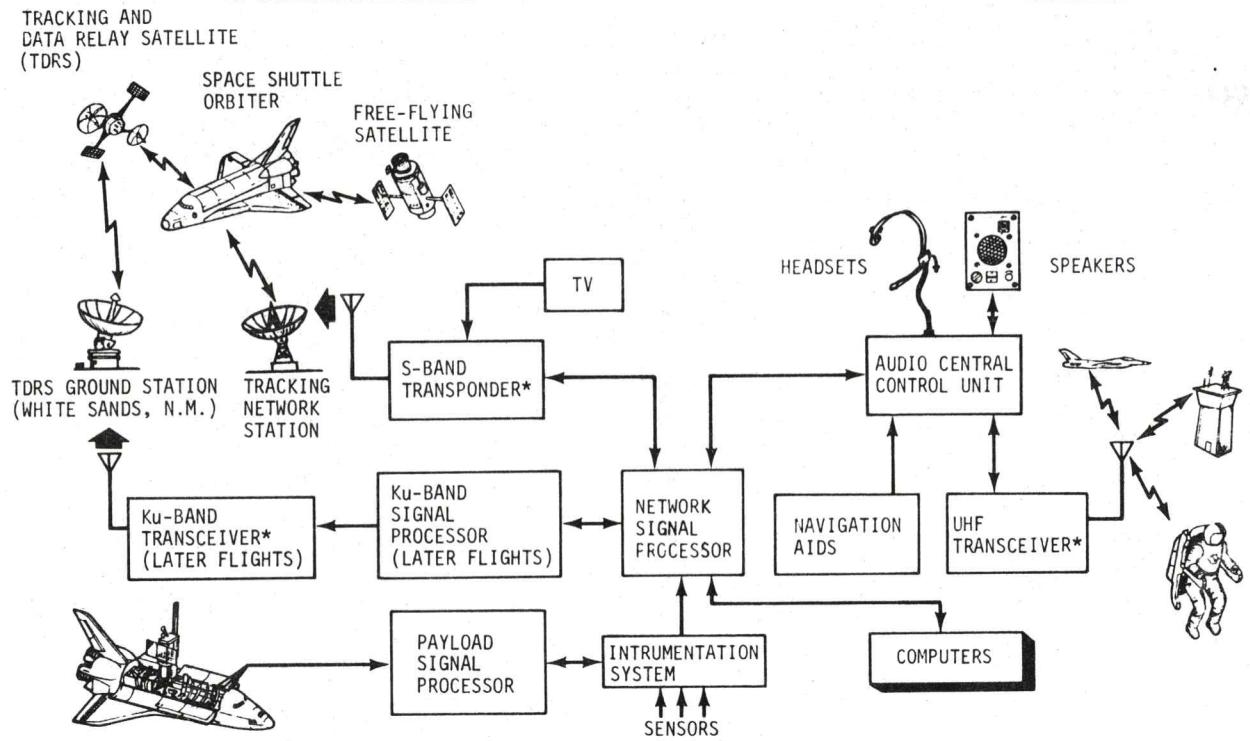


Figure 4-18.- Closed circuit television system.

#### 4.3.15 Orbiter Communications and Tracking System

The Communications and Tracking (C&T) system (fig. 4-19) provides voice and data exchange between the Orbiter, payloads, and ground personnel. Signals from the Orbiter to the ground are called downlink (voice, telemetry, and video information). Signals from the ground to the Orbiter are called uplink (voice and commands, or inputs, to the computers). The major components are the following.

- **Audio Distribution System (ADS).** This system uses a switchboard called the Audio Central Control Unit (ACCU) to route crew intercomm through the headsets and speakers, route crew voice for downlink, route uplinked voice data to the headsets and speakers, send C&W audio tones to the headsets and speakers, and route navigation aid identification tones to the headsets and speakers.
- **Ultrahigh Frequency (UHF) system.** This system is used during approach and landing for voice communication with the control tower and chase aircraft. On flights that require EVA, the UHF system will be used between the Orbiter and EVA spacesuit. The UHF system is also used as a backup for the S-band system.
- **S-band system.** This system provides the main link between the Orbiter and ground during the development phase of the program. All voice, telemetry, and television data are downlinked via the S-band system. All voice and commands to the computers are also uplinked via the S-band system. The S-band system uses a Phase Modulated (PM) transponder for digital data, and two Frequency Modulated (FM) transmitters for TV and analog data.
- **Ku-band system.** This system will be used on later flights. Two TDRS's in geocentric orbits will provide the uplinks and downlinks between the Orbiter and ground. The Ku-band system can also be used as onboard radar for tracking and rendezvous with other satellites.



\* NOTE : A TRANSCEIVER CAN TRANSMIT AND RECEIVE VOICE AND DATA.

A TRANSPOUNDER CAN ALSO TRANSMIT AND RECEIVE; HOWEVER, THE INCOMING AND OUTGOING SIGNALS ARE INTERLOCKED SO THE GROUND STATION CAN USE THE DOPPLER EFFECT TO CALCULATE THE ORBITER'S VELOCITY AND POSITION.

Figure 4-19.- Communications and tracking system.

#### 4.3.16 Orbiter Data Processing System

The Data Processing System (DPS) (fig. 4-20) is the "brains" of the Space Shuttle. There are five GPC's used for controlling and monitoring the Orbiter. The GPC's support guidance, navigation, and flight control, including calculation of trajectories, engine burn data, and vehicle attitude control data. The DPS also monitors and controls vehicle systems (RCS, EPS, ECLSS, etc.), and processes data for transmission to the ground. The vehicle can be controlled from the ground by using uplinked commands to the GPC's. The major components of the DPS are the following.

- GPC's. The GPC's do all the work of the DPS with programs or software. Each GPC is made up of an IBM model AP-101 Central Processor Unit (CPU) and an IBM model 4-PI Input/Output Processor (IOP). Each has some memory and, together, they comprise what is referred to as main memory.
- Mass Memory Unit (MMU). There are two MMU's onboard. Each is a magnetic tape recorder which provides the GPC's with large volume data storage. Each MMU contains all of the Cathode Ray Tube (CRT) display backgrounds and a duplicate copy of all the flight software.
- Multifunction CRT Display System (MCDS). This system consists of CRT's and keyboards (and associated electronics) which enable the crew to monitor and control GPC software. The MCDS also provides the crew with the capability to observe and control vehicle systems (instrumentation, RCS, hydraulics, etc.).
- Data Bus Network (DBN). The DBN is actually miles of shielded wires which transmit data between the GPC's and the rest of the Orbiter. The DBN is subdivided into several specific bus groups which connect GPC's to GPC's, MCDS to GPC's, and so on.
- Multiplexer/Demultiplexer (MDM). The MDM's convert (and format or arrange) parallel data from the Orbiter systems (RCS, MPS, COMM, etc.) to serial-digital data for processing by the GPC's. They also reverse the conversion and formatting function so the GPC's can control the various Orbiter systems.

During critical phases of the mission (ascent and entry), up to four of the GPC's operate redundantly as the Primary Avionics Software System (PASS). A fifth GPC contains special standby software called the Backup Flight System (BFS). The BFS will be engaged, and take control of the SSV, for certain failures of the PASS.

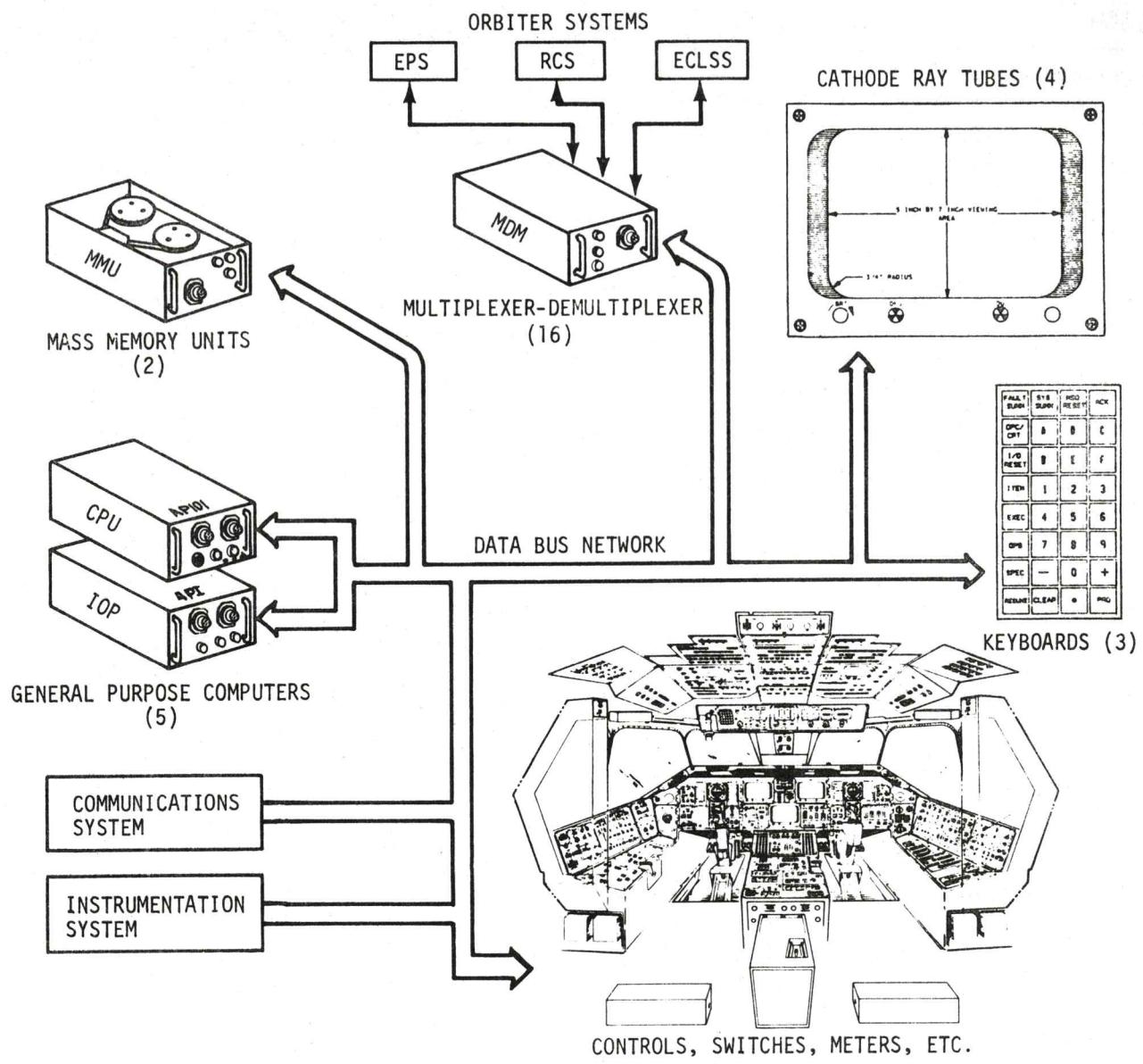


Figure 4-20.- Data processing system.

#### 4.3.17 Orbiter Guidance, Navigation, and Control

Guidance, Navigation, and Control (GNC) are interrelated functions performed by GPC software, executing redundantly in up to four GPC's at a time. Guidance is where you want to be, navigation is where you really are, and flight control is how you get there. Guidance, navigation, and flight control sensors are depicted in figure 4-21.

Guidance software contains equations and tables of numbers which will guide the Shuttle to some desired position and velocity. For example, first-stage ascent guidance is designed to steer the Shuttle to the proper altitude and velocity for SRB separation. This is usually referred to as automatic, or AUTO, guidance. The crew can steer the SSV with hand controllers, and this is called manual or Control Stick Steering (CSS) guidance.

The function of navigation is to maintain an accurate estimate of the Shuttle's current position and velocity. This is called a state vector. The state vector is mathematically determined from equations of motion using sensed velocity changes from the Inertial Measurement Units (IMU's). The alignment of the IMU and, hence, the accuracy of the state vector, deteriorate with time. The Crewman Optical Alignment Sight (COAS) and star trackers are celestial navigation instruments which are used to realign the IMU's while on-orbit. During TAEM, data from four navigation aids are blended into the state vector to provide the accuracy necessary to bring the Orbiter to a pinpoint landing. The Air Data System (ADS) provides airspeed and barometric altitude. The Tactical Air Navigation (TACAN) system furnishes slant range and magnetic bearing to various fixed stations around the landing site. The Radar Altimeter (RA) measures altitude above the nearest ground object. The Microwave Landing System (MLS) provides the slant range, azimuth, and elevation of the Orbiter from the end of the runway.

Flight control software issues commands to effectors, such as the main engines, SRB's, RCS jets, and aerosurfaces, depending on flight phase. The purpose of flight control is to keep the Shuttle under control and to make changes to the trajectory if required. Flight control receives commands from AUTO or CSS guidance and converts them into effector commands based on the acceleration, rate, and attitude of the Shuttle. Normal and lateral acceleration data are supplied by the Accelerometer Assemblies (AA's). Roll, pitch, and yaw body rates are supplied by the Rate Gyro Assemblies (RGA's). Attitude data are supplied by the IMU's.

GNC software requires only one number from each of the sets of sensors. However, there are three (or four) sensors operating redundantly, and they could disagree slightly. To avoid this situation, a separate set of software called Redundancy Management (RM) cooperates with GNC software to resolve differences between conflicting sensors and deselect sensors which have failed.

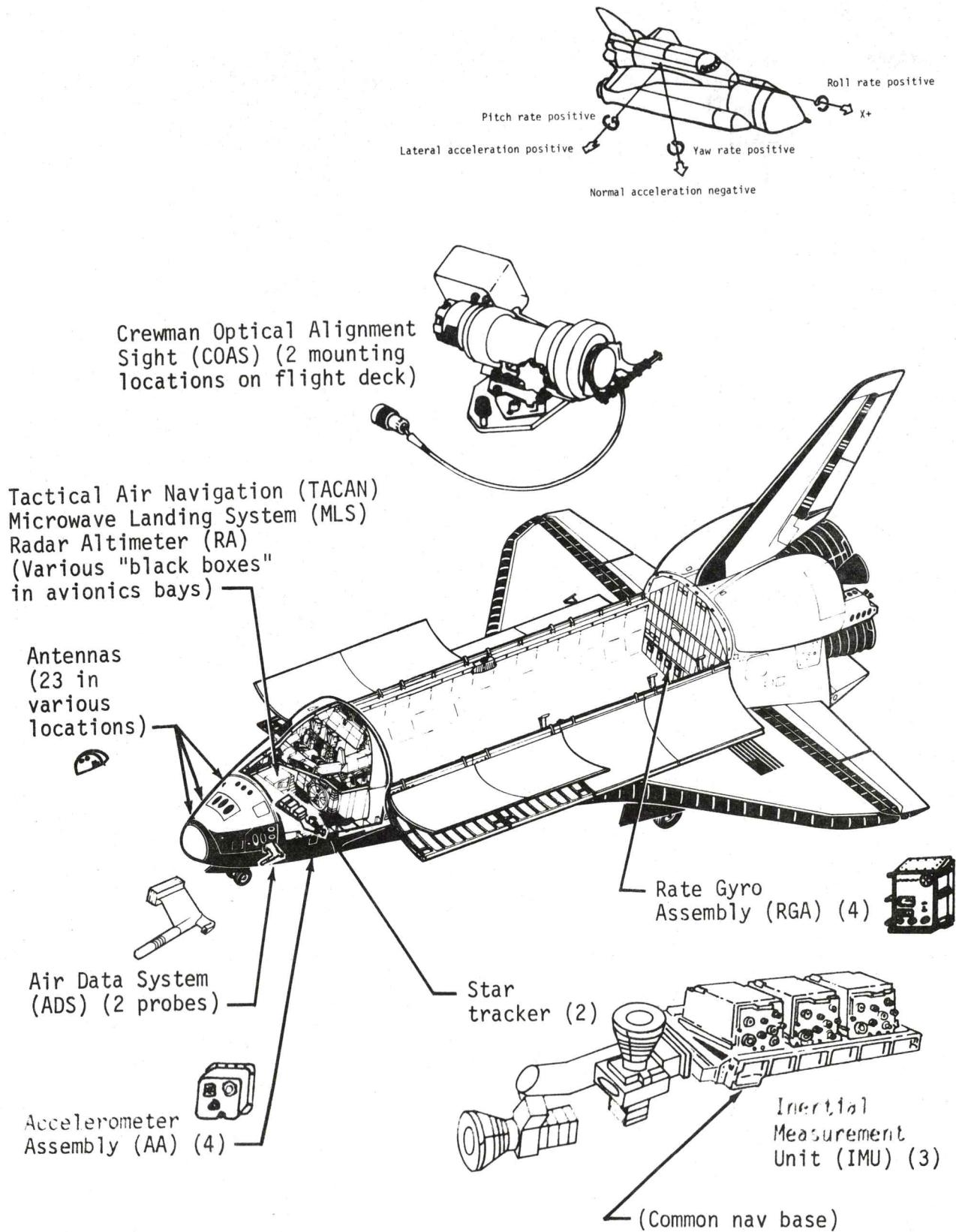


Figure 4-21.- Guidance, navigation, and flight control sensors.

#### 4.3.18 Orbiter Extravehicular Activity

Anytime a crewmember is required to leave the CM to perform EVA, that crewmember must be protected from the vacuum and harsh environment of space. The EVA Mobility Unit (EMU) is stowed in the Orbiter's airlock, and is a kind of mini-spacecraft. The EMU consists of a suit (gloves, helmet, etc.), and a backpack (oxygen, water, and communications gear). The module worn on the chest contains controls and displays (switches, meters, etc.) used to monitor the life support systems of the EMU. Umbilical lines with tether hooks connect the EMU to the Orbiter.

The airlock provides access to space through the payload bay without depressurizing the entire CM. The airlock may be mounted inside the crew module or in the payload bay.

For extensive EVA the Orbiter will have onboard a self-contained propulsion device called the Manned Maneuvering Unit (MMU). The MMU uses low-thrust, dry nitrogen for mobility and attitude control. It also has electrical outlets for power tools, lights, and other equipment. The MMU is stowed in the payload bay and is designed to fit over the backpack of the EMU. (A crewmember simply backs into the MMU and latches it onto the EMU.) The MMU can be operated untethered (no umbilicals) to reach all parts of the Orbiter for inspection, repair, or monitoring equipment.

Various handholds throughout the payload bay and on the bulkheads aid the crewmember performing EVA. A Modular Equipment Stowage Assembly (MESA) installed in the payload bay contains the tools and hardware that may be required during EVA.

An EVA may be planned before launch as part of the mission. Contingency EVA may be required to repair Orbiter hardware.

The EVA equipment is shown in figure 4-22.

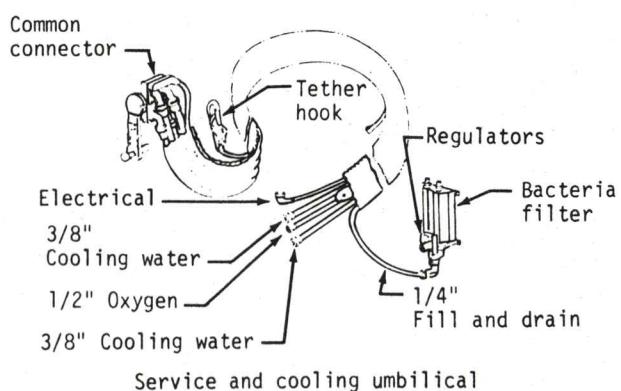
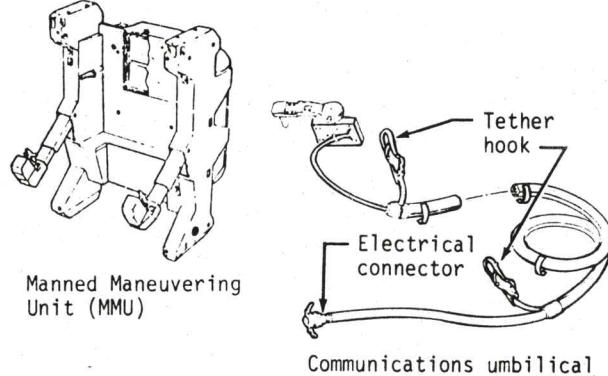
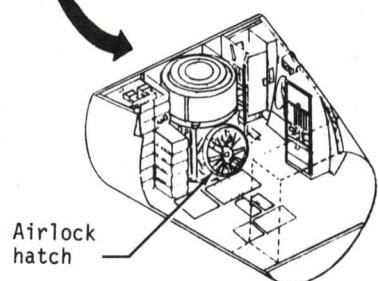
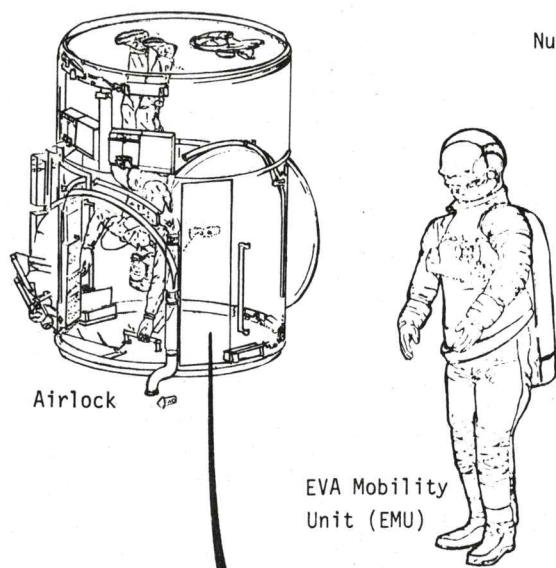
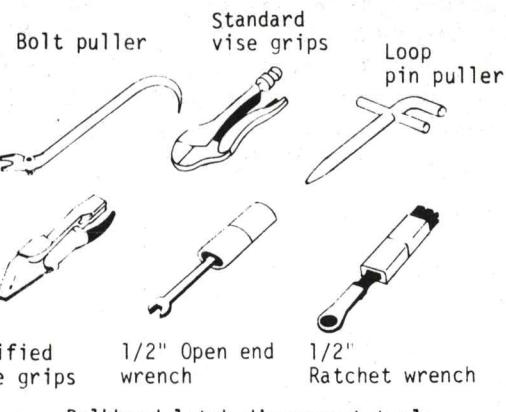
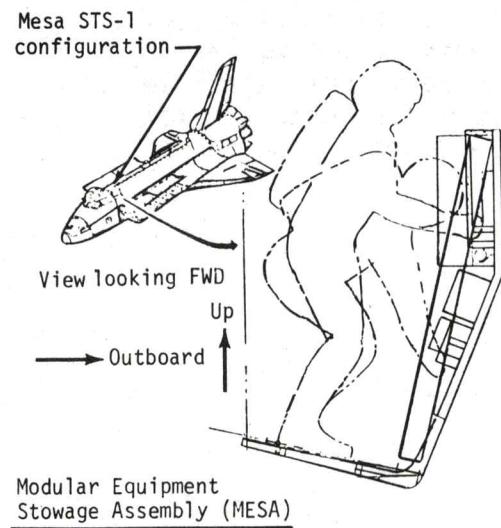


Figure 4-22.- Extravehicular activity equipment.

#### 4.3.19 Orbiter Flight Data File

Experience gained from the Apollo program has shown that all crew activity during a mission had to be optimized to achieve as many objectives as possible and still maintain efficiency and safety. The Flight Data File (FDF), consisting of various checklists, charts, reference data, and log books will be carried onboard the Orbiter for each mission. Typical FDF items may be seen in figure 4-23.

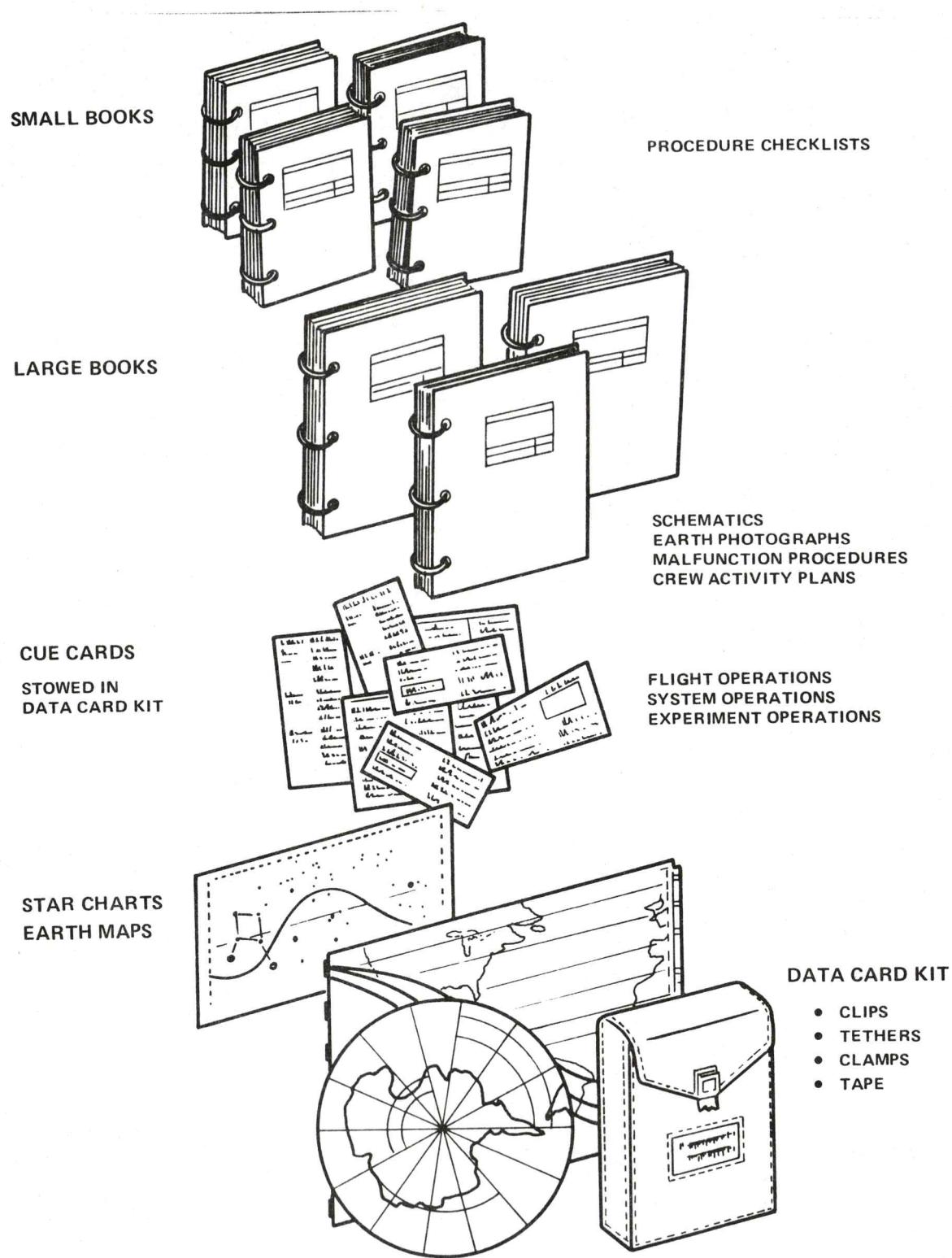


Figure 4-23.- Flight data file items (typical).

APPENDIX A  
ACRONYMS AND ABBREVIATIONS

**APPENDIX A**  
**ACRONYMS AND ABBREVIATIONS**

The following acronyms and abbreviations are used in this document. They are defined in the text as they are used, but are provided here in one comprehensive listing.

AA	Accelerometer Assembly
ac	alternating current
ACCU	Audio Central Control Unit
ACS	Attitude Control System
ADS	Air Data System
AOA	Abort Once Around
APU	Auxiliary Power Unit
ARS	Atmospheric Revitalization System
ATCS	Active Thermal Control System
ATO	Abort to Orbit
BFS	Backup Flight System
C&T	Communications and Tracking
C&W	Caution and Warning
CCTV	Closed Circuit Television
CDR	Commander
CLS	Contingency Landing Site
CM	Crew Module
COAS	Crewmen Optical Alignment Sight
CPU	Central Processor Unit
CRT	Cathode Ray Tube
CSS	Control Stick Steering
DBN	Data Bus Network
dc	direct current
DFI	Development Flight Instrumentation
DPS	Data Processing System
EAFB	Edwards Air Force Base
ECLSS	Environmental Control and Life Support System
EI	Entry Interface
EMU	EVA Mobility Unit
EPS	Electrical Power System
ET	External Tank
EVA	Extravehicular Activity
FC	Fuel Cell
FCP	Fuel Cell Powerplant
FDF	Flight Data File
FM	Frequency Modulation
FRSI	Felt Reusable Surface Insulation
GNC	Guidance, Navigation, and Control
GPC	General Purpose Computer
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center

HRSI	High Temperature Reusable Surface Insulation
IMU	Inertial Measurement Unit
IOP	Input/Output Processor
IUS	Inertial Upper Stage
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
KSC	Kennedy Space Center
LDEF	Long Duration Exposure Facility
LH <sub>2</sub>	Liquid Hydrogen
LO <sub>2</sub>	Liquid Oxygen
LRSI	Low Temperature Reusable Surface Insulation
LRU	Line Replaceable Unit
LST	Large Space Telescope
MCC	Mission Control Center
MCDS	Multifunction CRT Display System
MDM	Multiplexer/Demultiplexer
MECO	Main Engine Cutoff
MESA	Modular Equipment Stowage Assembly
MLG	Main Landing Gear
MLP	Mobile Launch Platform
MLS	Microwave Landing System
MMH	Monomethyl Hydrazine
MMS	Multimission Modular Spacecraft
MMU	Manned Maneuvering Unit
MMU	Mass Memory Unit
MPS	Main Propulsion System
MS	Mission Specialist
NASA	National Aeronautics and Space Administration
NLG	Nose Landing Gear
NSP	Network Signal Processor
OI	Operational Instrumentation
OMS	Orbital Maneuvering System
OPF	Orbiter Processing Facility
OPS	Operational Sequence
PASS	Primary Avionics Software System
pbi	Pushbutton Indicator
PCS	Pressure Control System
PDRS	Payload Deployment and Retrieval System
PLBD	Payload Bay Door
PLT	Pilot
PM	Phase Modulation
POCC	Payload Operations Control Center
PS	Payload Specialist
PVDS	Purge, Vent, Drain System

RA	Radar Altimeter
RCC	Reinforced Carbon-Carbon
RCS	Reaction Control System
RF	Radio Frequency
RGA	Rate Gyro Assembly
RM	Redundancy Management
RMS	Remote Manipulator System
RPC	Remote Power Controller
RTLS	Return to Launch Site
SM	Systems Management
SRB	Solid Rocket Booster
SRM	Solid Rocket Motor
SSUS	Spinning Solid Upper Stage
SSV	Space Shuttle Vehicle
STDN	Spacecraft Tracking and Data Network
STS	Space Transportation System
TACAN	Tactical Air Navigation
TAEM	Terminal Area Energy Management
TDRS	Tracking and Data Relay Satellite
TPS	Thermal Protection System
TVC	Thrust Vector Control
UHF	Ultra High Frequency
VAB	Vehicle Assembly Building
VAFB	Vandenberg Air Force Base
WSTF	White Sands Test Facility

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