

Space Flight Operations Contract

Space Shuttle Vehicle Familiarization

SSV FAM 11007

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FOREWORD

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

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1.0 THE SPACE TRANSPORTATION SYSTEM

In July 1969, the National Aeronautics and Space Administration (NASA) publicly announced the inception of a space shuttle program. The program to build a recoverable personnel and payload space transportation system was originally proposed as a ferry vehicle for a low Earth orbit space station. Congress and President Nixon decided that the development of both a space station and a space shuttle was too expensive. NASA opted to develop the space shuttle first and then develop the space station. By 1972, the Space Transportation System (STS), now called the Space Shuttle Program (SSP), became NASA's primary program.

The major elements of the SSP consist of the Space Shuttle Vehicle (SSV) and the required ground-based facilities, equipment, and personnel that support shuttle and payload operations.

The SSV, also called the shuttle, is composed of a reusable orbiter, an External Tank (ET), and two refurbishable Solid Rocket Boosters (SRBs) (Figure 1-1). This configuration has changed little since 1972 when the contract to build the shuttle was awarded to Rockwell International (Rockwell had previously developed the Apollo Command and Service module for NASA). The shuttle's design was based on years of study and experience gained from the Lifting Bodies, X-15 Rocket Plane, X-20 Dyna Soar, and Apollo programs. The original plan for the space shuttle concept called for a completely reusable system comprised of a piloted booster and piloted orbiter. As shuttle development became increasingly constrained by budget limitations, President Nixon directed NASA to choose low development costs over low operational costs. This resulted in dropping the fly-back boosters concept in favor of an expendable fuel tank and unpiloted recoverable booster system that would be cheaper to develop but ultimately more expensive to operate.

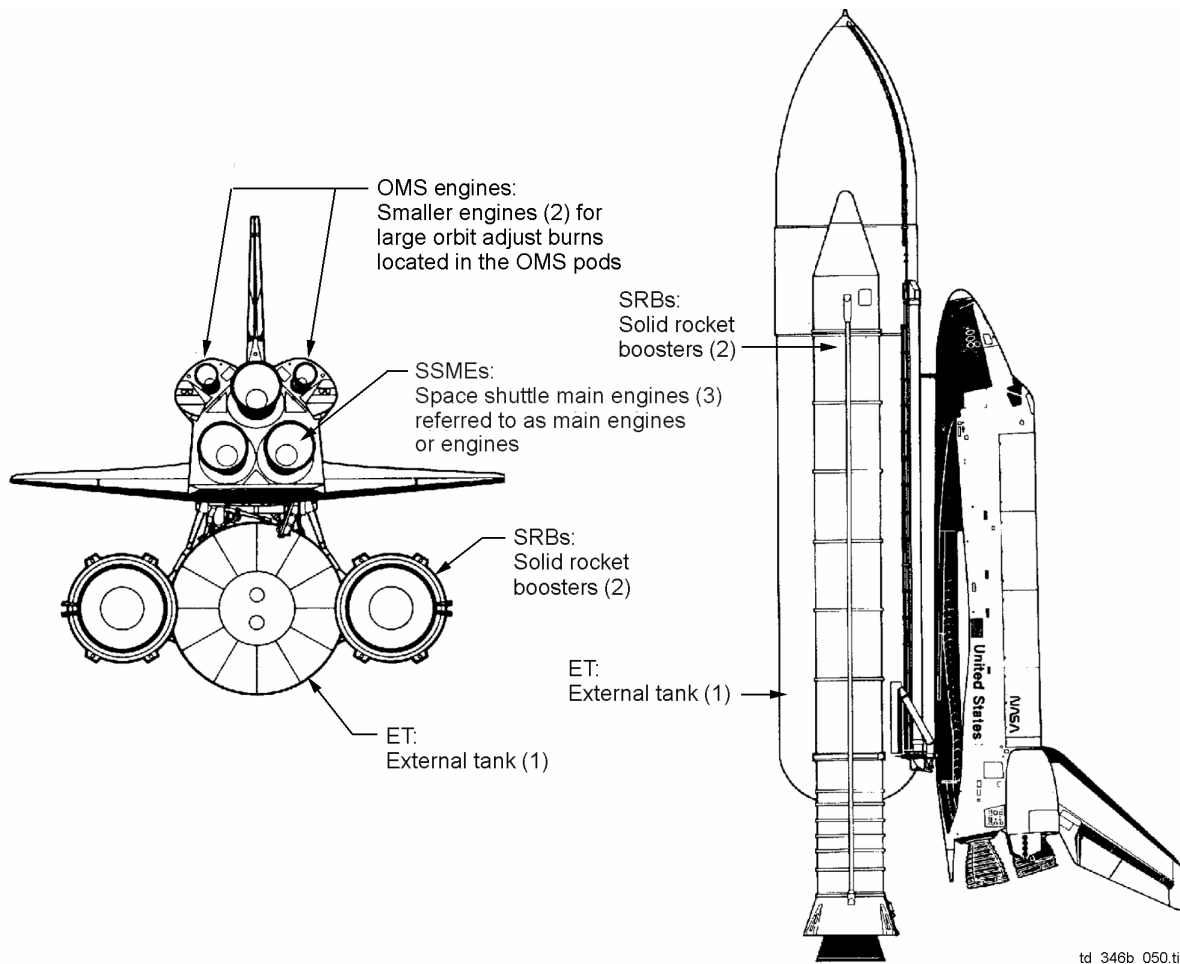


Figure 1-1. The Space Transportation System

Responsibility for shuttle and payload operations is distributed among the various NASA Centers. The Kennedy Space Center (KSC) in Florida is responsible for launch and landing operations, vehicle processing and checkout, and payload integration. The Lyndon B. Johnson Space Center (JSC) in Texas is responsible for mission control, flight planning, crew training, and mission scheduling.

The Mission Control center (MCC) at JSC maintains contact with the orbiter and payloads via the Tracking and Data Relay Satellite (TDRS) throughout the flight. TDRS is a communications satellite that relays signals to and from the ground station at the White Sands Test Facility (WSTF) in New Mexico. There are four TDRSs in geosynchronous orbits. Two TDRS satellites provide the orbiter with communication for approximately 90 percent of the groundtrack, while the other two serve as backup. Operating in conjunction with the MCC are the Payload Operations Control Centers (POCCs) located around the globe. Depending on payload requirements, one or more of the POCCs could be supporting a given shuttle mission.

The orbiter crew consists of a Commander (CDR), Pilot (PLT), one or more Mission Specialists (MSs), and possibly one or more Payload Specialists (PSs). During flight,

the commander has onboard responsibility for the vehicle, crew, mission success, and safety of flight. The pilot assists the commander in controlling and operating the vehicle and may assist in the deployment and retrieval of satellites using the Remote Manipulator System (RMS), referred to as the robot arm. Mission specialists are trained in the details of the orbiter onboard systems, as well as the operational characteristics, mission requirements/objectives, and supporting equipment for each of the experiments conducted on their assigned missions. Mission specialists perform Extravehicular Activities (EVAs), or space walks, operate the RMS, and are responsible for payloads and specific experiment operations. Payload specialists are persons other than NASA astronauts (including foreign nationals) who have specialized onboard duties related to the payloads.

Today the space shuttle program provides launch services to a diverse set of customers, supporting payloads that range from small handheld experiments to large laboratories. While most missions are devoted to NASA-sponsored payloads, industry partnerships, corporations, academia, and national and international agencies often participate. The shuttle can transport up to 55,000 pounds to low inclination orbits (28.5°) and 41,000 to high inclination orbits (57°). The orbiter's payload bay contains flexible payload retention, umbilical, and deployment mechanisms. Inside the shirtsleeve environment of the orbiter 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 familiarizes you with the SSV, its operations, and its elements.

2.0 SPACE SHUTTLE MISSION ACTIVITIES

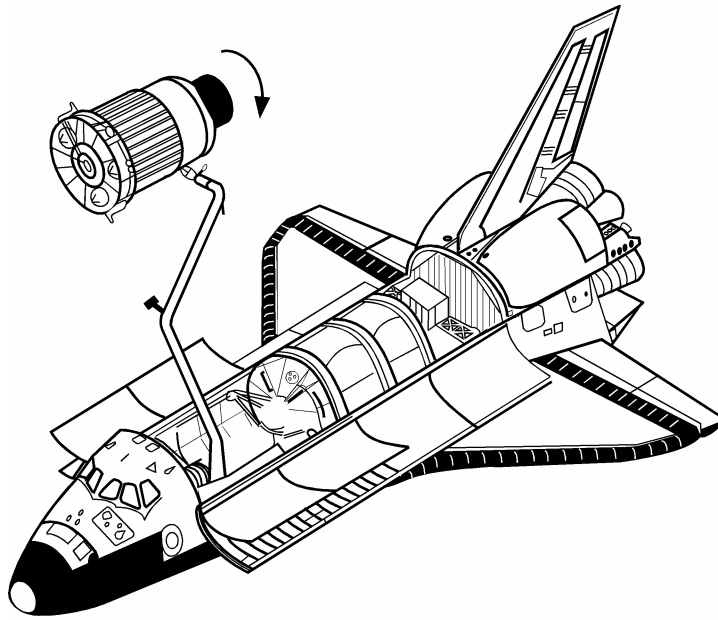
This section demonstrates the versatility of the space shuttle by acquainting you with some typical mission activities. Virtually all military or civilian uses of the shuttle employ one or more of these activities on a given flight. The activities by the space shuttle include science missions, deployment and/or retrieval of satellites, logistic supply, crew exchange, and delivery of station elements to begin the construction of the International Space Station (ISS).

2.1 PAYLOAD DEPLOYMENT AND RETRIEVAL

One of the principal missions is to use space shuttle Payload Deployment and Retrieval System (PDRS) to support various on-orbit activities. These activities include:

- a. Deployment of satellites that are released by the orbiter and left to function on their own, such as the Hubble Space Telescope (HST), which was flown on STS-31 and the GAMMA Ray Observatory flown on STS-37.
- b. Recapture of satellites that have been deployed and are later retrieved during the mission, such as the SPARTAN free flyer satellite, flown on STS-95 (Figure 2-1).
- c. Recapture of satellites that have been deployed and later retrieved on another mission, such as the Long Duration Exposure Facility, which was deployed on STS-41C and later retrieved on STS-32.
- d. Delivery of station elements to begin the construction of the ISS beginning with STS-88.

Before launch, a satellite is installed into the payload bay and checked out by ground crews. Once the shuttle has achieved the desired orbit, the mission specialist and payload specialist conduct predeployment activation and checks of the satellite. The satellite is then ejected from the payload bay by springs, or positioned and released by the RMS. If a failure occurs after deployment, the satellite can be recovered and returned to Earth for repair and launched again. A malfunctioning or deactivated satellite already in orbit can be recovered in a similar manner.



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Figure 2-1. Placement and recovery of satellites

2.2 ON-ORBIT SATELLITE SERVICING

A servicing mission allows for the repair of damaged satellites and the routine replacement of equipment and experiments to ensure continued operation. An example of such a mission would be the HST servicing, usually scheduled every 2 or 3 years. The typical sequence is as follows:

1. If required, the satellite is maneuvered from a higher operational orbit to a lower altitude servicing orbit.
2. The orbiter is inserted into the service orbit for rendezvous with the satellite.
3. The orbiter captures the satellite using the RMS.
4. The crew attaches the satellite to a platform in the payload bay. The satellite can be attached using controls located in the aft crew station inside the crew module.
5. Installation of replacement modules or repair work can be performed with automatic preprogrammed mechanisms or by crewmembers. The most common method is for two crewmembers to exit the orbiter in spacesuits and perform the servicing. This activity is called EVA.
6. The satellite is deployed, reactivated, 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 is available.

A typical sequence of satellite servicing in Earth orbit is shown in Figure 2-2.

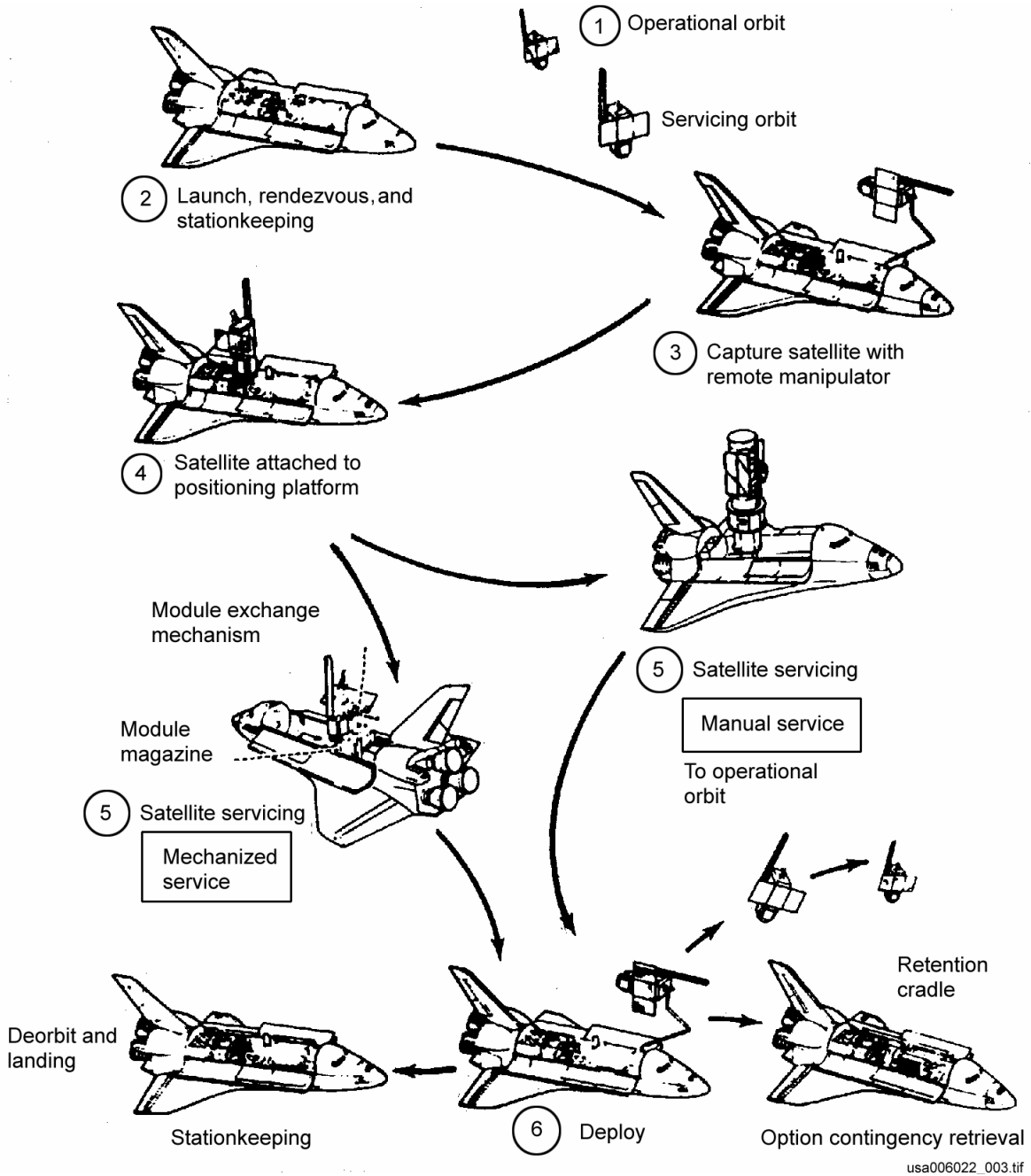


Figure 2-2. On-orbit satellite servicing

2.3 RENDEZVOUS AND DOCKING

Some shuttle missions may require the orbiter to rendezvous with another spacecraft (or space station). There are two types of rendezvous.

- a. Deploy-retrieve rendezvous - The orbiter deploys a spacecraft and returns later in the same flight for retrieval. The SPARTAN satellite, flown on STS-95, is an example of a deploy-retrieve rendezvous mission.
- b. Ground-up rendezvous - The shuttle is launched to rendezvous with a spacecraft already in orbit, such as the ISS or HST.

Both types of rendezvous could conclude in proximity operations or an actual docking. Proximity Operations (Prox Ops) allow the orbiter to fly in formation with another spacecraft in order to conduct observations or allow for capture of the spacecraft by the RMS. Proximity operations also serve as precursors to an actual docking. Shuttle missions to the ISS will typically require the orbiter to dock (Figure 2-3) with the ISS. These missions usually involve the transfer of personnel, equipment, and supplies to and from the orbiting ISS.

The typical sequence of events for a ground-up rendezvous begins with the precisely timed launch of the shuttle on a course for the target. During the first 2 days of the mission, periodic firing of the Orbital Maneuvering System/Reaction Control System (OMS/RCS) will gradually close the distance between the target and the orbiter. The orbiter will reach a point about 8 miles behind the target on flight day 3. At about 3 hours before docking, the Terminal phase initiation (Ti) burn will begin the final phase of rendezvous.

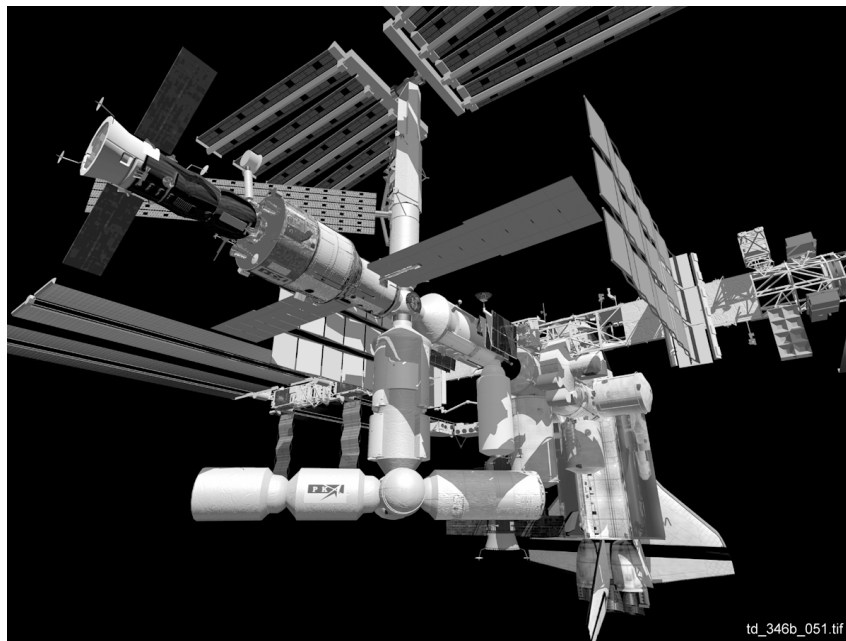


Figure 2-3. Shuttle docked with ISS

Extravehicular Activity

Some shuttle missions may require crewmembers wearing space suits to exit the vehicle through the airlock for the purpose of performing repairs, conducting experiments, servicing spacecraft, and assembling space structures (Figure 2-4). These space walks are called EVAs. There are three basic categories of EVA:

- a. Scheduled - An EVA planned prior to launch and included in the nominal flight plan
- b. Unscheduled - An EVA not included in the nominal scheduled mission activities but required to achieve payload or mission operational success
- c. Contingency - An EVA required to ensure the safe return of the orbiter and crew



Figure 2-4. STS-88 EVA

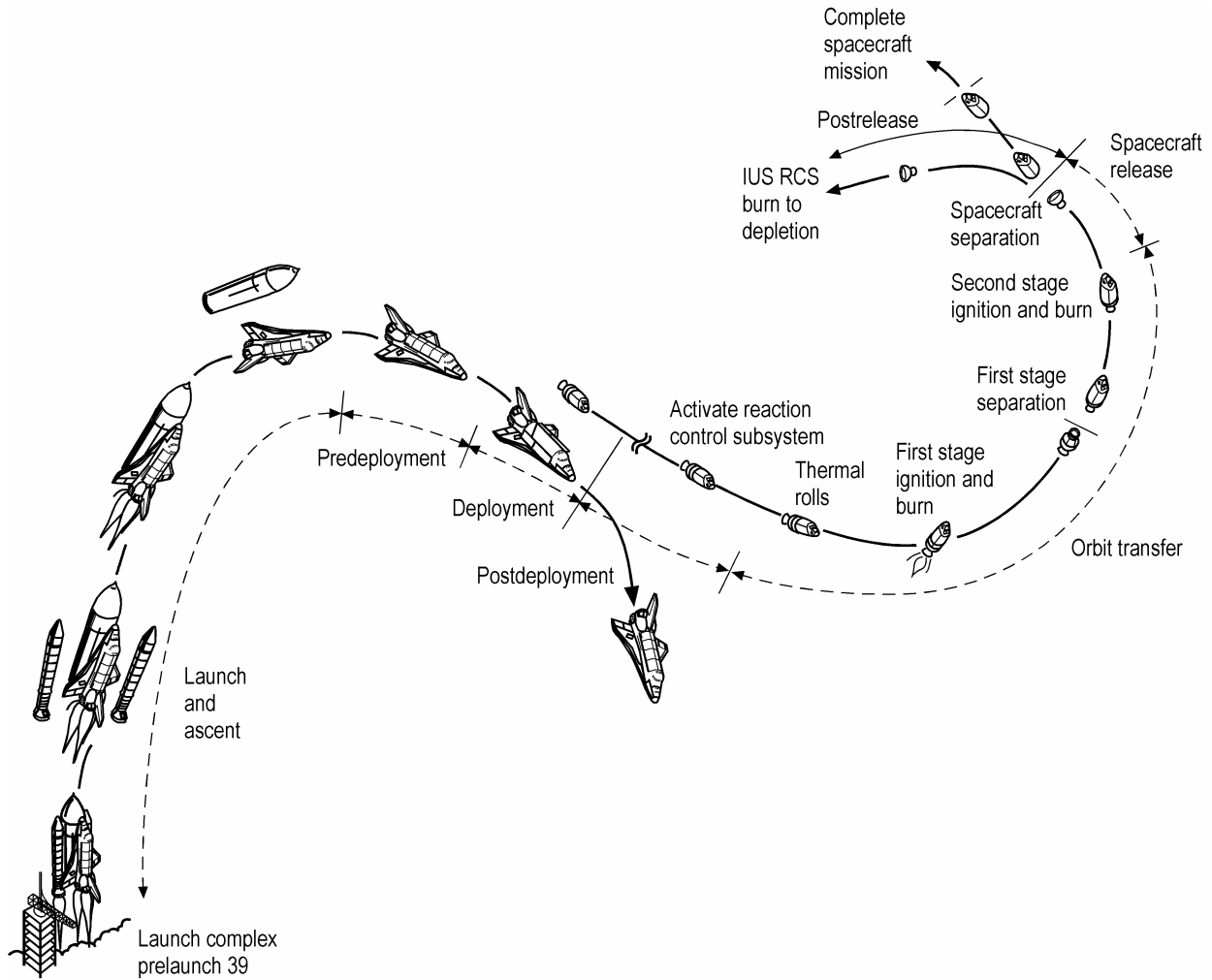
2.4 LAUNCHING OF SPACECRAFT

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

The Inertial Upper Stage (IUS) carrier is a shuttle-deployable booster built to launch payloads into orbits much higher than the shuttle can reach. The IUS/satellite payload is stowed horizontally in the payload bay with respect to the orbiter. The assembly is mounted on a tilt table. The IUS Airborne Support Equipment (ASE) provides the IUS and its payload with load-bearing and structural support, an electronics interface with the orbiter, and thermal protection. The carrier is capable of placing up to 5100 pounds into geosynchronous orbit and up to 5000 pounds into interplanetary trajectory. The IUS carrier has two stages powered by Solid Rocket Motors (SRMs); thrust vector

control capability; its own Guidance, Navigation, and Control (GNC) avionics and computer; and an RCS. The RCS controls attitude and roll and provides precise orbital insertion. Each IUS weighs 32,500 pounds and is 17 feet long and 9.5 feet wide.

The delivery of a spacecraft to orbit is depicted in Figure 2-5.

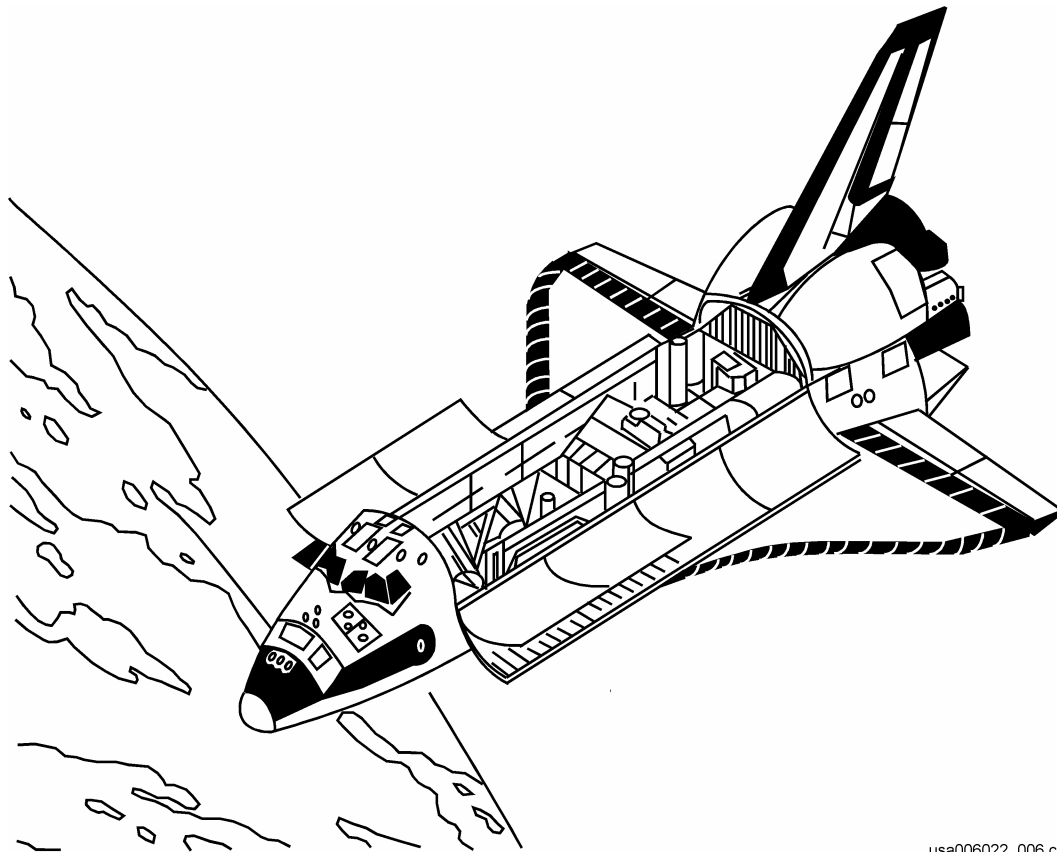


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Figure 2-5. Delivery of a spacecraft to orbit

2.5 ON-ORBIT SCIENCE

The shuttle can support a wide variety of scientific disciplines such as materials processing, microgravity research, Earth sciences, biology, life sciences, and astronomy. The orbiter's crew cabin and large payload bay provide versatile accommodations for these activities (see Figure 2-6). Experiments requiring a pressurized cabin or crew interaction can be conducted in the orbiter middeck or in a pressurized module called Spacehab that is sometimes carried in the orbiter payload bay. Other experiments that do not have these requirements, or need to be exposed to the vacuum of space, can be mounted on pallets in the payload bay.



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Figure 2-6. Mixed and attached payloads

3.0 SHUTTLE FLIGHT PROFILE

This section acquaints you with the following major phases of a shuttle flight.

- a. Ascent
- b. Aborts
- c. On orbit
- d. Entry
- e. Ground turnaround

3.1 ASCENT

The flight crew boards the orbiter approximately 2 hours 45 minutes before lift-off to prepare the vehicle for ascent. At lift-off, the three main engines are burning in parallel with the two SRBs. This phase is first-stage ascent. During first stage, aerodynamic loads, engine thrust, and vehicle weight are the primary factors used to shape the trajectory. The SRBs are used along with the main engines for steering. About 2 minutes into flight, the boosters burn 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 8.5 minutes of flight, the main engines are shut down. The ET is jettisoned about 18 seconds later. These processes are referred to as Main Engine Cutoff (MECO) and ET separation, respectively. The tank reenters the atmosphere, begins to disintegrate, and falls harmlessly into a remote area of the Indian or the South Pacific Ocean. The next maneuver is designed to circularize the orbit of the orbiter. Based on the ascent profile, one or two burns are performed with two small OMS engines. The burns change the shape of the elliptical orbit to a circular one, ranging from 100 to 300 n. mi. The final orbit is dictated by the mission requirements.

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

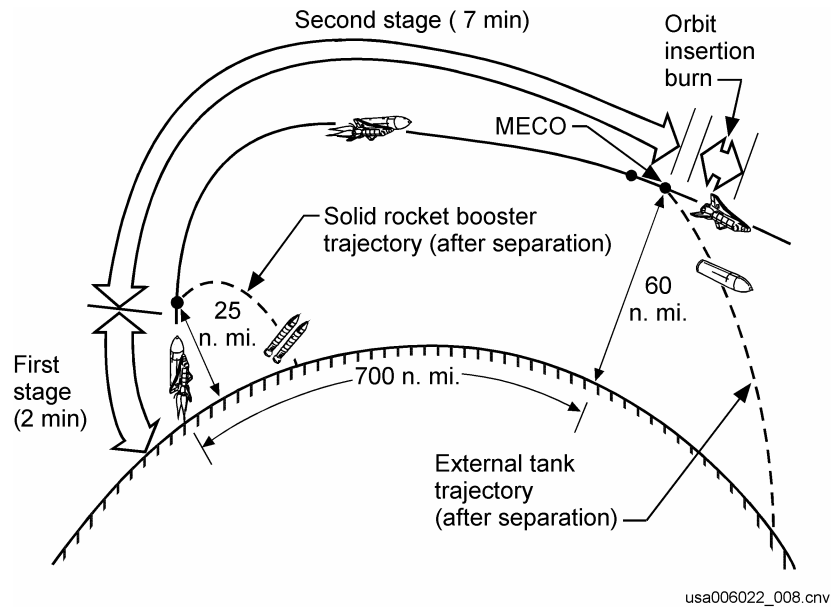


Figure 3-1. Nominal ascent trajectory

3.2 ABORTS

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

During the first 4 minutes of flight, the orbiter can return for an emergency landing on the runway at the launch site. This contingency procedure is called a Return to Launch Site (RTLS) abort. After the SRBs have separated, the orbiter and ET continue downrange to use up fuel. The vehicle then turns around, begins to slow, and eventually start back toward the runway. After MECO, the tank (now empty) is jettisoned, and the orbiter glides to a safe landing.

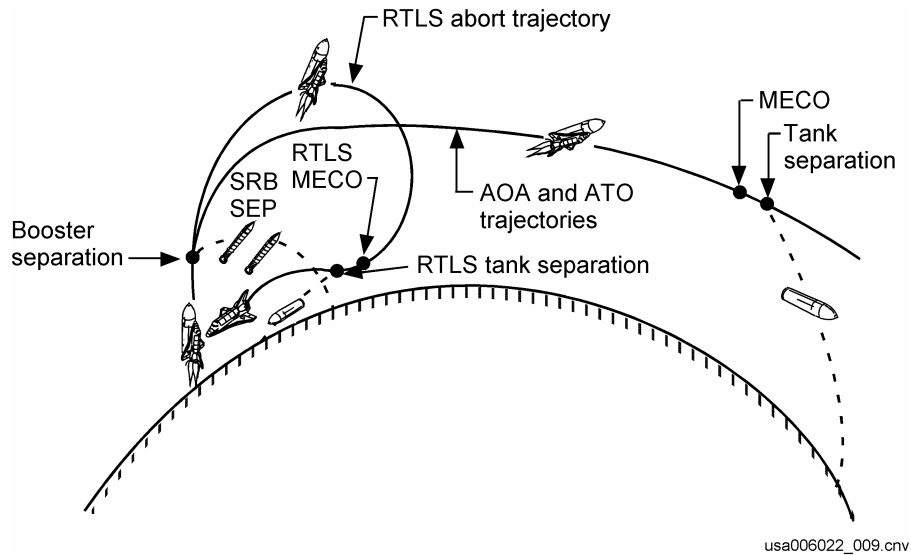


Figure 3-2. Abort trajectories

After about 4 minutes, the shuttle is so far downrange that it can no longer return to the launch site. If failures in the SSV system require the orbiter to land, an abort known as a Transoceanic Abort Landing (TAL) can be initiated. In this abort, the orbiter lands on the next available landmass. For launches from KSC, the TAL site would be a runway in Europe or Africa.

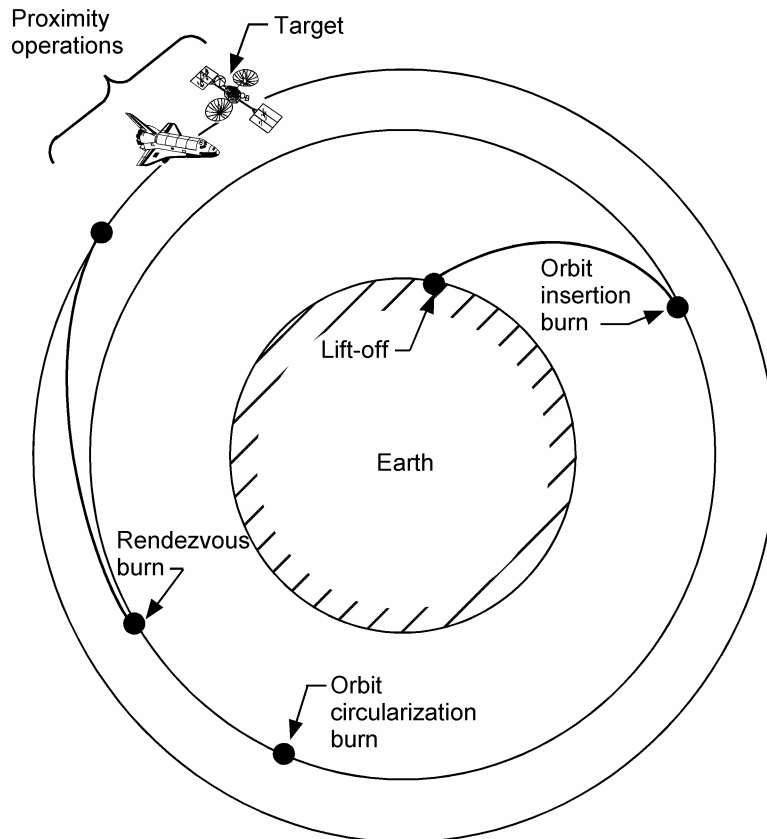
In some instances, an Abort to Orbit (ATO) may be necessary. When performing an ATO, the two orbital maneuvering engines are used to place the orbiter in a lower-than-nominal orbit. A serious problem may require the orbiter to land at Edwards in California or Northrop in New Mexico. This procedure is called Abort Once Around (AOA). The OMS 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. This method is referred to as a non-intact abort, because the orbiter and payload cannot be recovered.

3.3 ON ORBIT

As soon as the vehicle reaches orbit, the crew begins configuring various systems for mission operations. On-orbit activities include opening the Payload Bay Doors (PLBDs), configuring the communications systems, activating the RMS (if flown), and powering up payloads. The crew may be required to fire the OMS engines to raise or lower the orbiter's altitude or execute rendezvous maneuvers (as shown in Figure 3-3). They may also perform proximity operations or orbiter attitude changes with the RCS to satisfy vehicle and payload requirements. Typical missions, such as those to the ISS, will last 5 to 10 days. The orbiter does have the capability for extended duration missions of up to 18 days.

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 with maximum safety during the flight.



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Figure 3-3. On-orbit operations

3.4 ENTRY

The entry trajectory (Figure 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 OMS engines ignite and then decrease the orbiter speed. The orbiter begins to descend toward the Earth and encounters atmospheric effects at 400,000 feet, or Entry Interface (EI). External insulation protects the orbiter from the heat generated by friction with the atmosphere; however, radio communication may be temporarily interrupted (blackout) if the use of a lower antenna is necessary. At relative velocity (V_{REL}) ≈ 2500 ft/s, Terminal Area Energy Management (TAEM) is initiated to provide the proper airspeed, altitude, and heading for the orbiter 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 exits the vehicle.

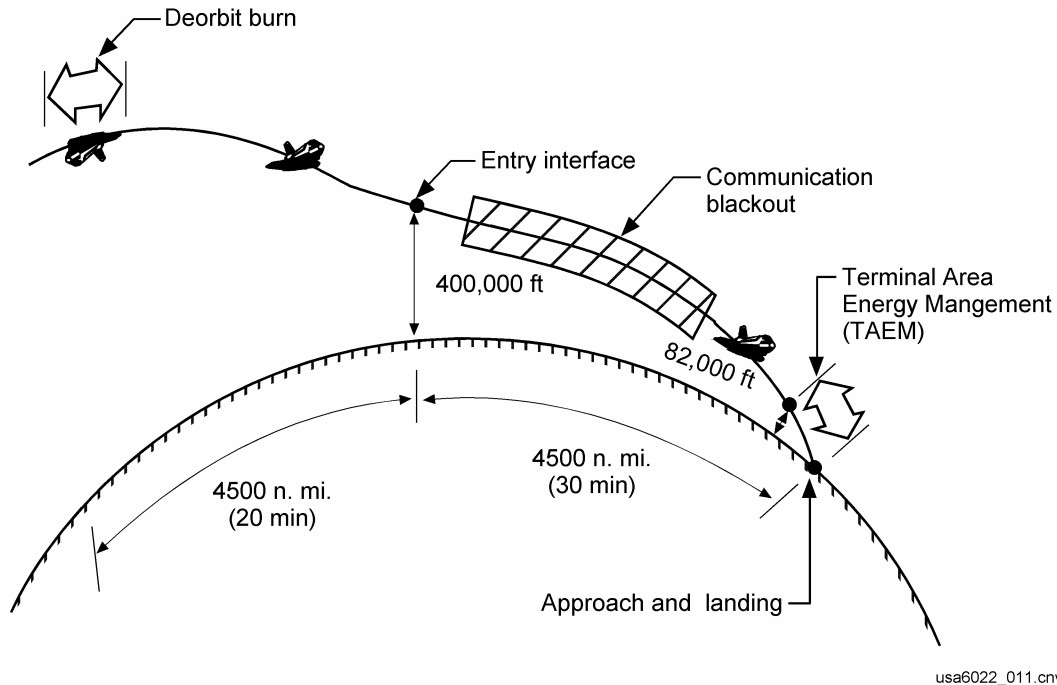


Figure 3-4. Nominal entry trajectory

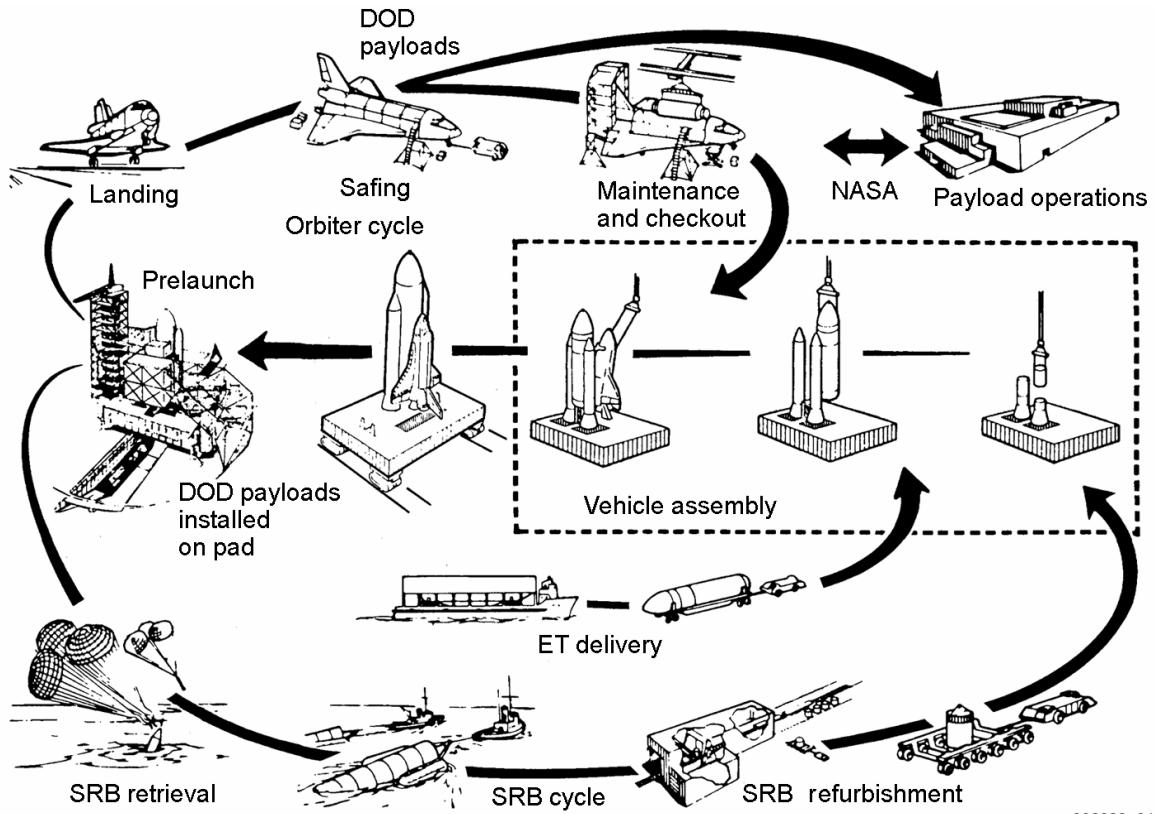
3.5 GROUND TURNAROUND

Immediately after the orbiter rolls to a stop after landing, a convoy of ground personnel drives out on the runway to perform initial safing procedures. The ground crew connects cooling and purge equipment to the vehicle and assists the flight crew as they egress the orbiter. Within hours of landing, the orbiter is towed to the Orbiter Processing Facility (OPF). If the orbiter lands at Edwards, it is placed atop a modified Boeing 747 Shuttle Carrier Aircraft (SCA) and then ferried to KSC. Upon arrival at the OPF, the safing process continues, payload removal is performed, and post-flight troubleshooting (of in-flight anomalies) is conducted. The orbiter systems are checked out and certified ready for flight, a new payload may be installed, and the orbiter is prepared for transfer to the Vehicle Assembly Building (VAB).

In parallel with orbiter operations, the SRBs are stacked and aligned on the Mobile Launch Platform (MLP) inside the VAB. The external tank arrives by barge and is transported to the VAB, where it is mated with the boosters. After the orbiter arrives from the OPF, it is lifted by an overhead crane and attached to the tank. Interface checks of all the elements are performed, and the MLP, with the stacked vehicle, is rolled out to the launch pad.

At the launch pad, fluid and electrical connections are made between the vehicle and the Ground Support Equipment (GSE). Payload preparations continue at the pad, if necessary, and loading of propellants is performed. About 3½ days before lift-off, the countdown process begins.

Ground turnaround is depicted in Figure 3-5.



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Figure 3-5. Ground turnaround

4.0 SHUTTLE VEHICLE ELEMENTS

This section presents the individual elements of the SSV (Figure 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.

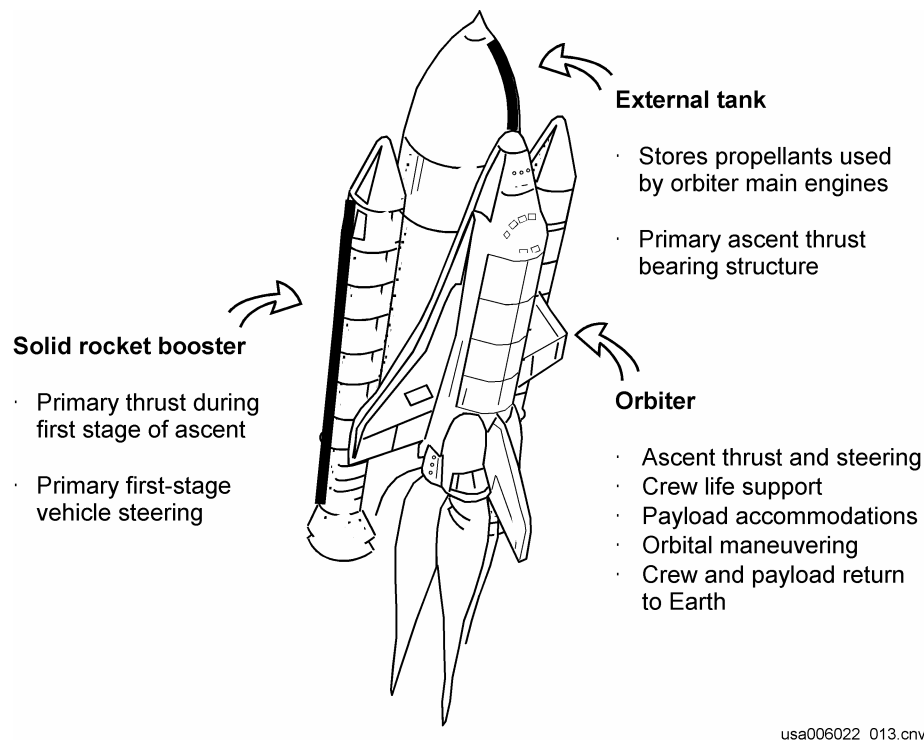
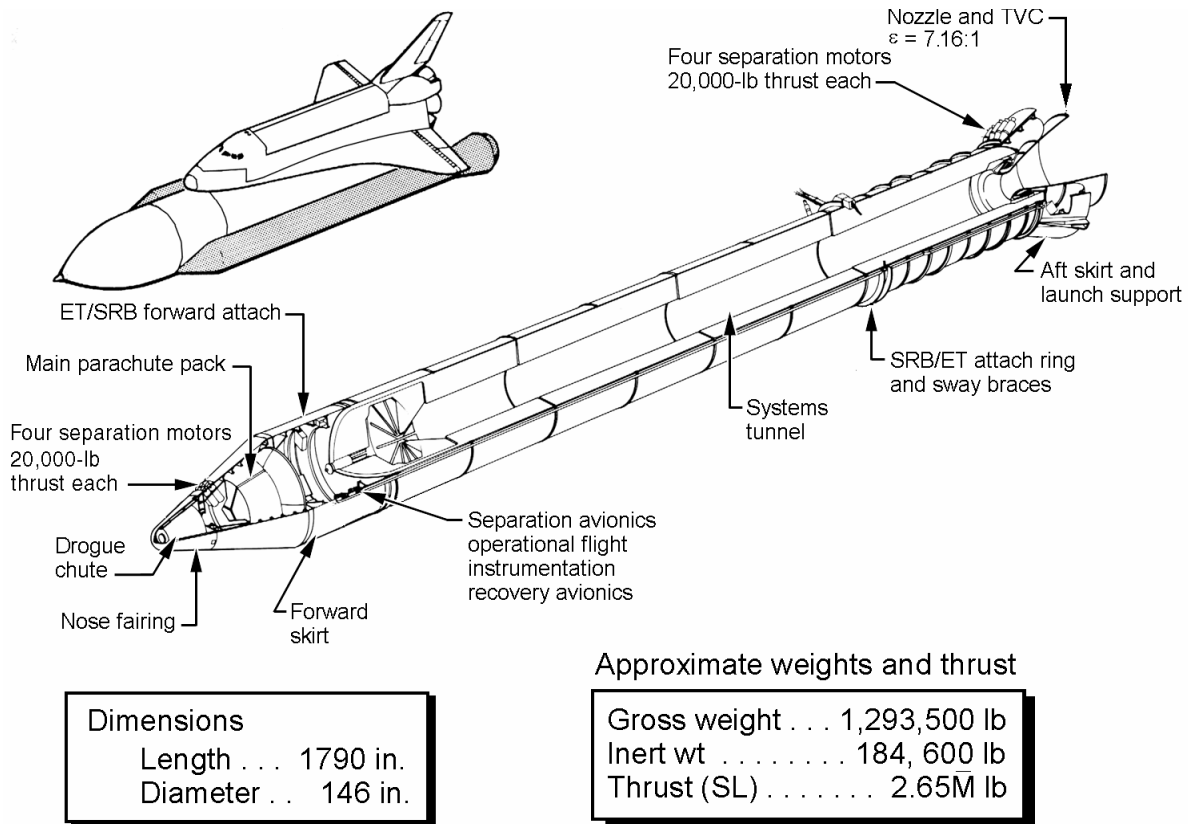


Figure 4-1. SSV elements and functions

4.1 SOLID ROCKET BOOSTER

Two SRBs burn for slightly over 2 minutes in parallel with the three main engines of the orbiter to provide the initial thrust during ascent (Figure 4-2). The propellant mixture consists of an ammonium 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 an SRM; an aft skirt; a forward skirt, containing avionics; and a nose cap, containing parachutes and recovery aids. An SRM is built from 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 SRBs are attached to the ET at the forward skirt by a single thrust attachment and by sway braces at the aft segment.



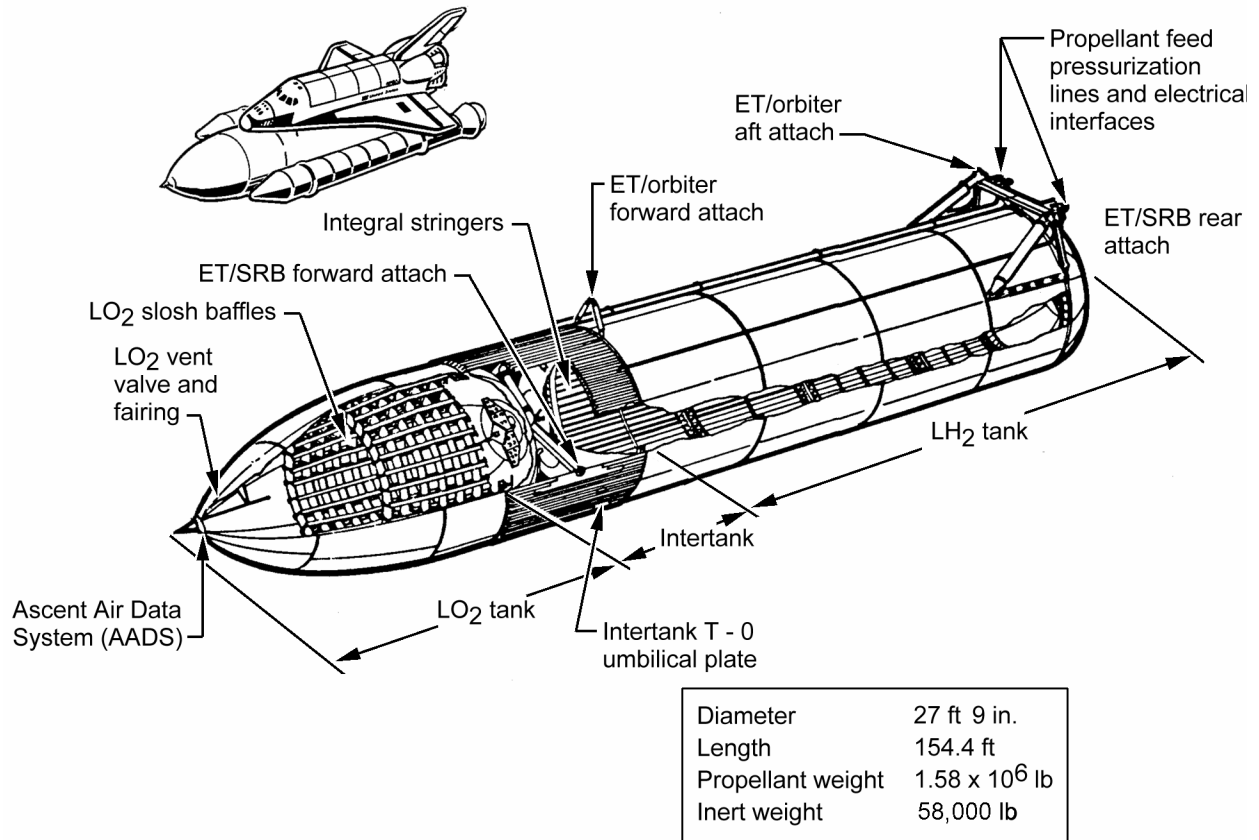
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Figure 4-2. Solid rocket booster

4.2 EXTERNAL TANK

The ET contains the propellant for the orbiter main engines. These propellants are liquid hydrogen (LH₂) fuel and liquid oxygen (LO₂) oxidizer. The ET (Figure 4-3) is composed of an LO₂ tank (19,500 ft³) and an LH₂ tank (53,800 ft³) that are held together by a rigid intertank sleeve. Slosh and antivortex baffles are mounted in the two tanks to damp fluid motion and to minimize liquid residuals. Five lines (three for LH₂ and two for LO₂) 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 SSV. The SRBs 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.



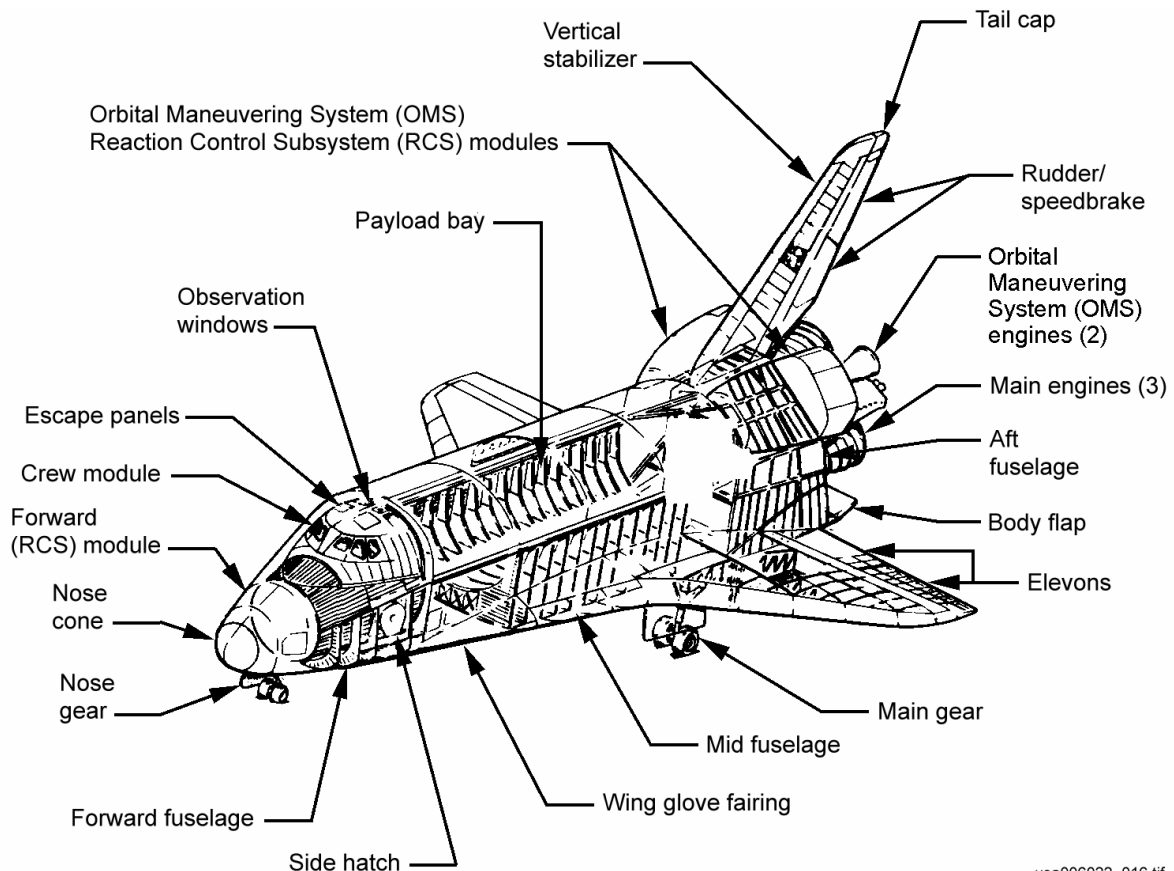
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Figure 4-3. External tank

4.3 ORBITER

The general configuration of the orbiter (Figure 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 Section 4 is devoted to the orbiter and its support systems. Most of the support systems in the orbiter use at least three items to perform the same function. This redundancy has been designed into the shuttle to make it fail-operational/fail-safe. For example, a failure of one fuel cell does not jeopardize the flight (fail-operational); the failure of a second fuel cell does not jeopardize the crew, orbiter, or payload (fail-safe).

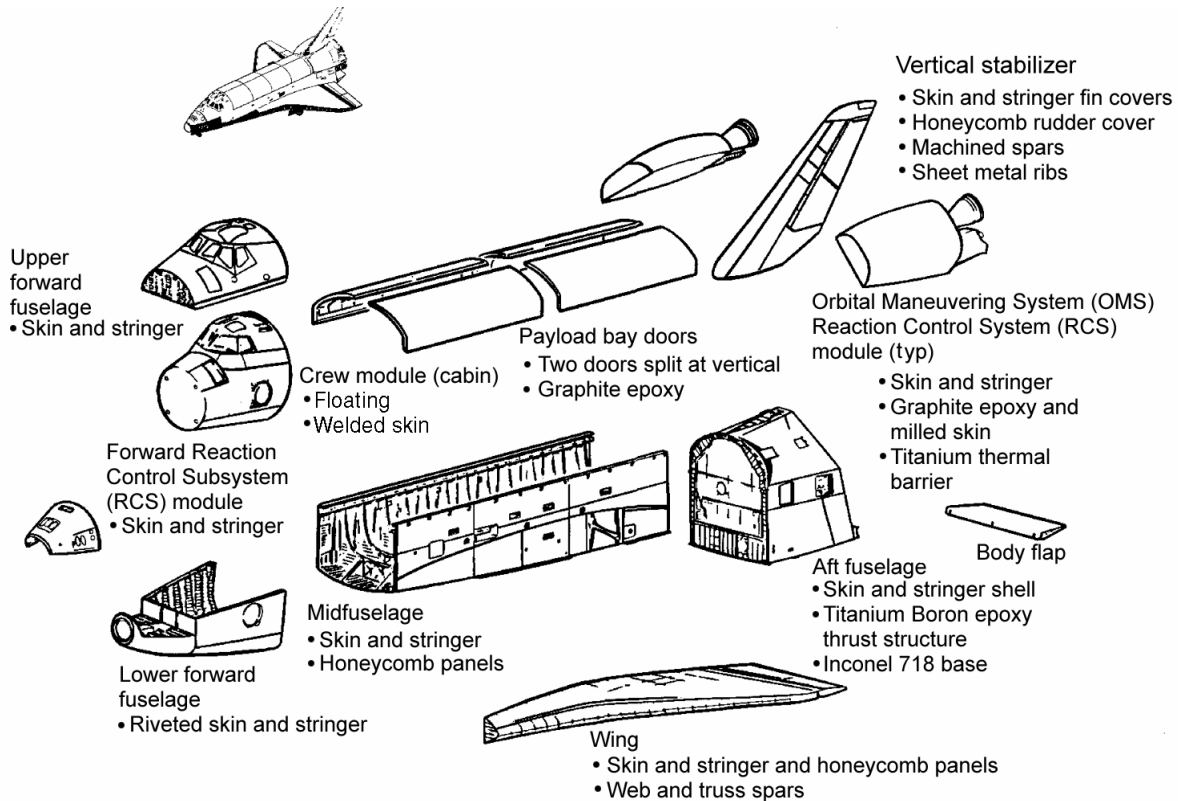


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Figure 4-4. Orbiter general arrangement

4.3.1 Orbiter Structure

The orbiter is made up of three major structural elements: the forward fuselage, the midfuselage, and the aft fuselage. These elements are fastened by bolts and rivets, as are the wings and vertical tail. The outer skin is aluminum that is covered with special thermal protection. The orbiter structural groups are shown in Figure 4-5.



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Figure 4-5. Orbiter structural groups

4.3.2 Orbiter Forward Fuselage

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

The CM is designed as a combination working and living area. It is pressurized to 14.7 psia. The temperature is maintained between 65° to 80° F and the humidity at about 50 percent. Cabin air is circulated to prevent stagnation and is filtered to remove carbon dioxide and odors. The total volume is 2525 ft³.

The upper level (flight deck) contains the displays and controls used to pilot, monitor, and control the orbiter, the integrated SSV, and the mission payloads. Seating for as many as eight 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. The side hatch is used for normal crew ingress and egress on the ground.

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

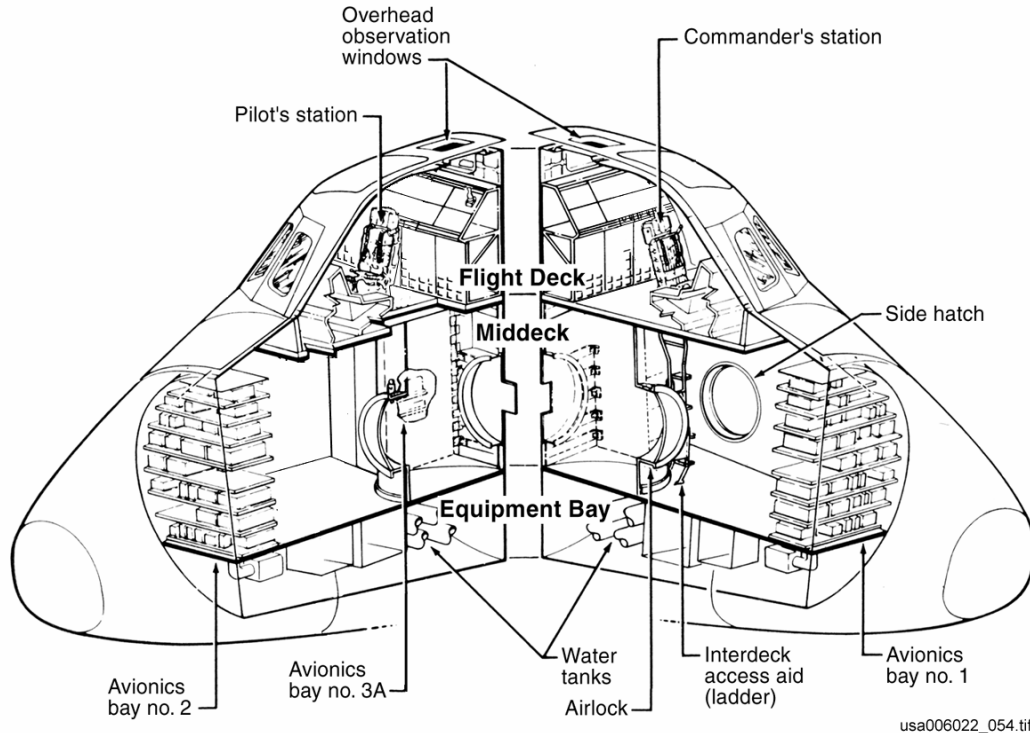


Figure 4-6. Crew module

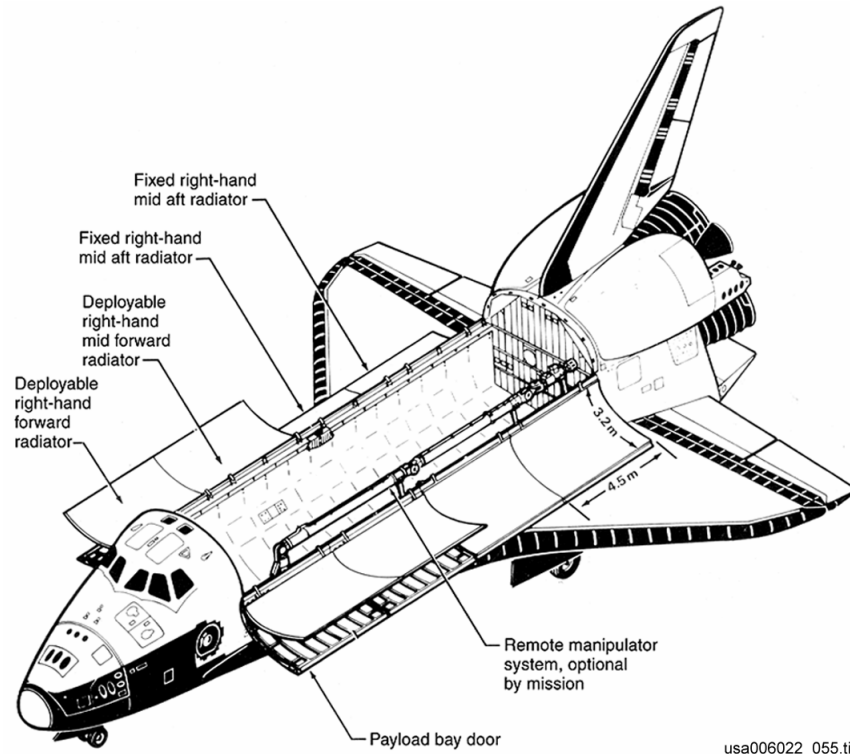
4.3.3 Orbiter Midfuselage

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

The midfuselage is also used as a payload bay. The envelope for payloads is a cylinder 60 feet long and 15 feet in diameter. Numerous attachment points along the sides and bottom of the payload bay allow 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 midfuselage. The deployment of payloads can be accomplished by using a general purpose RMS. A 50-foot-long, four-joint arm is attached at the forward end of the midfuselage. The arm is controlled by the crew from the flight deck of the CM. The RMS also can assist in retrieval of a payload or in support of EVA operations.

Attached to the upper portion of the midfuselage are the two PLBDs (Figure 4-7). The doors, closed during ascent and entry, are opened by the crew on orbit and are controlled from the flight deck of the CM. Attached to the inside of the doors are four radiator panels used as the primary heat rejection system by radiating excess heat (from avionics and other equipment) into space.

The wings are attached to the bottom of the midfuselage, and the elevons are used for control of the orbiter during reentry. The two main landing gears are located in the wells in the wings.



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Figure 4-7. Payload bay doors and radiators

4.3.4 Orbiter Aft Fuselage

The aft fuselage (Figure 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 midfuselage through the outer shell structure.

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

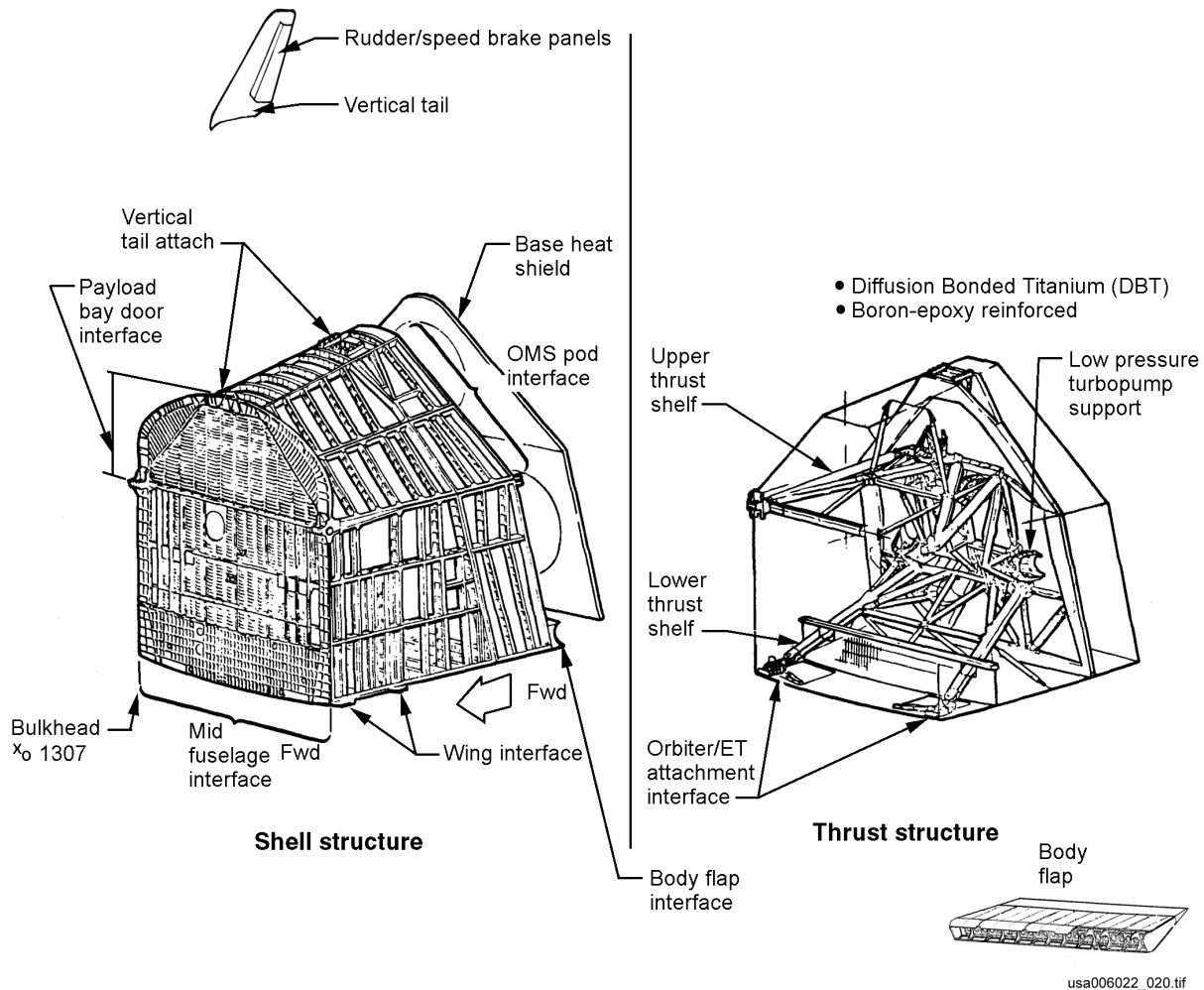


Figure 4-8. Aft fuselage

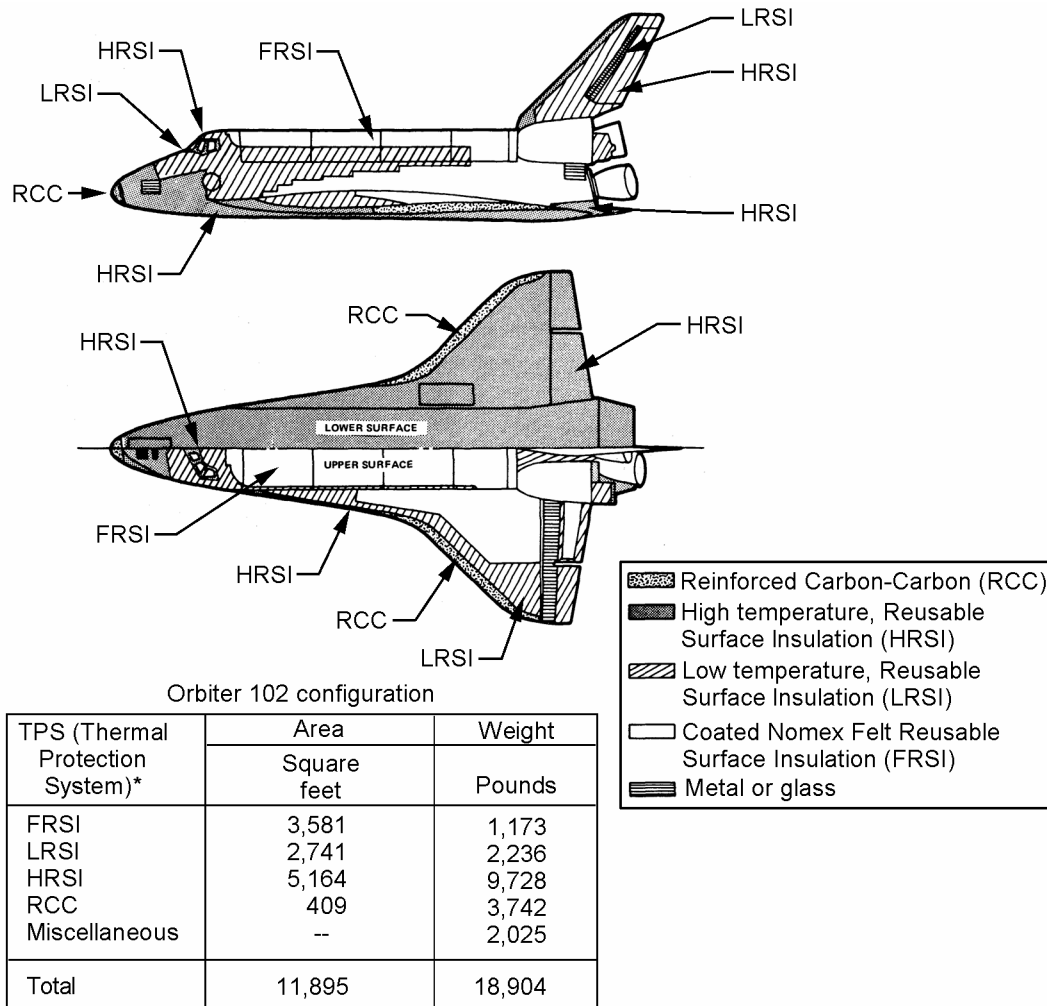
4.3.5 Orbiter Thermal Protection System

The Thermal Protection System (TPS) (Figure 4-9) includes those materials that 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 PLBDs and upper wing.

The TPS is composed of the following:

- a. Two types of reusable surface tiles - Low Temperature Reusable Surface Insulation (LRSI) and High Temperature Reusable Surface Insulation (HRSI)
- b. A structure that is resistant to very high temperatures - Reinforced Carbon-Carbon (RCC)
- c. A flexible covering - Felt Reusable Surface Insulation (FRSI)

- d. Thermal windowpanes and high-temperature metals
- e. Thermal seals at the hinge lines of the rudder, elevons, body flap, PLBDs, and side hatch



*Includes bulk insulation, thermal barriers, and closeouts.

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Figure 4-9. Thermal protection system

4.3.6 Orbiter Main Propulsion System

The MPS provides the thrust for vehicle acceleration from liftoff to main engine cutoff (MECO), a period referred as “two-staged powered flight.” During the first stage, the MPS is assisted by two SRBs, which are actually providing most of the thrust. Eventually, the SRBs burn out and jettisoned about two minutes after lift-off. This ends first stage. During the second stage, the MPS works either alone or with the help of the orbital maneuvering system (either through what called an “OMS Assist” or through an “OMS abort dump”) to provide the thrust leading up to MECO.

The MPS consists of three space shuttle main engines (SSMEs), each of which produces around 470,000 pounds of thrust in a vacuum. The SSMEs use liquid hydrogen as the fuel and liquid oxygen as the oxidizer. These propellants are stored in separate compartments within the External Tank (ET), which is jettisoned shortly after MECO. The SSMEs are gimbaled via hydraulic actuators, which provide the ability to steer the vehicle during powered flight.

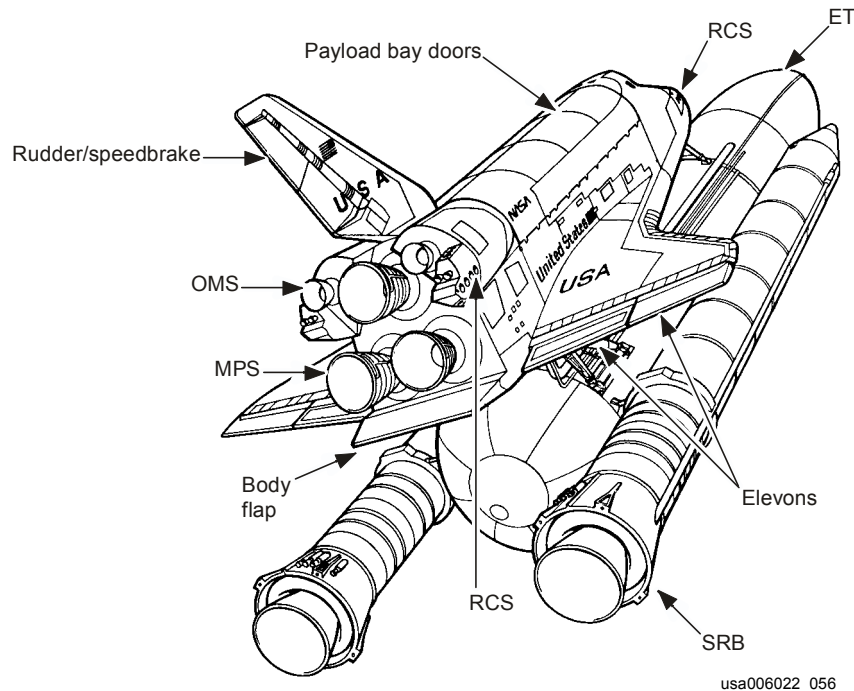


Figure 4-10. Main propulsion system

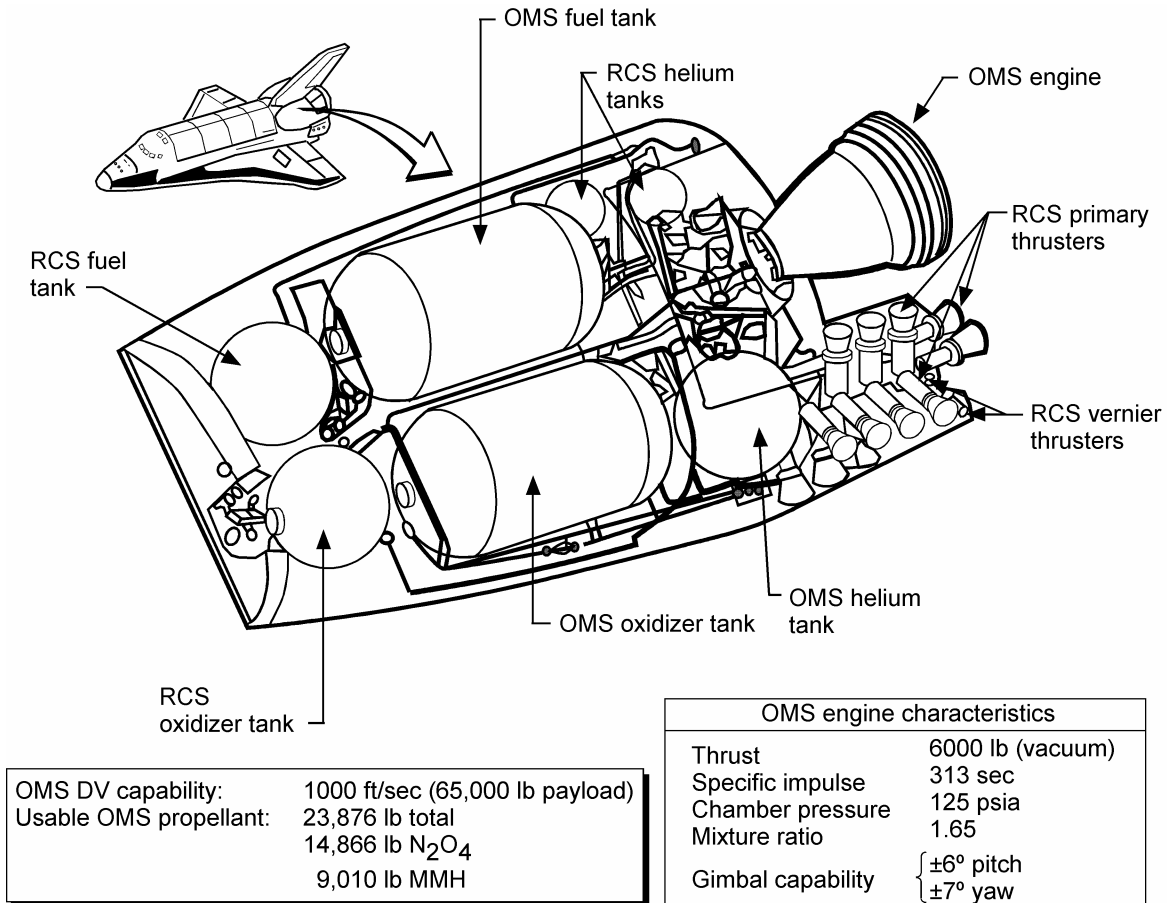
4.3.7 Orbiter Orbital Maneuvering System

The OMS provides the thrust needed to transfer the space shuttle from one orbit to another. This particularly applies during orbital insertion after MECO, during rendezvous maneuvers, and during deorbit maneuvers. The OMS can also provide additional thrust during ascent, either through what is called an “OMS Assist” or through an “OMS abort dump.”

The OMS consists of two engines, each producing around 6000 pounds of thrust. These engines use monomethyl hydrazine for fuel and nitrogen tetroxide for oxidizer—two hypergolic chemicals that combust upon contact with each other. This eliminates the need for an ignition source inside the engine. The propellants are stored in separate tanks inside two OMS pods, located at the aft of the vehicle on either side of the vertical stabilizer. For redundancy, propellant lines extend from one pod to the other. Through these lines, the propellant from one pod can be used to feed the engine in the opposite pod (in what is called an “OMS-to-OMS crossfeed”). For further redundancy, these same lines can be used to feed OMS propellant to the aft jets of the reaction control system (in what called an “OMS-to-RCS interconnect”). The OMS

engines are gimbaled via electric motors, which provide the ability to steer the vehicle during an OMS burn.

Figure 4-11 shows the OMS.



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Figure 4-11. Orbital maneuvering system

4.3.8 Orbiter Reaction Control System

The vehicle uses the RCS for attitude control and for small translation maneuvers while in orbit. The vehicle also uses the RCS for attitude control for entry. However, as the vehicle gets lower into the atmosphere, the RCS is gradually phased out as the aerosurfaces become more effective.

The RCS consists of three pods: one in the orbiter's nose and two in the aft, coupled with OMS. The RCS consists of two types of jets: primary and vernier. The 38 primary jets (14 jets located in the forward pod; 12 located in each of the aft pods) each produce around 870 pounds of thrust. These jets are used for translations and coarse attitude adjustments. The six vernier jets (two jets in each pod), each produce only about 24 pounds of thrust and are used only for fine attitude adjustments while in orbit.

The RCS uses monomethyl hydrazine for fuel and nitrogen tetroxide for oxidizer: two hypergolic chemicals that combust upon contact with each other. This eliminates the need for an ignition source inside the jets. Each RCS pod contains its own set of propellant tanks. For redundancy, propellant lines extend from one aft pod to the other. Through these lines, the propellant from one pod can be used to feed all of the aft jets (in what called an "RCS-to-RCS crossfeed"). Further, since the OMS and RCS use the same fuel and oxidizer, these same lines can be used to feed OMS propellant to all the aft jets (in what is called an "OMS-to-RCS interconnect"). However, the crossfeeds and interconnects only apply to the aft RCS. They do not apply to the forward RCS. The weight associated with running propellant lines along the length of the vehicle made crossfeeding and interconnecting to the forward RCS impractical.

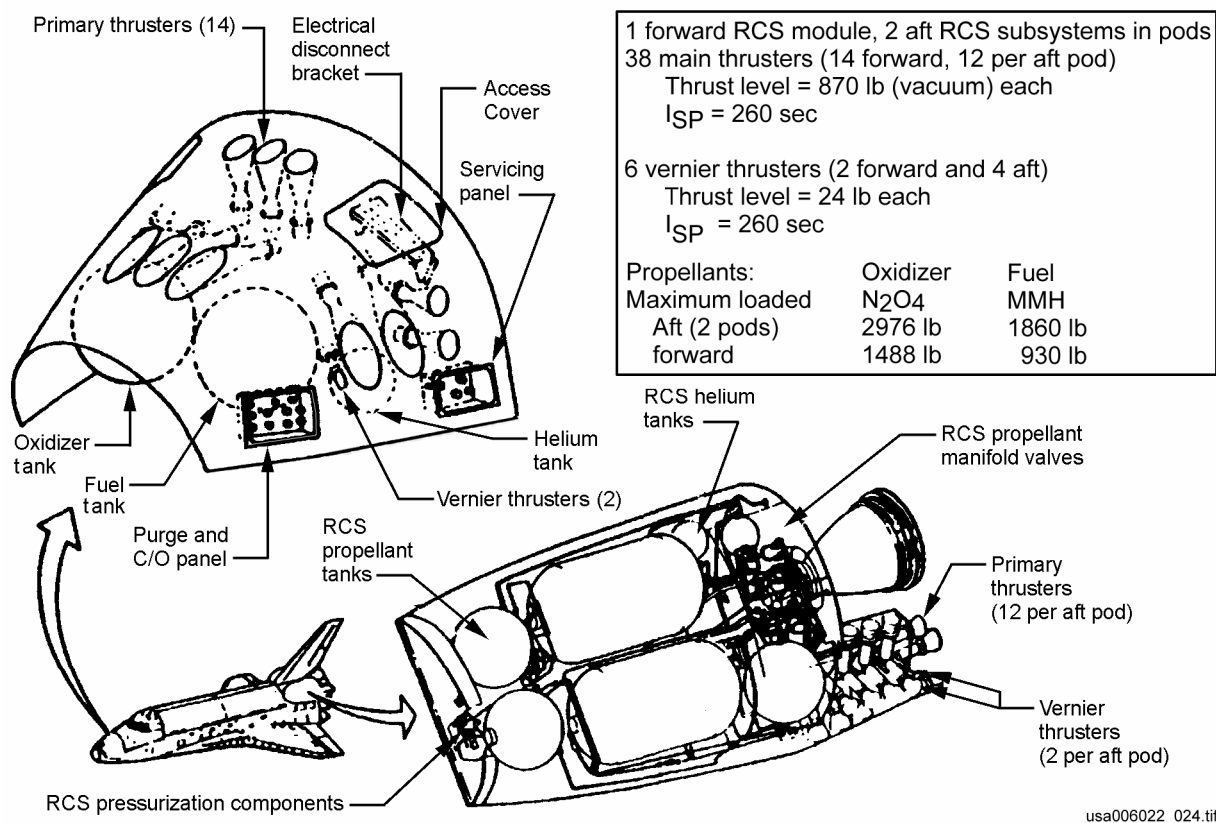
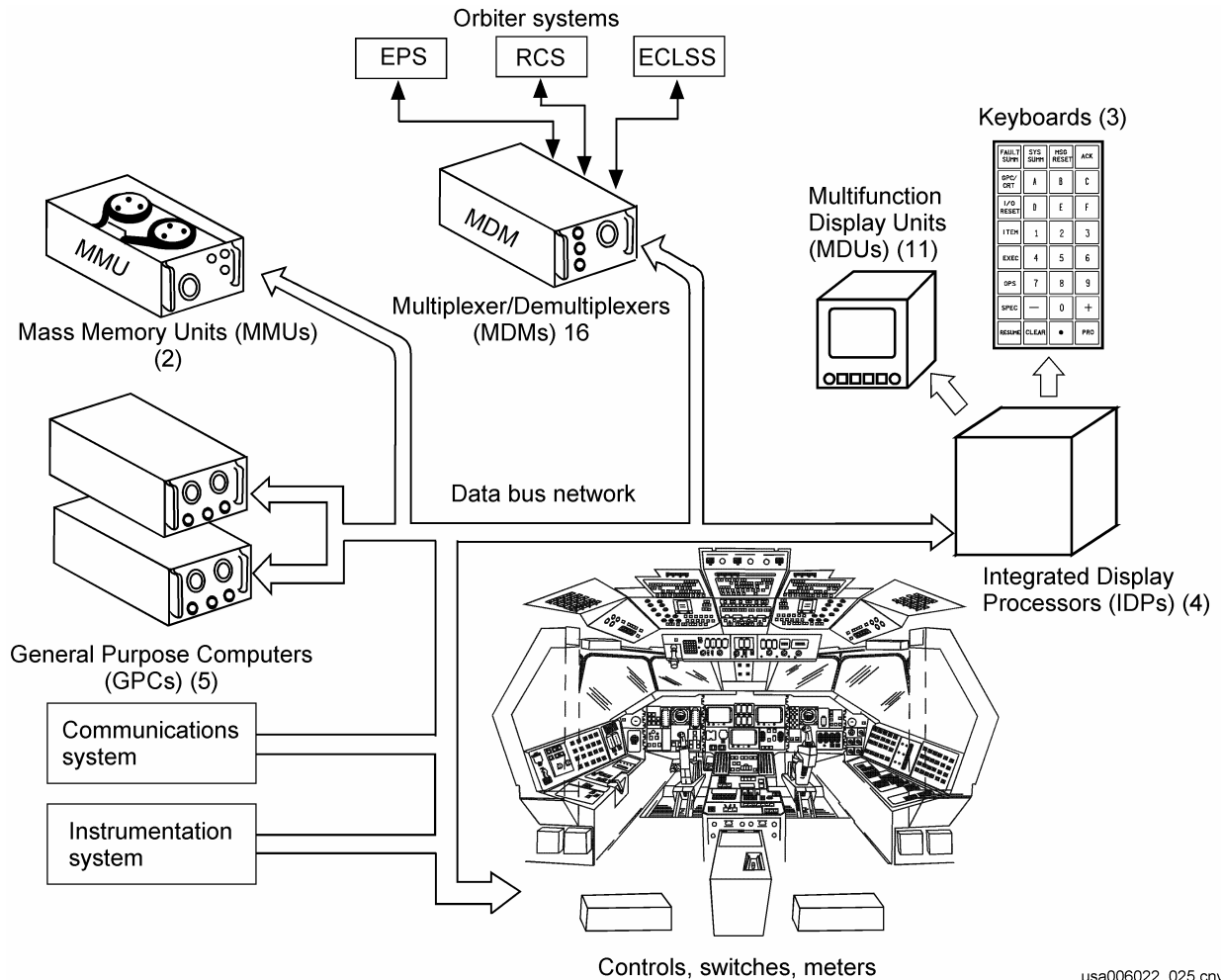


Figure 4-12. Reaction control system

4.3.9 Orbiter Data Processing System

The Data Processing System (DPS) (Figure 4-13) is the "brains" of the space shuttle. Five General Purpose Computers (GPCs) are used for controlling and monitoring the orbiter. The GPCs 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 (Electrical Power System (EPS), ECLSS, and so forth) through the Systems Management (SM) portion of the software and processes data for transmission to the ground. The vehicle can be controlled from the ground by using uplinked commands to the GPCs.



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Figure 4-13. Data processing system

The major components of the DPS are as follows:

- a. GPC - The GPCs do all the work of the DPS with programs or software. Each GPC is an IBM AP-101 and includes both the Central Processor Unit (CPU) and the Input/Output Processor (IOP). All the Primary Avionics Software System (PASS) GPCs operate in unison, providing redundancy to all systems. In addition, the Backup Flight System (BFS) provides limited support during ascent and entry flight phases.
- b. Mass Memory Unit (MMU) - Two MMUs are onboard. Each is a magnetic tape recorder that provides the GPCs with large-volume data storage. Each MMU contains multiple copies of the PASS and BFS software. Some Vehicles have Solid State Mass Memory (SSMM) Units. The SSMM includes a solid state MMU and the OPS/PL recorders.
- c. Multifunction Electronic Display System (MEDS) - This system consists of 4 Integrated Display Processors (IDPs), 11 Multifunction Display Units (MDUs) and 3 keyboards that enable the crew to monitor and control GPC software. The MEDS

also provides the crew with the capability to observe and control vehicle systems (flight instruments, RCS, hydraulics, and so forth).

- d. Data Bus Network (DBN) - The DBN is actually miles of shielded wires that transmit data between the GPCs and the rest of the orbiter. The DBN is subdivided into several specific bus groups that connect GPCs to GPCs, MEDS to GPCs, and so on.
- e. Multiplexer/Demultiplexers (MDMs) - The MDMs convert (and format or arrange) parallel data from the orbiter systems (RCS, MPS, COMM, and so forth) to serial digital data for processing by the GPCs. MDMs also reverse the conversion and formatting function to allow the GPCs to control the various orbiter systems.

During critical phases of the mission (ascent and entry), up to four of the GPCs operate redundantly as the PASS. A fifth GPC contains special standby software called the BFS. The BFS will be engaged and take control of the vehicle for certain failures of the PASS.

4.3.10 Orbiter Guidance, Navigation, and Control

Guidance, navigation, and control are interrelated functions performed by GPC software, executing redundantly in up to four GPCs 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 4-14.

Guidance software contains equations and tables of numbers that 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 guidance is usually referred to as automatic, or AUTO, guidance. The crew can steer the shuttle with hand controllers, a method 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 information is called a state vector. The state vector is mathematically determined from equations of motion by using sensed velocity changes from the Inertial Measurement Units (IMUs). The alignment of the IMU and, hence, the accuracy of the state vector deteriorate with time. The star trackers are celestial navigation instruments that are used to realign the IMUs while on orbit. The Heads-Up Display (HUD) is also used as a backup to the star trackers. During entry, data from three 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 Microwave Landing System (MLS) provides the slant range, azimuth, and elevation of the orbiter from the end of the runway. Radar Altimeters (RAs) are used for crew reference but are not incorporated into the state vector.

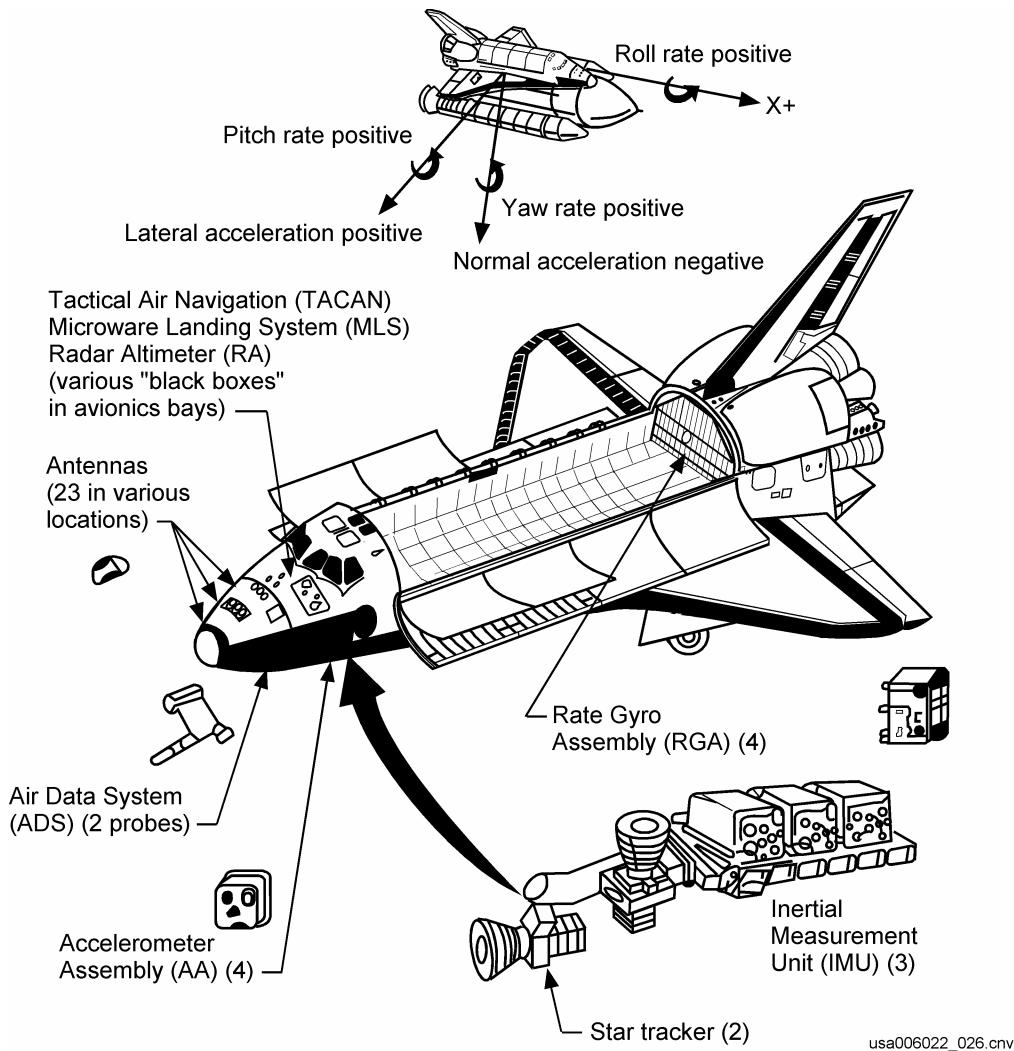


Figure 4-14. Guidance, navigation, and flight control sensors

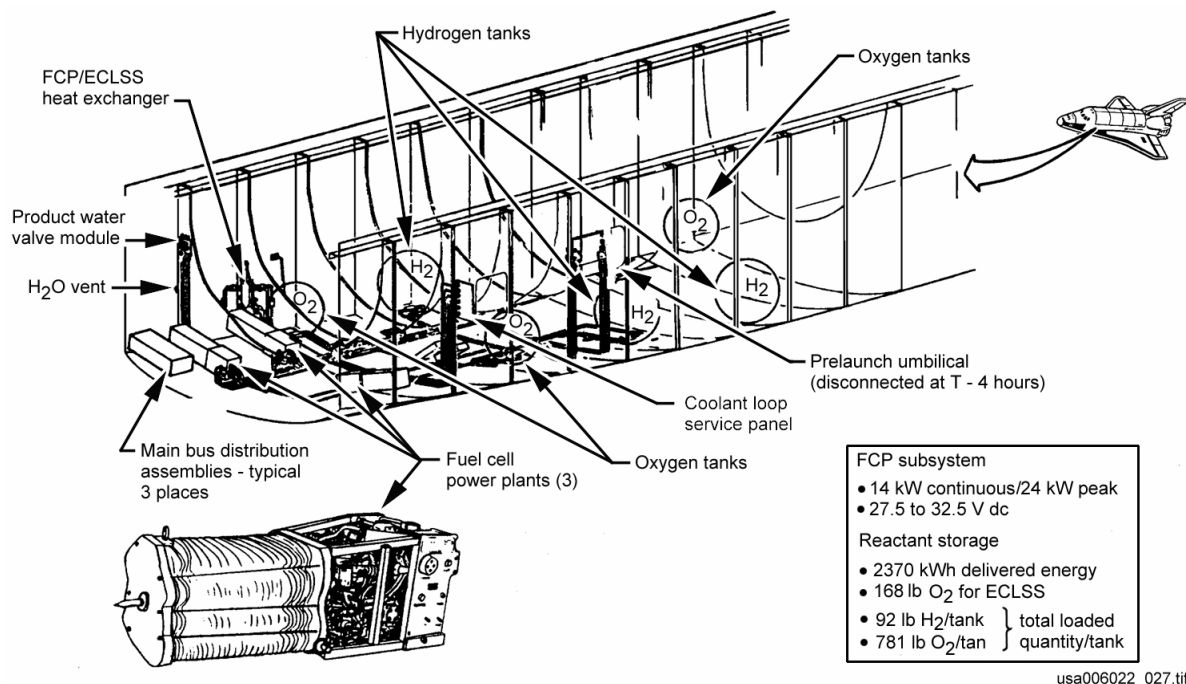
Flight control software issues commands to effectors, such as the main engines, SRBs, RCS jets, and aerosurfaces (elevons, body flap, and so on), depending on the flight phase. The purpose of flight control is to keep the shuttle under control and to make changes to the trajectory, if required. Flight 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 (AAs). Roll, pitch, and yaw body rates are supplied by the Rate Gyro Assemblies (RGAs). Attitude data are supplied by the IMUs.

GNC software requires only one sensor 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 to deselect sensors that have failed.

4.3.11 Orbiter Electrical Power System

The EPS (Figure 4-15) for the orbiter is generated by three separate Fuel Cells (FCs) 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 provide for longer duration flights.

A network of three main dc buses, each of which is connected to an FC, distributes electrical power. Critical systems use two or three main dc buses for redundancy; all three buses are protected by Remote Power Controllers (RPCs) and circuit breakers.



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Figure 4-15. Electrical power system

4.3.12 Orbiter Hydraulic System and Auxiliary Power Unit

Three independent hydraulic systems drive the aerosurfaces (rudder, speedbrake, 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 APU uses hydrazine as a fuel that decomposes into a hot gas, driving a turbine, which, through a gearbox, drives the main pump. Each APU/hydraulic system (Figure 4-16) uses a water boiler to cool the APU gearbox lube oil and hydraulic fluid. All three systems are used for about 15 minutes during ascent and for about 1 hour during entry.

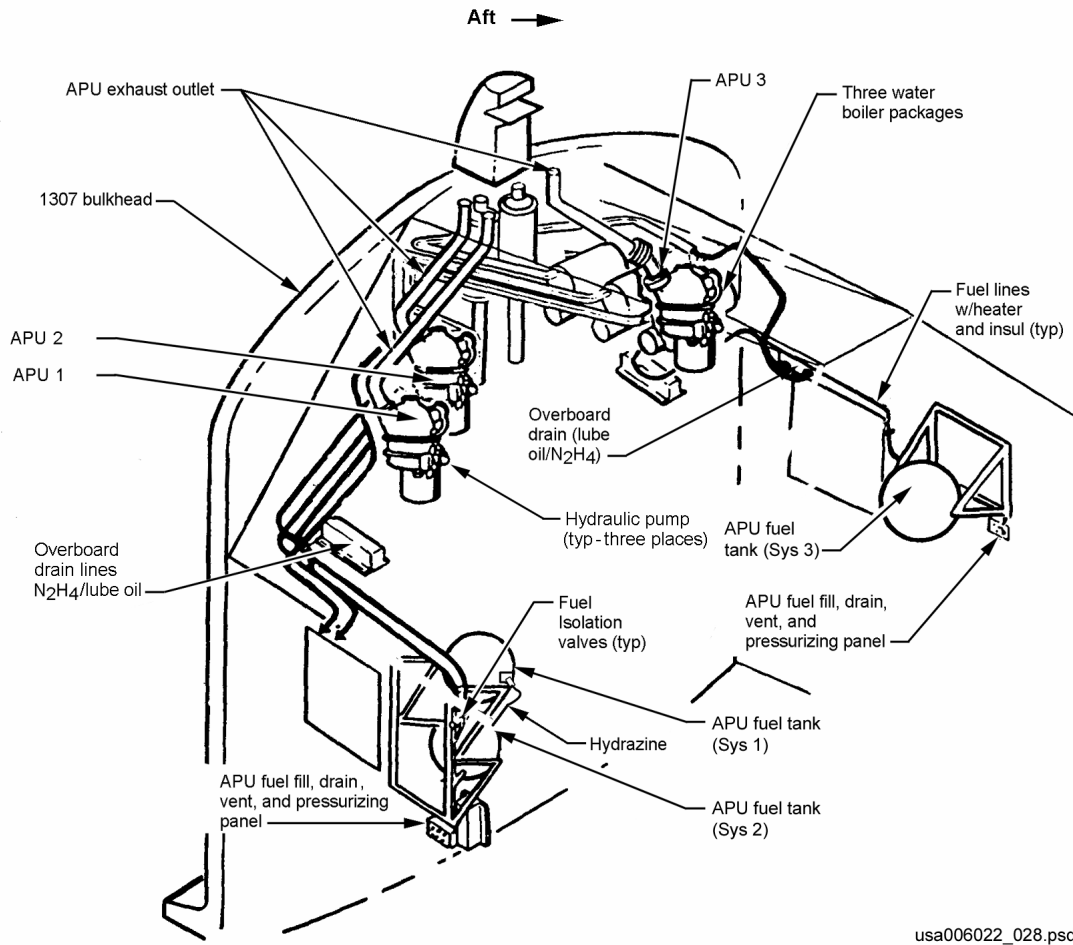
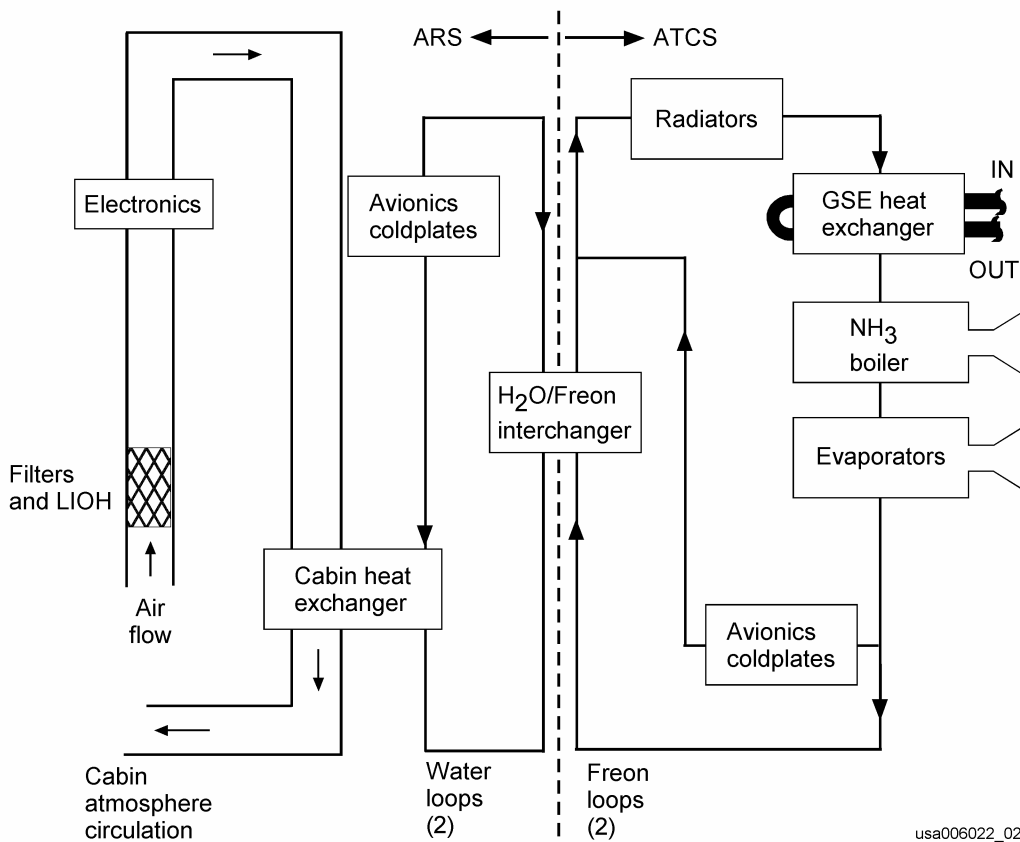
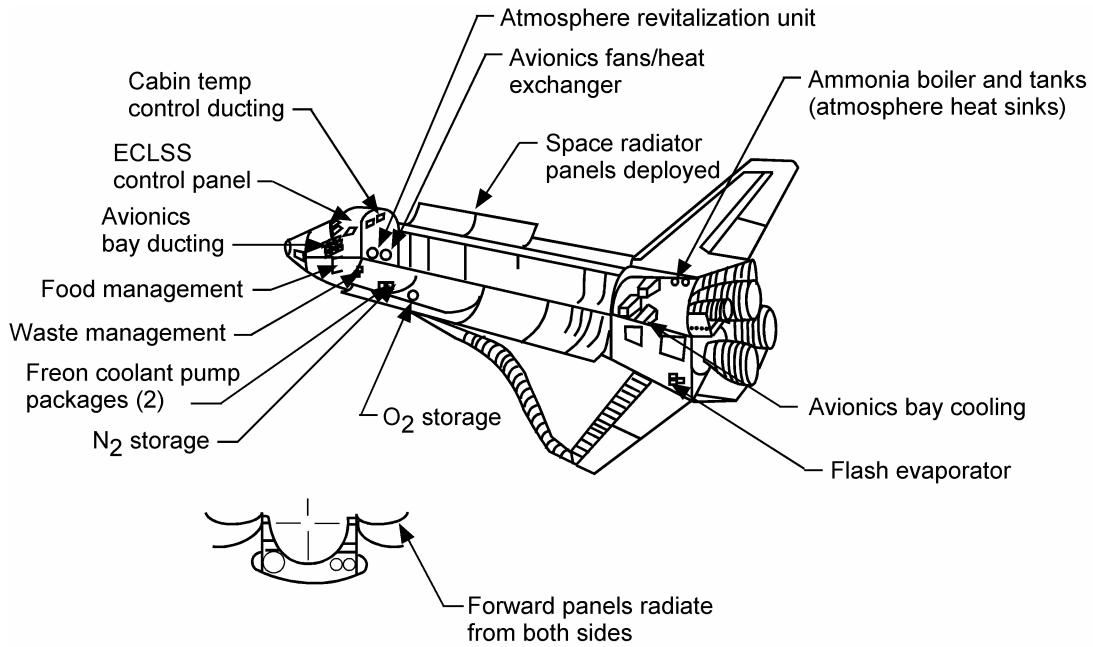


Figure 4-16. Hydraulic system, auxiliary power unit, and water spray boiler equipment location

4.3.13 Orbiter Environmental Control and Life Support System

The ECLSS (Figure 4-17) provides a comfortable, shirtsleeve environment inside the CM and rids the orbiter of unwanted heat. This system operates continuously throughout the flight.



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Figure 4-17. Environmental control and life support system

The four major components of the ECLSS are as follows:

- a. Atmosphere Revitalization System (ARS) - This system circulates air throughout the cabin, avionics bays, and across the IMUs in order to control humidity; reject heat via heat exchanger interfaces; and condition the cabin air by removing odor and floating particles.

The ARS also interfaces with the water coolant loops. These loops collect heat at air/H₂O heat exchangers and provide conductive cooling for electronic equipment mounted onto water-cooled coldplates. The ARS is able to maintain a thermally stable cabin because it transfers all heat to the H₂O loops, which, in turn, transfer heat to the exterior of the cabin via the Freon/H₂O heat exchanger.

- b. Active Thermal Control System (ATCS) - This system uses Freon 21 to remove heat from avionics bays in the aft and midfuselage, in the FCs, and in the ARS water loop. The Freon can be cooled by its interface with the flash evaporator (above 140,000 ft), the radiators on the PLBDs, and the ammonia boiler on entry (below 120,000 ft).
- c. Pressure Control System (PCS) - The PCS uses cryogenically stored oxygen that is mixed with nitrogen to provide a habitable oxygen/nitrogen environment for the crew at a cabin pressure of 14.7 psia. This atmosphere also is necessary for cabin air-cooled equipment. The PCS maintains the cabin pressure around 14.7 psia and protects the cabin from over- or under-pressurization by positive and negative pressure relief valves.
- d. Supply and wastewater storage system - The supply water storage system comprises four tanks: A, B, C, and D. Each tank has a capacity of 165 pounds, and is pressurized by nitrogen. Water stored in these tanks is generated by the FCs. Tank A is reserved primarily for crew consumption. Tanks B, C, and D are used by the Flash Evaporator System (FES) to cool the Freon coolant loops. The wastewater storage system has only one tank that stores liquid waste and humidity condensate. This tank is identical in capacity and pressurization to the supply water tanks. The supply and wastewater can be dumped overboard as the tanks fill to capacity and still maintain required quantities for cooling and consumption purposes. The supply water can also be transferred to the ISS.

4.3.14 Orbiter Instrumentation System

The Operational Instrumentation (OI) system (Figure 4-18) 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. Multiplexers take several digital data streams and combine them into a single digital data stream for easier processing. A telemetry formatter called the Pulse Code Modulation Master Unit (PCMMU) receives the digital data from

the multiplexers and arranges the parameters in the proper order for sequential transmission to the Network Signal Processor (NSP). The PCMMU also sends these parameters to the computer. The computer monitors the data (for backup C&W and 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) and to the onboard recorders. The data stored on the onboard recorders can be played back and transmitted to the ground stations. Ground stations relay the data to the MCC, where flight controllers analyze the data to assist the crew. (Data can be recorded when the orbiter is not over a ground station or in view of a TDRS.)

A Modular Auxiliary Data System/Orbiter Experiment System (MADS/OEX) has additional instrumentation to support payloads and experiments and measures orbiter environments. The MADS/OEX has a separate Pulse Code Modulation Unit (PCMU) from the OI and the following additional equipment:

At least one Frequency Division Multiplexer (FDM)

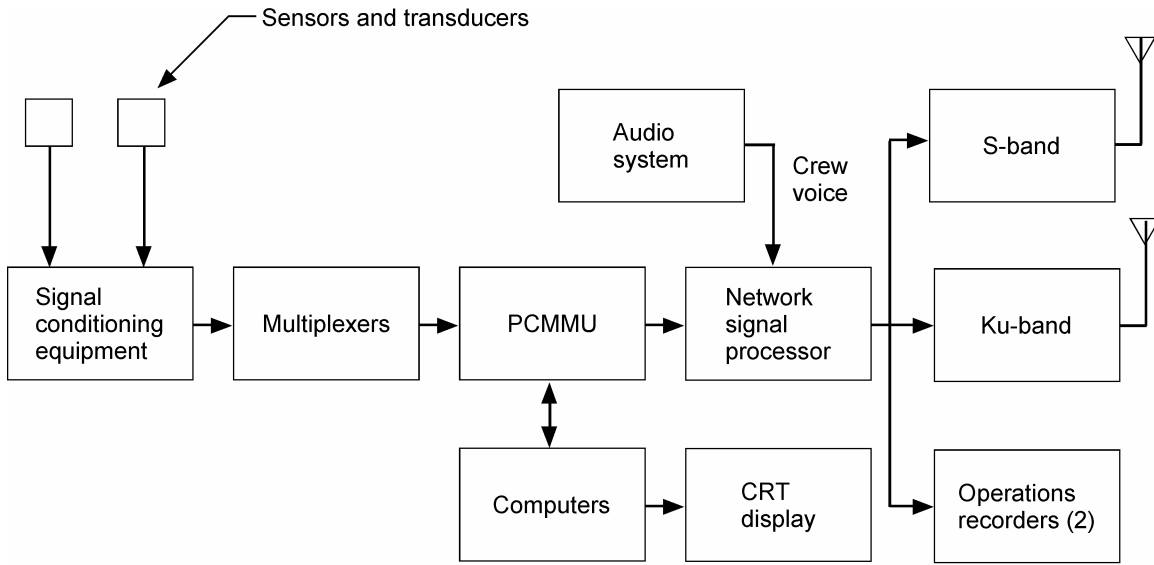
A Power Distribution Assembly (PDA)

A MADS Control Module (MCM)/System Control Module (SCM)

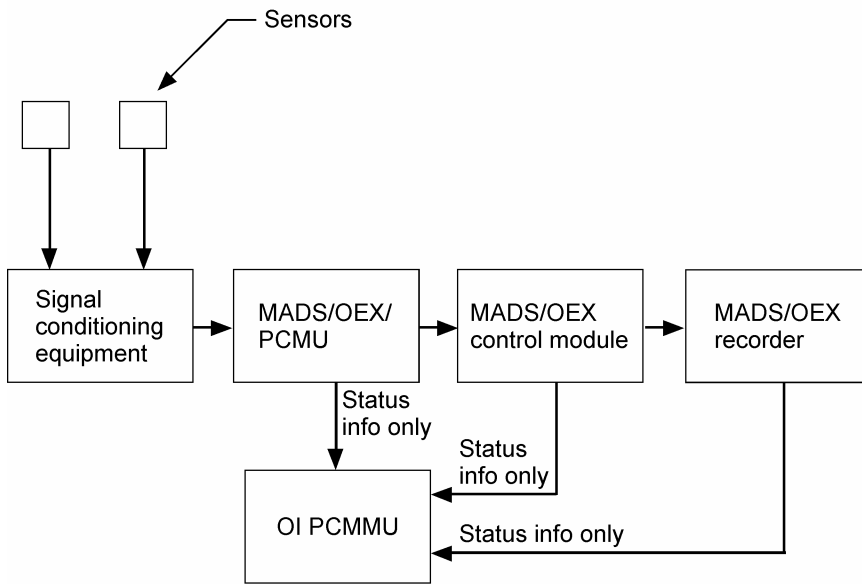
A MADS/OEX recorder

Various signal conditioners and sensors

MADS/OEX status information is sent to the OI PCMMU for downlink; all other data are recorded for analysis after landing only.



(a) OI signal flow



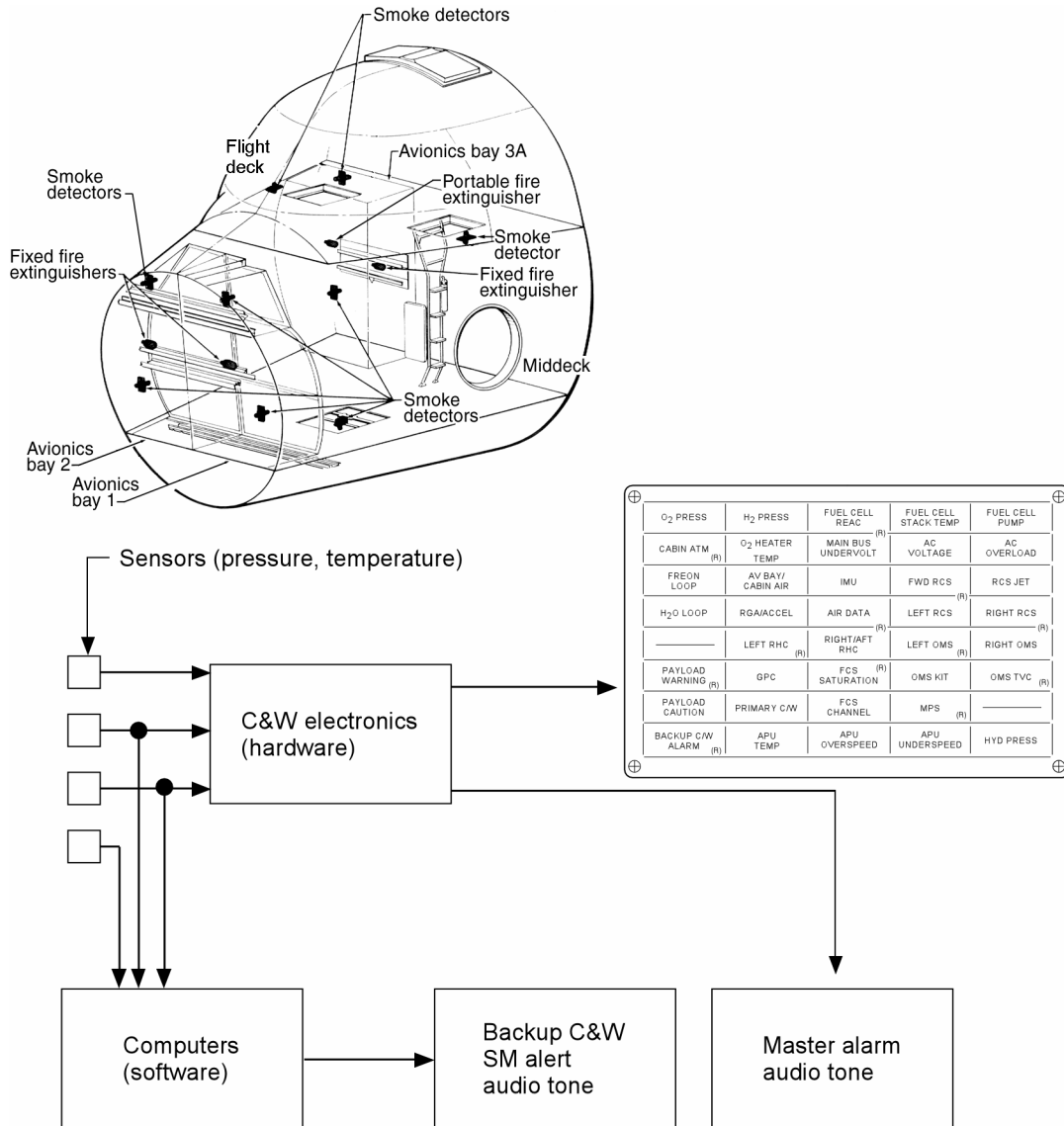
(b) MADS/OEX signal flow

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Figure 4-18. Instrumentation system

4.3.15 Orbiter Caution and Warning System

The C&W system (Figure 4-19) uses audio and visual alerts to inform the crew of out-of-limit conditions and emergency situations.



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Figure 4-19. C&W system

The primary C&W hardware system senses temperatures, pressures, quantities, and so forth, from the various systems in the orbiter. A failure of a component or an out-of-limit condition causes an audio alarm, illuminates a master alarm pushbutton indicator (pbi), and illuminates 1 of the 40 lights on the annunciator matrix. The matrix is 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 in the GPCs is used to sense out-

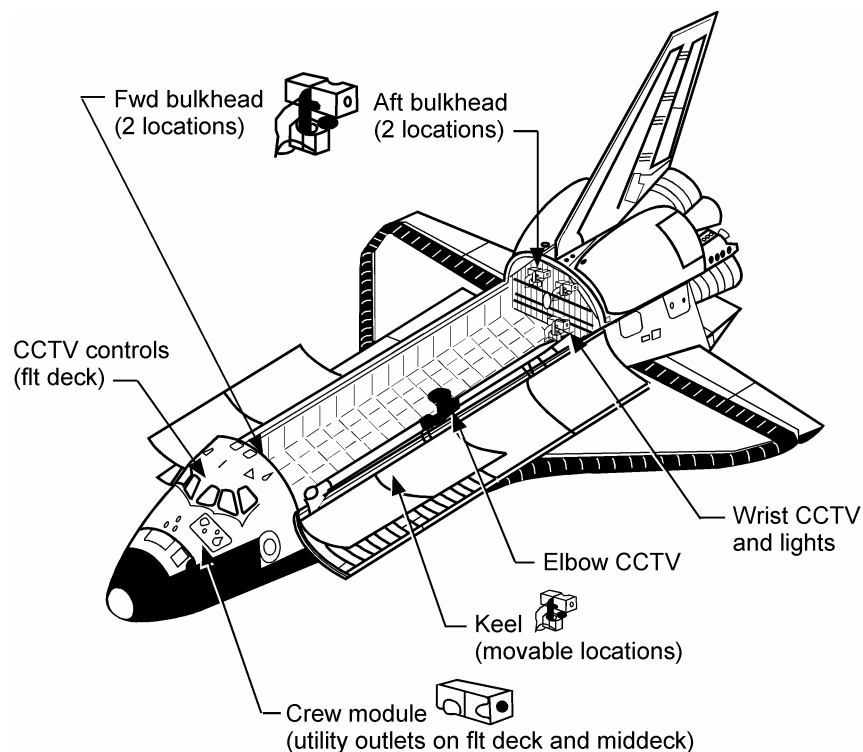
of-limit conditions and generate alarms. The SM alert system also uses software in the computers to inform the crew of a situation that may be leading up to a C&W alarm or a situation that may require additional procedures.

The fire and smoke emergency system consists of three permanent fire extinguishers that are located in the avionics bays on the middeck and smoke detectors located throughout the CM. Portable fire extinguishers also are 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 decreasing at a greater than normal rate (that is, $dP/dt > \text{some value}$).

4.3.16 Orbiter Closed-Circuit Television System

The Closed-Circuit Television (CCTV) system (Figure 4-20) 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 grappaling a satellite. Remote cameras in the CM are used for monitoring crew activities and for various hardware inspections. All video data available to the crew can be recorded onboard or transmitted to the ground. The onboard video is crew selectable, black-and-white or color. The video transmitted to the ground can be black-and-white, or color, depending on the camera sending the video. The flight controllers and the national television networks use this video.



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Figure 4-20. Closed-circuit television system

4.3.17 Orbiter Communications and Tracking System

The Communications and Tracking (C&T) system (Figure 4-21) 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 as follows:

- a. Audio Distribution System (ADS) - This system uses a switchboard called the Audio Central Control Unit (ACCU) to perform the following:
 - Route crew intercom 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
- b. S-band system - This system, in conjunction with the Ku-band system, currently provides the main link between the orbiter and ground. Voice, telemetry, and other data can be downlinked via the S-band system. Voice and commands to the computers also are uplinked by the S-band system. The system uses a Phase Modulated (PM) transponder for audio and digital data and two Frequency Modulated (FM) transmitters for other data.
- c. Ku-band system - This system employs multiple TDRSs in geostationary orbits that provide uplink and downlink between the orbiter and ground. The Ku-band system also can be used as onboard radar for tracking and rendezvous with other satellites. The channel bandwidths of the Ku-band system are greater than those for either the S-band PM or the S-band FM systems and TV. This permit higher data rates, especially for payload telemetry. However, Ku-band is available for on-orbit operations only.
- d. Ultra High Frequency (UHF) system - This system is used primarily as a backup system. On flights that require EVA, the UHF system is used between the orbiter and EVA crewmembers.
- e. Payload communication system - This system supports hard-line and RF communications with a wide variety of payloads. The payload communication system processes commands and tracks the status of various payload-related controls and displays. This system also processes ground commands and telemetry to and from the payload through the S-band or Ku-band subsystems.

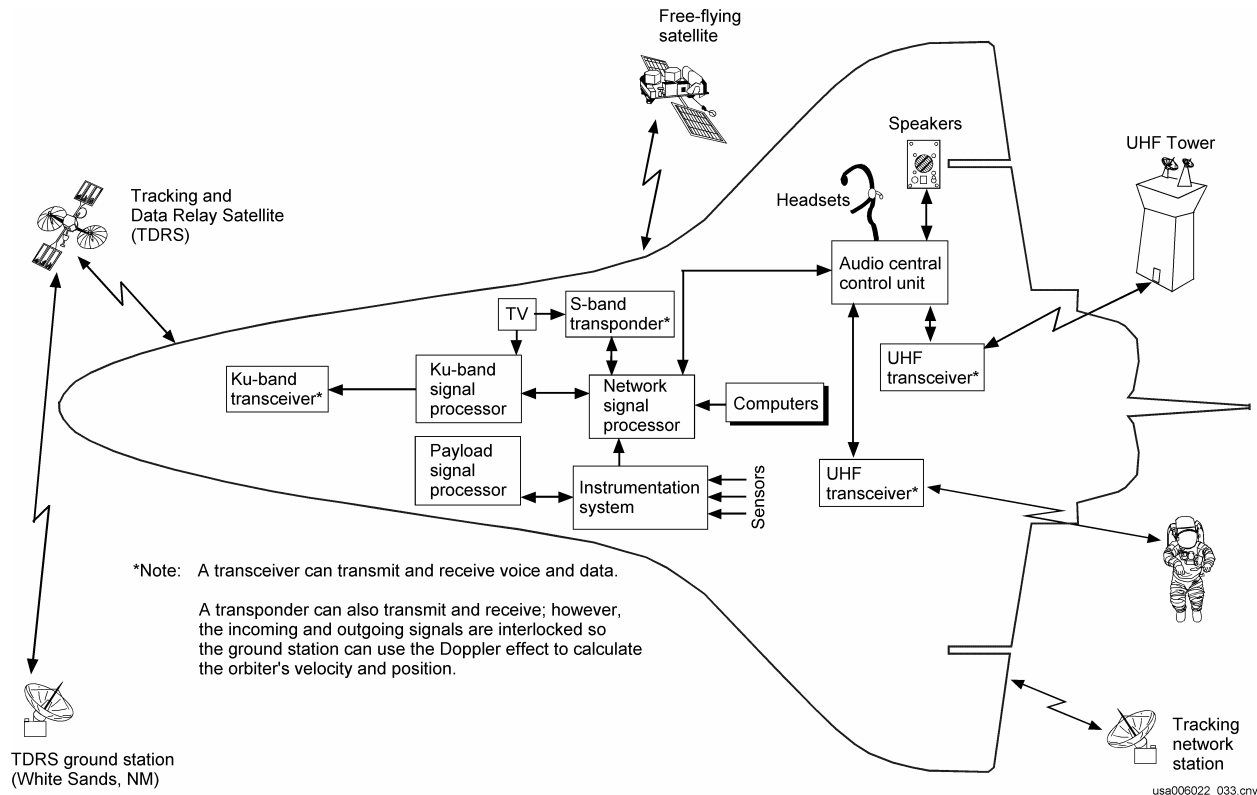


Figure 4-21. Communications and tracking system

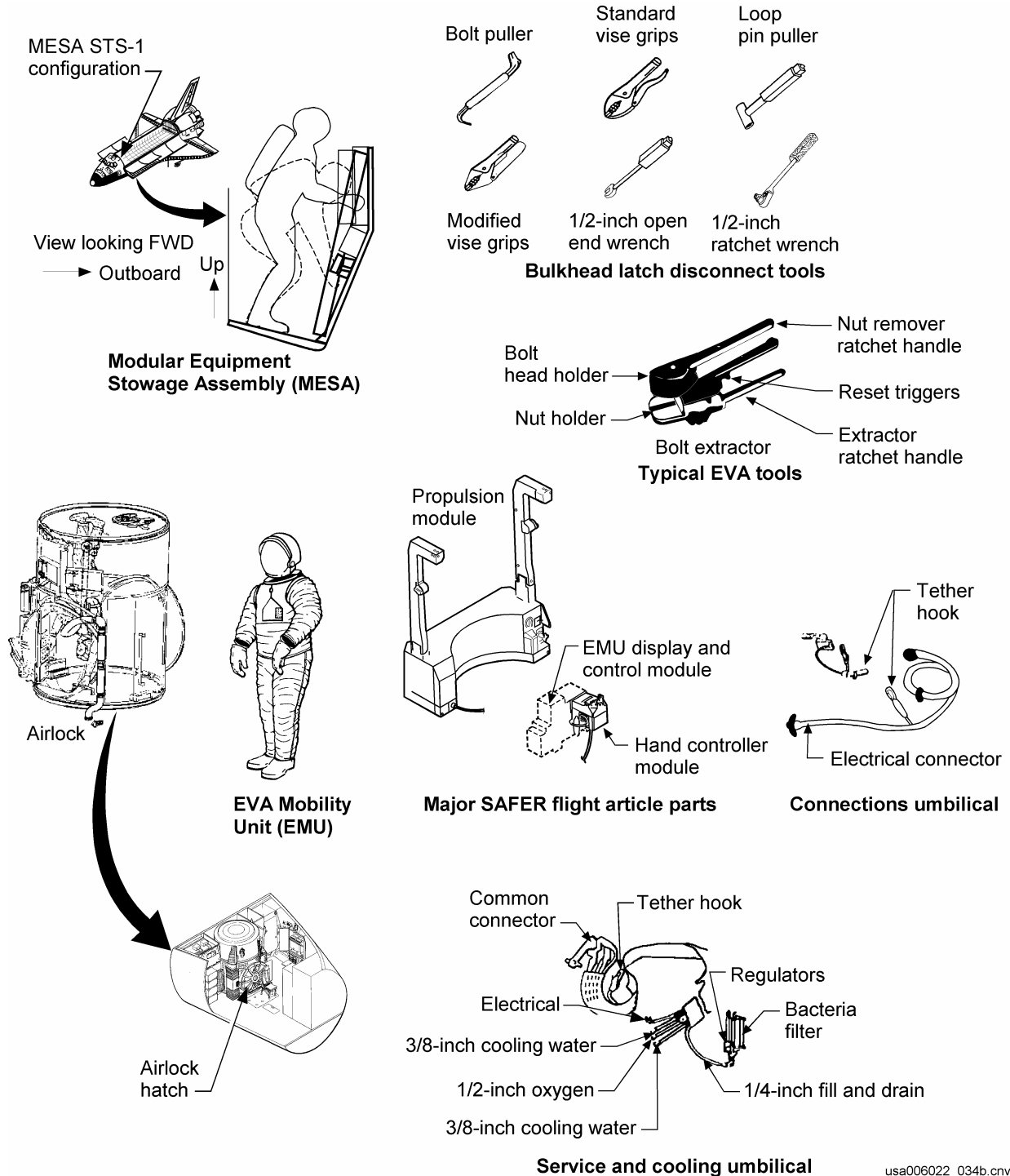
4.3.18 Orbiter Extravehicular Activity

Any time a crewmember is required to leave the crew module to perform an EVA, that crewmember must be protected from the vacuum and harsh environment of space. The Extravehicular Mobility Unit (EMU) is stowed in the orbiter airlock and is a kind of minispacecraft. The EMU consists of a suit (gloves, helmet, and so forth) and a backpack (oxygen, water, and communications gear). The module worn on the chest contains controls and displays (switches, meters) 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.

A small self-contained propulsive backpack called the Simplified Aid For EVA Rescue (SAFER) is sometimes flown on the orbiter. SAFER was designed as a self-rescue device for a separated EVA crewmember in situations where the orbiter is unavailable to provide rescue capability. An example of such a situation would be when the orbiter is docked to the ISS. The SAFER offers 13 minutes of propellant (pressurized nitrogen gas) and control authority to stabilize and return a tumbling/separating EVA crewmember. Early in the shuttle program a larger backpack called the Manned Maneuvering Unit (MMU) was sometimes used for EVA tasks. The MMU has not flown since 1984 and there are no plans for its use in the future.

Various handholds throughout the payload bay and on the bulkheads aid the crewmember performing an EVA. A crew stowage assembly installed in the payload bay contains the tools and hardware that may be required during an EVA. Examples of EVA equipment are shown in Figure 4-21.



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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 has 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 logbooks, is carried onboard the orbiter for each mission. Figure 4-23 shows typical FDF ascent checklist procedures. Typical FDF items may be seen in Figure 4-24.

1: GNC SYS SUMM 1	2: BFS, GNC SYS SUMM 2
-------------------	------------------------

3: BFS, LAUNCH TRAJ 1

C HTR RECONFIG

L2 FLASH EVAP FDLN HTR (two) - OFF

NOTE

Motion/Vibration may be felt in crew module due to Main Engine gmb1 profile cks at -3:25 and move to start at -3:10

-2:30 P **CLEAR C/W MEMORY**

1: GNC FAULT	2: BFS, GNC FAULT
--------------	-------------------

Verify no unexpected errors
CRT1, GNC, SPEC 99 PRO
CRT2

1: GNC SYS SUMM 1	2: BFS, GNC SYS SUMM 1
-------------------	------------------------

C3 C/W MEM - CLEAR

-2:00 A **SUIT PREP**

Tabs/visor - cl/LES O2 - ON

MS1 ICOM RCDR - ON (if reqd)

Figure 4-23. FDF (typical Ascent Checklist procedures)



Figure 4-24. FDF items (typical)

APPENDIX A ACRONYMS AND ABBREVIATIONS

AA	Accelerometer Assembly
ac	alternating current
ACCU	Audio Central Control Unit
ADS	Air Data System
	Audio Distribution System
AOA	Abort Once Around
APU	Auxiliary Power Unit
ARS	Atmosphere Revitalization System
ASE	Airborne Support Equipment
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
CPU	Central Processor Unit
CRT	Cathode Ray Tube
CSS	Control Stick Steering
DBN	Data Bus Network
dc	direct current
DPS	Data Processing System
ECLSS	Environmental Control and Life Support System
EI	Entry Interface
EMU	Extravehicular Mobility Unit
EPS	Electrical Power System
ET	External Tank
EVA	Extravehicular Activity
FC	Fuel Cell
FDF	Flight Data File
FDM	Frequency Division Multiplexer
FES	Flash Evaporator System
FM	Frequency Modulated
FRSI	Felt Reusable Surface Insulation
GNC	Guidance, Navigation, and Control
GPC	General Purpose Computer
GSE	Ground Support Equipment

HRSI	High Temperature Reusable Surface Insulation
HST	Hubble Space Telescope
HUD	Heads-Up Display
IDP	Integrated Display Processor
IDS	Integrated Documentation Services
IMU	Inertial Measurement Unit
IOP	Input/Output Processor
ISS	International Space Station
IUS	Inertial Upper Stage
JSC	Lyndon B. Johnson Space Center
KSC	Kennedy Space Center
LH ₂	liquid hydrogen
LO ₂	liquid oxygen
LRSI	Low Temperature Reusable Surface Insulation
MADS	Modular Auxiliary Data System
MCC	Mission Control Center
MCM	MADS Control Module
MDM	Multiplexer/Demultiplexer
MDU	Multifunction Display Unit
MECO	Main Engine Cutoff
MEDS	Multifunction Electronic Display System
MLG	Main Landing Gear
MLP	Mobile Launch Platform
MLS	Microwave Landing System
MMU	Manned Maneuvering Unit
	Mass Memory Unit
MOD	Mission Operations Directorate
MPS	Main Propulsion System
MS	Mission Specialist
NASA	National Aeronautics and Space Administration
NLG	Nose Landing Gear
NSP	Network Signal Processor
OEX	Orbiter Experiment System
OI	Operational Instrumentation
OMS	Orbital Maneuvering System
OPF	Orbiter Processing Facility
PASS	Primary Avionics Software System
pbi	pushbutton indicator
PCMU	Pulse Code Modulation Unit
PCMMU	Pulse Code Modulation Master Unit
PCS	Pressure Control System

PDA	Power Distribution Assembly
PLBD	Payload Bay Door
PLT	Pilot
PM	Phase Modulated
POCC	Payload Operations Control Center
PS	Payload Specialist
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
RTL	Return to Launch Site
SAFER	Simplified Aid for EVA Rescue
SCA	Shuttle Carrier Aircraft
SCM	System Control Module
SM	Systems Management
SRB	Solid Rocket Booster
SRM	Solid Rocket Motor
SSMM	Solid State Mass Memory
SSP	Space Shuttle Program
SSV	Space Shuttle Vehicle
STS	Space Transportation System
TACAN	Tactical Air Navigation
TAEM	Terminal Area Energy Management
TAL	Transoceanic Abort Landing
TAMS	Training Administration Management System
TDRS	Tracking and Data Relay Satellite
Ti	Terminal (phase) initiation
TPS	Thermal Protection System
UHF	Ultra High Frequency
VAB	Vehicle Assembly Building
WSTF	White Sands Test Facility

Training Materials Evaluation

Please answer the following questions regarding the lesson you have just completed. Your feedback will allow us to produce more effective training materials. When complete, mail to Shuttle Systems Group/DT36. For an immediate response, e-mail your comments to DT36-Feedback @ems.jsc.gov or DL DT36 Feedback on NASA global.

TITLE/CODE OF LESSON: Space Shuttle Vehicle Familiarization/SSV FAM 11007

SIZE OF AUDIENCES/CLASS:

1. How well did this lesson meet its purpose?

For each statement below, mark one box on the scale

- The lesson objectives are clearly stated.
- The lesson objectives are clearly defined.
- The lesson effectively teaches skills and information.
- The lesson meets its purpose and objectives.

Strongly Disagree				Strongly Agree	
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
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<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

2. How satisfying is the content of this lesson?

For each statement below, mark one box on the scale

- The information is structured in a logical flow.
- The content is clear.
- The content is complete.
- The level of detail is correct for this information.
- The amount of information is effective.
- The graphics contribute to my understanding.

Strongly Disagree				Strongly Agree	
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
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<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

3. How appealing was the presentation of this lesson?

For each statement below, mark one box on the scale

- The overall presentation is appealing.
- The visuals chosen are appropriate for the lesson.
- The visuals make the information more interesting.
- The graphics are legibly reproduced.
- The audio/visual or print quality is good.

Strongly Disagree				Strongly Agree	
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
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<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

4. How valuable is this information?

For each statement below, mark one box on the scale

- The lesson teaches skills and information I need.
- The lesson meets my expectations.
- This information is useful for later reference.
- I would recommend this lesson to others.

Strongly Disagree				Strongly Agree	
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
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<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

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EXPLAIN ANY NEGATIVE ANSWERS IN SPECIFIC TERMS
THANK YOU IN ADVANCE FOR YOUR ASSISTANCE!**

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